S. Braumiller, U.S. Fish and Wildlife Service Hydrogeologist (Groundwater Hydrologist) – 17 July 2020

Per your recent request, enclosed are highlights of technical comments under development by the Service Hydrogeologist (Groundwater Hydrologist) regarding the 2020 Twin Pines Minerals, LLC/TTL permit application based on a detailed hydrologic review of the 2020 (and 2019) permit application(s), TTL 2019 technical reports, and other available relevant technical resources:

- **Existence of an intimate hydraulic connection:** Okefenokee Swamp (a National Wildlife Refuge) should be presumed to be in intimate hydraulic connection with the surficial aquifer underlying Trail Ridge and wetlands south and east of the swamp, the swamp's water surface (the southeast portion of the swamp) being an extension of the local water table. Areas in intimate hydraulic connection with this portion of the swamp include locations west of and within the 2020 (and 2019) proposed Twin Pines Minerals permit and mining areas, and more so portions of the 12,000 acre study (exploration) area east of the swamp itself.

- **Impoundment of the swamp by Trail Ridge (USGS, 1989):** Trail Ridge bounds Okefenokee Swamp on the east along its full length (approximately 30 miles). In 1989, the U.S. Geological Survey (USGS) concluded that Trail Ridge impounds the Okefenokee Swamp (easterly movement of water from the swamp, through the ridge, toward coastal lowlands), but did not advance a hydrogeologic explanation. Rather, their conclusion was based on the largely geologic observation that natural drainages are commonly blocked during the formation of Eolian dunes (Force and Rich 1989).

- **Topographically-induced groundwater divide proposed as the mechanism for impoundment (2019):** Twin Pines Minerals/TTL proposed the first hydrogeologic hypothesis concerning the role of Trail Ridge in impounding the Okefenokee Swamp in 2019 (based on this reviewer's literature search to date) – implying, but not explicitly stating, that impoundment of the swamp is entirely due to the presence of a groundwater divide within the surficial aquifer created by the infiltration of rain on Trail Ridge.

  If indeed a topographically-induced groundwater divide persists through the full thickness of the surficial aquifer in the Twin Pines study/exploration area as hypothesized, the divide would be reestablished at the close of mining once the site is completely backfilled and recontoured, and if anything enhanced by the replacement of native sediments with higher-conductivity processed mine tailings (clay and humic content diminished), as long as rain continues to fall on the ridge. The existence of such a groundwater divide, however, depends on the shape of the land surface and, among other things, rate of groundwater recharge – which is unknown.

- **Existing groundwater level measurements, piezometers, and monitoring wells insufficient to confirm, or deny, the presence of a topographically-induced groundwater divide through the full thickness of the surficial aquifer:** Topographically-controlled groundwater flow in the vicinity of Trail Ridge, including the 2020 (and 2019) proposed permit and mining area(s) and overall study/exploration area, must persist through the full thickness of the surficial aquifer in order to impound, or contribute to the impoundment, of Okefenokee Swamp. In support of their hypothesis, Twin Pines/TTL has provided water level contour maps (2020 permit application and TTL 2019 "Local Groundwater/ Surface Water Hydrology" report) that are implied to depict conditions and directions of groundwater flow through the full thickness of the surficial aquifer. However, upon careful inspection and comparison of information in the referenced TTL technical report (Table 4) and the annotation provided on the contour maps, this reviewer confirms that the contoured data are limited to water level measurements collected using staff gages installed at the land surface and shallow (water table) piezometers only. Consequently, while the contour maps provided in the 2020 permit application and technical reports accurately depict the shape of the water table and near-water table conditions (which are topographically-controlled, as expected), conditions at depth in the surficial aquifer may differ. Theoretically, flow from west to east could still exist at depth in the surficial aquifer underlying Trail Ridge depending on a number of factors[1] (hypothetical example shown in Freeze and Witherspoon 1967, Figures 1c and 2f).

Moreover, neither the available groundwater level measurements (TTL 2019 "Local Groundwater/ Surface Water Hydrology" report, Table 4), or the existing piezometers and monitoring wells, are sufficient to confirm, or deny, the presence of a topographically-induced groundwater divide to the bottom of the surficial aquifer (throughout the study area) in view of the completions/locations of the piezometers/wells. The latter based on a careful inspection of completion/location information for the existing piezometers and wells, including a detailed examination of the driller's logs for the (86) piezometers and (12) UD-monitoring wells to confirm the extent and depths of sandpacked (monitored) intervals versus the thickness of the surficial aquifer (TTL 2019 "Geologic Characterization" report, Appendices C, D, and E)[2].

- **Alternative, or at a minimum additional, significant mechanism for impoundment of the swamp based on key data collected by Twin Pines Minerals/TTL:** TTL has correctly interpreted the responses to 23 slug tests performed in 2018/2019 across the Twin Pines study/exploration area to show that the hydraulic conductivity of sediments composing the surficial aquifer drops substantially and consistently below an elevation of about 120 ft above mean sea level (see figure entitled "Slug Test Hydraulic Conductivity with Depth" in TTL's 2019 "Hydrogeologic Field Characterization" report); an important trend confirmed and further analyzed by this reviewer using data provided in TTL's technical report. Although this trend has been clearly identified by TTL, its implications have not.

  The elevation identified (120 ft above mean sea level, amsl), plus or minus a few feet (given the vertical "resolution" of the TTL slug tests)[3], corresponds closely to the elevation of the water's surface in the southeast portion of nearby Okefenokee Swamp, which is about 118 ft above mean sea level (amsl) based on a digital elevation model constructed using Lidar data collected by NOAA for the State of Georgia. At a minimum, this suggests that lower conductivity sediments at and below roughly 120 ft amsl in the surficial aquifer (not limited to Trail Ridge per se, but including the whole of the Twin Pines study/exploration area) contribute significantly to the impoundment of water in the swamp at its current levels. At the very least, lower conductivity sediments below 120 ft amsl must impede (reduce) any leakage that occurs from the swamp to the east through Trail Ridge (across an area where water levels drop some 40 ft, west to east). Alternatively, given the similarity of these two elevations (unlikely to be a coincidence), lower conductivity sediments at depth in the surficial aquifer within Trail Ridge and the general vicinity, may be primarily responsible for impoundment of the swamp along its eastern perimeter.

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[1] Factors determining the vertical extent of local topographically-induced groundwater flow cells in the aquifer include the shape of the land surface, rate of recharge (to the water table), thickness of the aquifer, and vertical trends in hydraulic conductivity within the aquifer (Freeze and Witherspoon 1967).

[2] Specifically, 12 of the 14 UD-holes are screened over 10 ft intervals, but sandpacked from the land surface to the bottom of hole. Consequently, they cannot be used to detect changes (differences) in the direction of groundwater flow that may occur at depth in the surficial aquifer (versus shallower depths). Comparing the depths of the tops and bottoms of sandpacked intervals in the 86 piezometers to the thickness of the surficial aquifer at the locations of the piezometers (based on a detailed examination of their logs/completion diagrams – TTL's 2019 "Geologic Characterization" report, Appendix E), at most six (pz-31d, -33d, -34d, -35d, -36d, and -37d) monitor conditions which include the bottommost several feet of the aquifer. However, due to their completions over 9 to 12 ft intervals in an area where the aquifer is only 40 to 50 ft thick, water levels measured in the piezometers represent average conditions within the bottom 20 to 30 percent of the aquifer; as such, cannot be used to detect changes (differences) in the direction of flow that may occur near the bottom of the aquifer. Moreover, the 6 piezometers are limited to the southwest corner of the study/exploratory area. Consequently, data that can be used to confirm, or deny, the presence of the hypothesized groundwater divide (to the bottom of the aquifer) cannot be obtained with the existing piezometers and monitoring wells.

[3] Sandpacked intervals in the slug tested piezometers range from 7 to 12 or more feet in length (TTL 2019 "Hydrogeologic Field Characterization" and "Geologic Characterization" reports).

- **Ambiguities regarding the proposed depth of mining and implications for the usefulness of the current proposal as a "demonstration" of potential Phase 1 impacts:** The 2020 permit application describes the depth of proposed mining as 50 ft below ground surface (bgs) within the Keystone Tract and 25 ft bgs in the TIAA Tract (both definitive depths). Of note, mining to a depth of 50 ft in the Keystone portion of the proposed mine would result in the excavation (and replacement) of native sediments to an elevation just above the 120 ft amsl hydraulic conductivity threshold, or marginally below it at most locations (124 to 118 ft amsl)[4]. In the TIAA portion of the proposed "demonstration mine", mining to a depth of 50 ft would result in the excavation and replacement of native sediments to elevations well below the 120 ft amsl conductivity threshold. However, per the 2020 proposal, mining within the TIAA Tract would be limited to 25 ft bgs, keeping the depth of excavation and replacement of native sediments well above the 120 ft amsl threshold, or again marginally below it (roughly 113 ft amsl or higher) – i.e., the depth at which the hydraulic conductivity of native sediments drops markedly and consistently[5], contributing significantly to, if not responsible for, impoundment of the Okefenokee Swamp.

  Inasmuch as the 2019 Phase 1 project proposal was ambiguous regarding the depth of mining outside the TIAA Tract, the 2020 proposal is unlikely to serve as a useful demonstration of the potential impacts of the Phase 1 proposal. In the 2019 Phase 1 project, the depth of mining within the TIAA Tract was 25 ft (a definitive depth), keeping the excavation/replacement of native sediments above, or marginally below, the 120 ft amsl hydraulic conductivity threshold (≥ 113 ft amsl). However, the depth of mining elsewhere in the Keystone and Adirondack tracts was described (only) as an *average* of 50 ft. As such, native sediments might have been excavated and replaced to a depth of 50 ft everywhere in the Keystone and Adirondack tracts, or alternatively to less than 50 ft in some areas and more in others. At a minimum, this would have meant excavating and replacing native sediments well below the 120 ft amsl hydraulic conductivity threshold within the Adirondack Tract; or if not, keeping the excavation/replacement of native sediments to an elevation of 120 ft amsl or above in the Adirondack Tract, while mining to a somewhat greater depth (below 120 ft amsl) in the Keystone Tract; or possibly excavating/replacing native sediments below the 120 ft amsl conductivity threshold at some locations in both tracts.

  Although somewhat confusing due to the ambiguities in the 2019 project description, it seems clear that the Phase 1 proposal would have resulted in the excavation and replacement of native sediments below the 120 ft amsl hydraulic conductivity threshold within the Keystone Tract, Adirondack Tract, or both; whereas the "demonstration" project proposed in 2020 *would not*. Consequently, in addition to the fact that the areas affected by the two proposals (2020 and 2019) differ very little, the proposed 2020 project is unlikely to serve as a useful demonstration of the potential impacts of the proposed Phase 1 project given mining would be effectively restricted to the 120 ft amsl hydraulic conductivity threshold or above – the current elevation of water in nearby Okefenokee Swamp.

- **Usefulness of the 2019 Phase 1 proposal as an indicator of the potential impacts of mining within the remainder of the 12,000 acre Twin Pines Minerals study/exploration area:** Moreover, mining to a depth of 50 ft in the remainder of the Twin Pines 12,000 acre study/exploration area would result in the excavation and replacement of native sediments to elevations 20 to 30 ft or more below the 120 ft amsl hydraulic conductivity threshold at most locations[6] (and 20 to 30 plus feet below the current elevation of water in nearby Okefenokee Swamps). Consequently, neither the 2019 Phase 1 proposal, nor the 2020

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[4] Based on calculations using ground surface elevations provided in TTL's 2019 "Geologic Characterization" report for EB-borings, UD-borings/wells, and the PZ-series piezometers located within the 2020 proposed mining area, and Figure 12 in the same (Lidar Topographic Map, 1 ft Contours).

[5] Based on this reviewer's expanded interpretation of TTL's 2019 slug tests, about 4-fold from ≥ 8 to about 2 ft/day.

[6] Calculated using ground surface elevations provided in TTL's 2019 "Geologic Characterization" report for 16 EB- and PB-borings (Table C1).

"demonstration" project, is likely to provide useful information regarding the potential impacts of mining within the remainder of the Twin Pines study/exploration area on the Okefenokee Swamp.

- **Feasibility of identifying low conductivity sediments at or below the 120 ft amsl hydraulic conductivity threshold in the field (during mining) based on visual inspections of lithology:** Based on a detailed examination of the driller's logs for EB-borings, PB-borings and piezometers installed through, or nearly through, the full thickness of the surficial aquifer, and taking into account the vertical "resolution" of the 2019 slug tests[3], it appears that sediments responsible for the substantial drop in hydraulic conductivity at about 120 ft amsl include, but are not limited to, easily identified clays (CL and CH) and clayey sands (SC); but as often as not are silty sands (SM) or clayey-silty sands (SC-SM) with fines equal to or greater than roughly 90 and 75 percent, respectively[7]. As such, mining below an elevation of 120 ft amsl based on visual inspections of lithology in the field during active dragline operations (or other large-scale excavation) could result in the unintended removal and replacement of low conductivity sediments that, at a minimum contribute to, if not are responsible for, impoundment of the Okefenokee Swamp.

- **Impacts of excavating and replacing native sediments in 100 ft wide, 500 ft long east-to-west trenches extending below the 120 ft amsl hydraulic conductivity threshold:** It follows that any replacement of low conductivity sediments below about 120 ft amsl with higher-conductivity processed mine tailings would compromise, or risk compromising, the impedance of leakage out of Okefenokee Swamp to the east, or create leakage out of the swamp that is not currently occurring *on a permanent basis*, even if a groundwater divide is created or reestablished beneath Trail Ridge to the original depth of the surficial aquifer. Of note, the results of numerical model simulations provided by the project proponent, which purport to predict the impacts of the proposed mining, simulated all mining as occurring at or above 119 ft amsl (2020 model report, page 6; and 2020 permit application, page 22); i.e., just below the 120 ft amsl hydraulic conductivity threshold and about one foot higher than the current elevation of water in nearby Okefenokee Swamp.

- **Hydraulic conductivity of processed mine tailings unknown:** It follows that the hydraulic conductivity of processed mine tailings (clay and humic content diminished) would be higher than that of the native sediments they would replace – an important input to model simulations (both analytical and numerical) submitted as part of this permit application which purport to predict the impacts of the proposed project. Sediment samples (0 to 12 ft bgs) were obtained in the vicinity of UD-holes 338, 25, 228, and 43 without the use of drilling mud after samples collected during the installation of the 14 original UD-holes were found to be contaminated with bentonite. Based on laboratory-scale permeability tests conducted by TTL, the hydraulic conductivities of the uncontaminated samples were reportedly 1 to 4 orders of magnitude higher than that of the original UD-hole samples (TTL 2019 "Laboratory Testing Data" report). Nonetheless, sediment porosities reported by TTL (in the same report) appear to be based on the testing of the original bentonite-contaminated samples, skewing those results to a degree that has not been evaluated. Likewise, based on a careful reading of TTL's "Laboratory Testing Data" report, the same bentonite-contaminated UD-hole samples were processed by a third-party to approximate onsite extraction and then tested for their permeability (conductivity) in the laboratory, and were also used to investigate how the addition of known quantities of bentonite would affect the conductivity of processed mine tailings.

  Although the results of the laboratory-scale permeability tests are unreported for the majority of the original UD-hole samples, a hydraulic conductivity of 2.7 feet per day (ft/d), 9.6E-4 cm/s, is reported for one of them: a "simulated processed" composite sample from holes UD338 and UD25 (1 – 50 ft bgs), which was also compressed to 4,500 pounds (lbs) for 24 hours prior to testing (TTL 2019 "Laboratory

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[7] This finding based on a detailed examination/interpretation of the lithologic/driller's logs for EB-holes, PB-holes, and piezometers installed through, or nearly through, the full thickness of the surficial aquifer (TTL's 2019 "Geologic Characterization" report, Appendices C and E).

Testing Data" report). Whereas higher than the conductivity of the corresponding uncontaminated UD338 and UD25 samples (collected 0 – 12 ft bgs), the hydraulic conductivity of the "simulated processed" UD338/UD25 sample was 3-fold lower than the average conductivity of sediments tested at or above 120 ft amsl in TTL's slug tests[8] – the geometric mean of those conductivities being 8.6 ft/d (3.0E-3 cm/s) based on this reviewer's further analyses of the slug test results. Since the laboratory-scale conductivity of "processed"/"homogenized" sediments should be about the same as their field-scale conductivity (given the lack structure), the conductivity reported for the "simulated processed" UD338/UD25 sample confirms that the test sample was: 1) still contaminated with bentonite following the "simulated processing" (consistent with TTL's observations of a dark brown liquid in the "processed" samples prior to testing); 2) compressed beyond that representative of in situ conditions (4,500 lbs for 24 hours); or both. Consequently, the conductivity of actual processed mine tailings could be, if not is likely to be, significantly higher than the 2.7 ft/d (9.6E-4 cm/s) reported based on this single "processed"/compressed test sample. For all practical purposes, including the numerical and analytical predictive modeling submitted as part of the current permit application, the conductivity of mine tailings following onsite extraction is unknown.

Since the same bentonite-contaminated UD338/UD25 sample was used to evaluate how the addition of known quantities of bentonite would affect the hydraulic conductivity of processed mine tailings, and the degree of residual bentonite contamination in the UD338/UD25 test sample is unknown, the utility of the results of that bench-scale study are also unclear.

- **Unknown rate of groundwater recharge in the vicinity of the Twin Pines study area (and Trail Ridge generally) – with implications for the proposed conceptual, numerical, and analytical groundwater flow models:** Based on this reviewer's search of the USGS and Georgia Geological Survey literature to date, no estimate of groundwater recharge is available for the Twin Pines study/exploration area, or other parts of Trail Ridge, or elsewhere in the region. A series of USGS RASA (regional-scale) and subsequent subregional-scale groundwater flow models have been constructed that include the vicinity of the Twin Pines study/exploration area (e.g., Bush 1982, Krause 1982, Bush and Johnston 1988, Krause and Randolph 1989, Randolph et al. 1991, Clark and Krause 2000, Payne et al. 2005, Cherry 2015); but few simulated the surficial aquifer, and none have directly simulated groundwater recharge to the surficial aquifer – the explanation provided (Payne et al. 2005 and Cherry 2015): no reliable estimates of recharge available.

  The baseflow of local streams/rivers serves as a lower constraint on the rate of recharge to the surficial aquifer[9]. However, no stream baseflow estimates appear to be available for the two watersheds that include the Twin Pines study/exploration area (e.g., in Priest 2004), and only one of several streams exiting the watersheds[10] has been gaged for any period of time[11] (continuous discharge data necessary to estimate baseflow). Nor has Twin Pines/TTL reported the collection of any continuous, or intermittent, streamflow measurements within the study/exploration area, or in the larger area delineated by their numerical groundwater flow model (which includes numerous MODFLOW "drains" simulating the discharge of groundwater from the surficial aquifer into local streams and drainages); only stage

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[8] Note: At the location of UD338 and UD25, 0 – 50 ft bgs corresponds to at or above 120 ft amsl, or just below it (TTL 2019 "Geologic Characterization" report, Appendix D).

[9] Based on fundamental water budget considerations and given that groundwater outflow from any particular portion of the surficial aquifer should be assumed to be equal to or greater than zero (e.g., on the east side of Trail Ridge), the rate of recharge to the surficial aquifer must be equal to or greater than the baseflow of local streams/rivers; in this case, all streams/rivers exiting the watershed of the Twin Pines study/exploration area.

[10] HUCs 030702040301 (Soldiers Camp Island) and 030702040602 (Boone Creek).

[11] USGS Site No. 02228500, North Prong St. Marys River at Moniac, GA (USGS 2020).

measurements, most of which appear to be located in ephemeral channels (TTL's 2019 "Local Groundwater/Surface Water Hydrology" report, Figure 3 and Appendix C). With no lower constraint on the rate of recharge to the surficial aquifer (only an upper limit equal to the average rate of precipitation less evapotranspiration which assumes no runoff occurs to streams during rainfall events[12]), no reliable numerical groundwater flow model can be constructed that conclusively (or reliably) demonstrates that a topographically-induced groundwater divide exists, would persist, or would be reestablished through the full depth of the surficial aquifer now, during active mining, or post-mining, respectively. Specifically, given the lack of constraints on the rate of recharge to the surficial aquifer and rates of groundwater discharge from the aquifer to local streams/drainages, the predictive capacity of the numerical model and veracity of its impact predictions are greatly compromised *in the absence* of adequate groundwater level model calibration data (addressed in a later comment).

- **Preliminary identification of questions, issues, and uncertainties regarding the numerical groundwater flow model and current impact predictions:** Minimal information has been provided regarding the construction and calibration of the numerical (MODFLOW) model and subsequent impact simulations (TTL 2020 "Impact of the Proposed Twin Pines Mine on the Trail Ridge Hydrologic System" report; and Twin Pines Minerals/TTL 2020 permit application). As a consequence, these "highlights" are necessarily limited to a preliminary identification of questions, issues, and uncertainties affecting the calibration of the numerical model, its predictive capacity, and the veracity of its impact predictions. In lieu of additional explanatory text, the model files (MODFLOW input/output files, or preferably Groundwater Vistas files) would be helpful to this and other reviewers in developing a more complete set of comments if needed.

  - The use of ***indicator kriging to develop a distribution of hydrostratigraphic units*** (as a basis for an initial assignment of hydraulic conductivities within the model domain) is a technically valid approach; particularly in heterogeneous media including numerous lenses, and particularly if the development of a traditional deterministic geologic (in this case hydrostratigraphic) model through the construction of vertical sections is *infeasible* due to the sparsity of borehole information.

    Elements of the indicator kriging analysis and initial computation of hydraulic conductivities needing clarification.

    1. What was the source of lithologic data used to construct the variograms (or semivariograms) for the indicator kriging?

       The source of this data (71 "19-series" boreholes drilled in the southeast portion of the TIAA Tract in 2019) was clarified during a TTL presentation on 13 May, 2020, but is not easily located in the 2020 "model report" or "modeling section" of the permit application (if documented).

    2. How was information contained in the driller's logs for the "19-series" holes interpreted to evaluate the value of indicator functions for the 6 kriged sediment types[13] (i.e., "1" for sediment type present, "0 for sediment type not present)?

       Although fundamentally important to the outcome of the analysis, it is unclear how the U.S.C.S. designations (unified soil classifications) and detailed lithologic descriptions contained in the

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[12] The rate of precipitation minus evapotranspiration is only equal to the rate of groundwater recharge if no runoff occurs to streams during rainfall events; not generally the case within the region based on streamflow hydrographs published by Priest 2004. More specifically, runoff occurs to the North Prong of the St. Marys River during rainfall events based on the hydrograph for the only gaged site within the watersheds of the project area, the North Prong St. Marys River at Moniac, GA, Site No. 02228500 (USGS 2020).

[13] "Unconsolidated sand", "semi-consolidated sand", "consolidated sand", "silty-clayey sand", "clayey sand", and "clay" (TTL 2020 "Impact of the Proposed Twin Pines Mine on the Trail Ridge Hydrologic System" report, Table 1).

driller's logs for the "19-series" holes (TTL 2019 "Geologic Characterization", Appendix B) were interpreted to categorize sediments in a way that is consistent with the qualitative descriptions provided in the 2020 model report (pages 2-3) and permit application (Section 3.2) for 4 of the 6 sediment types[14]. Reproducible criteria for the evaluation of the "indicator functions" should be clearly described since the "link" between the lithologic data and kriging analysis.

3. *As a follow-up to the previous comment*: The "support" (spatial scale) of the borehole data used to determine the values of the indicator functions determines the scale of the variograms (scale at which correlation structure is characterized), which in turn determines the "scale" of the kriged sediment field and ultimately the scale of hydraulic conductivities initially assigned to the model – irrespective of the choice of kriging (or numerical model) grids. Given its implications for the "kriged field" and initial assignment of conductivities to the model, the "support" of information analyzed to evaluate the indicator functions and construct the variograms should be clarified.

4. The full set of directional experimental variograms for the 6 kriged sediment types should be provided in the 2020 model report and/or permit application, in addition to the estimated correlation lengths (Tables 2-3 of the 2020 permit application), since key to the evaluation of the kriging analysis.

5. The 2020 permit application (pages 21-22) indicates that for the purposes of the kriging analysis, no differentiation was made between black unconsolidated sands and consolidated sands without humate-staining. Although no experimental variograms have been provided for either in the 2020 model report or permit application, the directional variograms for both were presented at the May 13 public meeting. Given that the variograms and correlation lengths for black unconsolidated sand and unconsolidated sand without humate-staining are considerably different, the way in which these two sets of directional variograms were combined to create the variograms used to krig "unconsolidated sand" should be clarified.

6. The reason for selecting the 71 "19-series" holes (installed in 2019) as the source of lithologic data for the development of variograms, rather than some or all of the 385 "18-series" exploratory holes (installed, logged and assayed in 2018/2019)[15], should be clarified. Presumably the "19-series" holes, concentrated in the southeast portion of the TIAA Tract on the west side of Trail Ridge, were chosen in anticipation of the correlation lengths of the kriged sediment types being less than the distance between many of the "18-series" holes.

7. What boreholes (presumably some subset of the 385 "18-series" exploratory holes) were used as locations of "known" lithology (i.e., "measurement points" in kriging parlance) around which the kriging was performed? Neither their existence, nor locations, are discussed or shown in the 2020 model report or permit application, although key to the kriging analysis and outcome.

8. For the reading public, it would be helpful to clarify that indicator kriging was used to generate probability maps for the *occurrence of each of the 6 kriged sediment types* (their probabilities normalized to a total of 1.0 within each cell "block kriged") – rather than the initial estimates of hydraulic conductivity being a direct result of the kriging process. The former, in combination with hydraulic conductivities attributed to each of the 6 chosen sediment types in Table 1 (2020 model report and permit application) were used in a second step to compute average horizontal (and vertical) conductivities within the blocks of the kriging grid (which in this case are

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[14] For example, "unconsolidated sand" is described as "generally consisting of silty sands (SM) and well sorted sands (SP)"; the latter also recognized as key components of "semi-consolidated sand" (SM, SP, and SC-SM), "consolidated sand" (SM and SP), silty-clayey sands, etc. – the distinction largely related to the predominance of fines and subjective evaluations of the degree of consolidation?

[15] See Figures 4 versus 3 in TTL's 2019 "Geologic Characterization" report.

coincident with the cells of the MODFLOW model). As such, the initial distribution of conductivities assigned to the model was greatly influenced by the values of conductivities attributed to each of the kriged sediment types in Table 1.

9. The basis for the hydraulic conductivities attributed to each of the 6 sediment types in Table 1 (presumably representative of horizontal conductivities) is unclear. Text of the 2020 model report and permit application describes the hydraulic conductivity values assigned in Table 1 as being consistent with those estimated from the two pumping tests and 23 slug tests performed in the study area in 2019; and also provides an example of representative conductivities (K_h = 6.36E-3 centimeters per sec (cm/s) and K_v = 2.60E-4 cm/s). The origin of the latter is unclear based on information provided in TTL's 2019 "Hydrogeologic Field Characterization" report). Moreover, there is no clear correspondence between the hydraulic conductivities attributed to any of the 6 sediment types in Table 1 and hydraulic conductivities estimated from the two pumping tests or 23 slug tests (as reported in the TTL report); nor does there appear to be a basis for arriving at such hydraulic conductivity values based on this reviewer's further analyses of the pumping and slug test results[16].

   If the conductivity values attributed to each of the 6 sediment types in Table 1 are assumed, the latter should be disclosed, along with any implications (or lack thereof) for the final calibrated model and subsequent impact simulations.

10. Text describing the application of indicator kriging (if it is to be retained) should be expanded to include a discussion of steps taken to evaluate whether the assumption of second-order stationarity with finite variance is satisfied by the indicator values used to construct the variograms and perform the kriging; or whether, at a minimum, the "intrinsic hypothesis" is satisfied as described by de Marsily 1986 (page 291) – that is, whether the variances of the first-order increments of the interpreted indicator values are finite and their increments second-order stationary. Or if not (or such an analysis was not undertaken), was kriging in "neighborhoods" considered as a means of improving the likelihood of satisfying the assumption of second-order stationarity or second-order stationarity in the increments (an underlying assumption of the kriging theory employed).

11. Some of the information provided in the 2020 permit application regarding the construction and calibration of the model and outcome of the numerical modeling is not included in the 2020 model report, and visa versa; making it difficult to follow what information is available. In addition to expanding on the information currently provided, all of the relevant information should be accessible in one document.

Issues related to the indicator kriging and computation of initial estimates of hydraulic conductivity assigned to the model.

12. *Potential effects of basing indicator kriging on lithologic data obtained from boreholes limited to the southeast portion of the TIAA Tract, west side of Trail Ridge*: Notwithstanding that there appear to be issues with the interpretation of the PWB and PWA pumping tests[17], the reported

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[16] Specifically, given the completion (sandpacked) intervals of the wells and piezometers used in the pumping and slug/bail tests (TTL 2019 "Geologic Characterization" report, Appendices E and F), it is unlikely that hydraulic conductivity estimates from these field tests can be attributed specifically to, for example, "unconsolidated sand" versus "semi-consolidated sand" (both of which occur in many of the test intervals).

[17] The Newman-Witherspoon solution (1969) was inappropriately applied to an unconfined problem. In some cases, application of Newman's unconfined/delayed-gravity response solution (1974) resulted in parameter estimates that appear to be unreasonable and in other respects inconsistent (TTL 2019 "Hydrogeologic Field Characterization" report, Tables 4 and 5); e.g., specific yield estimates range from one extreme value to another (0.50 or 0.02); vertical conductivity of aquitard estimated where no aquitard exists.

results suggest that the hydraulic conductivities of sediments on the west side of Trail Ridge are lower than on the east side of the ridge and along the ridgeline (TTL 2019 "Hydrogeologic Field Characterization" report, Tables 4 and 5); the difference likely depositional in origin. Because of the significance of this finding, this reviewer has further analyzed the results of TTL's slug tests to confirm the same[18]; i.e., the hydraulic conductivity of sediments on the west side of the ridge are about one-third that on the east side of the ridge and along the ridgeline (above 120 ft amsl) – both sets of estimates essentially field-scale.

To the extent that horizontal and vertical conductivities are lower in the vicinity of the "19-series" holes than at other locations in the study area and model domain because of the predominance of certain lithologies (e.g., clays, clayey sands, etc.), and differences in the lateral or vertical continuity of those lithologies, the data interpreted to evaluate the indicator functions for several of the kriged sediment types (clays, clayey sand, and silty-clayey sand) were likely not second-order stationary, *or* second-order stationary in the increments, as required by kriging theory (de Marsily 1986) – in addition to not being stationary in the mean.

Had this kriging analysis succeeded in other respects (see comments Nos. 13-15), the use of variograms constructed using indicator values based on the lithology of the "19-series" holes might have led to the underestimation of hydraulic conductivities at many locations within the model domain; e.g., along the ridgeline and east side of Trail Ridge. Alternatively, it might have been possible to improve the second-order stationarity of the analysis by, for example, kriging within "neighborhoods". However, even if a more refined kriging grid had been employed, kriging in neighborhoods was unlikely to succeed for reasons provided in comment No. 15. At a minimum, the potential effects of this nonstationarity on the kriged distribution of hydro-stratigraphic units and initial assignment of hydraulic conductivities to the model should be acknowledge/discussed.

13. *Regarding the distribution of the initial horizontal conductivity estimates*: First, the units of horizontal hydraulic conductivity provided in the legends of Figures 15-29 (and likely Figures 32-46 and 49-63) of the 2020 model report (and Figures 44-46, and likely Figures 49-51 and 54-56, of the 2020 permit application), depicting the initial assignment of horizontal model conductivities (and model-calibrated values and simulated post-mining values), are in error. Rather than units of feet per second (as shown), the units must be cm/s since the highest initial value assigned to a cell cannot be higher than the highest value attributed to the 6 sediment types in Table 1.

    Having established this, the vast majority of the initial horizontal conductivity estimates (depicted in Figures 15-29) are value 0.7E-2 cm/s, a little less than the 1.0E-2 cm/s attributed to "unconsolidated sand" in Table 1. This makes physical sense in that the vast majority of sediments encountered during drilling are in fact unconsolidated sands. However, in order for kriging (the interpolation process) to produce this result, one or both of the horizontal correlation lengths attributed to "unconsolidated sand" would have to be greater, if not much greater, than the size of the cells on which the block-kriging was performed (> 500 x 500 ft). Additionally, it also appears that many of the "18-series" boreholes were used as locations of "known" lithology ("measurement points" around which the kriging was performed) in order to produce this result, although this information is not provided.

    Two issues arise in this connection. First, a correlation length >> 500 ft for "unconsolidated sand" is inconsistent with the experimental variograms constructed for either black unconsolidated sand

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[18] Hydraulic conductivities estimated from TTL's slug tests (effectively field-scale given test intervals of 7 to 12 ft) are on average lower on the west side of Trail Ridge, geometric means 8.1 f/t and 1.7 ft/d above and below 120 ft amsl, respectively; than on the ridge and east side of the ridge, where the geometric mean conductivities are 9.2 ft/d and 4.4 ft/d above and below 120 ft amsl.

or unconsolidated sand without humate-staining. These two variograms (and their estimated correlation lengths), both presented during the May 13 public meeting, have been combined in some way to create the directional variograms and establish the correlation lengths use to krig "unconsolidated sand". Secondly, the initial horizontal conductivity estimates with a value 0.7E-2 cm/s extend well beyond the area of the relatively densely-spaced "18-series" exploratory holes, all the way to the edges of the model domain – that is, into areas where piezometers and other holes/wells of "known" lithology (potential "measurement points" for the kriging) are relatively sparse. The only apparent explanation for the predominance of 0.7E-2 cm/s initial horizontal conductivity estimates throughout so much of the model domain (Figures 15-29 of the 2020 model report) is that the correlation length(s) attributed to "unconsolidated sand" were considerably larger than the size of the kriging blocks (>> 500 ft). Since the correlation lengths attributed to "unconsolidated sand" are unknown to this and other reviewers (not listed in Table 2 of the 2020 permit application), the reasonableness of the initial horizontal conductivities assigned to the model cannot be evaluated.

14. *As a follow-up to the previous comment*: Non-0.7E-2 cm/s values within the field of initial horizontal conductivity estimates (Figures 15-28 of the 2020 model report) occur largely at isolated locations (within isolated kriging blocks), except for the area of the densely-spaced "19-series" holes. This appears to be due to the resolution of the kriging grid (roughly 500 x 500 ft) *compared to* most of the horizontal correlation lengths estimated for the other 5 kriged sediment types ("unconsolidated sand" excluded)[19]. Where the horizontal correlation lengths of a sediment type identified at a location considered to be of "known" lithology (a borehole, piezometer, or well serving as a "measurement point" for the kriging interpolation) are less than the distance from the center of the kriged block to the center of its neighboring blocks (< 500 ft), no interpolation occurred; giving rise to isolated values that are incongruous with those in the surrounding blocks.

    In support of this hypothesis (and in lieu of a more complete description of the kriging analysis): (i) at least some of the locations where isolated non-0.7E-2 cm/s values occur repeat from layer to layer (see Figures 15-28); and (ii) this also explains the proliferation of non-0.7E-2 cm/s values in the area of the densely-spaced "19-series" holes. As such, this reviewer concludes that the kriging analysis was *unsuccessful*; due in significant part to the choice of kriging grid, which was efficient in that it coincided with the grid on which the MODFLOW model was constructed, but otherwise unsuitable given that it undermined the intended interpolation.

15. *Regarding the usefulness of the kriging analysis*: The kriging analysis was unsuccessful due to the choice of the kriging grid relative to the magnitude of the horizontal correlation lengths of many of the sediment types chosen for indicator kriging; possibly complicated by issues related to the second-order stationarity of the kriged indicator values (which was neither identified nor mitigated). However, even if a more refined kriging grid had been employed and steps taken to mitigate second-order nonstationarity, indicator kriging (of the chosen sediment types) was unlikely to produce desirable (defensible) results in those portions of the model domain located outside the area of the relatively densely-spaced "18-series" holes; if only because the distance between the available piezometers and other holes/wells in those areas ("measurement points" around which the kriging must be performed) generally exceeds the horizontal correlation lengths of most of the kriged sediment types. This necessarily limits the success of kriging between locations where mining has been contemplated (the vicinity of the 385 "18-series" exploratory

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[19] Based on the experimental variograms and correlation lengths presented for the other 5 sediment types during the May 13 public meeting, only "silty-clayey sand" has a horizontal correlation length that is significantly greater than the size of the blocks over which the kriging was performed (912 ft, azimuth 30 degrees), and only "semi-consolidated sand" possesses a horizontal correlation length that is somewhat greater than the size of the kriging blocks utilized (624 ft, azimuth 60 degrees).

boreholes) and Okefenokee Swamp and the wetlands to the south and east of the swamp; roughly one quarter of the model domain and most of the TIAA Tract.

16. *Regarding the computation of initial vertical hydraulic conductivity estimates*: Based on a literal reading of the explanation provided in the text of the 2020 model report and permit application, the initial assignment of horizontal hydraulic conductivities within each block of the kriged field (coincident with the cells of the MODFLOW model) were calculate as the arithmetic mean of the sediment type conductivities assigned in Table 1, weighted by the kriged probability of each sediment type being present in the kriged block. Similarly, the text states that the initial assignment of vertical hydraulic conductivities within each block of the kriged field (and cell of the MODFLOW model) were calculated as the harmonic mean of sediment type conductivities assigned in Table 1, weighted by the kriged probability of each sediment type being present in the kriged block.

    This was equivalent to assuming that each of the sediment types with a probability of being present in the kriged block were encountered "in parallel" by groundwater flowing within the x-y plane of the model (in this case a model layer), which is physically tenable given flat-lying sand strata observed elsewhere within Trail Ridge and other paleobarrier complexes[20]. Regarding the estimation of vertical hydraulic conductivities, the computation of harmonic means is equivalent to assuming that each sediment type with a probability of being present in a kriged block (also a model cell) is encountered "in series" by groundwater flowing in the "z"-direction, which again is physically tenable given generally flat-lying strata within the ridge. However, it appears that the values used to compute the harmonic mean vertical conductivity estimates (values assigned in Table 1) are on the order of horizontal hydraulic conductivities for the sediments under consideration (although nowhere clearly stated); rather than vertical conductivities which are much lower for the sediments of Trail Ridge based on TTL's interpretation of the two pumping tests conducted in the study area[21].

    The harmonic mean vertical hydraulic conductivity estimates should have been calculated using conductivities derived from a table analogous to Table 1 (2020 model report and permit application), but with values approximating vertical conductivities for the 6 kriged sediment types. Although no single sample is representative of an entire class of sediments, as a first approximation, at least one sample of each of the 6 sediment types could and should have been collected in the field (uncontaminated by drilling fluids containing bentonite) and tested in the laboratory as a basis for assigning reasonable representative values of vertical hydraulic conductivity to the 6 kriged sediment types.

17. *Regarding the computation of initial vertical hydraulic conductivity estimates using values corresponding to horizontal conductivities:* The initial vertical conductivity estimates assigned to the numerical model, based in part on the kriging analysis, are nowhere disclosed in the 2020 model report or permit application. However, given that they are described as being computed using the values listed in Table 1, it appears that the initial assignment of hydraulic conductivities to the model was essentially isotropic (i.e., horizontal and vertical conductivities the same order of magnitude); potentially biasing the calibration of the model and simulations of pre- and post-mining groundwater levels in ways that have not been discussed. Additionally, to the extent that

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[20] As shown on the cover and Figure 3 of Van Gosen and Ellefsen 2018, the cover and Figures 1 and 2 of Van Gosen et al. 2014, and the cover of Kellam et al. 1967.

[21] Whereas there appear to be issues with the interpretation of the PWA and PWB pumping tests[17], the results of analyses performed using Neuman's unconfined delayed-gravity response solution (TTL 2019 "Hydrogeologic Field Characterization" report, Tables 4 and 5) suggest that K_v's are about 30-fold smaller than K_h's for sediments on the east side of Trail Ridge (and along the ridgeline), and K_v's are even smaller (and a smaller fraction of K_h's) for the sediments on the west side of the ridge – based on this reviewer's further analysis of the pumping test results.

vertical conductivities in the final calibrated model (translated into MODFLOW specific terms) exceed real values, the model would tend to simulate topographically-induced flow cells that extend deeper into the surficial aquifer (than they may occur); but consistent with the hypothesized groundwater divide and proposed conceptual model (Figure 4 of the 2020 model report and permit application).

18. *Regarding the influence of the initial conductivity estimates (horizontal and vertical) on the final calibrated model*: The influence of the initial conductivity estimates (horizontal and/or vertical) assigned to the model, or lack thereof, depends on the adequacy of the model calibration data (groundwater level measurements in this and most cases), nature of the objective criterion and other constraints imposed on the model calibration (e.g., pilot point locations and values), and degree of optimization achieved. Because the groundwater level data used to calibrate the model were spatially (as well as temporally) inadequate, and the objective function and other constraints imposed on the optimization of the model have only been described in the broadest of terms (2020 model report and permit application), it is unclear to what degree, if any, the initial conductivity estimates assigned to the model influenced the final configuration of model-calibrated conductivities (or subsequent impact simulations).

Alternative to indicator kriging to arrive at an initial assignment of hydrostratigraphic units and conductivities in the model.

19. It is unclear why kriging (indicator or otherwise) based on lithologies identified in boreholes limited to the southeast portion of the TIAA Tract, known to be of lower conductivity and representing less than 2.5 percent of the modeled area, was undertaken as the starting point for the model development in lieu of a traditional deterministic geologic (in this case hydrostratigraphic) model based on the construction of vertical sections using lithologies logged in the available boreholes: 385 “18-series” exploratory boreholes logged and assayed by Twin Pines in 2018/2019, plus the 71 “19-series” boreholes installed and logged in 2019 (ultimately used for the kriging); all together, a total of 456 logged boreholes that effectively and densely cover the portion of the model domain in which mining has been contemplated[22] (TTL 2019 “Geologic Characterization” report, Figures 3 and 4).

    The kriging undertaken gave rise to a number of issues and ultimately was unsuccessful. Moreover, it seems unlikely that indicator kriging could be successful if revisited for reasons provided in comment No.15. Notwithstanding the challenge of interpreting lithologic contacts in numerous boreholes to construct a three-dimensional hydrostratigraphic model (undertaken routinely at hardrock mines), an effort to arrive at an intentionally simplified interpretation of the hydrogeologic structure of the surficial aquifer (a preferable starting point in any case in this reviewer’s experience), based on actual observations and professional judgement, could pay dividends in terms of arriving at a physically plausible, more clearly scientifically defensible numerical analysis of what is unavoidably a nonidentifiable problem. The other argument for such an approach is that the alternative is the assignment of some choice of homogeneous horizontal and vertical conductivities based on, for example, the properties of “unconsolidated sand” as characterized in the pumping and slug tests, and letting the optimization “do the work”. However, even this is unlikely to yield reliable results due to the inadequacies of the available groundwater level calibration data (and lack of constraints in terms of stream baseflow measurements), as discussed in later comments.

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[22] The whole of the Keystone, Dallas Police & Fire, Loncala, most of the Adirondack, and the southeastern portion of the TIAA tracts.

***Preliminary comments regarding boundary conditions, the calibration of the model, model-calibrated hydraulic conductivities, and the simulation of post-mining conditions*:**

In view of the volume of comments to follow and lack of detailed information provided in the 2020 model report and "modeling" section of the 2020 permit application (and also in the interest of time), these comments are provided in the form of "highlights" with information added only where necessary to clarify the issue.

- Comments regarding the *assignment and/or calibration of model boundary conditions*:

20. *Issues related to the assignment of lateral boundary conditions*: Heads prescribed on the west and east boundaries of the model are described as one foot below land surface, and at the same time "constant" (2020 model report, page 4 and Figure 10). Whereas groundwater levels appear to be relatively constant along the west model boundary (roughly 118 ft amsl based on a digital elevation model constructed using Lidar data collected by NOAA for the State of Georgia); the latter, as well as surface elevations shown in Figures 15-29, 32-46, and 49-63 of the 2020 model report, clearly show that the land surface, and presumably the elevation of the water table, are not constant along the east model boundary. First, it is unclear whether heads prescribed on the west and east model boundaries, respectively, are actually constant in space, or only time – the terminology "constant head boundary" normally reserved for instances in which head is constant in space, as well as time. Secondly, the prescribed (or constant) heads assigned on the west and east boundaries have not been provided.

21. *Issues related to the assignment of areally-distributed groundwater recharge*: As discussed in some detail in an earlier "highlight", the rate of groundwater recharge (recharge to the water table) in the vicinity of the Twin Pines study/exploration area and numerical model domain, Trail Ridge generally, or indeed elsewhere in the region, is unknown.

    Regarding the manual (trial-and-error) calibration of the rate of groundwater recharge, it is unclear whether groundwater level measurements were used as part of that calibration, or the calibration of recharge was only conditioned on the perceived reasonableness of simulated leakances to the modeled streams (i.e., the "drains"). Second, given that the calibration of groundwater recharge was judged to be complete based, perhaps among other things, on the "reasonableness" of the simulated leakances to the modeled streams, it follows that the model-calibrated value of recharge is uncertain if only because no information is available from which to judge the "reasonableness" of the simulated leakances; i.e., no baseflow flow estimates, which are required to compute leakance rates, have been made for any stream/ephemeral channel in the model domain (see comment No. 22).

    Lastly, the rate of groundwater recharge was initially set to the difference between the annual average rate of precipitation, less the annual average rate of evapotranspiration, at the site without clarifying that this only approximates the rate of groundwater recharge if *no runoff* occurs to local streams during rainfall events – a claim not made in describing this site and condition that, at a minimum, may not be universally true in the vicinity of the site/model domain. For example, the hydrograph for USGS Site No. 02228500 (USGS 2020) suggests that storm runoff in excess of baseflow occurs regularly on the North Prong of the St. Marys River at Moniac, GA, near the site. Moreover, the usefulness of stream baseflows as a lower constraint on the rate of groundwater recharge is not discussed, nor the lack of baseflow estimates for any stream, river, or other drainage in the model domain.

22. *Issues related to the assignment of point sink boundary conditions (i.e., MODFLOW "drains")*: Notwithstanding that it is unclear how many, or in some cases which, of the MODFLOW "drains" incorporated in the numerical model represent ephemeral channels versus perennial streams (by

comparison to the USGS Hydrography Plus Version 2.1 dataset), key parameters determining the effect of the modeled streams (i.e., amount of water carried out of the model domain by the simulated streams) are not provided in either the 2020 model report or permit application. Specifically, neither the depths of the "drains" below land surface (elevations of the center of the drains), nor the MODFLOW "conductance(s)" assigned to drains or various sections of drains, are described. Without this information, the effect of the "drains" on the trial-and-error (manual) calibration of groundwater recharge, the subsequent calibration of hydraulic conductivities, and finally simulations of pre- and post-mining conditions, cannot be assessed even in the most qualitative sense.

- Comments regarding the ***adequacy of the model calibration data***:

23. *Issues related to the spatial inadequacy of the available groundwater level calibration data*: The spatial distribution of groundwater level measurements collected on 26 July, 2019 (or any of the individual dates reported in 2019, January through September; TTL 2019 "Local Groundwater/Surface Water Hydrology" report, Table 4) are not adequate to calibrate hydraulic conductivities within the model domain; nor can such data be collected using the existing piezometers and monitoring wells due to the completions/locations of the piezometers/wells relative to the thickness of the surficial aquifer (as described in an earlier "highlight").

24. *Issues related to the temporal inadequacy of the groundwater level data used to calibrate hydraulic conductivities*: The groundwater level measurements used to calibrate conductivities were limited to a single day in a single season and single year: 26 July, 2019. Precipitation, less evapotranspiration, is typically at a seasonal low in the month of July (Rykiel 1976, Appendix A, Tables 33 and 34), and groundwater levels are often at a minimum in June or July and trending downward before trending upward (TTL 2019 "Local Groundwater/Surface Water Hydrology report, Table 4). As such, groundwater levels collected on 26 July, 2019 were transient and are not an appropriate basis for the calibration of a groundwater model based on the solution of the equation for steady (nontransient) groundwater flow, devoid of storage coefficients. Nor can the model be said to possess the capacity to predict the long-term behavior of the system.

    At best, the model-calibrated hydraulic conductivities would be unbiased by such a calibration if the groundwater recharge prescribed during the calibration corresponded to the actual rate of recharge on or just prior to the date on which the data were collected – which is unlikely in this case given that the rate of recharge was initially set to the difference between the *annual average rate* of precipitation, less the *annual average rate* of evapotranspiration, follow by a weakly constrained calibration, the nature of which is not clear. Failing that, any lack of compatibility between the recharge rate imposed during the calibration of conductivities versus actual conditions on 26 July, 2019 were offset by errors in the estimated conductivities (see comment No. 26).

25. *Bias related to the incorporation of "soft" groundwater level calibration targets*: The reason provided for incorporating 19 "soft targets" to the groundwater level calibration dataset (enumerated in Table 2 of the 2020 model report) is that initial simulations performed (using the manually-calibrated groundwater recharge rate?) resulted in water above land surface in areas where the groundwater level calibration data were sparse or absent (2020 model report, page 6). As always when this happens during the calibration of a model, there was information in this. However, in this instance the "excess water" may have simply been discharged to the simulated streams ("drains"), while the recharge rate remained too high and/or model-calibrated hydraulic conductivities remained too low.

26. *Issues related to uncertainties in the rate of recharge during the calibration to groundwater level data collected on 26 July, 2019*: To the extent that the rate of groundwater recharge imposed

during the calibration of conductivities to groundwater level measurements collected on 26 July, 2019 was not representative of the rate of recharge actually occurring on or just prior to 26 July, errors were created in the model-calibrated conductivities, the nature and magnitude of which is unknown and cannot be determined. Additionally, to the extent that the rate of recharge imposed during the calibration of conductivities was uncertain due to the effects of the incorporated MODFLOW "drains" (see comment No. 22), it follows that this also introduced uncertainties/errors in the model-calibrated conductivities.

- Comments regarding the ***trial-and-error calibration of groundwater recharge***:

27. *Lack of information regarding the rate of groundwater recharge in the proposed project area, Trail Ridge generally, or within the region*: The lack of independent estimates of the rate of groundwater recharge in the vicinity of the Twin Pines study/exploration area and model domain, Trail Ridge generally, or elsewhere in the region is not disclosed/discussed; albeit a pivotal input to the development of the calibrated model and subsequent impact simulations.

28. *Information regarding the implications of using the rate of precipitation, less the rate of evapotranspiration (annual average or otherwise), as the starting point for the calibration of groundwater recharge*: Not provided or discussed (also see comment No. 21).

29. *Lack of clarity regarding how the rate of recharge could be manually calibrated to reproduce leakance rates into streams when leakance rates are unknown;* i.e., no baseflow estimates (required to calculate leakance rates) available for any streams in the model domain: Self-explanatory.

30. *Lack of clarity regarding the utility of a recharge rate for the purpose(s) of predictive simulations/analyses which appears to have been "calibrated" based on the perceived reasonableness of simulated leakance rates to modeled streams*: Also addressed in comments Nos. 21 and 22.

- Comments regarding the ***objective criterion and other constraints imposed during the optimization of hydraulic conductivities***:

31. *Lack of clarity regarding the objective criterion employed*: The objective criterion utilized during the PEST optimization of hydraulic conductivities is not provided.

32. *Lack of clarity regarding other constraints imposed during the optimization of hydraulic conductivities*: Pilot points were employed as a constraint on the PEST calibration of hydraulic conductivities (2020 model report, page 5). This same text implies that pilot points may have been assigned in every cell of the model (i.e., every "grid block" in which the indicator kriging was performed), and that the values assigned to the pilot points were the initial values of horizontal and vertical conductivities computed at the conclusion of the kriging exercise using the assumed conductivity values listed in "Table 1" (commented on extensive in earlier "highlights"). First, pilot points are not typically assigned to every cell of a model, which could constrain the optimization to measured groundwater levels to an undesirable degree given that the initial estimates of conductivity are uncertain and not conditioned on actual observations. Although the weights applied to the pilot point values during the PEST optimization are not provided, it follows that the influence of the initial assignment of horizontal and vertical conductivities on the final calibrated conductivities may have been significant after all and contributed to issues identified in comments Nos. 39-42.

33. *Inadequate information regarding whether adjustments to "PEST parameters" were attempted during the model calibration, or PEST was only run once*: Neither the text of the 2020 model

report or permit application indicate that any efforts were made to adjust PEST parameters during the optimization of hydraulic conductivities. Moreover, Figure 30 of the model report (Figure 47 of the 2020 permit application) suggests that PEST may have only been run once – or this is at least unclear given that both lambdas and the value of the objective criterion are reported at the completion of every iteration during a single PEST run.

34. *Alternative constraint on the optimization of hydraulic conductivities*: An alternative, and often utilized, constraint on the optimization of conductivities is the assignment of pilot points at the locations of hydraulic field tests, values assigned to the pilot points set equal to analytical parameter estimates based on the interpretation of the tests – highly recommended in any revision of this model, specifically using conductivities estimated from TTL's slug tests.

- Comments regarding the ***fit of simulated to observed groundwater levels by the final calibrated model***:

35. *Inadequacy of information provided regarding groundwater level residuals produced by the final calibrated model*: No map(s) showing the final groundwater level residuals (i.e., observed groundwater levels, minus those simulated by the model) as a function of location have been provided, but is essential for adequate review of a model (consequently typically provided). Rather, only Figure 31 of the 2020 model report (Figure 48 of the 2020 permit application), showing an x-y plot of simulated versus observed heads and summary statistics, including but not limited to the root mean squared error, has been made available (see comment No. 45 for implications).

36. *In view of the proposed conceptual model, groundwater level residuals produced by the final calibrated model should be depicted in both map view and vertical cross-section(s)*: Given the proposed conceptual model and hypothesized existence of a topographically-induced groundwater divided through the full thickness of the surficial aquifer (pre- and post-mining), the modeling report should include maps showing both the areal and vertical distributions of head residuals, respectively.

- Comments regarding the ***lack of standard sensitivity runs***:

37. *Lack of standard sensitivity runs to key boundary conditions*: No sensitivity runs, a standard following model calibration, have been provided. At a minimum, runs assessing the sensitivity of simulated groundwater levels (head) to the rate of groundwater recharge, elevations of MODFLOW "drains" simulating streams (specifically, their depths below land surface), "conductances" assigned to the MODFLOW "drains", and any simplifications employed to prescribe head on the lateral model boundaries (east and west), should have been provided – key information without which the sensitivity of the model calibration to the prescribed boundary conditions (largely assumed) cannot be judged.

- Comments regarding ***water budget information provided for the final calibrated model***:

38. *Inadequacy of "zone budget" information provided for the final calibrated model*: Whereas water budget information for simulated pre- and post-mining conditions have been summarized for groundwater recharge to the surficial aquifer on the east and west sides of Trail Ridge, respectively; no water budget information has been provided for zones of the prescribed (presumably not constant) head boundaries; and equally important, no water budget information has been provided in zones for the multiple streams simulated as carrying water out of the model domain.

- Comments regarding the ***distribution of final model-calibrated hydraulic conductivities***:

39. *Physically untenable discontinuity in the model-calibrated horizontal conductivities coincident with the northern boundary of the 2020 permit and proposed mining area*: See Figures 32-43 of the 2020 model report.

40. *Physically untenable discontinuity in the model-calibrated horizontal conductivities at the periphery of the ridgeline just north of the 2020 permit and proposed mining area in Figures 33-43 of the 2020 model report*. Notwithstanding that the model-calibrated conductivities with values 1E-4 cm/s (0.28 ft/d) represent sediments closer to the land surface than the adjacent cells with model-calibrated conductivity values 1E-1 cm/s (283 ft/d) within this sequence of model layers (and the TTL slug tests indicate that the conductivity of sediments is markedly lower close to the land surface than at somewhat greater depths), the depicted three order of magnitude contrast in conductivity is inconsistent with anything observed in the field tests.

41. *Physically untenable vertical uniformity of model-calibrated horizontal conductivities at all locations in the surficial aquifer/model domain; i.e., vertically "through" all 15 model layers* – which is physically untenable given the depositional environment and additionally inconsistent with TTL's interpretation of the 2019 slug tests: See Figures 32-46 of the 2020 model report (particularly concerning).

42. *Lack of consistency of model-calibrated horizontal conductivities with trends identified based on the pumping and slug tests*: Specifically, with respect to both their areal distribution (values on the east side of Trail Ridge and along the ridgeline versus west side of the ridge), and as a function of elevation (above and below the identified 120 ft amsl conductivity threshold which appears to coincide with model layer 8): See Figures 33-43 of the 2020 model report.

43. *Information regarding the values and distribution of model-calibrated vertical conductivities*: Not provided.

44. *Issues regarding the effects of uncertainties in the simulated rate of recharge on the model-calibrated hydraulic conductivities (horizontal and vertical) and predictive capacity/reliability of the final calibrated model*: Significant, but not discussed.

45. *Root mean squared error of acceptable magnitude despite all of the above (and why)*: The root mean squared error described in Figure 31 of the 2020 model report (Figure 48 of the 2020 permit application) is of acceptable magnitude despite physically untenable model-calibrated (horizontal) conductivities described in comments Nos. 39-42, and lack of information regarding the model-calibrated vertical conductivities described in comment No. 43; the former possible in this case because of the spatial inadequacies of the groundwater level calibration data and lack of constraints on the rates of discharge to model-simulated streams and simulated recharge.

- Comments regarding the ***model-simulated pre-mining configuration of groundwater flow versus the proposed conceptual model***:

46. *Description of the model-simulated pre-mining configuration of groundwater flow limited to the water table*: Given the conceptual model proposed by the project proponent, and purpose(s) of the numerical groundwater flow modeling (not limited to anticipating impacts to the water table given the proximity of Okefenokee Swamp), contour maps should also be provided depicting the model simulated heads and implied directions of groundwater flow: (i) at several depths in the surficial aquifer, including the bottom 10 to 15 percent or 5 to 7 ft; and (ii) vertical cross-sections (oriented west-east perpendicular to the ridgeline).

47. *Depiction of model-simulated heads and implied groundwater flow directions needed in map view at several depths in the surficial aquifer, and particularly in vertical cross-section(s)* – key to evaluating the consistency between the proposed conceptual model (2020 model report and permit application, Figure 4) and pre-mining configuration of groundwater flow predicted by the final calibrated model.

- Comments regarding the ***simulation of mining and post-mining conditions***:

48. *Implications of restricting the simulation of mining to 119 ft amsl*: The simulation of mining and replacement of native sediments with processed mine tailings to 119 ft amsl is roughly consistent with the depth of mining proposed in the 2020 permit application; however, provides no insights into the potential impacts of the 2019 Phase 1 proposal, or mining elsewhere in the 12,000 acre study/exploration area (as described in earlier "highlights").

49. *Implications of using a groundwater recharge rate calibrated to groundwater level measurements collected on July 26, 2019 to simulate post-mining conditions*: The groundwater recharge rate calibrated at the outset of the model calibration process was used to simulate groundwater levels, and changes in groundwater levels, under post-mining conditions post-2019. Inasmuch as the groundwater recharge rate, which was presumably calibrated to groundwater level measurements collected on July 26, 2019 (as well as the "reasonableness" of simulated leakance to modeled streams) may not be representative of average post-mining conditions, the effects of that potential incompatibility on the results of the post-mining simulation should be discussed.

50. *Physically untenable horizontal conductivity assigned to processed mine tailings above 119 ft amsl in the area of the proposed "demonstration" mine for the prediction of post-mining conditions:* The horizontal conductivity assigned in the area of the proposed "demonstration mine" above 119 ft amsl for the simulation of post-mining conditions is an order of magnitude lower than most of the model-calibrated horizontal conductivities in the same area (see Figures 32-37 versus Figures 49-54 of the 2020 model report) – a physically untenable assumption given that the conductivity of processed mine tailings (clay and humic content diminished) should be higher than that of the native sediments. Specifically, the value used to simulate processed mine tailings was 1E-3 cm/s. This conductivity value, in turn, appears to be based on the outcome of a single laboratory-scale permeability test of a composite sample from holes UD338 and UD25 (TTL 2019 "Laboratory Test Data", Table 6); notwithstanding that the sample is documented as potentially containing residual bentonite from drilling (TTL 2019 "Laboratory Testing Data" report, page 7, para. 2), which has been confirm in an earlier "highlight".

51. *No disclosure of the vertical conductivities assigned to processed mine tailings in the area of the proposed "demonstration" mine*: Although they should be roughly the same as the horizontal conductivities used to simulate processed mine tailings, they are not disclosed.

52. *Effect of under-simulating the horizontal (and possibly vertical) conductivity of processed mine tailings on the predicted areal extent of changes in the post- versus pre-mining elevation of the water table*: Replacement of native sediments with higher-conductivity processed mine tailings should not result in an increase in the elevation of the water table (based on fundamentals of groundwater flow). Rather, it appears that the horizontal, as well as possibly the vertical conductivities, assigned to simulate processed mine tailings were low, inasmuch as the elevation of the water table has been predicted to increase (2020 permit application, Figure 58), contrary to what should be expected. Additionally, because the horizontal conductivities assigned to the simulated mine tailings was low (comment No. 50), but is also unknown to date (addressed in detail in an earlier "highlight"), the simulation of post-mining conditions cannot be revised/improved at this time and changes in the elevation of the water table in the area of wetlands south and east of Okefenokee Swamp (and the swamp itself) remains undetermined.

53. *Simulation of drawdown created by dewatering of open pits during active mining*: The current numerical model cannot be used to simulate drawdown created by dewatering of the open pits (moving or otherwise) since no storage coefficients have been estimated as part the model calibration to *assumed steady-state conditions*. However, it follows that if the horizontal conductivities attributed to processed mine tailings in the numerical simulation (which are at least an order of magnitude too low) were also employed in the analytical modeling performed by TTL (not yet evaluated in detail by this reviewer), the areal extent of the predicted drawdown created by pit dewatering may have been significantly underestimated, unless compensated for by assigning overly high storage coefficients.

Implications of the above for the predictive capacity of the final calibrated model and veracity of the current impact predictions: Issues identified with the assignment and/or calibration of boundary conditions, including point sinks (drains simulating discharge to streams), the adequacy of the groundwater level calibration data (spatially and temporally), the lack of clarity regarding the optimization process or outcome, and deficiencies in the simulation of post-mining conditions (comments Nos. 20-53) are numerous and substantial. As a consequence, the predictive capacity of the calibrated numerical model is, at a minimum, *poor to speculative, and at best unknown*.

Error in conclusions drawn concerning the impact of the proposed mining on swamps to the west of the 2020 proposed mining area, including Okefenokee Swamp, based on the current numerical modeling: Based on the numerical modeling performed to date, TTL concludes (2020 permit application, page 23) that "… the swamps to the west of the study area, including the Okefenokee Swamp, will receive a fractional increase in both stream and groundwater discharge due to the proposed mine". This conclusion is unsupported given the uncertainties and errors addressed in comments Nos. 20-53, individually and cumulatively. Moreover, no distinction is made in the 2020 model report between conclusions drawn based on the numerical versus analytical modeling, or perhaps both (four points listed on pages 9-10), hampering independent review.

***Potential for capture of Okefenokee Swamp by proposed onsite project water supply pumping from the Upper Floridian Aquifer*:** To be addressed in future comments.

***Potential water quality impacts on adjacent wetlands and Okefenokee Swamp*:** To be addressed in future comments.

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