Twin Pines Minerals, LLC

HYDROGEOLOGIC FIELD CHARACTERIZATION AT TWIN PINES MINE

Prepared For:

TWIN PINES MINERALS, LLC
PROPOSED HEAVY MINERALS MINE
ST. GEORGE, CHARLTON COUNTY, GEORGIA

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TTL

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INTRODUCTION

On July 3, 2019, Twin Pines Minerals (TPM) submitted an individual permit application to the U.S. Army Corps of Engineers for impacts to waters of the United States to develop a heavy mineral sand mine along Trail Ridge in Charlton County, Georgia (Figure 1). The proposed mine is located 3.2 miles west of St. George, Georgia, along Georgia State Highway Route 94. Trail Ridge is a 0.6 to 1.2 mile wide and 99 mile long topographic ridge that separates the Okefenokee Basin and Swamp from the coastal plain of Georgia (Force and Rich, 1979). It represents the crest of a former beach complex and was formed as inland sand dunes near the proposed Twin Pines Mine (e.g., Pirkle et al. 1993). The ridge is underlain by a shallow aquifer, locally known as the surficial aquifer, which forms a hydrologic divide between the Okefenokee swamplands to the west and the Saint Mary's River to the east. At the proposed mine site, the water table is very shallow with water depths of only a few feet. The surficial aquifer is perched on the clays of the upper Hawthorn Group, which is considered to be the upper confining unit to the Floridian Aquifer in the region (e.g., Williams and Kuniansky, 2016).

The proposed permit area is approximately 2,414-acres, located southeast of the Okefenokee National Wildlife Refuge (ONWR) boundary; however, TPM will only mine an approximate 1,268-acre area located about 2.7 miles from the ONWR boundary (Figure 2). The portion of the proposed permit area extending from the western mining boundary to the edge of the permit boundary will be avoided and will provide a buffer to the ONWR.

The project study area consists of approximately 12,000-acres of land located near St. George, Charlton County, Georgia. This area is comprised of five (5) contiguous tracts identified as Loncala, Dallas Police & Fire, Keystone, TIAA, and Adirondack. Reference to "project study area" in this report refers to activities conducted within the proposed mining area and adjacent tracts.

This report is being submitted to document field activities performed to characterize the hydraulic properties of the surficial aquifer beneath the project study area. As part of these field activities, TTL conducted two 24-hour pumping tests along the crest of Trail Ridge and 24 slug and bail tests at piezometers across the project study area.

AQUIFER PUMPING TESTS

TTL contracted with Hydro Geo Chem, Inc. (HGC) of Phoenix, Arizona for assistance in design, data collection for the two pumping tests, and analysis of the pumping test data. Included in this report are figures depicting the location of each pumping test area, boring logs and well construction diagrams for pumping/ observation wells, and HGC's report analyzing the pumping tests.

Pumping Well Installations

In December 2018, TTL subcontracted Partridge Well Drilling Company, Inc. (Partridge) of Jacksonville, Florida to install two (2) pumping wells (PWA and PWB) within the project study area (Figure 3). The northernmost pumping well on the eastern crest of Trail Ridge was designated PWA and the southernmost well on the western crest of Trail Ridge was designated PWB. The logic for the pumping test locations along Trail Ridge was that the ridge represents a hydrologic divide between drainage to the Okefenokee Swamp to the west and drainage to the St. Mary's River to the east. Exploratory borings (OWAEB and OWBEB) were advanced near the proposed pumping well locations to confirm target depths to the top of the Hawthorn Group. Each pumping well was installed to a depth of approximately 115 feet below ground surface (bgs). TTL's on-site geologist was present during the drilling activities to supervise well installations for PWA and PWB.

Prior to initiating drilling, a mud pit for storing and circulating drilling mud was excavated near each pumping well boring. The soils excavated from the pits were temporarily stockpiled adjacent to each pit. The dimensions of each mud pit were approximately 8 feet wide by 10 feet long by 4 feet deep. On December 10, 2018 drilling commenced utilizing a truck-mounted mud-rotary drilling rig equipped with a 12-inch diameter roller/tri-cone drill bit. Once each borehole was drilled to a depth of 115 feet bgs, 60 feet of 6-inch diameter, 0.020-inch machine slotted PVC screen was installed from 55 feet to 115 feet bgs. A 6-inch diameter solid PVC casing was installed from the top of the screen to land surface. All screen and solid casing were flush-thread scheduled 40 PVC. A 16/30 silica sand was then placed from the bottom of the borehole to five feet above the top of the well screen (50 feet bgs). A five-foot bentonite plug was placed on top of the sand pack, and the remainder of the borehole annulus from the top of the bentonite seal to land surface was grouted with a cement/bentonite mixture. After grouting, the cement/bentonite mixture was allowed to cure for a minimum of twenty-four (24) hours. Next, each well was initially an partially developed by Partridge at an approximate rate of 150 gallons per minute (gpm) using an air-lift method. Once installation of the pumping wells was completed, the drilling mud was pumped from the mud pits and each pit was backfilled with the nearby stockpiled soils. Following the initial development efforts, each pumping well was subsequently redeveloped by Donald Smith Company using a submersible pump at pumping rates ranging from 150 to 300 gpm.

__Observation Well Installation__

During November 2018 through January 2019, Betts provided drilling services for the installation of 22 observations wells at the site. Eleven (11) observation wells were constructed adjacent to pumping wells PWA and PWB, respectively. These observation wells were installed to depths and distances from the pumping wells listed in Table 1.

The observation wells were installed using a Terra-Sonic Rig equipped with 6-inch diameter outer casing and a 4-inch diameter 10-foot long core barrel. Soil samples were collected continuously from each borehole for the observation wells. TTL's on-site geologist was present during drilling activities to describe soils recovered from each boring and supervise well installations.

With the exception of OWA3BS, OWA4BS, OWA5BS, OWB3BS, OWB4BS, and OWB5BS, each observation well was constructed with 10-foot sections of 2-inch diameter 0.010-inch slotted PVC screen with attached PVC riser. A natural sand pack was allowed to cave-in around the annulus between the PVC screen and the borehole wall from termination depth to two feet above the top of screen. A 2-foot bentonite plug was placed on top of natural sand pack and a Portland cement/bentonite mixture was placed from the top of the bentonite plug up to about 0.5-foot bgs. Permanent flush-mount protective covers and concrete pads were installed for surface protection at each observation wells. Observation well construction details are provided in Table 2.

Observation wells OWA3BS, OWA4BS, OWA5BS, OWB3BS, OWB4BS, and OWB5BS were constructed with five-foot sections of 2-inch diameter, 0.010-inch slotted PVC screen with attach PVC riser. A natural sand pack was allowed to cave-in around the annulus between the PVC screen/riser and the borehole wall from termination depth to ground surface. A flush-mounted, steel, protective cover was installed at the surface of each piezometer in a 2-foot by 2-foot concrete pad, and a locking, water-tight cap was placed in the top of each 2-inch casing. Pumping wells and observation are shown on Figures 4 and 5. Boring logs for pumping and observation wells are provided in Appendix A.

Following installation activities, each observation well was developed using a 12-volt submersible pump. Each observation well was developed until its turbidity was less than 10 nephelometric turbidity units (NTU) and/or until the extracted groundwater appeared to be relatively free of sediment. A cumulative of about 1,673 gallons and 2,019 gallons of groundwater were developed from the observation wells at pump areas A and B, respectively.

Aquifer Pumping Tests

In order to further evaluate surficial aquifer characteristics at the Twin Pines site, two independent pumping tests were performed within the project area. On February 14 and 15, 2019, Level-Troll 700 pressure transducers were installed at the pumping wells and observation wells for continuous monitoring of water-level data prior to and during the pumping tests. In addition to the transducers installed in the wells, BaroTroll transducers were placed near each pumping well to constantly record barometric pressure at land surface prior to and during the pumping tests.

Between February 19 and 22, 2019, two 24-hour pumping tests were conducted at Pumping Well A and Pumping Well B (Figure 3). Each pumping test was comprised of three steps:

Pump Test A	Pump Rate (gallons per minute)	Pump Test B	Pump Rate (gallons per minute)
Step 1 (2 hours)	75	Step 1 (2 hours)	50
Step 2 (2 hours)	150	Step 2 (2 hours)	75
Step 3 (20 hours)	250	Step 3 (20 hours)	120

At each pumping well, Donald Smith Company installed an electric-submersible pump connected to metal discharge piping. The discharge piping at the wellhead was equipped with a flow meter and gate valve. An 8-inch diameter 1,000-foot long flexible hose was attached to the metal discharge piping at each wellhead. These discharge hoses were used to direct groundwater away from the pumping wells and minimize impacts to the pumping tests from infiltrating discharge water. The discharge line for the pumping well PWA was oriented to the east-northeast and the discharge line for the pumping well PWB was oriented to the northwest.

Personnel with TTL and HGC were on-site for the full duration (24 hours per day) of each pumping test. Additionally, field verification of water-level monitoring using tape-down measurements was also performed by TTL personnel as backup for the transducer measurements. Upon completion of the tests, the transducer data was downloaded and submitted, along with the field verification of water-level monitoring data, to HGC for analysis. A complete copy of HGC's pumping test report is included in Appendix B.

Slug and Bail Tests

To estimate the horizontal hydraulic conductivity of the surficial aquifer, slug and bail tests were performed in the 24 piezometers within the project study area (Figure 6 and Table 3). Slug and bail tests were conducted by creating an instantaneous change in water level in the piezometer and recording the rate of groundwater recovery relative to the initial measured water level. The following testing equipment was rented from In-Situ, Inc. in Fort Collins, Colorado for performance of each test:

- SLG 3-segment thermoplastic mandrel with known displacement values for each segment was used to displace water during the slug and bail tests.
- Level-Troll 700 pressure transducers were employed to record changes in water levels during the slug and bail tests.

Upon completion of the tests, the test data was downloaded from the transducers and submitted to HGC in Phoenix, Arizona for calculation of the horizontal hydraulic conductivity and specific storage values. HGC evaluated the data using AQTESOLV® Pro software. The rate of recovery versus time data was evaluated using the *Hyder et al. (1994) Solution of a Slug Test in an Unconfined Aquifer (KGS Model)* and the *Bower and Rice (1976) solution for a Slug Test in an Unconfined Aquifer*.

RESULTS

Pumping Test Results

Pumping test results are summarized in Table 4 (Pumping Well A) and Table 5 (Pumping Well B). HGC's interpretation of pumping test data indicated that the results of both qualitative and quantitative analyses are consistent with the following observations/conclusions:

- Results of quantitative analysis indicate that both pumping wells are efficient and properly designed and developed (negligible skin effects or non-linear losses).
- Transmissivity (T) estimates are generally higher at the pumping well PWA compared to the pumping well PWB site, consistent with the larger achievable pumping rates at pumping well PWA site. Except for a few outliers, horizontal hydraulic conductivity (Kh) estimates computed from T estimates generally range from several ft/day to nearly 20 ft/day for pumping well PWA, and from a few ft/day to as much as 11 ft/day for pumping well PWB, with some values exceeding 50 ft/day. HGC considered these high values to be unreliable; however, they are close to values determined from slug and bail tests conducted in the project study area (values of up to 75.1 ft/day, see below).
- Heterogeneity possibly resulting from non-horizontal structure within the sands may be present within the pumped aquifer. Such heterogeneity may result in more direct connection between the pumping and shallow observation wells at larger distances from the pumping wells.
- Such heterogeneity would be consistent with the substantial increase in the ratio of shallow observation well drawdowns to deep observation well drawdowns with distance from the pumping wells, and the unexpected increase in this ratio above 1.0 at the more distant observation well nests.
- Flattening of pumping well and shallow observation well drawdowns is consistent with another (presumably shallow) source of water, either local wetlands or vertical leakage from the shallowest groundwater through the shallow 'black sand', or both. Substantially less flattening of the deep observation well drawdowns indicates that the deeper portion of the aquifer is less impacted by the additional source of water.

Pumping Test PWA

For pumping test PWA, estimates of T and storage coefficient (S) from pumping well PWA data range from 1,490 ft^2/day to 1,967 ft^2/day and from 3.5×10^{-4} to 1.1×10^{-2}. Although estimates of T from observation well data range from approximately 1 ft^2/day to 2,288 ft^2/day, the majority of estimates are lower than for the pumping well and average 875 ft^2/day. Estimates of S from observation well data range from approximately 1.6×10^{-5} to 1.7×10^{-2}; estimates of Kh range from <1 to 20 ft/day; estimates of Kv range from 0.06 ft/day to 1.8 ft/day; and estimates of aquitard Kv range from 2.4×10^{-6} ft/day to 0.75 ft/day. The lowest T of 1 ft^2/day was derived from one interpretation of data from OWA-3D, where, due to non-uniqueness, T estimates from alternate interpretations ranged from 1 ft^2/day to 1700 ft^2/day.

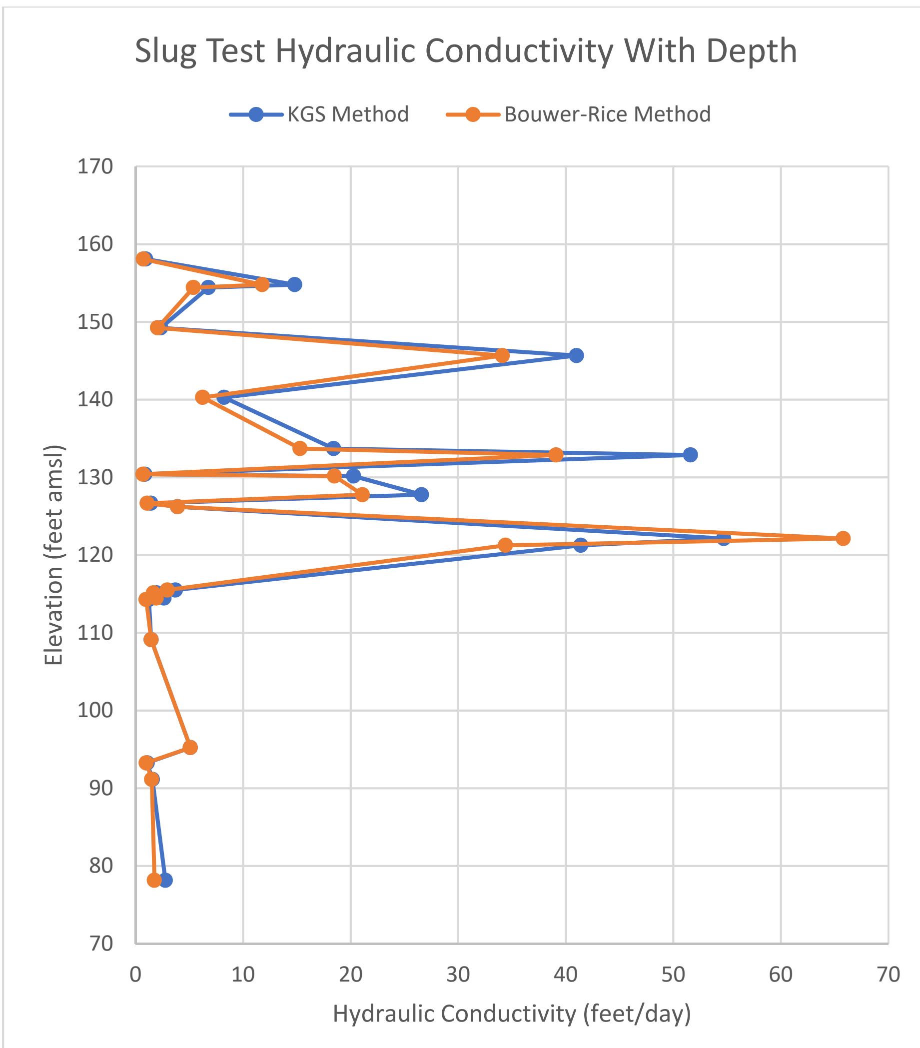
Pumping Test PWB

For pumping test PWB, estimates of T and S from pumping well PWB data range from 530 ft^2/day to 697 ft^2/day and from 2.4×10^{-3} to 0.11. T estimates from the shallowest water table well data that range from 5,455 ft^2/day to 9,500 ft^2/day. Excluding these estimates, observation well data yield T estimates ranging from approximately 53 ft^2/day to 1,100 ft^2/day; however, the majority of the estimates are lower than for the pumping well and average 432 ft^2/day. Estimates of S from observation well data range from approximately 1×10^{-10} to 5×10^{-3}; estimates of Kh range from <1 to 11 ft/day; estimates of Kv range from 8.6×10^{-5} ft/day to 1.5 ft/day; and estimates of aquitard Kv range from 1.1×10^{-6} ft/day to 0.3 ft/day.

<u>Slug and Bail Tests</u>

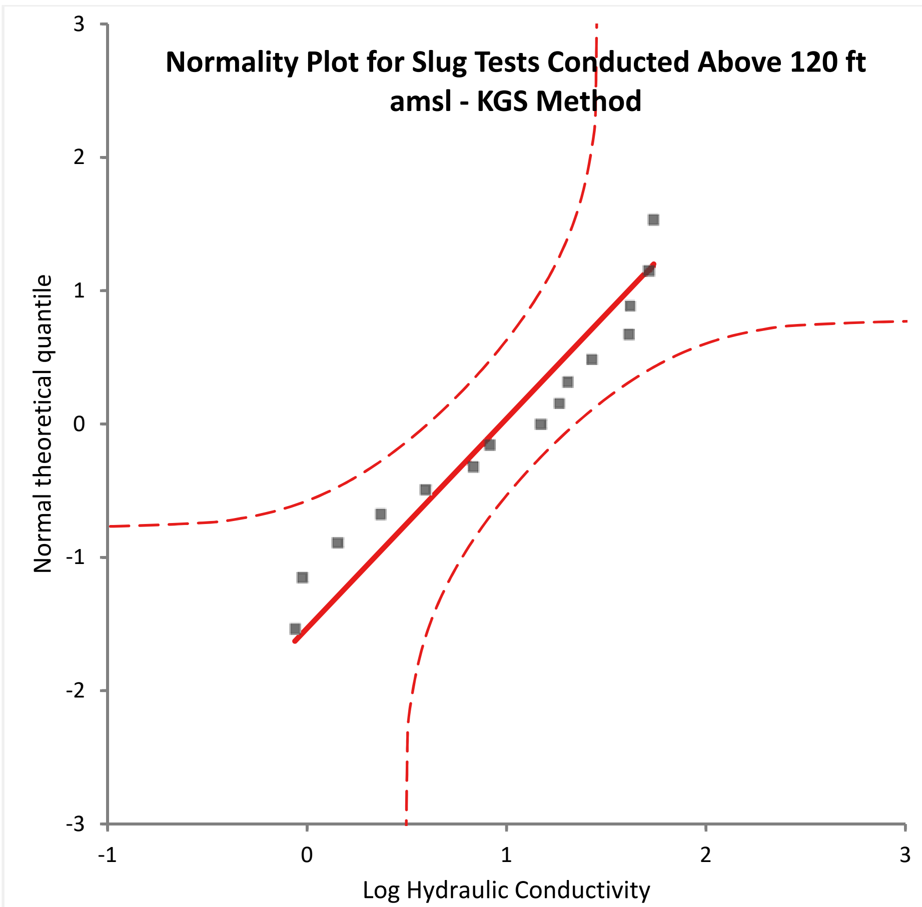
The slug and bail tests were interpreted by HGC (Appendix C). Slug test data were analyzed using the Kansas Geological Survey (KGS) method (Hyder et al., 1994) and the Bouwer-Rice method (Bouwer and Rice, 1976). The results from the 24 slug and bail tests performed in the study area are shown in Table 6 and Figures 7 and 8. Both methods produced similar estimates of hydraulic conductivity. Hydraulic conductivities estimated using the KGS method range from 0.2 to 75.1 ft/day and average 12.2 ft/day. The Bouwer-Rice method yields a hydraulic conductivity range of 0.24 to 54.7 ft/day and an average of 13.5 ft/day. Estimates of aquifer specific storage from the KGS method range from 3.8 x 10^{-20} to 2.2 x 10^{-3} 1/ft and average specific storage of 1.6 x 10^{-4} 1/ft.

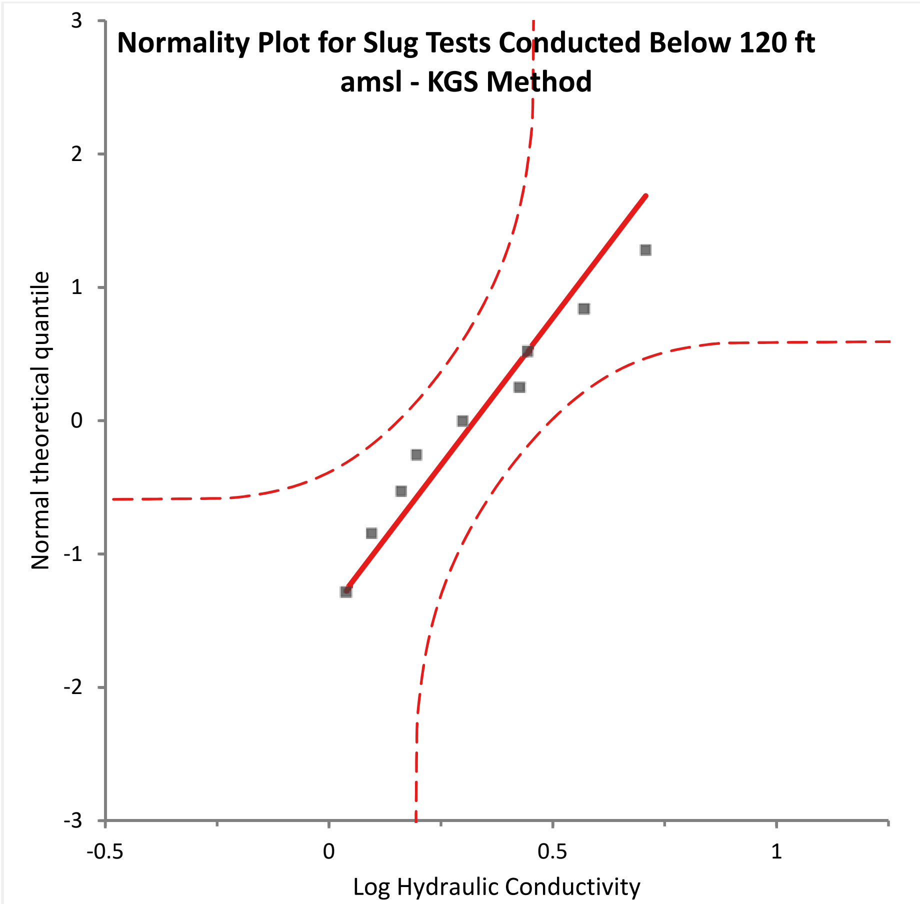
The averages of the hydraulic conductivity estimated from a slug test and corresponding bail test at each well show a distinct vertical pattern, with lower hydraulic conductivities found below an elevation of 120 ft amsl and much higher hydraulic conductivities found above 120 ft amsl.



Holt et al. (2019) showed that the subsurface lithology is dominated by unconsolidated sands. They also found that humate-cemented sands are more common above 120 ft amsl and that silty-clayey sand, clayey sand, and clay are more common below 120 ft amsl. The vertical distribution of hydraulic conductivity estimated from slug tests reflects the occurrence of clays below 120 ft amsl. The data presented here suggest that there are two distributions of hydraulic conductivity: one for elevations above 120 ft amsl and another for elevations below 120 ft amsl.

The log of the averaged (slug and bail) hydraulic conductivity for both the upper and lower elevations appears to be log normal for both types of estimates (KGS and Bouwer Rice). The geometric means for the upper elevations are 9.4 and 7.9 ft/day for hydraulic conductivities estimated using the KGS and Bouwer-Rice methods, respectively. In the lower elevations, the geometric means are 2.1 and 1.8 ft/day for the KGS and Bouwer-Rice methods, respectively. Note: only the results for hydraulic conductivities for the KGS method are shown, as the results for hydraulic conductivities determined using the Bouwer-Rice method are similar.





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