TTL
2743 B Gunter Park Dr. W.
Montgomery, AL 36109
334-244-0766
www.TTLUSA.com

TRANSMITTAL

TO: Georgia Environmental Protection Division
Water Supply Program – Groundwater Withdrawal Unit
2 Martin Luther King Jr. Dr., S.E.
East Floyd Towers, Suite 1362
Atlanta, GA 30334-9000

DATE: October 2, 2023

ATTN: Mr. Bill Frechette

PROJECT:

Updated Industrial Groundwater Withdrawal Permit Application
Twin Pines Minerals, LLC
Saunders Demonstration Mine

WE ARE SENDING:

One copy to Mark Fowler at Twin Pines Minerals, LLC

REMARKS:
If you have any questions, please call me at (334) 244-0766.

TTL, INC.

James R. Smith

James R. Smith, P.G.
Senior Project Professional

Georgia Environmental Protection
Department of Natural Resources

Application for a Permit to Use Groundwater

Part A – General System Information

(Part A must be accompanied by one copy of the Part B – Well Data form for each well in your system)

☒ New Permit
☐ Renewal
☐ Modify Existing GW Withdrawal Permit No. *Please enter GW Withdrawal Permit No. _ _ _ - _ _ _ _*

(Print or type ALL information)

Contact Person: Mark Fowler	Phone: 205-545-8759 Fax: 205-518-8388	Email: mfowler@twinpinesminerals.com

Company / Permittee: Twin Pines Minerals, LLC

Permittee Address: 2100 Southbridge Parkway, Suite 540	Birmingham	Alabama	35209
(No. and Street)	(City)	(State)	(Zip)

Water Use Name & Address (if different than above): Saunders Demonstration Mine, GA-94, St. George, GA

Monthly Average Withdrawal Limit requested: 1,440,000 Gallons Per Day (GPD)

Annual Average Withdrawal Limit requested: 1,440,000 Gallons Per Day (GPD)

For a beneficial use of Make-up water, sanitary supply gallons of water per day, to be pumped from 2 well(s)

Averaging 24 hours pumping per day utilizing the Floridan aquifer(s) for a

☐ Consumptive use **OR**
☒ Nonconsumptive use

For…

☒ Sanitary Facilities
☐ Central Water Supply
☐ Cooling Water
☒ Process Water for Minerals mining processing
☐ Other (please specify) _____

County where well(s) is located: Charlton

All applications shall be accompanied by a map showing the location of the existing and proposed well(s); each well to be identified by number. The location map shall be the best map available, which may be a portion or a copy of a U.S. Geological Survey 7.5 min. quadrangle map, or latest county highway MAP, or city MAP, provided the submitted map is properly identified and should be no larger than 8½ x 11 inches.

Mark Fowler
Print or Type Name

Mark Fowler
Sign Name

Environmental Manager
Title

9/29/2023
Date

Return Application To:
Georgia Environmental Protection Division
Water Supply Program
Groundwater Withdrawal Unit
2 Martin Luther King Jr. Dr., S.E.
East Floyd Towers, Suite 1362
Atlanta, Georgia 30334-9000
Fax: (404) 651-9590

Georgia Environmental Protection
Department of Natural Resources

Application for a Permit to Use Groundwater

Part B – Well Data

(Submit one (1) form for each well in the system)

(Print or type ALL information)

Applicant Information

Contact Person: Mark Fowler	Phone: 205-545-8759 Fax: 205-518-8388	Email: mfowler@twinpinesminerals.com
Company / Permittee: Twin Pines Minerals, LLC		

Address:			
2100 Southbridge Parkway, Suite 540	Brimingham	Alabama	35209
(No. and Street)	(City)	(State)	(Zip)

Well Information:

Well No.: FPW-01 (Key to attached location map)	Ground elevation at well (if available): _____
County where well(s) is located: Charlton County	Latitude: 30.520333°N Longitude: -82.09759°W

Well Construction Description

☐ Existing well ☒ Proposed well

Name of aquifer(s) being or to be utilized Floridan

Well Drilling Information	☒ Rotary ☐ Percussion ☐ Bored
Total depth of well: 650 ft.	Date drilled:
Static water level: 93 ft.	Date to be drilled:
	Driller:

Drill Hole Diameter	**Grouting**
Size 24 in., from 0 ft. to 125 ft.	☒ Yes ☐ No
Size 17.875 in., from 125 ft. to 475 ft.	Type
Size 11.875 in., from 475 ft. to 650 ft.	From 0 ft. to 125 ft.
Size in., from ft. to ft.	From 125 ft. to 475 ft.
Size in., from ft. to ft.	From ft. to ft.

Casing Record	**Test Pump Data**
Type material Steel	Pumped Bailed
Wall thickness	Estimated
Weight/Foot	Date tested
Size 18 in., from 0 ft. to 125 ft.	Pump rated GPM HP
Size 12 in., from 125 ft. to 475 ft.	Pump yield GPM after hrs of pumping
Size in., from ft. to ft.	Water level before test ft.
Size in., from ft. to ft.	Drawdown ft.
Size in., from ft. to ft.	Specific Capacity GPM/ft.

Well Screen	**Permanent Pump Data (if available)**
Type material NA	Pump type Line Shaft
Size in., from ft. to ft.	Outlet size
Size in., from ft. to ft.	Powered by
Size in., from ft. to ft.	Horsepower
Size in., from ft. to ft.	Rate 500 GPM
Size in., from ft. to ft.	Pumping level
	Average hours pumped per day 24

Note: Detailed well construction specifications of a proposed well may be required by the Division upon review of the submitted application.

Complete WELL LOG on reverse side, if available.

Well Log / Driller's Log

Feet		Type Material Encountered	Remarks	Indicate Water Bearing Zones
from	to			
0				

(If more space is required, use an additional sheet)

I certify that the above information is true to the best of my knowledge

____
Sign Name

____
Title

____
Date

Georgia Environmental Protection
Department of Natural Resources

Application for a Permit to Use Groundwater

Part B – Well Data

(Submit one (1) form for each well in the system)

(Print or type ALL information)

Applicant Information

Contact Person: Mark Fowler	Phone: 205-545-8759 Fax: 205-518-8388	Email: mfowler@twinpinesminerals.com
Company / Permittee: Twin Pines Minerals, LLC		

Address: 2100 Southbridge Parkway, Suite 540	Brimingham	Alabama	35209
(No. and Street)	(City)	(State)	(Zip)

Well Information:

Well No.: FPW-02 (Key to attached location map)	Ground elevation at well (if available): _____
County where well(s) is located: Charlton County	Latitude: 30.528859°N Longitude: -82.096598°W

Well Construction Description

☐ Existing well ☒ Proposed well

Name of aquifer(s) being or to be utilized Floridan

Well Drilling Information	☒ Rotary ☐ Percussion ☐ Bored
Total depth of well: 650 ft.	Date drilled:
Static water level: 93 ft.	Date to be drilled:
	Driller:

Drill Hole Diameter	**Grouting**
Size 23 in., from 0 ft. to 125 ft.	☒ Yes ☐ No
Size 17.875 in., from 125 ft. to 475 ft.	Type
Size 11.875 in., from 475 ft. to 650 ft.	From 0 ft. to 125 ft.
Size in., from ft. to ft.	From 125 ft. to 475 ft.
Size in., from ft. to ft.	From ft. to ft.

Casing Record	**Test Pump Data**
Type material Steel	Pumped Bailed
Wall thickness	Estimated
Weight/Foot	Date tested
Size 18 in., from 0 ft. to 125 ft.	Pump rated GPM HP
Size 12 in., from 125 ft. to 475 ft.	Pump yield GPM after hrs of pumping
Size in., from ft. to ft.	Water level before test ft.
Size in., from ft. to ft.	Drawdown ft.
Size in., from ft. to ft.	Specific Capacity GPM/ft.

Well Screen	**Permanent Pump Data (if available)**
Type material NA	Pump type Line Shaft
Size in., from ft. to ft.	Outlet size
Size in., from ft. to ft.	Powered by
Size in., from ft. to ft.	Horsepower
Size in., from ft. to ft.	Rate 500 GPM
Size in., from ft. to ft.	Pumping level
	Average hours pumped per day 24

Note: Detailed well construction specifications of a proposed well may be required by the Division upon review of the submitted application.

Complete WELL LOG on reverse side, if available.

Georgia Environmental Protection
Department of Natural Resources

Well Log / Driller's Log

Feet		Type Material Encountered	Remarks	Indicate Water Bearing Zones
from	to			
0				

(If more space is required, use an additional sheet)

I certify that the above information is true to the best of my knowledge

Sign Name

Title

Date

APPLICATION FOR INDUSTRIAL GROUNDWATER WITHDRAWAL PERMIT
TWIN PINES MINERALS, LLC
SAUNDERS DEMONSTRATION MINE

Twin Pines Minerals, LLC

Submitted To:

Georgia Environmental Protection Division
Water Supply Program – Groundwater Withdrawal Unit
2 Martin Luther King Jr. Dr., S.E.
East Floyd Towers, Suite 1362
Atlanta, GA 30334-9000

Prepared for:

Twin Pines Minerals, LLC
4599 East Lake Boulevard
Birmingham, AL 35217

Prepared by:

TTL, Inc.
3516 Greensboro Avenue
Tuscaloosa, Alabama 35401

Project No. 000180200804.00
October 2, 2023

TTL

TABLE OF CONTENTS

ATTACHMENTS

1 INTRODUCTION

The Twin Pines Minerals, LLC (TPM) Saunders Demonstration Mine in Charlton County (Figures 1 and 2) will recover essential Heavy Mineral Sands from Trail Ridge through a safe, cost-effective, and environmentally sound process that poses no threat to surrounding lands, the Okefenokee National Wildlife Refuge, or the broader environment.

The deposits that can be recovered from Trail Ridge include the primary ores of titanium dioxide (TiO2) and zircon (ZrSiO2) — minerals the United States Government has deemed both “critical” and scarce, such that shortages threaten the national defense and/or the national economy. TiO2 is primarily obtained from mining and processing the minerals ilmenite, rutile, leucoxene, and staurolite. Leucoxene, not technically a mineral, is a higher quality derivative of ilmenite resulting from the preferential weathering and leaching of iron, increasing the percentage of TiO2 to more than 70 percent. Zircon is recovered as a co-product from the processing of Heavy Mineral Sands deposits. The proposed mine site is one of the last, best sites at which these critical minerals can be sourced from within the United States.

The minerals will be extracted, separated, and processed on-site and at a Mineral Separation Plant directly across Highway 94, maximizing the number of high-paying jobs that will be created and retained within Charlton County. After the Heavy Minerals Sands products have been separated, the final products will be containerized, bulk shipped or loaded onto trucks or rail dependent upon customer requirements.

The project will demonstrate in practice what extensive studies have already proved: that these critical minerals can be recovered without impact to the Okefenokee National Wildlife Refuge, the boundary of which is three miles away at its closest corner, and with negligible environmental impacts beyond the mine site.

2 GENERAL DESCRIPTION OF THE MINING PROCESS

2.1 Mine Progression and Timeline

The mining site layout is shown on Figure 3. The progression of the mine is shown on Figure 4. A mine pit approximately 100-feet wide and 500-feet long, and no more than 50-feet deep, will move from West to East, and then East to West, in bands across the site until the entire Mining Footprint has been mined.

It will take approximately six months to a year to prepare the site and construct the necessary infrastructure after a permit is issued. Active mining will commence promptly after this work is completed.

Once the operation begins, the moving mine pit will progress at a rate of approximately 100-200 feet per day, or approximately 10 to 15 acres per month. The entire process is expected to take 4 years. Reclamation will be completed within 24 months after the mining process is completed.

Attachment A provides flow diagrams for the excavation and beneficiation process. The steps in this process are described further below.

2.2 Active Mining: Excavation

Excavation of the mining cuts will commence after the topsoil is removed. TPM has developed a completely land-based heavy mineral sand mining technique using a dragline excavator, conveyor system for materials transport, and processing plants. The dragline is a large crane-like earthmoving machine equipped with a large-capacity bucket to scoop material. The bucket swings from cables on the end of a boom, scooping material that is then moved to adjacent areas. The dragline is powered by electricity.

The dragline technique is different from conventional “wet mining,” which utilizes a dredge and floating concentration plant to mine and process heavy mineral-bearing sands. The dragline method is more efficient when long mining cuts can be utilized. Elongated cuts allow for excavation and backfilling to occur simultaneously in the same pit. Backfilling and rough grading will occur within 500 feet of the dragline dig face.

The excavation will be approximately 100-feet wide by 500-feet long. Its depth will vary depending on the depth of heavy minerals sands; but its maximum depth will be 50 feet. A profile and cross-section of the mining cut is shown in Figure 5.

Because dragline mining is a “dry” technique, it will be necessary to remove standing water in the mine pit above a depth of about 8 feet. Water removed from the mine pit will be pumped to the Water Management Ponds, where it will be conserved for use in the beneficiation process.

2.3 Transport by Conveyor to the Pre-Concentration Plant

An electric-powered conveyor system will be used to transport excavated sands from the mine pit to the Pre-Concentration and Wet Concentration Plants. Excavated material will initially be stockpiled near the mine pit before being transferred to an apron feeder that feeds to a screen. The screen will be used to remove roots and other large objects, which will be placed near the screen area and then returned to the mining pit during the reclamation process.

The screened material will be transferred to a pit/feed conveyor system, which feeds a mainline feed conveyor system. The mainline feed conveyor system will incline (or feed a stacker conveyor) and then feed the trommel (screen). The under-sized material from the trommel will be fed to the Pre-Concentration Plant as a slurry.

2.4 Pre-Concentration Plant and Wet Concentration Plant

In the Pre-Concentration Plant and Wet Concentration Plant, spirals will be used to separate heavy mineral sands from the lighter clays and quartz sand. From the Pre-Concentration Plant, the heavy mineral sands will be fed to the Wet Concentration Plant, which further separates lighter minerals from heavy mineral sands. The result is a Heavy Mineral Sands concentrate that will be trucked to the off-site Mineral Separation Plant for additional processing.

Process water used in the Pre-Concentration Plant and Wet Concentration Plant will be reclaimed through a series of dewatering screens and hydrocyclones. Humates and clays will be separated from the process water as “slimes.” The slimes will be separated from process water in a thickener. The underflow, which includes the slimes, from the thickener will be dewatered and temporarily stored before being transported back to and placed in the mined pit area for reclamation.

Tailings and slimes from the Pre-Concentration Plant will be stockpiled until they can be fed to the conveyor system and returned to the pit.

2.5 Mineral Separation Plant

A portion of the Heavy Mineral Sands concentrate from the Wet Concentration Plant will be packaged as finished product and shipped to customers. The remaining concentrate will be trucked to the Mineral Separation Plant across Highway 94. The locations of these plants are shown on Figure 3. The close proximity of the Mineral Separation Plant to the Mineral Processing Plant decreases the distance and energy needed to transport materials.

The Mineral Separation Plant further separates mineral products such as zircon, titanium minerals (ilmenite, leucoxene, rutile), and staurolite etc. After products have been separated, the final products will be containerized, bulk shipped or loaded on truck or rail depending upon customer requirements.

2.6 Reclamation

The reclamation objective is to restore the land surface and groundwater elevations approximately to pre-mining levels. The reclaimed pit will be contoured to match pre-mining elevations before being revegetated with plant communities appropriate to pine flatwoods. Although some wetlands may be restored and/or created, no lakes will be developed.

2.7 Water Use and Water Management

A detailed Water Use Management Plan is provided as part of the Surface Mine Land Use Plan (SMLUP). As explained in that document, the beneficiation process requires a water supply of approximately 3,000 gallons per minute (“gpm”), but only about 10% will be used consumptively. The rest will be returned and used again.

Water will be managed in four Process Water Ponds (P1–P4) and four Water Management Ponds (M1-M4). All of the ponds will be lined, and all will be above-ground. The Process Water Ponds will feed the Pre-Concentration and Wet Concentration Plants. The Water Management Ponds will receive water from the mine pit, and any overflow from the Process Water Ponds. The Water Management Ponds will conserve this water and feed it to the Process Water Ponds as necessary. Evaporators will be installed in the Water Management Ponds to dispose of any excess water and ensure there is no discharge to the environment.

Water will be supplied initially from two wells screened in the Upper Floridan Aquifer with a combined permitted capacity of 1,000 gpm. The primary purpose of the wells is to charge the system Process Water Ponds before active mining begins. Once the system is charged and mining has begun, most or all of the water needed for the beneficiation process will be supplied by seepage water evacuated/pumped from the mine pit, which will be conserved in the Water Management Ponds for subsequent use in mineral processing. The Upper Floridan Aquifer wells will continue to be available as a backup water supply if needed.

3 WELL SURVEY

TTL conducted a water well survey to determine the location of public and/or private water supply wells located adjacent to the proposed Saunders Demonstration Mine. TTL contacted the Charlton County Health Department, Environmental Health Division for supply well information in the area. Charlton County reported no public supply wells are located in the vicinity of the proposed Saunders Demonstration Mine. Charlton County representatives indicated that most all residences in the area would be on well water since there were no public water utilities in the area.

TTL contacted a local licensed professional water well driller. The driller reported that domestic supply wells in the area would most likely be constructed to depths of about 100 to 140 feet below ground surface, into the Intermediate Aquifer within the Upper Hawthorn Group sediments.

TTL's research indicated Fulghum Fibers formerly operated a wood chipping mill located approximately one mile east of the proposed Saunders Demonstration Mine. Twin Pines has entered into a lease agreement for the former wood chip mill property and will construct the MSP at this location. TPM contracted TTL to conduct a Phase I Environmental Site Assessment (Phase I ESA) for the property, prior to entering into the lease agreement. Results of the Phase I ESA confirmed the presence of the three potable water wells on the former chip mill property. Twin Pines **does not** plan to use the three wells on the chip mill property.

In order to determine the location and estimated number of private domestic supply wells located adjacent to the proposed Saunders Demonstration Mine, TTL reviewed the Charlton County Tax Assessor maps to identify adjacent residences. Under the assumption that every residential structure (not including utility type buildings) would potentially have a domestic supply well, the following table lists the inventory of estimated well sites by street address. Based on this survey, there are an estimated 11 private supply wells located in the vicinity of the project, including the supply wells located at the former Fulghum Fibers facility.

Address	Number of Structures	Estimated Number of Wells
8006 GA-HWY 94	1	1
8024 GA-HWY 94	1	1
8208 GA-HWY 94	1	1
8242 GA-HWY 94	2	2
8296 GA-HWY 94	1	1
8374 GA-HWY 94	1	1
8422 GA-HWY 94	1	1
8906 GA-HWY 94	NA (Chip Mill)	3
	Total Estimated Wells	11

4 WATER CONSERVATION PLAN

The objective of Twin Pines' Saunders Demonstration Mine Water Conservation Plan is to minimize water use and maximize water recycling and recirculation. The Water Conservation Plan will be utilized to establish site operating policies and procedures.

4.1 Water Conservation Policy

Potable drinking water and other water resources, such as other natural resources, are limited and must be conserved. Twin Pines is committed to conserving water at its operations and will also conserve water in its Charlton County mining operation. The Saunders Demonstration Mine operation will be essentially a closed-loop system. The proposed mining operation is designed to be water-efficient by recycling and re-circulating water to minimize the amount of make-up water required from the Upper Floridan Aquifer (UFA).

The proposed Water Conservation Plan at the Twin Pines Saunders Demonstration Mine will minimize the amount of MUW by recycling and reusing water. Water losses will result from evaporation, retention on tailings returned to the reclamation cut, and with minor amounts of water retained in the final product.

Pipelines transporting water from the PCP will be inspected on a regular basis as part of the daily operations and maintenance program. Pipelines will be above ground allowing for observation and leak detection. Leaks will be repaired promptly in an effort to conserve water. Meters will be installed at various points in the process loop in order to manage mineral production and water use. Meters will be maintained, calibrated, and tested in accordance with to manufacturer's recommendations.

4.2 Water Flow Throughout Operation

The lined process water ponds and the lined water management ponds will be utilized as the primary water supply to extract and process the ore, tailings, and final heavy mineral product. The MUW use will be based on the amounts of water lost to evaporation, retention on the tailings returning to the reclamation cut, and minor amounts of water retained in the final product. Attachment A illustrates the normal operating conditions of the mine water balance, and the process flow and water use for the proposed mining and mineral extraction operations.

Twin Pines will install two wells (FPW-01 and FPW-02) into the UFA at a location east of the mining area to provide for a source of water to charge the processing plant. A conceptual construction detail of an UFA well is shown on Figure 6. Twin Pines will apply for a Groundwater Use Permit, requesting a maximum daily permitted amount from the UFA of 1.44 MGD at the Saunders Demonstration Mine. The Upper Floridan wells will be pumped at a rate of approximately 1.44 MGD for three days to provide the 4.32 MG of water needed to charge the processing plant. Process water will flow through in a generally closed-loop water recycling system. The mineral extraction process requires a flow rate of approximately 3,000 gpm within the recycling system, of which approximately 10% or 300 gpm is consumed. Therefore, once the plant is charged, daily make-up water needs are substantially reduced. The MUW will be provided by water pumped out of the mining pit and stored in the water management ponds and the Upper Floridan wells will be reserved as a “backup” water supply

Water required at the Mineral Separation Plant will be hauled, utilizing tanker trucks, from Water Management Pond M-3. Process water from the Mineral Separation Plant will be hauled, by tanked trucks, to the Process Water Ponds for reuse.

4.3 Upper Floridian Aquifer Water Quantity

The PCP is designed for optimum water conservation when compared to the typical "wet mining" process. The Upper Floridan wells will be pumped at a rate of approximately 1.44 MGD for three days to provide the 4.32 MG of water needed to charge the processing plant. The processing technique uses a closed loop system designed for water reuse and recycling. Daily water losses due to evaporation, retention on the tailings returning to the reclamation cut, and minor amounts of water retained in the final product are anticipated to be 10% or 300 gpm. Makeup water will be provided by water pumped out of the mining pit and stored in the water management ponds and the Upper Floridan wells will be reserved as a “backup” water supply. This process reduces environmental impacts by decreasing UFA withdrawals.

Twin Pines will only pump water from the Upper Floridan wells when water is needed to be added to maintain the optimal water volume in the process water pond(s). Water usage will be monitored by installing flow meters on the production wells in the UFA and throughout the mineral processing system. Twin Pines will perform regular meter maintenance, testing, and calibration to ensure best practice water conservation. Attachment A illustrates the process flow for the proposed mining operations.

4.4 Percentage of Make-Up Water (MUW)

The proposed system at the Saunders Demonstration Mine operations inherently minimizes the amount of MUW needed by recycling and reusing water. The mineral extraction process requires a flow rate of approximately 3,000 gpm within the recycling system, of which approximately 10% or 300 gpm is consumed.

4.5 Water Conservation Measures

Twin Pines will implement the following conservation measures at the proposed Saunders Demonstration Mine:

- Recycling and reuse of water within the mining system,
- Pipeline inspection for detection of leaks,
- Meter maintenance, testing, replacement, calibration,
- Promote a water conservation education program,
- Prevention of unauthorized or excessive water use.

This will be a new mine site using a mining technique that is different from conventional "wet mining", which utilizes a dredge and floating concentrator to mine and process heavy mineral- bearing sands. The "dragline" method is flexible and allows for strategic recovery of ore resources. The maximum mining depth will be 50 feet. This method provides for more precision than is possible with typical dredge mining methods. In addition, having the PCP located in close proximity of the Wet Processing Plant and lined process water ponds will allow for concentrating activities in one centralized location, thereby decreasing energy demands and creating an efficient method for process water reuse and recirculation.

Most of the pipelines will be installed above ground and will be inspected on a regular basis. Twin Pines will train their employees to inform them of the importance of water conservation practices at the plant.

4.6 Water Conservation Measures and Upgrades

Conservation measures and improvements are selected based on operational benefits and cost savings. Measures and improvements will be reviewed periodically as part of an audit and review process by site management and those measures deemed appropriate will be implemented.

4.7 Plumbing Ordinances and/or Codes

Twin Pines will comply with applicable plumbing code provisions requiring the use of ultra-low flow plumbing fixtures and the installation of other applicable water saving technologies for the water distribution system to support water conservation. However, the proposed Saunders Demonstration Mine will not be operating a water system and therefore will not be enforcing plumbing ordinances.

4.8 Recycle-Reuse

The proposed system at the Saunders Demonstration Mine operations inherently minimizes the amount of unaccounted for water by recycling and reusing of water. Attachment A depicts the process flow diagram and details how the process water is recycled and re-used.

4.9 Progress Reports

The proposed Saunders Demonstration Mine is planning on operating for approximately 4 years. Twin Pines will submit a water conservation progress report for every five (5) years of operation or at the end of operations whichever is first, to the Georgia EPD in accordance with Georgia Rule 391-3-2.04(11)(h). The report will outline water use and recycling in the mineral processing closed-loop system, describing improvements and summarizing water conservation activities.

Twin Pines will submit a summary water quality report to Georgia EPD on a quarterly basis during the first year of mining and annually thereafter, in accordance with the Groundwater & Surface Water Monitoring & Adaptive Monitoring Plan; provided to Georgia EPD - Groundwater Withdrawal Unit as a standalone document. Water quality reports will include groundwater contour maps, results of water quality analysis for the period of monitoring, and trend graphs of concentrations. Water chemistry data will be evaluated and compared to background concentrations and applicable regulatory standards. In addition, a statistical summary of water quality data collected at each sampling location will be prepared and selected data will be presented graphically to illustrate trends or seasonal changes in water quality.

4.10 Water Use Data

Twin Pines will submit a monthly groundwater use data report to the Georgia EPD. The report will include data on the amount of water withdrawn from the UFA during the reporting period.

5 GROUNDWATER USAGE

Water evacuated from the mine pit during active mining operations will contribute substantial volumes that can be used for process water. The seepage rate will vary as the mine moves, but is conservatively estimated at 783 gpm. This water will be evacuated from the mine pit using pumps as necessary to ensure that no more than 8 feet of water remains. Once the mining process is initiated, seepage water will likely supply most, if not all, of the 300 gpm needed for makeup process water.

5.1 Groundwater Modeling Study

Twin Pines conducted a groundwater modeling study for the effects on the UFA system during the anticipated 4-year life span of the Saunders Demonstration Mine (Attachment B). A summary of the results of the groundwater modeling study are provided below.

As part of the Twin Pines Minerals, LLC Demonstration Project groundwater modeling study, the model assumed two production wells will be installed in the Upper Floridan Aquifer, and each well will be pumped at 500 gpm for 4 years. The Theis (1935) solution was used to predict drawdown in each well. Solutions for each well were linearly superimposed using codes developed in MATLAB to predict total drawdown. Three scenarios were developed using literature values: 1) a Base Case (determined from an average of literature values), 2) a Maximum-Drawdown Case (determined from the literature values with the largest hydraulic diffusivity), and 3) a Minimum-Drawdown case (determined from the literature values with the smallest hydraulic diffusivity). These results show that:

- The maximum drawdown at each well is 14.3 ft for the Base Case Scenario, 31.0 ft for the Maximum-Drawdown Scenario, and 6.7 feet for the Minimum-Drawdown Scenario.
- The maximum drawdown of the Upper Floridan Aquifer at the edge of the ONWR is 3.8 ft in the Base Case Scenario, 13.2 ft for the Maximum-Drawdown Scenario, and 1.3 feet for the Minimum-Drawdown Scenario.
- One year after pumping stops (5 years after mining is initiated), the Upper Floridan Aquifer shows significant recovery and the drawdown has reduced to 1.3 ft in the Upper Floridan Aquifer for the Base Case Scenario at the edge of the ONWR.

The leakage potential for the upper confining unit of the Upper Floridan Aquifer was evaluated to address public concern that pumping in the Floridan Aquifer will induce leakage from the Okefenokee Swamp, through the upper confining unit of the Floridan Aquifer (the Hawthorn Group in the vicinity of the proposed project), into the Floridan Aquifer. The evaluation showed:

- That the conditions leading to leakage across the upper confining unit in the vicinity of St. Mary's Georgia do not exist at the project site or the adjacent Okefenokee Swamp.
- Flaws in a study presented by Kitchens and Rasmussen (1995), which suggested that the Darcy flux (leakage) through the upper confining unit could be between 1.1×10^{-3} to 0.11 ft/day.

- That the volume per unit area of water removed from the surficial aquifer and the Okefenokee Swamp after 4 years of pumping from the Floridan Aquifer is negligible and insignificant (1.17×10^{-11} ft^3/ft^2) and that the time required to achieve a new equilibrium is long, greater than 289 years, compared to the duration of the project (4 years).

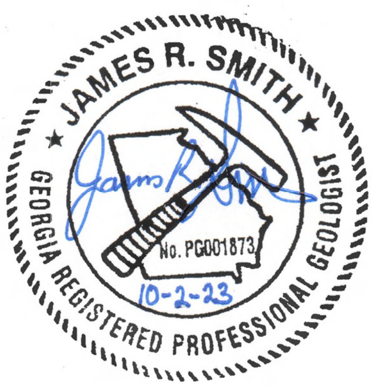
As part of a response to the Georgia EPD's April 14, 2021 Permit Coordination Document, Twin Pines addressed comments 7b and 7c related to the groundwater withdrawal permit application. For comment 7b, Twin Pines performed additional analysis to quantify the impact to the surficial aquifer at the edge of the ONWR as a result of the Floridan Aquifer "Maximum-Drawdown Scenario." The results of the analysis show that the drawdown of the Surficial Aquifer at the edge of the ONWR is essentially zero. A detailed description of the analysis performed, entitled, "Analysis of Impacts to Surficial Aquifer" is provided in Attachment C of this document.

For comment 7c, Twin Pines evaluated the range of possible hydraulic conductivities for the aquitard and provided supporting evidence for the value used in the analysis (Attachment C).

6 SIGNATURES OF PROFESSIONALS

Senior Project Professional, James R. Smith prepared this report, with final senior review by Principal Engineer, Sheryle G. Reeves.

Should you have any questions, please contact either of us at (334)-244-0766.



James R. Smith, P.G.
Senior Project Professional

Sheryle G. Reeves, P.E.
Principal Engineer

7 REFERENCES

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FIGURES

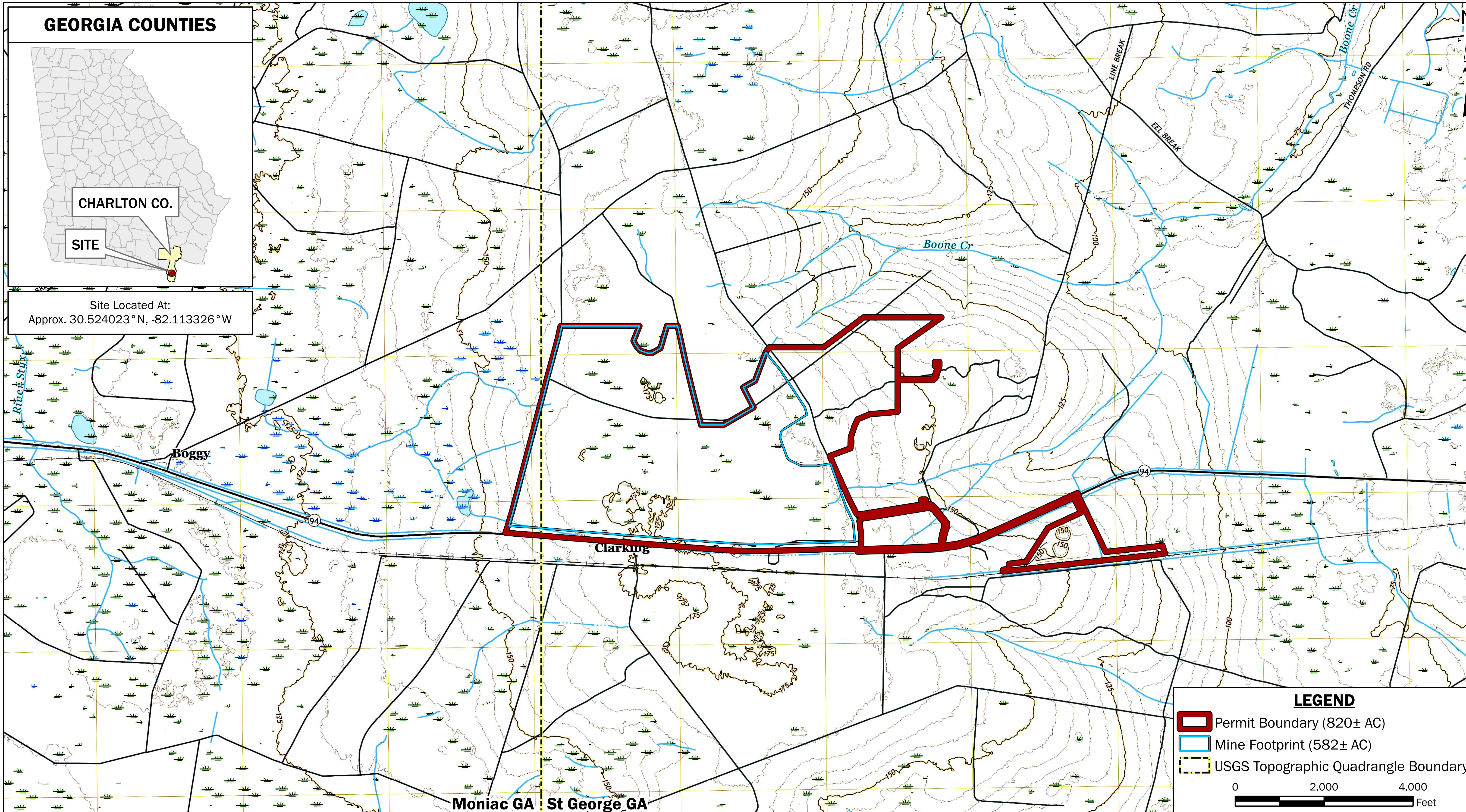

FIGURE 1: SITE LOCATION & TOPOGRAPHIC MAP

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

BASEMAP: Moniac (W) & Saint George (E), Georgia, USGS 7.5 Minute Quadrangle Map, 2020 (5-ft Contour Interval).

DRAWN BY: DEK	
CHECKED BY: JRS	
DRAWING DATE: 12/4/2020	
REVISION DATE: 9/14/2023	
TTL JOB NO.: 000180200804.00	
APPROX. SCALE: 1 in = 2,000 ft	

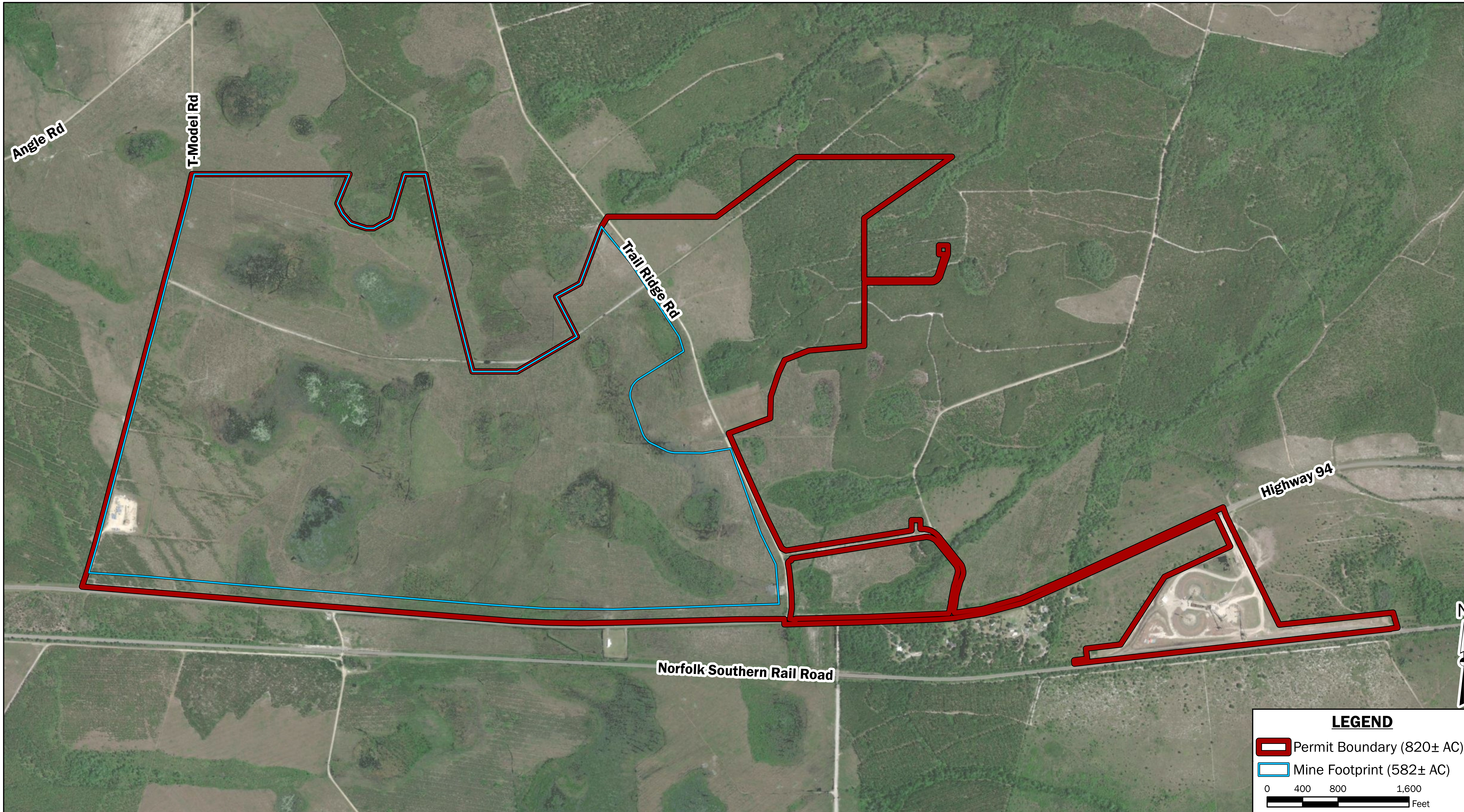

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FIGURE 2: SITE LOCATION & AERIAL PHOTOGRAPH

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

BASEMAP: Maxar Technologies, Vivid Imagery, 5/7/2021 (0.5 m Resolution).

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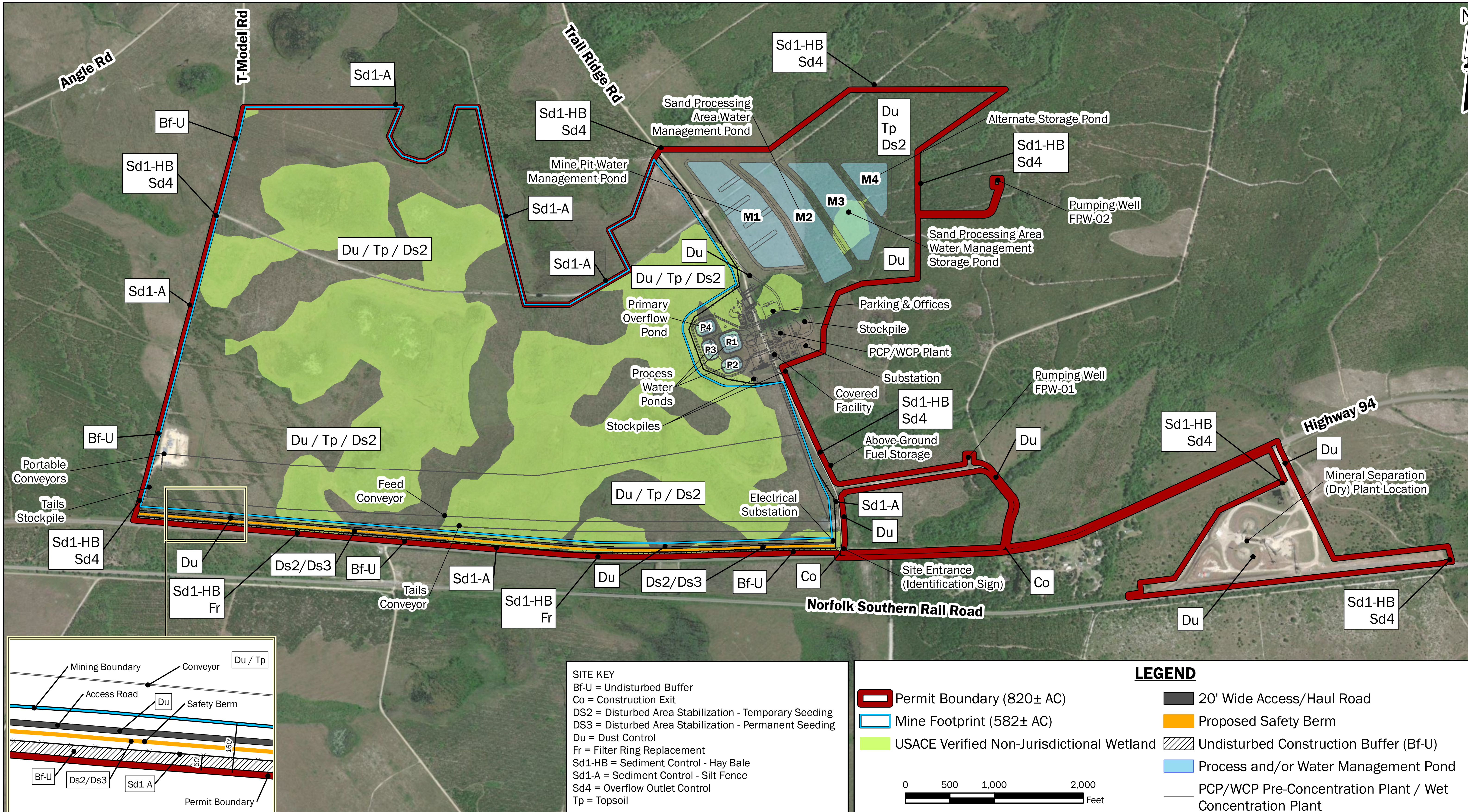

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FIGURE 3: PROPOSED SITE LAYOUT

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

BASEMAP: Maxar Technologies, Vivid Imagery, 5/7/2021 (0.5 m Resolution).

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APPROX. SCALE: 1 in = 1,000 ft

NOTES:
- Estimated timing is based on a mining progress rate of 10-15 acres per month. The illustration represents the average of those values (170 feet per day). Actual timing for extraction of heavy mineral sands is expected to be 4 years.
- See Figure 5 for cross-sections of the typical dragline mining operation.
- Tails stockpile and conveyors will move in accordance with the moving mine pit and are not permanent features.

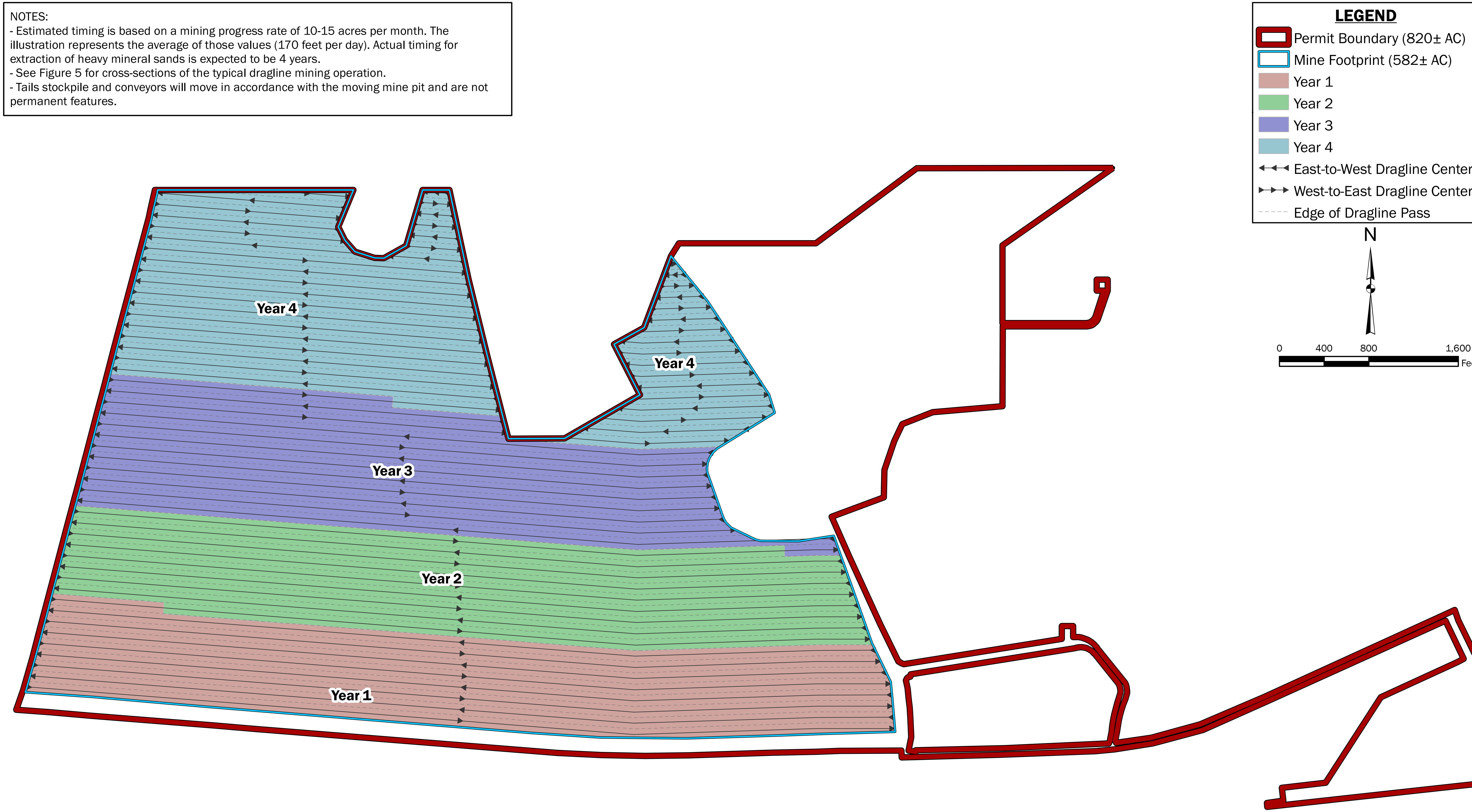

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FIGURE 4: ESTIMATED PROGRESSION OF MINING

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

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CHECKED BY: JRS
DRAWING DATE: 12/4/2020
REVISION DATE: 9/14/2023
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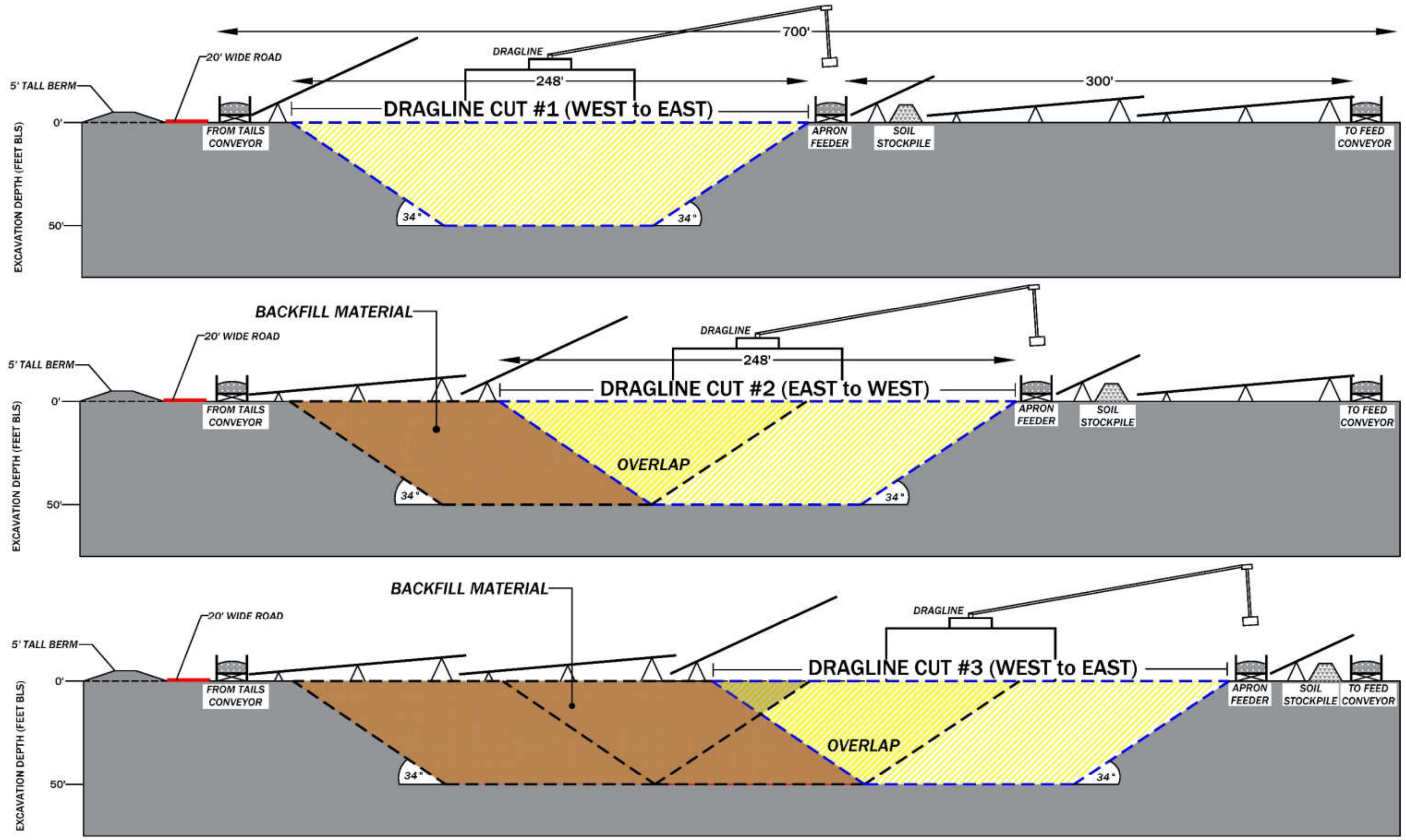
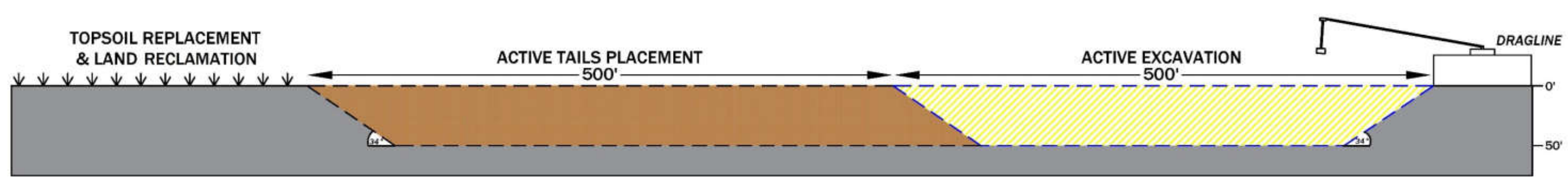
APPROX. SCALE: 1 in = 800 ft



SECTION A - A'

NOT TO SCALE



SECTION B - B'

NOT TO SCALE

LEGEND

UNEXCAVATED MATERIAL | DRAGLINE EXCAVATION | BACKFILLED MATERIAL | OVERLAP

NOTE: Dragline advancement shall be 100 to 200 feet per day (average = 170 ft/day); backfilling shall proceed no more than 500 feet (i.e. 5 to 7 days) behind the progressing mine pit.

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FIGURE 5: IMPACT EXCAVATION DESIGN - CROSS-SECTIONS OF TYPICAL MINING PIT

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

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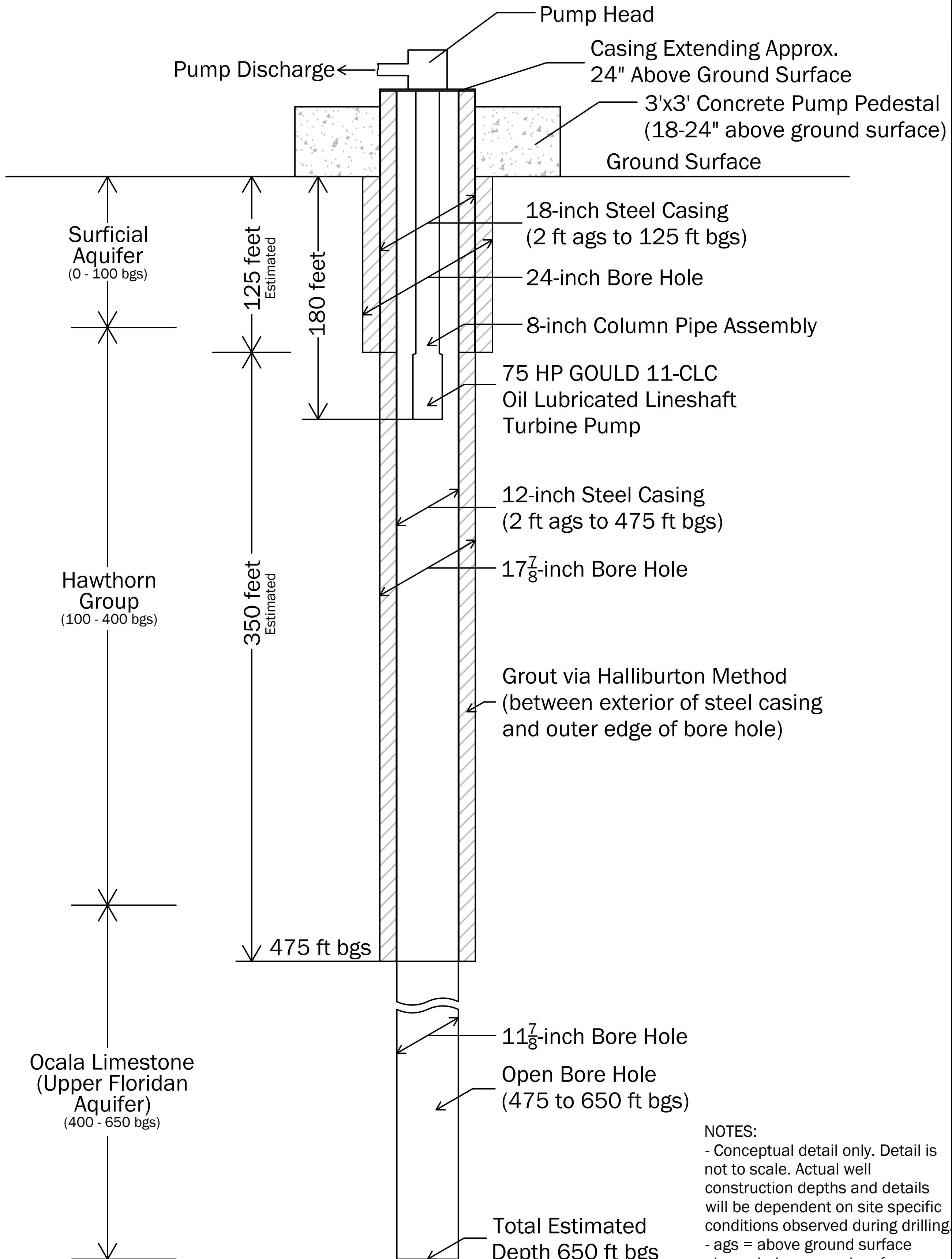
CHECKED BY:	JRS
DRAWING DATE:	12/4/2020
REVISION DATE:	11/26/2022
TTL JOB NO.:	000180200804.00
APPROX. SCALE:	Not To Scale



NOTES:
- Conceptual detail only. Detail is not to scale. Actual well construction depths and details will be dependent on site specific conditions observed during drilling.
- ags = above ground surface
- bgs = below ground surface

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FIGURE 6: CONCEPTUAL CONSTRUCTION DETAIL OF UPPER FLORIDAN AQUIFER WELL

TWIN PINES MINERALS, LLC
SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

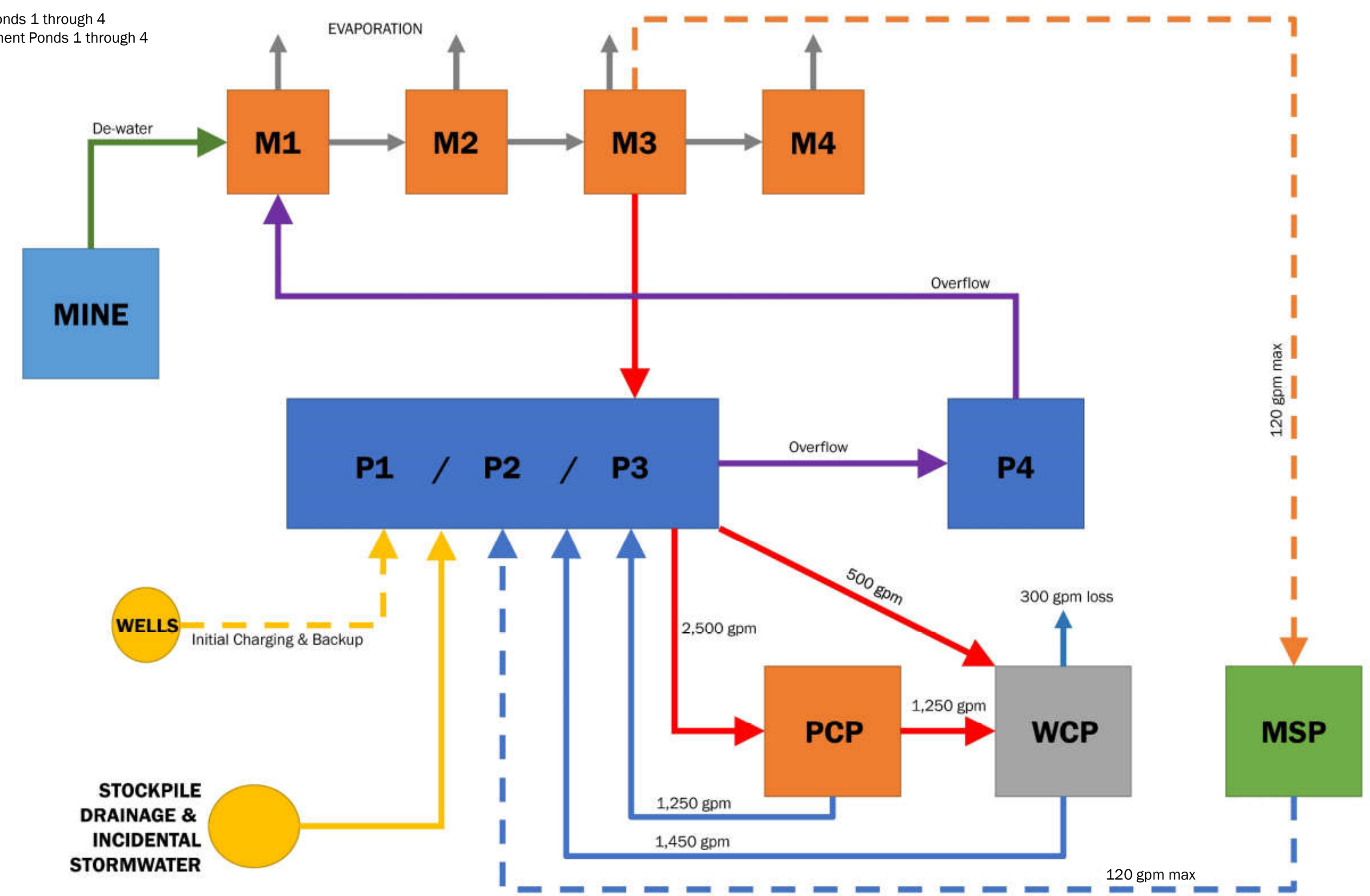
Drawn By: D E K
Checked By: J M T
Date: 05/19/2022
Proj. No.: 18-02-00804.00
File Name: Well_Detail.dwg

Sheet Title
PUMPING WELL DETAIL

ATTACHMENT A

PROCESS FLOW DIAGRAM

LEGEND:
P1 through P4 = Process Water Ponds 1 through 4
M1 through M4 = Water Management Ponds 1 through 4
PCP = Pre-Concentration Plant
WCP = Wet Concentration Plant
MSP = Mineral Separation Plant
gpm = gallons per minute



NOTES:
1. All material shall be hauled, utilizing trucks, between the permitted mine, wet processing areas, and Mineral Separation Plant (MSP) south of Highway 94.
2. Water required at the Mineral Separation Plant with be hauled, utilizing tanker trucks, from Water Management Pond M3. Any wastewater from the Mineral Separation Plant will be hauled, by tanked trucks, to the Process Water Ponds for re-use.

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MINING WATER PROCESS FLOW DIAGRAM

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

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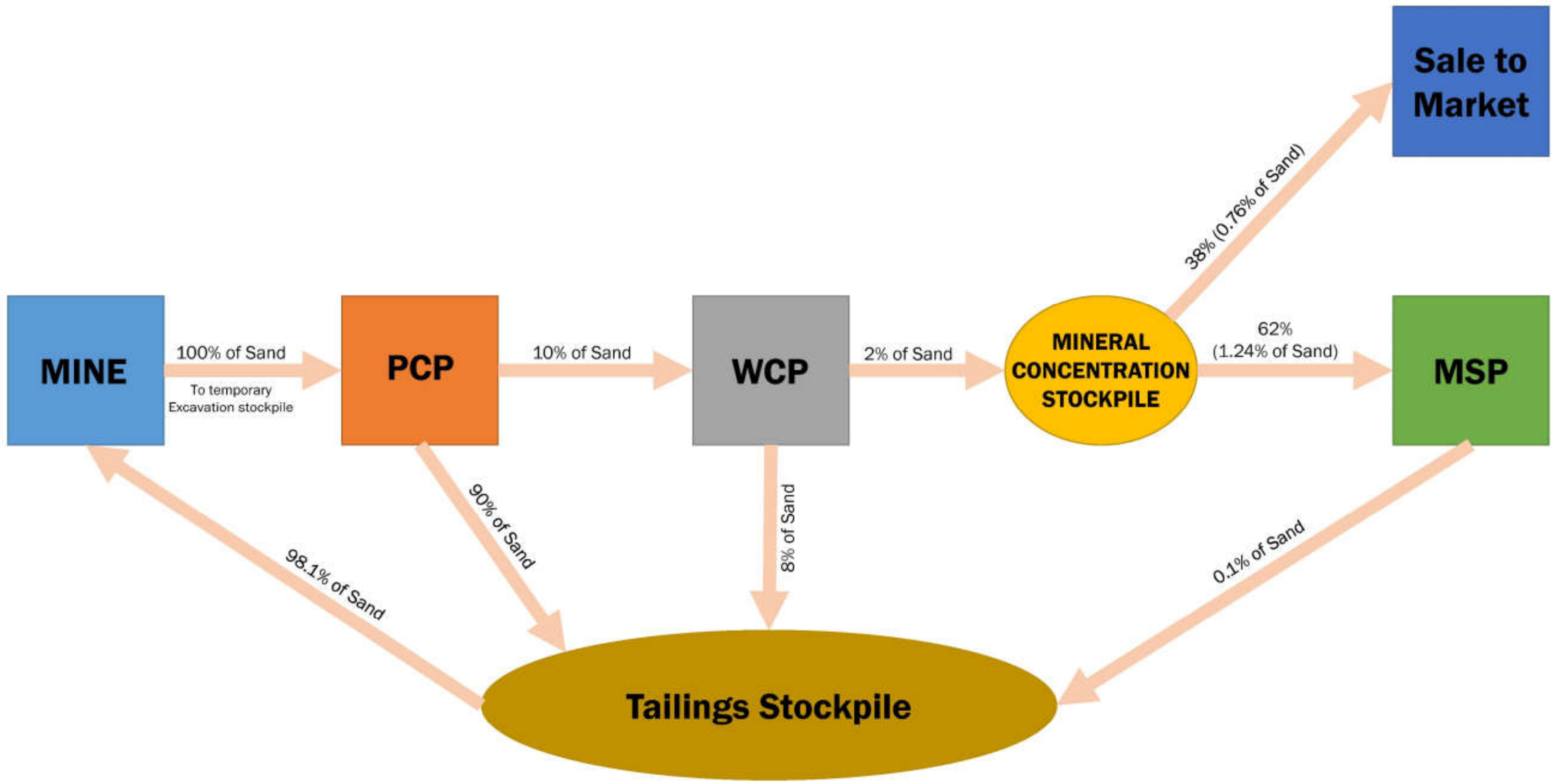
APPROX. SCALE:	Not To Scale

LEGEND:
PCP = Pre-Concentration Plant
WCP = Wet Concentration Plant
MSP = Mineral Separation Plant
gpm = gallons per minute



MINING SAND PROCESS FLOW DIAGRAM

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE (ID NO. 2073)

ST. GEORGE, CHARLTON COUNTY, GEORGIA

DRAWN BY: DEK
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DRAWING DATE: 12/4/2020
REVISION DATE: 9/14/2022
TTL JOB NO.: 000180200804.00
APPROX. SCALE: Not To Scale

ATTACHMENT B

AN EVALUATION OF DRAWDOWN FROM FLORIDAN WELLS

FPW-01 AND FPW-02 AT THE TWIN PINES MINERALS, LLC MINE SITE

AN EVALUATION OF DRAWDOWN FROM FLORIDAN WELLS

FPW-01 AND FPW-02 AT THE TWIN PINES MINERALS, LLC MINE SITE

Robert M. Holt

University of Mississippi

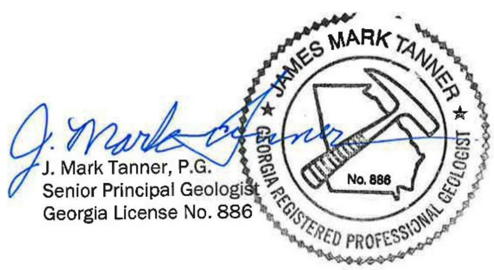
Department of Geology and Geological Engineering

Professor

J. Mark Tanner, P.G.

TTL, Inc.

Senior Principal Geologist



Introduction

Twin Pines Minerals, LLC is proposing to drill two production wells (FPW-01, FPW-02) in the upper Floridan aquifer at their proposed demonstration mine site located in Charlton county, Georgia (Figure 1). The production wells will supply water for heavy-minerals concentration plants at the mine, and each well will be pumped at a maximum of 500 gallons per minute (gpm). The proposed demonstration mine will operate for 4.0 years, and pumping will begin at the start of mining and will end upon the completion of mining.

The USGS (Bellino, 2019) estimated that pumping rates from the Floridan Aquifer in 2010 were 11.1 million gallons per day from the four counties containing the Okefenokee Swamp, including Charlton County, Ware County, Brantley County, and Clinch County. Twin Pines Minerals, LLC proposes to pump 1.44 million gallons per day.

In the following report, we first estimate the drawdown in the Floridan Aquifer caused by pumping from the proposed production wells. We use literature values to consider three pumping scenarios: a Base Case (determined from an average of literature values), a Maximum-Drawdown Case (determined from the literature values with the largest hydraulic diffusivity), and a Minimum-Drawdown case (determined from the literature values with the smallest hydraulic diffusivity). The maximum drawdown is determined for each case at the pumping wells and the closest boundary of the Okefenokee National Wildlife Refuge (ONWR).

The public has expressed concern that pumping in the Floridan Aquifer could lead to leakage through the upper confining unit of the Floridan Aquifer, potentially influencing water levels in the Okefenokee National Wildlife Refuge (ONWR). We first show that the conditions leading to leakage across the upper confining unit in the vicinity of St. Mary's, GA do not exist at the project site or the adjacent ONWR. Second, we examine the flaws in a study presented by Kitchens and Rasmussen (1995), which suggested that significant leakage could occur from the Okefenokee Swamp, through the upper confining unit of the Floridan Aquifer, into the Floridan Aquifer. Finally, we use a conservative analytical approach to show that the volume per unit area of water removed from the surficial aquifer and the ONWR is insignificant after 4.0 years of pumping in the Floridan Aquifer.

Drawdown Modeling

The Theis (1935) solution is used to predict well drawdowns (s) caused by pumping in wells FPW-01 and FPW-02 over the 4.0 year life of the mine. The Theis (1935) equation is given by

$$s(r,t) = \frac{Q}{4\pi T} W(u)\,, \qquad (1)$$

where Q is the pumping rate (500 gpm or 96,250 ft^3/day for each well), r is the radial distance from the well, T is the aquifer transmissivity, and $W(u)$ is the Theis well function, given by the exponential integral

$$W(u) = \int_u^\infty \frac{e^{-y}}{y} dy \, . \qquad (2)$$

The variable u is

$$u = \frac{r S}{4Tt}, \qquad (3)$$

where S is the aquifer storage coefficient and t is time. The Theis solution assumes that the aquifer is infinite, confined, and homogeneous; that equipotentials are vertical; and that the well diameter is negligible. The total drawdown from both wells in the aquifer is determined by linearly superimposing (summing) the contributions from each well.

Two MATLAB codes were developed to predict the drawdown (Appendices A, B, and C). The first MATLAB code (Appendix A) calculates the time-dependent drawdown at a specified location (e.g., near the pumping well or at the edge of the ONWR). The second MATLAB code (Appendix B) predicts the spatial drawdown due to pumping at several wells at a specified time. Both codes allow the user to define the number of wells, aquifer properties (T and S), and a pumping schedule for each well. Example MATLAB commands for each code are shown in Appendices A and B. Both codes require the text file Welldat.dat (Appendix C), which includes the X-location, Y-location, time that pumping starts, time that pumping ends, and pumping rate for each well.

Both MATLAB codes require estimates of T and S. Williams and Kuniansky (2016) report T and S values for 11 wells in the upper Floridan Aquifer. One well had an anomalously low T value and was excluded from our analysis. The T and S values for the remaining 10 wells were averaged to define a Base Case scenario (Table 1). Hydraulic properties for the “Minimum-Drawdown” and “Maximum-Drawdown” scenarios were determined by selecting the well pairs with the highest and lowest hydraulic diffusivity (Table 1).

The predicted drawdown at the proposed production wells is shown for each scenario in Figures 2 and 3. The maximum drawdown of the Floridan Aquifer at each of the wells and at the closest boundary of the ONWR is shown in Table 2. The pumping schedules for both wells are identical, and drawdown peaks when the wells are shutoff at 4.0 years. The maximum drawdown at each well is 14.3 ft for the Base Case, 31.0 ft for the Maximum-Drawdown Scenario, and 6.7 feet for the Minimum-Drawdown Scenario.

The aerial distribution of the predicted drawdown in the Floridan Aquifer for the Base Case scenario is shown in Figures 4 – 7, representing times of 1 year, 2 years, 4 years, and 5 years. Near the pumping wells, drawdown appears elliptical, and at larger distances the drawdown appears radial. The drawdown in the Floridan Aquifer at the nearest edge of the ONWR is 2.7 ft after 1 year of pumping, 3.2 ft after 2 years of pumping, and 3.8 ft after 4 years of pumping. One year after pumping (5 years), the upper Floridan Aquifer shows significant recovery (Figure 7) and the drawdown has reduced to 1.3 ft. For the Maximum-Drawdown Scenario, the drawdown at the edge of the ONWR is 13.2 ft after 4 years (Table 2), and the drawdown for the Minimum-Drawdown Scenario is 1.3 ft after 4 years.

Leakage Potential for the Upper Confining Unit of the Floridan Aquifer (Hawthorn Group)

Based on groundwater data from a long-term pumping site in St. Mary's Georgia (e.g., Peck et al., 2005), members of the public have expressed concern that pumping in the Floridan Aquifer will induce leakage from the Okefenokee Swamp, through the upper confining unit of the Floridan Aquifer (the Hawthorn Group in the vicinity of the proposed project), into the Floridan Aquifer. Here, we address these issues. First, we show that the conditions leading to leakage across the upper confining unit in the vicinity of St. Mary's, GA do not exist at the project site or the adjacent ONWR. Second, we reveal the flaws in a study presented by Kitchens and Rasmussen (1995), which suggested that the Darcy flux (leakage) through the upper confining unit could be between 1.1×10^{-3} to 0.11 ft/day. Finally, we use a conservative analytical approach to show that the volume per unit area of water removed from the surficial aquifer and the Okefenokee Swamp after 4 years of pumping in the Floridan Aquifer is negligible and insignificant (1.17×10^{-11} ft^3/ft^2) and that the time required to achieve a new equilibrium is long, greater than 289 years, compared to the duration of the project (4 years).

Leakage Near St. Mary's, Georgia

In St. Mary's, Georgia (Camden County), a pulp and paper mill that pumped 35.6 million gallons per day from the Upper Floridan aquifer ceased operation in October 2002 (Peck et al., 2005). Following the cessation of pumping, recovery was observed in nearby confined surficial, upper Brunswick, and Upper and Lower Floridan aquifer monitoring wells over a period of 8 to 12 months (Peck et al., 2005). While the plant was operating, there was a downward gradient between the surficial and Brunswick aquifers. Once pumping stopped, the gradient reversed with a total apparent recovery response of 17.6 ft in a Brunswick well after 12 months. In the St. Mary's area, substantial leakage occurred across the upper confining unit due to local pumping in the Floridan aquifer. This type of leakage cannot occur in the vicinity of the proposed Twin Pines Minerals, LLC mine.

Around St. Mary's, GA, the upper confining unit Floridan Aquifer contains the upper and lower Brunswick aquifers (Clarke et al., 1990). Both units consist of phosphatic, slightly dolomitic sand and local carbonates. The upper Brunswick aquifer is found between geophysical markers A and B of Williams and Kuniansky (2015), while the lower Brunswick aquifer occurs between geophysical markers B and C (Williams and Kuniansky, 2015; Steele and McDowell, 1998). In Camden County GA, high transmissivity values are reported for the upper and lower Brunswick aquifer due to thicker, more permeable sand and carbonate beds (Clarke, 2003). The Brunswick aquifers pinch-out west of St. Mary's GA, and are absent in the vicinity of Folkston GA and beneath the Okefenokee Swamp (e.g. Payne et al., 2005). A series of calibrated groundwater flow models developed by the USGS (Payne et al., 2005; Cherry, 2015; and Cherry, 2019) assign a vertical hydraulic conductivity of 1×10^{-5} ft/d to the upper confining unit (Hawthorn Group) in the vicinity of the proposed mine and the Okefenokee swamp.

West of Folkston, GA, the upper confining unit (Hawthorn Group) consists of greenish-gray, low-permeability clays. At the Twin Pines Minerals, LLC site, the upper confining unit is ~ 325 ft thick (Williams and Kuniansky, 2015). Where clays are present in the upper confining unit, the vertical hydraulic conductivity is small (less than 1×10^{-4} ft/d), and leakage across the upper confining unit is negligible (Williams and Kuniansky, 2015). Below the Okefenokee Swamp, the upper Floridan aquifer is overlain by more than 300 ft of low-permeability sediments that effectively isolate the Floridan aquifer from vertical leakage and recharge (Torak et al., 2010).

Kitchens and Rasmussen (1995) Study

Kitchens and Rasmussen (1995) determined an impulse response function that related time series observations of water level in the swamp to observations of water levels in a well located in the Floridan aquifer beneath the swamp using regression deconvolution. Based on their deconvolution, they estimated an average time lag of one month for the aquifer to respond to changes in swamp water levels. They then estimated the hydraulic diffusivity of the upper confining unit to be 3,143 ft^2/d. Using this diffusivity value with a range of specific storage values derived from the literature for clays, they estimated the hydraulic conductivity of the upper confining unit to range from 1.1 ft/day to 0.011 ft/day. Using these hydraulic conductivity values and assuming a downward hydraulic gradient of 0.1, the authors estimated the Darcy flux (leakage) through the upper confining unit to be between 1.1×10^{-3} to 0.11 ft/day.

There are several flaws with this analysis. First, measured hydraulic conductivities in the upper confining unit are much lower than those estimated by Kitchens and Rasmussen (1995). Where clays are present in the upper confining unit, the vertical hydraulic conductivity is small (less than 10^{-4} ft/day), and leakage across the upper confining unit is negligible (Williams and Kuniansky, 2015). Calibrated groundwater models that include the proposed mine and the Okefenokee Swamp area use a vertical hydraulic conductivity of 10^{-5} ft/day for the upper confining unit (Payne et al., 2005; Cherry, 2015; and Cherry, 2019). Samples of the upper confining unit taken at the Twin Pines Minerals, LLC site show hydraulic conductivity values of 3.66×10^{-2} ft/day, 2.63×10^{-5} ft/day, and 4.56×10^{-6} ft/day (Holt et al., 2019), consistent with the values used in calibrated groundwater models.

A second flaw is that the model of Kitchens and Rasmussen (1995) assumes that all the fluctuations in the water levels of the Floridan aquifer are due strictly to vertical leakage through the upper confining unit. This is not the case. The Floridan aquifer is recharged from areas west of the Okefenokee Basin (Torak et al., 2010). Because of the high permeability of the Floridan aquifer, Floridan aquifer water levels beneath the swamp will respond rapidly to increases in recharge west of the swamp. We can estimate the time required for recharge to influence water levels in the Floridan Aquifer beneath the Okefenokee Swamp using an aquifer time constant. The time constant can be defined as

$$\tau_h = \frac{S\ L^2}{T}, \tag{4}$$

where L is the distance to the point of recharge. The time constant is related to a half-life and nominally represents the time required to move from one steady state condition to another. Using the Base Case values of T and S reported above and a distance (L) of 10 miles, the time constant is 172 days, indicating that head changes caused by recharge will quickly manifest beneath the swamp.

A third flaw in their model is that they assume that the hydraulic gradient is always downward. Torak et al. (2010) reported that the Floridan aquifer had artesian conditions during September 2006 in the Okefenokee Basin and Swamp. Torak et al. (2010) attribute the elevated groundwater levels and artesian condition in the vicinity of the Swamp to lower permeability of the Floridan aquifer and more than 300 ft of low-permeability overburden.

Impact of Floridan Pumping on Leakage from the Okefenokee Swamp

The change in the vertical flow between the Okefenokee Swamp and the Floridan Aquifer can be determined using an analytical approach. The governing equation for one dimensional, saturated groundwater flow in a homogeneous aquifer is

$$S_s \frac{\partial h}{\partial t} = K \frac{\partial^2 h}{\partial x^2}, \tag{5}$$

where S_s is the specific storage of the upper confining unit (assumed to be 10^{-4} 1/ft), K is the hydraulic conductivity of the upper confining unit (assumed to be 10^{-4} ft/day from Williams and Kuniansky, 2015), x is the vertical coordinate, and h is the hydraulic head. Equation 5 can be solved using the following boundary and initial conditions

$$h(x=0,t) = h_1 = 0 \text{ ft}, \tag{6}$$

$$h(x=L,t) = h_0 = -3.788, \tag{7}$$

$$h(x,t=0) = 0 \text{ ft}, \tag{8}$$

to yield (Crank, 1975)

$$h(x,t) = h_1 + (h_2 - h_1)\frac{x}{L} + \frac{2}{\pi}\sum_{n=1}^{\infty}\left[\left(\frac{h_2 \cos(n\pi) - h_1}{n}\right)\sin\left(\frac{n\pi x}{L}\right)\exp\left(-\frac{Kn^2\pi^2 t}{S_s L^2}\right)\right], \tag{9}$$

where L is the thickness of the upper confining unit (325 ft). Here we assume that there is an instantaneous decrease of the head in the upper Floridan Aquifer of -3.788 ft (the maximum drawdown at the ONWR boundary for the Base Case Scenario) and that this head change persists for 4.0 years; this is conservative, as the decrease in head in the Floridan will be gradual and reach -3.788 ft at 4.0 years. Figure 8 shows the change in the hydraulic head in this situation. Note that most of the head change in the confining unit occurs below 200 ft.

Using the results shown in Figure 8, we can calculate the Darcy flux using

$$q(x,t) = -K\frac{dh(x,t)}{dx}, \tag{10}$$

Integrating Equation 6 with respect to time gives the total volume of flow per unit area passing location (x) at time (t), e.g.,

$$\frac{V(x,t)}{A} = -\int_0^t K \frac{dh(x,t)}{dx} dt \,, \tag{11}$$

At the top of the confining unit (x=0), the total volume per unit area of water lost from the surficial aquifer due to a hydraulic head decrease of 3.788 ft in the Floridan Aquifer is 1.17×10^{-11} ft^3/ft^2. This would mean that an area of 3,587 square miles would lose a total of 1.17 cubic feet of water after 4 years of pumping. This volume of water is insignificant compared to the evapotranspiration of a 3,587 square mile area in the same period.

Finally, we can estimate the time required for water levels in the swamp to respond to changes in water levels in the Floridan Aquifer using a time constant for groundwater flow. The time constant can be defined as

$$\tau_h = \frac{S_s L^2}{K} \,, \tag{12}$$

For the upper confining unit, the time constant is estimated to be 289 years. Drawdown in the Floridan aquifer from pumping at the Twin Pines Minerals, LLC mine will have a negligible effect on water levels in the Okefenokee Swamp.

SUMMARY

As part of the Twin Pines Minerals, LLC Demonstration Project, two production wells will be installed in the Floridan Aquifer, and each well will be pumped at 500 gpm for 4 years. The Theis (1935) solution was used to predict drawdown in each well. Solutions for each well were linearly superimposed using codes developed in MATLAB to predict the total drawdown. Three scenarios were developed using literature values: 1) a Base Case (determined from an average of literature values), a Maximum-Drawdown Case (determined from the literature values with the largest hydraulic diffusivity), and a Minimum-Drawdown case (determined from the literature values with the smallest hydraulic diffusivity). These results show that:

- The maximum drawdown at each well is 14.3 ft for the Base Case Scenario, 31.0 ft for the Maximum-Drawdown Scenario, and 6.7 feet for the Minimum-Drawdown Scenario.
- The maximum drawdown of the Floridan Aquifer at the edge of the ONWR is 3.8 ft in the Base Case Scenario, 13.2 ft for the Maximum-Drawdown Scenario, and 1.3 feet for the Minimum-Drawdown Scenario.
- One year after pumping stops (5 years), the upper Floridan Aquifer shows significant recovery and the drawdown has reduced to 1.3 ft for the Base Case Scenario at the edge of the ONWR.

We evaluated the leakage potential for the upper confining unit of the Floridan Aquifer to address public concern that pumping in the Floridan Aquifer will induce leakage from the Okefenokee Swamp, through the upper confining unit of the Floridan Aquifer (the Hawthorn Group in the vicinity of the proposed project), into the Floridan Aquifer. The evaluation showed:

- That the conditions leading to leakage across the upper confining unit in the vicinity of St. Mary's GA do not exist at the project site or the adjacent Okefenokee Swamp.

- Flaws in a study presented by Kitchens and Rasmussen (1995), which suggested that the Darcy flux (leakage) through the upper confining unit could be between 1.1×10^{-3} to 0.11 ft/day.
- That the volume per unit area of water removed from the surficial aquifer and the Okefenokee Swamp after 4 years of pumping in the Floridan Aquifer is negligible and insignificant (1.17×10^{-11} ft^3/ft^2) and that the time required to achieve a new equilibrium is long, greater than 289 years, compared to the duration of the project (4 years).

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Williams, L.J., and Kuniansky, E.L., 2015, Revised hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1807, 140 p., 23 pls.

Table 1. Hydraulic properties for the upper Floridan Aquifer in north Florida (Williams and Kuniansky, 2016). *The hydraulic properties for well IWSD-TW were used for the minimum-drawdown scenario, and **the hydraulic properties for well BICY-TW were used for the maximum-drawdown scenario.

Well ID	Transmissivity (ft^2/day)	Storage Cofficient (dimensionless)	Hydraulic Diffusivity (ft^2/day)
IWSD-TW*	36000	1.00E-02	3.60E+06
ROMP14	6570	9.90E-04	6.64E+06
ROMP39	12000	1.60E-04	7.50E+07
36Q330	40000	2.00E-04	2.00E+08
ROMP43	13000	2.00E-05	6.50E+08
OSF-97	15500	2.20E-05	7.05E+08
ROMP45.5	26000	3.00E-05	8.67E+08
I75-TW	16000	1.70E-05	9.41E+08
M505	9880	7.30E-06	1.35E+09
BICY-TW**	11000	5.00E-06	2.20E+09
Average	**18595**	**1.15E-03**	

Table 2. Maximum drawdown at each pumping well over the 4.0 year life of the project for the Base Case, the Maximum Drawdown Scenario, and the Minimum Drawdown Scenario.

Well ID/Location	Base Case Drawdown (ft)	Maximum Drawdown Scenario (ft)	Minimum Drawdown Scenario (ft)
FPW-01	14.3	31.0	6.7
FPW-02	14.3	31.0	6.7
ONWR – Closest Edge	3.8	13.2	1.3

- ONWR = Okefenokee National Wildlife Refuge

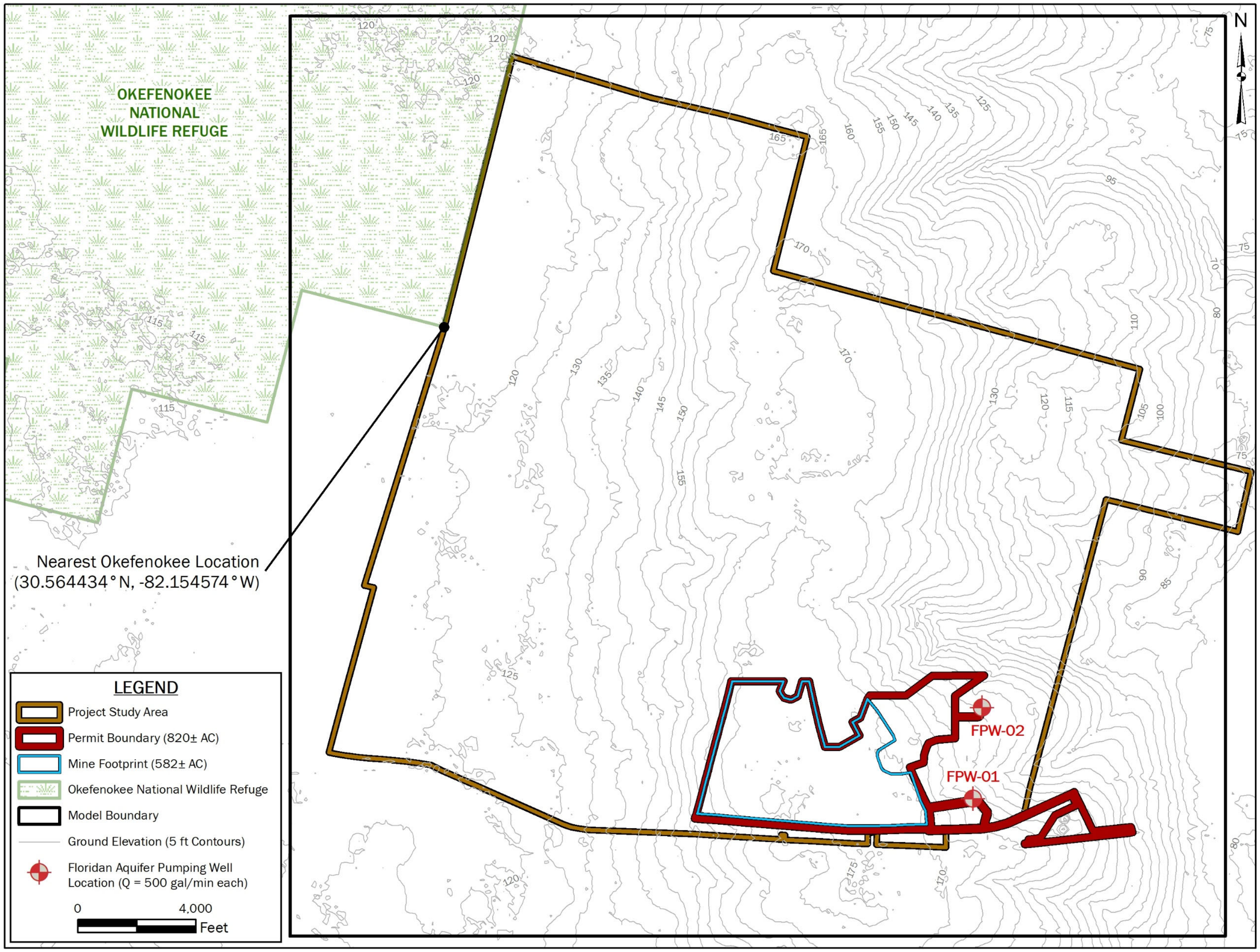

Figure 1. Location of proposed production wells at the Twin Pines Minerals, LLC mine site.

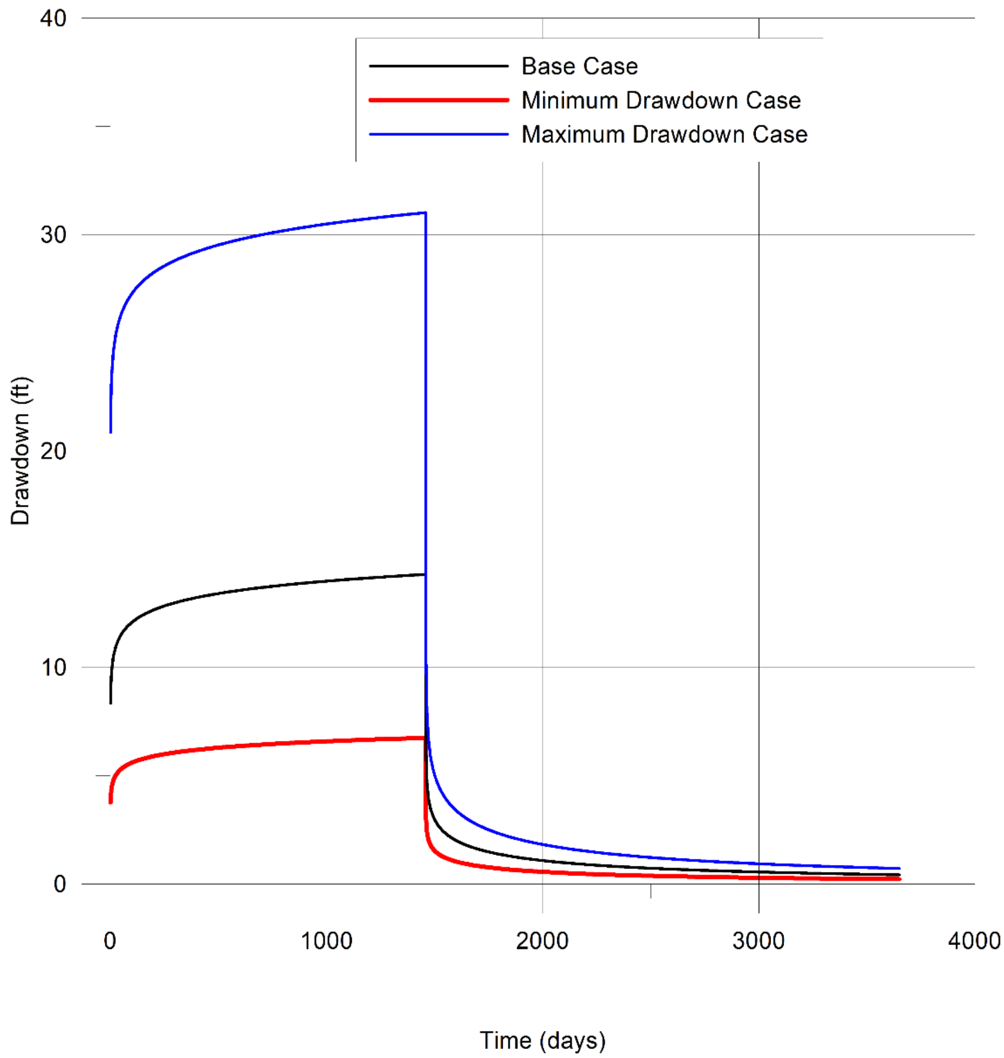

Figure 2. Predicted drawdown at well FWP-01 for the Base-Case Scenario, the Minimum-Drawdown Scenario, and the Maximum-Drawdown Scenario. Drawdowns are predicted for a ten-year (3,650 day) period.

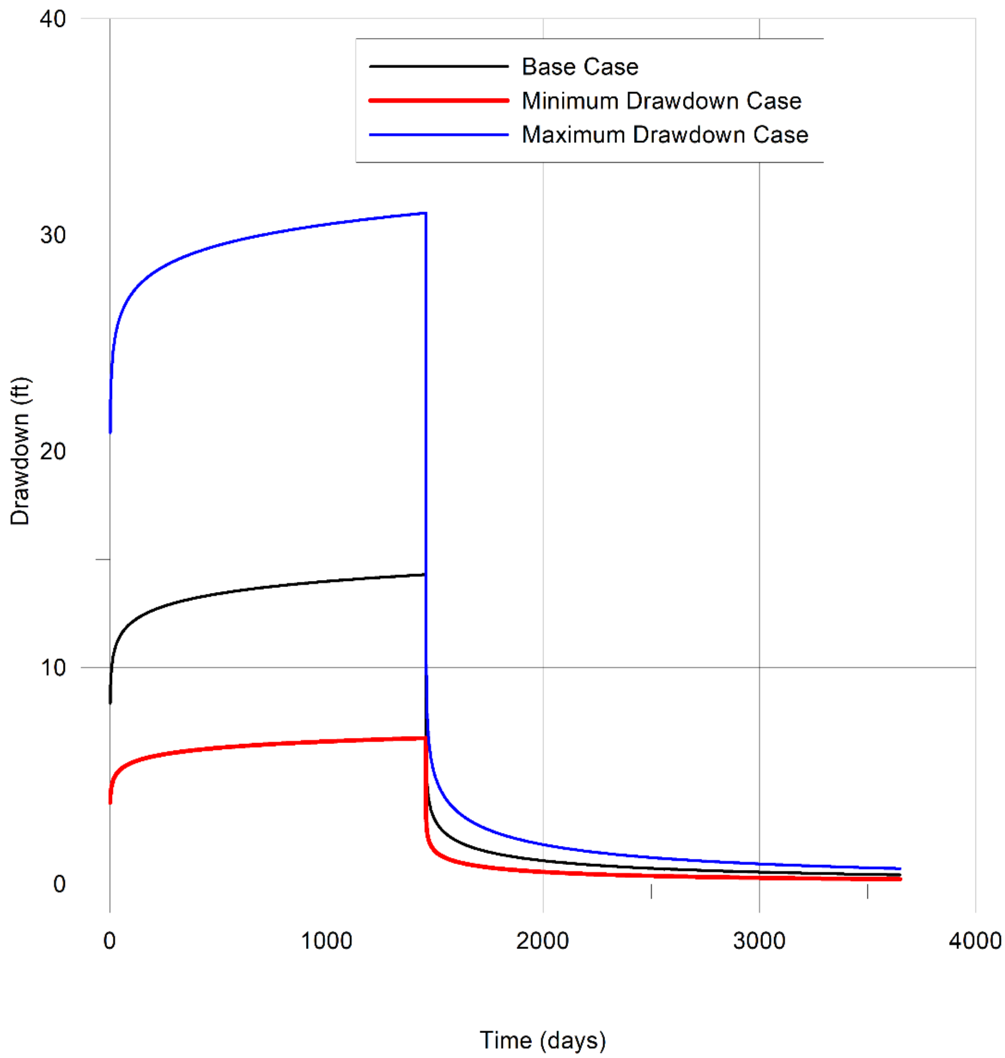

Figure 3. Predicted drawdown at well FWP-02 for the Base-Case Scenario, the Minimum-Drawdown Scenario, and the Maximum-Drawdown Scenario. Drawdowns are predicted for a ten-year (3,650 day) period.

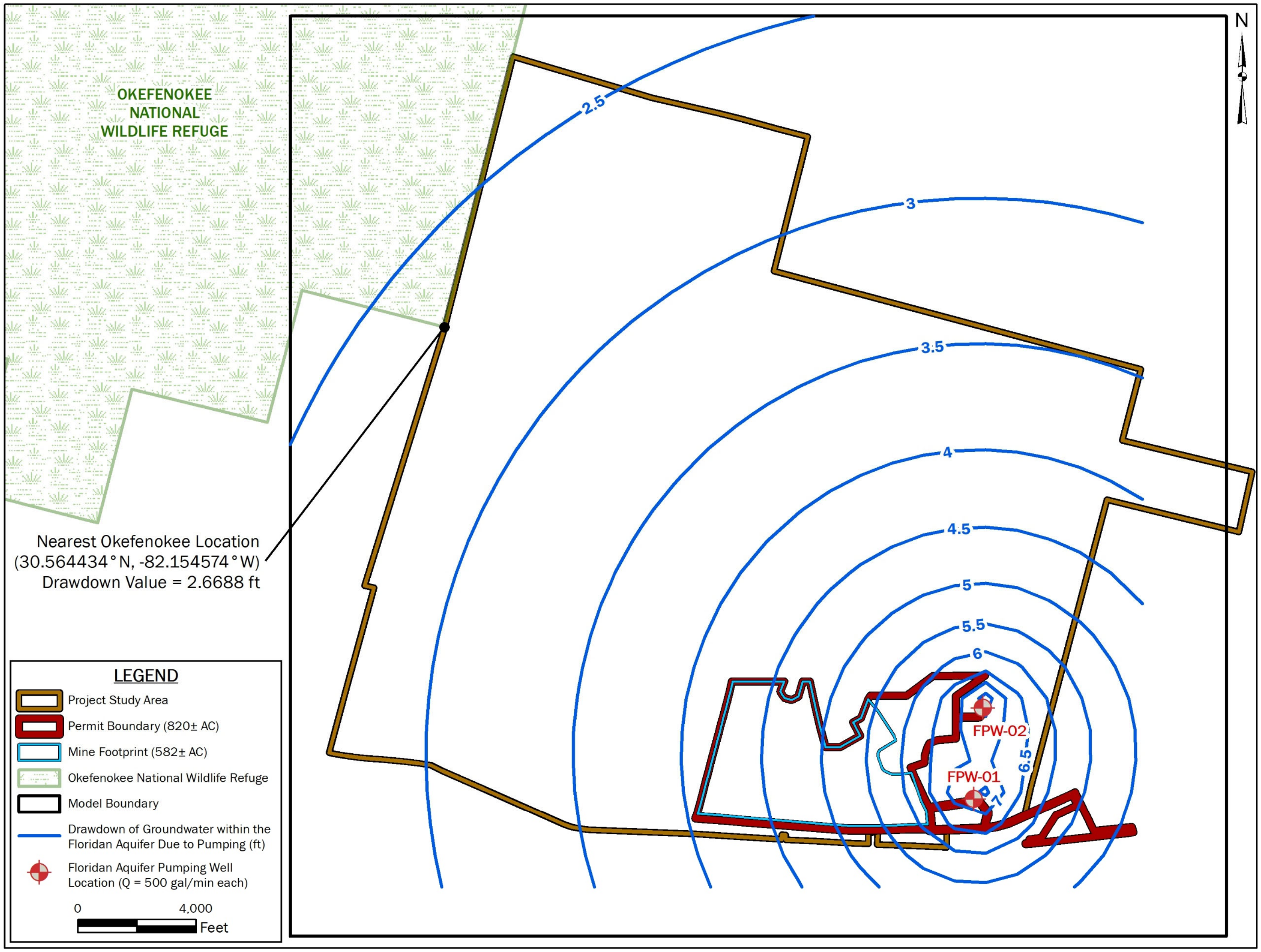

Figure 4. Drawdown (ft) in the Floridan Aquifer after 1 years of pumping.

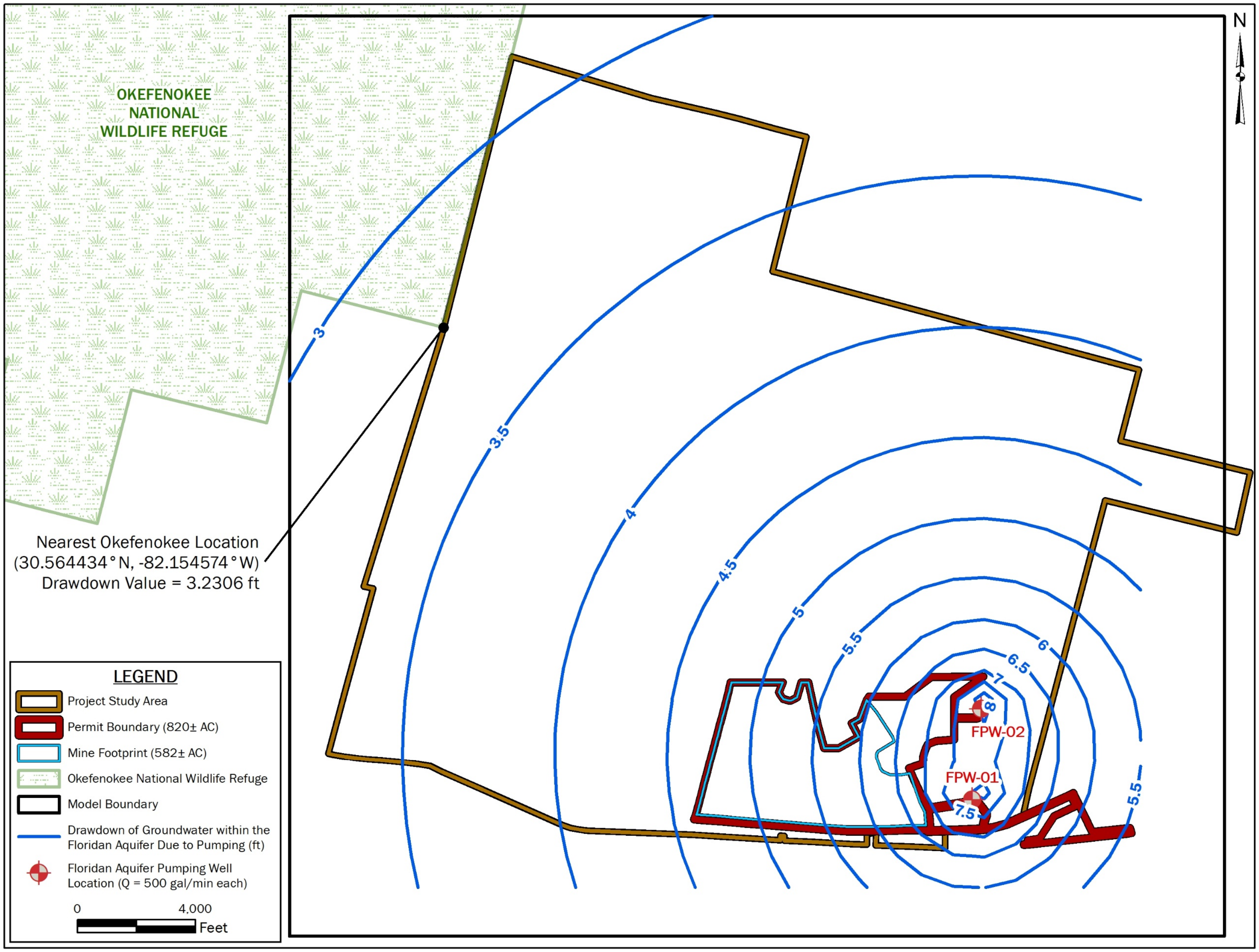

Figure 5. Drawdown (ft) in the Floridan Aquifer after 2 years of pumping.

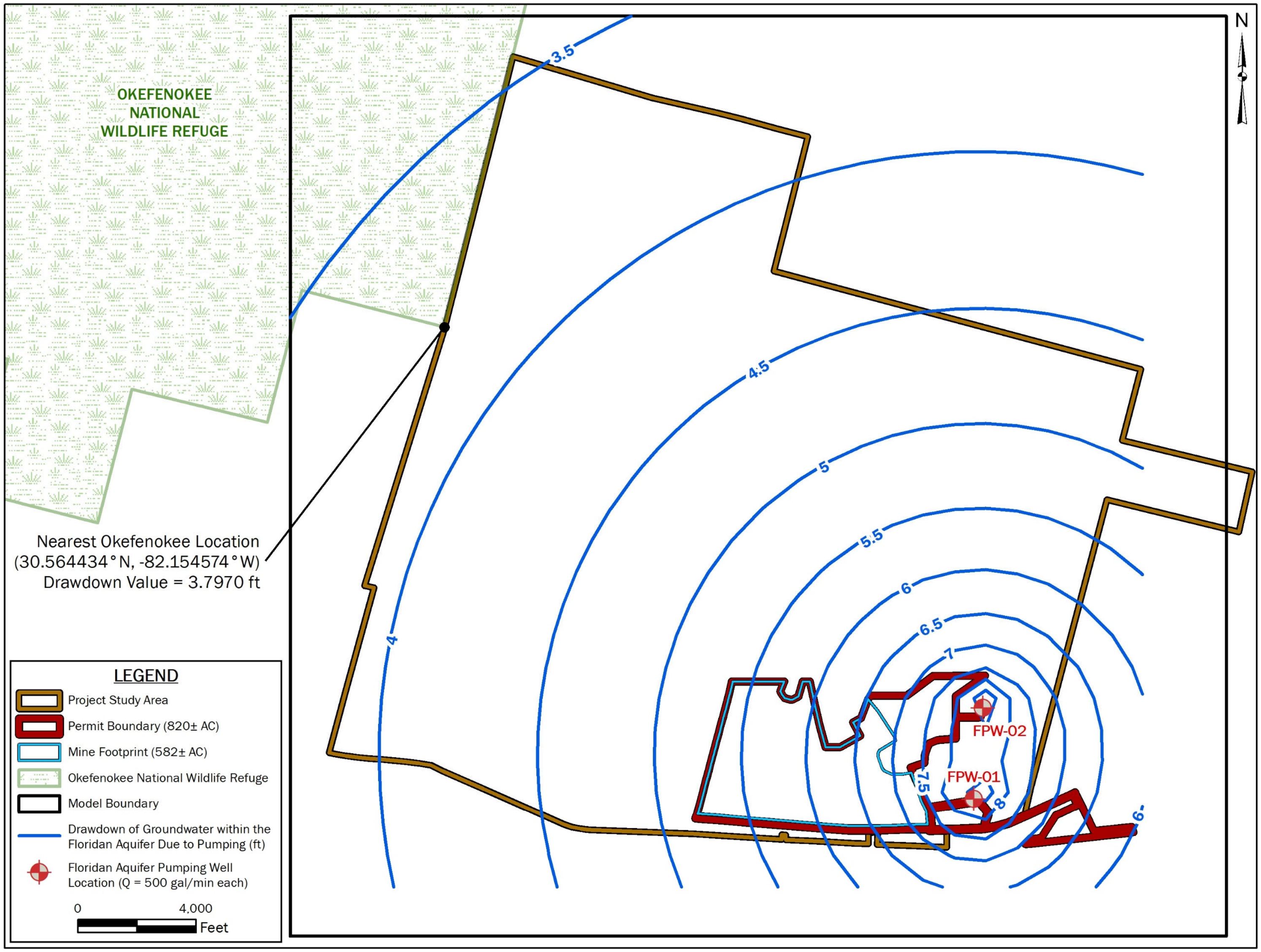

Figure 6. Drawdown (ft) in the Floridan Aquifer after 4 years of pumping.

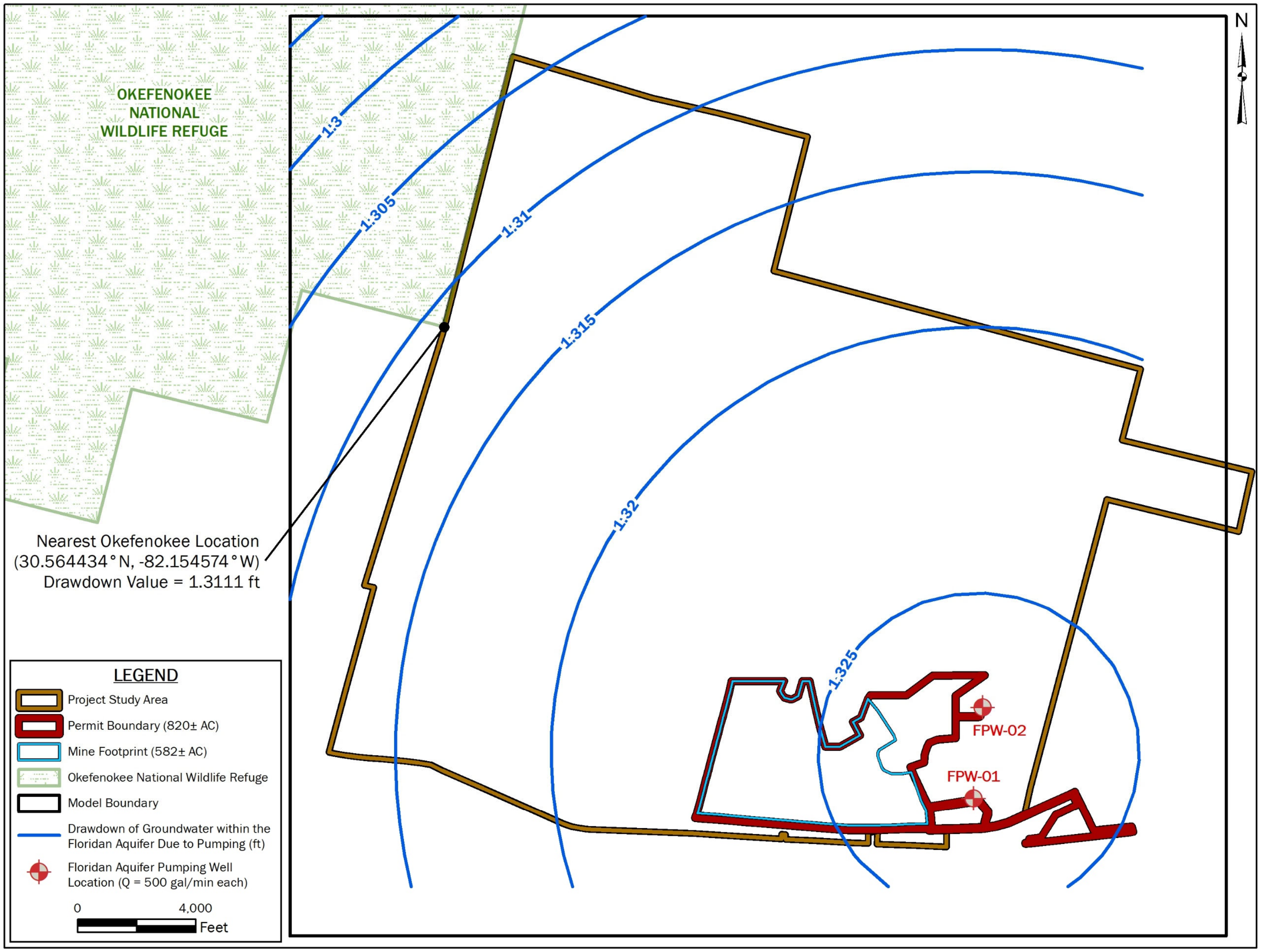

Figure 7. Drawdown (ft) in the Floridan Aquifer after 5 years (one year after pumping stopped).

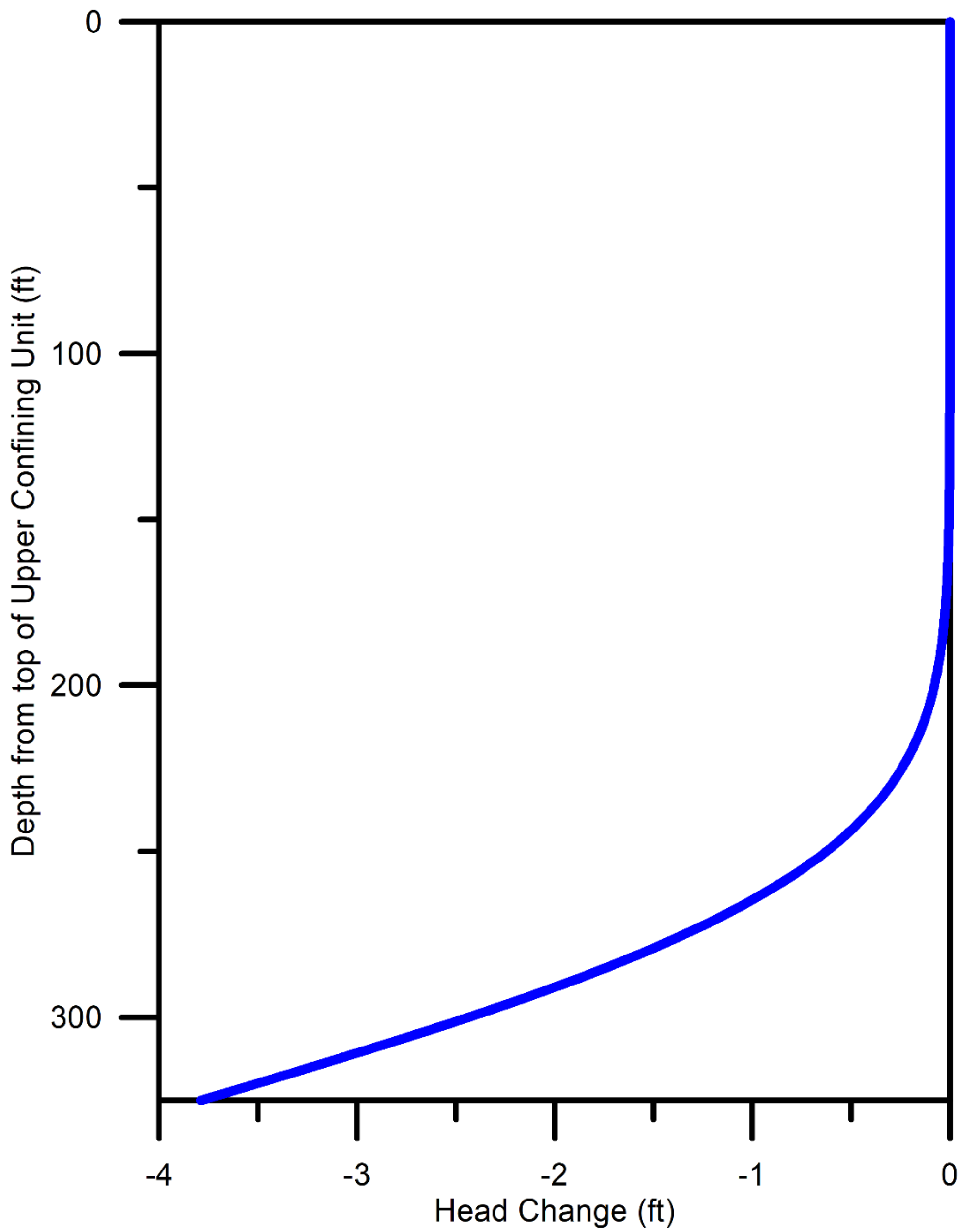

Figure 8. Head change in the upper confining unit of the Floridan Aquifer after 5.5 years of a constant decrease in the head in the Floridan Aquifer of 4.049 ft.

Appendix A

MATLAB Code for Predicting the Drawdown History at Wells

```
function hh=Theis_Time_Superposition_FLAQ(Nwell,nt,x,y,delt,T,S)
%nr = number of times to evaluate
%delt = time step
%Q = Volumetric discharge (L^3/T)
%T = K*B = Transmissivity
%t = time to evaluate pressures
%S = Storage Coefficeint (dimensionless)
%h = Drawdown
%welldat= a predefined array (in file 'welldat.dat' of length Nwell with
%            x,y,start time,end time,Q data for each well
welldat=dlmread('welldat.dat');
for i=1:nt
    t(i)=delt*i;
    for m=1:Nwell
        if (welldat(m,3)<=t(i))&&(welldat(m,4)>=t(i))
            %calculate radial distance from point x,y to the well
                r=((x-welldat(m,1))^2+(y-welldat(m,2))^2)^0.5;
            %calculate well function
                u=S*(r)^2/(4*T*(t(i)-welldat(m,3)));
            %calculate drawdown
                hw(m)=(welldat(m,5)/(4*3.14151*T))*expint(u);
        elseif (welldat(m,4)<=t(i))
            %calculate radial distance from point x,y to the well
                r=((x-welldat(m,1))^2+(y-welldat(m,2))^2)^0.5;
            %calculate well function for pumping
                u1=S*(r)^2/(4*T*(t(i)-welldat(m,3)));
                u2=S*(r)^2/(4*T*(t(i)-welldat(m,4)));
             %calculate drawdown
                hw(m)=(welldat(m,5)/(4*3.14151*T))*expint(u1)-(welldat(m,5)/(4*3.↙
14151*T))*expint(u2);
        else
                hw(m)=0;
        end
    end
    %superimpose drawdowns
    h(i)=sum(hw);
    hh(i,1)=t(i);
    hh(i,2)=h(i);
end
figure;
plot(t,h)
grid on
end
```

Example input for Theis_Time_Superposition_FLAQ.m

Base Case
Well 1

```
Theis_Time_Superposition_FLAQ(2,3650,677915.715,189234.47,1,18595,1.15e-3)
```

Well 2

```
Theis_Time_Superposition_FLAQ(2,3650,678226.035,192335.26,1,18595,1.15e-3)
```

Minimum Drawdown
Well 1

```
Theis_Time_Superposition_FLAQ(2,3650,677915.715,189234.47,1,36000,1.00E-02)
```

Well 2

```
Theis_Time_Superposition_FLAQ(2,3650,678226.035,192335.26,1,36000,1.00E-02)
```

Maximum Drawdown
Well 1

```
Theis_Time_Superposition_FLAQ(2,3650,677915.715,189234.47,1,11000,5.00E-06)
```

Well 2

```
Theis_Time_Superposition_FLAQ(2,3650,678226.035,192335.26,1,11000,5.00E-06)
```

Drawdown at the edge of the swamp - base case

```
Theis_Time_Superposition_FLAQ(2,4015,659996,205260,0.5,18595,1.15e-3)
```

Drawdown at the edge of the swamp - Minimum Drawdown

```
Theis_Time_Superposition_FLAQ(2,4015,659996,205260,0.5,36000,1.00E-02)
```

Drawdown at the edge of the swamp - Maximum Drawdown

```
Theis_Time_Superposition_FLAQ(2,4015,659996,205260,0.5,11000,5.00E-06)
```

Appendix B

MATLAB Code for Predicting the Areal Drawdown

```
function hh=Theis_Superposition_N_wells_FLAQ(nx,ny,delx,dely,xst,yst,Nwell,T,t,S)
%nx=number of points to evaluate in the x-direction
%ny=number of points to evaluate in the y-direction
%delx = Distance between points in the x-direction
%dely = Distance between points in the y-direction
%xst = starting x-coordinate of plot
%yst = starting y-coordinate of plot
%Nwell= number of wells
%welldat= a predefined array (in file 'welldat.dat' of length Nwell with
%            x,y,start time,end time,Q data for each well
%T = K*B = Transmissivity
%t = time to evaluate pressures
%S = Storage Coefficeint (dimensionless)
%h(k,5) = Drawdown
%h3(i,j) = 2D array of drawdowns for plotting
welldat=dlmread('welldat.dat');
for i=1:nx+1
    %define x location
    x=(i-1)*delx+xst;
    for j=1:ny+1
        %define y location
        y=(j-1)*dely+yst;
        %define global index for output
        k=(i-1)*(nx+1)+j;
        %calculate the drawdown for each well
        for m=1:Nwell
            if (welldat(m,3)<=t)&&(welldat(m,4)>=t)
                %calculate radial distance from point x,y to the well
                r=((x-welldat(m,1))^2+(y-welldat(m,2))^2)^0.5;
                %calculate well function
                u=S*(r)^2/(4*T*(t-welldat(m,3)));
                %calculate drawdown
                hw(m)=(welldat(m,5)/(4*3.14151*T))*expint(u);
            elseif (welldat(m,4)<=t)
                %calculate radial distance from point x,y to the well
                r=((x-welldat(m,1))^2+(y-welldat(m,2))^2)^0.5;
                %calculate well function for pumping
                u1=S*(r)^2/(4*T*(t-welldat(m,3)));
                u2=S*(r)^2/(4*T*(t-welldat(m,4)));
                %calculate drawdown
                hw(m)=(welldat(m,5)/(4*3.14151*T))*expint(u1)-(welldat(m,5)/(4*3.
14151*T))*expint(u2);
            else
                hw(m)=0;
            end
        end
        %superimpose drawdowns
        h(k)=sum(hw);
        %setup output array
        hh(k,1)=x;
```

```
        hh(k,2)=y;
        hh(k,3)=h(k);
        h3(j,i)=h(k); %build array for plotting
    end
end
%define x-coordinate vector for plot
for i=1:nx+1
    xx(i)=(i-1)*delx+xst;
end
%define y-coordinate vector for plot
for j=1:ny+1
    yy(j)=(j-1)*dely+yst;
end
%contour plot drawdowns
figure;
[C,h]=contour(xx,yy,h3);
%[C,h]=contour(h3);
clabel(C,h);
end
```

Example input for Theis_Superposition_N_wells_FLAQ.m

Base Case

```
Theis_Superposition_N_wells_FLAQ(355,527,200,200,612618,186269,2,18595,1460,1.15e-3
)
```

Minimum Drawdown D=3.60E+06 ft2/day

```
Theis_Superposition_N_wells_FLAQ(355,527,200,200,612618,186269,2,36000,1460,1.00e-2
)
```

Maximum Drawdown D=2.20E+09 ft2/day

```
Theis_Superposition_N_wells_FLAQ(355,527,200,200,612618,186269,2,11000,1460,5.00e-6
)
```

Appendix C

Input File Welldat.dat for MATLAB Codes

Contents of text file welldat.dat:

677916.21	189234.47	0	1460	96250
678226.53	192335.26	0	1460	96250

ATTACHMENT C

ANALYSIS TO QUANTIFY THE IMPACT TO THE SURFICIAL AQUIFER

AT THE EDGE OF THE OWNR AS A RESULT OF THE FLORIDAN AQUIFER

MAXIMUM DRAWDOWN SCENARIO

Supporting Documentation for Response to Comments 7(b) and 7(c)

Twin Pines Minerals, LLC (TPM) has conducted an analysis to evaluate the potential impacts to the Surficial Aquifer at the boundary of the Okefenokee National Wildlife Refuge due to the pumping of process water from the Upper Floridan Aquifer. This document specifically provides responses to the April 14, 2021, Georgia Environmental Protection Division's (EPD's) Permit Coordination review comments 7b and 7c.

Comment 7 b:

In Section 6 – page 14 of the application and Table 2 – page 9 of attachment B ("An evaluation of drawdown from Floridan wells") lists three scenarios for the total drawdown of the Floridan aquifer at the edge of the Okefenokee National Wildlife Refuge (ONWR), based on pumping two wells at 500 gpm for 4 years. "The maximum drawdown of the Floridan Aquifer at the edge of the ONWR is 3.8 ft in the Base Case Scenario, 13.2 ft for the Maximum-Drawdown Scenario, and 1.3 feet for the Minimum-Drawdown Scenario."

The application does not quantify the impact to the Surficial aquifer at the edge of the ONWR, as a result of the Floridan aquifer "Maximum-Drawdown Scenario" listed above. Please provide further analysis / detailed modeling to quantify the surficial aquifer drawdown at the edge of the ONWR, based on the Floridan aquifer drawdown numbers provided in the application. This may require a more detailed modeling of the drawdown in the Floridan aquifer, and its associated impact to the Surficial aquifer.

Response to Comment 7 b:

Dr. James Kennedy, in a meeting on April 29 2021, directed TPM to use an approach developed by Hantush (1967) to evaluate drawdown in the surficial aquifer caused by leakage through the Hawthorn Group due to TPM's proposed pumping in the Floridan Aquifer. Dr. Kennedy supplied TPM with a spreadsheet for these calculations. The spreadsheet implements Equation 26 of Hantush (1967), which is a pseudo steady-state solution for the drawdown in an upper aquifer separated by an aquitard from a lower aquifer that is pumped. Unfortunately, the Equation 26 of Hantush (1967) is an approximation which produces negative drawdowns (water-level increases) in the Surficial Aquifer using the parameters appropriate to hydraulic conditions found at the TPM site. To complete the analysis directed by Dr. Kennedy, we modified his spreadsheet to solve the steady-state form of Equations 45 and 46 of Hantush (1967) (Attachment 1). These equations solve for the steady-state drawdown in an un-pumped upper and a pumped lower aquifer separated by an aquitard. These solutions assume that the aquifer is circular with no drawdown at the boundary, and that the well is pumped at a fixed pumping rate for an infinite period of time.

The hydraulic properties used for the Floridan Aquifer are those used by Holt and Tanner (2020) for their Minimum, Base Case, and Maximum Drawdown Scenarios. The hydraulic conductivity of the Hawthorn Group was assumed to be 10^{-4} ft/day (e.g., Williams and Kuniansky, 2015) and the specific storage for the Hawthorn was assumed to be 10^{-4} 1/ft, which is typical for clay units. Instead of pumping 500 gpm from two wells, we assumed that all pumping was occurring in a single well that is closest to the ONWR with a pumping rate of 1,000 gpm. This represents a conservative case.

Initially, we determined the effective radius defined by Hantush (1967) and used in the spreadsheet provided by Dr. Kennedy. This effective radius ranged from 5,728 ft to 5,731 ft. It should be noted that the distance from the nearest TPM well to the edge of the ONWR is 22,304 ft. So, this model cannot be used to predict the drawdown at the edge of the ONWR, as the drawdown is 0 ft at the effective radius.

The radius of the model does not have to be defined as Hantush's effective radius; instead, it can be defined to match the distance of observed physical boundaries. Because no physical boundaries can be defined over reasonable distances in the Floridan Aquifer, we arbitrarily chose a radius of 44,608 ft, twice the distance between the boundary of the ONWR and the nearest pumping well. The results of this model are presented in Table 1, which shows the drawdown in the Surficial Aquifer and the Floridan Aquifer at the edge of the ONWR and 1 ft away from the pumping well. For the three cases considered by Holt and Tanner (2020), the drawdown in the Floridan Aquifer ranged from 9.1 to 29.8 ft at a distance of 1 ft from the pumping well and 0.6 to 1.9 ft at the edge of the ONWR. The drawdown in the Surficial Aquifer ranged from ~0.8 to 0.3 ft at a distance of 1 ft from the pumping well and ~ 0.05 to 0.15 ft at the edge of the ONWR. The predicted drawdown in the Floridan is consistent with that predicted by Holt and Tanner (2020) (their Table 2). The drawdown in the surficial aquifer is surprisingly small, considering that the model assumes that the well is pumped forever.

It is important to remember that these results reflect pumping 1,000 gpm from a single well for an infinite period of time; the drawdown in the Surficial Aquifer will be much smaller after pumping for a period of only 4 years. For models of this type, a time constant can be defined to evaluate whether or not drawdown in the unpumped aquifer remains zero (e.g., Hantush, 1960; Neuman and Witherspoon, 1969):

$$\tau_c = 0.1\frac{S_s^* b^{*2}}{K^*}$$

where S_s^* is the specific storage of the aquitard (here 10^{-4} 1/ft), b^* is the thickness of the aquitard (here 325 ft), and K^* is the hydraulic conductivity of the aquitard (here 10^{-4} ft/day). If the time for pumping is less than τ_c, then the drawdown in the unpumped aquifer is essentially zero. In our case, the duration of pumping is 1,460 days, and τ_c = 10,562.5 days; therefore, drawdown in the surficial aquifer will be essentially zero at the end of 4 years. To help put this in perspective, τ_c represents 6.3% of the time required to reach steady state in the aquitard (the Hawthorn), and the time of pumping (1,460 days) is 0.87% of the time required to reach steady state in the Hawthorn. For time periods this short, changes in the head in the Floridan Aquifer will not have time to propagate upward through the Hawthorn and reach the Surficial Aquifer.

Comment 7 c:

Consider possible range of hydraulic conductivity for the aquitard in this analysis. Provide supporting evidence of this range by either literature review or field investigation.

Response to Comment 7c:

We use a realistic value of 10^{-4} ft/day for the hydraulic conductivity of the Hawthorn aquitard; this value is one order of magnitude higher than that used in calibrated USGS groundwater models that include the TPM area. Supporting evidence is listed below.

Williams and Kuniansky (2015) indicate that the vertical hydraulic conductivity of the Hawthorn is small (less than 10^{-4} ft/day) when clays are present and that leakage across the Hawthorn is negligible. Calibrated groundwater models that include the proposed mine and the Okefenokee Swamp area use a vertical hydraulic conductivity of 10-5 ft/day for the Hawthorn (Payne et al., 2005; Cherry, 2015; and Cherry, 2019). In addition, samples of the Hawthorn taken at the Twin Pines Minerals, LLC site show hydraulic conductivity values of 3.66×10^{-2} ft/day, 2.63×10^{-5} ft/day, and 4.56×10^{-6} ft/day (Holt et al., 2019), consistent with the values used in calibrated groundwater models.

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Williams, L.J., and Kuniansky, E.L., 2015, Revised hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1807, 140 p., 23 pls.

Table 1. Predicted drawdown in the Surficial Aquifer and the Floridan Aquifer at the edge of the Okefenokee National Wildlife Refuge (ONWR) and 1 foot away from a proposed Twin Pines Minerals well pumping 1,000 gpm from the Floridan Aquifer. Note the well is located 22,304 ft from the ONWR boundary.

	Drawdown in the Surficial Aquifer (ft) at the edge of the ONWR	Drawdown in the Floridan Aquifer (ft) at the edge of ONWR	Drawdown in the Surficial Aquifer (ft) 1 ft from Pumping Well	Drawdown in the Floridan Aquifer (ft) 1 ft from Pumping Well
Minimum Drawdown Case	4.7E-02	0.6	8.1E-02	9.1
Base Drawdown Case	9.0E-02	1.1	1.6E-01	17.6
Maximum Drawdown Case	1.5E-01	1.9	2.7E-01	29.8

Attachment 1

Excel Spreadsheets for the Hantush (1967) Model

Surficial Aquifer Drawdown - 22,304 ft from well pumping 1,000 gpm - Minimum Drawdown Case

$s_1 = (Q_2/2\pi(T_1 + T_2))(\ln(r_e/r)-(K_0(\beta) - K0(\beta\varepsilon)I0(\beta)/I0(\beta\varepsilon)))$ Parameter	Value	Units	Upper Floridan Aquifer Pumping (Q_2 in gpm)	$Q_2/2\pi(T_1+ T_2)$ (ft)	Surficial Aquifer Drawdown (s_1 in feet)	Floridan Aquifer Drawdown (s_2 in feet)
Time since beginning of pumping (t)	4.0	years	1000	0.81705280	4.66E-02	0.59
Radial distance from Lower Floridan aquifer pumping well (r)	22304	feet				
Transmissivity of surficial aquifer (T_1)	1,500	ft^2/day				
Specific Yield of surficial aquifer (S_1)	0.30000					
Transmissivity of Upper Floridan aquifer (T_2)	36,000	ft^2/day				
Stortivity of Upper Floridan aquifer (S_2)	0.01000					
Hydraulic conductivity of confining unit (K')	1.00E-04	ft/day				
Thickness of confining unit (b')	325	feet				
$\nu_1 = T_1/S_1$	5,000	ft^2/day				
$\nu_2 = T_2/S_2$	3,600,000	ft^2/day				
$\nu_v = 2\nu_1\nu_2/(\nu_1 + \nu_2)$	9,986	ft^2/day				
$r_e = 1.5(\nu_v t)^{1/2}$ not used, chosen to be 44,608 ft	44,608	feet				
$B_1 = (T_1/(K'/b')^{1/2}$	69,821	feet				
$B_2 = (T_2/(K'/b')^{1/2}$	342,053	feet				
$\beta_1 = r/B_1$	0.31944452					
$\beta_2 = r/B_2$	0.06520634					
$\beta^2 = \beta_1^2 + \beta_2^2$	0.10629667					
β	0.32603170					
$\beta\varepsilon_1 = re/B_1$	0.63888905					
$\beta\varepsilon_2 = re/B_2$	0.13041268					
$\beta\varepsilon^2 = \beta\varepsilon_1^2 + \beta\varepsilon_2^2$	0.42518668					
$\beta\varepsilon$	0.65206340					
$\ln(r_e/r)$	0.693					
$K_0(\beta)$	1.297					
$K_0(\beta\varepsilon)$	0.713471027					
$I_0(\beta\varepsilon)$	1.109154965					
$I_0(\beta)$	1					
$\delta 1 = T1/T2$	0.041666667					

Surficial Aquifer Drawdown - 22,304 ft from well pumping 1,000 gpm - Basecase

$s_1 = (Q_2/2\pi(T_1 + T_2))(\ln(r_e/r)-(K_0(\beta) - K0(\beta\varepsilon)I0(\beta)/I0(\beta\varepsilon)))$ Parameter	Value	Units	Upper Floridan Aquifer Pumping (Q_2 in gpm)	$Q_2/2\pi(T_1+ T_2)$ (ft)	Surficial Aquifer Drawdown (s_1 in feet)	Floridan Aquifer Drawdown (s_2 in feet)
Time since beginning of pumping (t)	4.0	years	1000	1.52549067	9.00E-02	1.14
Radial distance from Lower Floridan aquifer pumping well (r)	22304	feet				
Transmissivity of surficial aquifer (T_1)	1,500	ft^2/day				
Specific Yield of surficial aquifer (S_1)	0.30000					
Transmissivity of Upper Floridan aquifer (T_2)	18,585	ft^2/day				
Stortivity of Upper Floridan aquifer (S_2)	0.00115					
Hydraulic conductivity of confining unit (K')	1.00E-04	ft/day				
Thickness of confining unit (b')	325	feet				
$\nu_1 = T_1/S_1$	5,000	ft^2/day				
$\nu_2 = T_2/S_2$	16,160,870	ft^2/day				
$\nu_\nu = 2\nu_1\nu_2/(\nu_1 + \nu_2)$	9,997	ft^2/day				
$r_e = 1.5(\nu_\nu t)^{1/2}$ not used, chosen to be 44,608 ft	44,608	feet				
$B_1 = (T_1/(K'/b'))^{1/2}$	69,821	feet				
$B_2 = (T_2/(K'/b'))^{1/2}$	245,767	feet				
$\beta_1 = r/B_1$	0.31944452					
$\beta_2 = r/B_2$	0.09075275					
$\beta^2 = \beta_1^2 + \beta_2^2$	0.11028086					
β	0.33208563					
$\beta\varepsilon_1 = re/B_1$	0.63888905					
$\beta\varepsilon_2 = re/B_2$	0.18150550					
$\beta\varepsilon^2 = \beta\varepsilon_1^2 + \beta\varepsilon_2^2$	0.44112346					
$\beta\varepsilon$	0.66417126					
$\ln(r_e/r)$	0.693					
$K_0(\beta)$	1.280					
$K_0(\beta\varepsilon)$	0.699587159					
$I_0(\beta\varepsilon)$	1.113358811					
$I_0(\beta)$	1					
$\delta 1 = T1/T2$	0.08071025					

Surficial Aquifer Drawdown - 22,304 ft from well pumping 1,000 gpm - Maximum Drawdown Case

$s_1 = (Q_2/2\pi(T_1 + T_2))(\ln(r_e/r)-(K_0(\beta) - K0(\beta\varepsilon)I0(\beta)/I0(\beta\varepsilon)))$ Parameter	Value	Units	Upper Floridan Aquifer Pumping (Q_2 in gpm)	$Q_2/2\pi(T_1+ T_2)$ (ft)	Surficial Aquifer Drawdown (s_1 in feet)	Floridan Aquifer Drawdown (s_2 in feet)
Time since beginning of pumping (t)	4.0	years	1000	2.45115841	1.51E-01	1.91
Radial distance from Lower Floridan aquifer pumping well (r)	22304	feet				
Transmissivity of surficial aquifer (T_1)	1,500	ft^2/day				
Specific Yield of surficial aquifer (S_1)	0.30000					
Transmissivity of Upper Floridan aquifer (T_2)	11,000	ft^2/day				
Stortivity of Upper Floridan aquifer (S_2)	0.000005					
Hydraulic conductivity of confining unit (K')	1.00E-04	ft/day				
Thickness of confining unit (b')	325	feet				
$\nu_1 = T_1/S_1$	5,000	ft^2/day				
$\nu_2 = T_2/S_2$	2,200,000,000	ft^2/day				
$\nu_v = 2\nu_1\nu_2/(\nu_1 + \nu_2)$	10,000	ft^2/day				
$r_e = 1.5(\nu_v t)^{1/2}$ not used, chosen to be 44,608 ft	44,608	feet				
$B_1 = (T_1/(K'/b'))^{1/2}$	69,821	feet				
$B_2 = (T_2/(K'/b'))^{1/2}$	189,077	feet				
$\beta_1 = r/B_1$	0.31944452					
$\beta_2 = r/B_2$	0.11796271					
$\beta^2 = \beta_1^2 + \beta_2^2$	0.11596000					
β	0.34052901					
$\beta\varepsilon_1 = re/B_1$	0.63888905					
$\beta\varepsilon_2 = re/B_2$	0.23592542					
$\beta\varepsilon^2 = \beta\varepsilon_1^2 + \beta\varepsilon_2^2$	0.46384001					
$\beta\varepsilon$	0.68105801					
$\ln(r_e/r)$	0.693					
$K_0(\beta)$	1.257					
$K_0(\beta\varepsilon)$	0.680809207					
$I_0(\beta\varepsilon)$	1.119365277					
$I_0(\beta)$	1					
$\delta 1 = T1/T2$	0.136363636					

Surficial Aquifer Drawdown - 1 ft from well pumping 1,000 gpm - Minimum Drawdown Case

$s_1 = (Q_2/2\pi(T_1 + T_2))(\ln(r_e/r)-(K_0(\beta) - K0(\beta\varepsilon)I0(\beta)/I0(\beta\varepsilon)))$ Parameter	Value	Units	Upper Floridan Aquifer Pumping (Q_2 in gpm)	$Q_2/2\pi(T_1+ T_2)$ (ft)	Surficial Aquifer Drawdown (s_1 in feet)	Floridan Aquifer Drawdown (s_2 in feet)
Time since beginning of pumping (t)	4.0	years	1000	0.81705280	8.15E-02	9.11
Radial distance from Lower Floridan aquifer pumping well (r)	1	feet				
Transmissivity of surficial aquifer (T_1)	1,500	ft^2/day				
Specific Yield of surficial aquifer (S_1)	0.30000					
Transmissivity of Upper Floridan aquifer (T_2)	36,000	ft^2/day				
Stortivity of Upper Floridan aquifer (S_2)	0.01000					
Hydraulic conductivity of confining unit (K')	1.00E-04	ft/day				
Thickness of confining unit (b')	325	feet				
$\nu_1 = T_1/S_1$	5,000	ft^2/day				
$\nu_2 = T_2/S_2$	3,600,000	ft^2/day				
$\nu_v = 2\nu_1\nu_2/(\nu_1 + \nu_2)$	9,986	ft^2/day				
$r_e = 1.5(\nu_v t)^{1/2}$ not used, chosen to be 44,608 ft	44,608	feet				
$B_1 = (T_1/(K'/b')^{1/2}$	69,821	feet				
$B_2 = (T_2/(K'/b')^{1/2}$	342,053	feet				
$\beta_1 = r/B_1$	0.00001432					
$\beta_2 = r/B_2$	0.00000292					
$\beta^2 = \beta_1^2 + \beta_2^2$	0.00000000					
β	0.00001462					
$\beta\varepsilon_1 = re/B_1$	0.63888905					
$\beta\varepsilon_2 = re/B_2$	0.13041268					
$\beta\varepsilon^2 = \beta\varepsilon_1^2 + \beta\varepsilon_2^2$	0.42518668					
$\beta\varepsilon$	0.65206340					
$\ln(r_e/r)$	10.706					
$K_0(\beta)$	11.249					
$K_0(\beta\varepsilon)$	0.713471027					
$I_0(\beta\varepsilon)$	1.109154965					
$I_0(\beta)$	1					
$\delta 1 = T1/T2$	0.041666667					

Surficial Aquifer Drawdown - 1 ft from well pumping 1,000 gpm - Basecase

$s_1 = (Q_2/2\pi(T_1 + T_2))(\ln(r_e/r)-(K_0(\beta) - K0(\beta\varepsilon)I0(\beta)/I0(\beta\varepsilon)))$ Parameter	Value	Units
Time since beginning of pumping (t)	4.0	years
Radial distance from Lower Floridan aquifer pumping well (r)	1	feet
Transmissivity of surficial aquifer (T_1)	1,500	ft^2/day
Specific Yield of surficial aquifer (S_1)	0.30000	
Transmissivity of Upper Floridan aquifer (T_2)	18,585	ft^2/day
Stortivity of Upper Floridan aquifer (S_2)	0.00115	
Hydraulic conductivity of confining unit (K')	1.00E-04	ft/day
Thickness of confining unit (b')	325	feet
$\nu_1 = T_1/S_1$	5,000	ft^2/day
$\nu_2 = T_2/S_2$	16,160,870	ft^2/day
$\nu_v = 2\nu_1\nu_2/(\nu_1 + \nu_2)$	9,997	ft^2/day
$r_e = 1.5(\nu_v t)^{1/2}$ not used, chosen to be 44,608 ft	44,608	feet
$B_1 = (T_1/(K'/b'))^{1/2}$	69,821	feet
$B_2 = (T_2/(K'/b'))^{1/2}$	245,767	feet
$\beta_1 = r/B_1$	0.00001432	
$\beta_2 = r/B_2$	0.00000407	
$\beta^2 = \beta_1^2 + \beta_2^2$	0.00000000	
β	0.00001489	
$\beta\varepsilon_1 = re/B_1$	0.63888905	
$\beta\varepsilon_2 = re/B_2$	0.18150550	
$\beta\varepsilon^2 = \beta\varepsilon_1^2 + \beta\varepsilon_2^2$	0.44112346	
$\beta\varepsilon$	0.66417126	
$\ln(r_e/r)$	10.706	
$K_0(\beta)$	11.231	
$K_0(\beta\varepsilon)$	0.699587159	
$I_0(\beta\varepsilon)$	1.113358811	
$I_0(\beta)$	1	
$\delta 1 = T1/T2$	0.08071025	

Upper Floridan Aquifer Pumping (Q_2 in gpm)	$Q_2/2\pi(T_1 + T_2)$ (ft)	Surficial Aquifer Drawdown (s_1 in feet)	Floridan Aquifer Drawdown (s_2 in feet)
1000	1.52549067	1.57E-01	17.64

Surficial Aquifer Drawdown - 1 ft from well pumping 1,000 gpm - Maximum Drawdown Case

$s_1 = (Q_2/2\pi(T_1 + T_2))(\ln(r_e/r)-(K_0(\beta) - K0(\beta\varepsilon)I0(\beta)/I0(\beta\varepsilon)))$ Parameter	Value	Units	Upper Floridan Aquifer Pumping (Q_2 in gpm)	$Q_2/2\pi(T_1+ T_2)$ (ft)	Surficial Aquifer Drawdown (s_1 in feet)	Floridan Aquifer Drawdown (s_2 in feet)
Time since beginning of pumping (t)	4.0	years	1000	2.45115841	2.65E-01	29.78
Radial distance from Lower Floridan aquifer pumping well (r)	1	feet				
Transmissivity of surficial aquifer (T_1)	1,500	ft^2/day				
Specific Yield of surficial aquifer (S_1)	0.30000					
Transmissivity of Upper Floridan aquifer (T_2)	11,000	ft^2/day				
Stortivity of Upper Floridan aquifer (S_2)	0.000005					
Hydraulic conductivity of confining unit (K')	1.00E-04	ft/day				
Thickness of confining unit (b')	325	feet				
$\nu_1 = T_1/S_1$	5,000	ft^2/day				
$\nu_2 = T_2/S_2$	2,200,000,000	ft^2/day				
$\nu_v = 2\nu_1\nu_2/(\nu_1 + \nu_2)$	10,000	ft^2/day				
$r_e = 1.5(\nu_v t)^{1/2}$ not used, chosen to be 44,608 ft	44,608	feet				
$B_1 = (T_1/(K'/b')^{1/2}$	69,821	feet				
$B_2 = (T_2/(K'/b')^{1/2}$	189,077	feet				
$\beta_1 = r/B_1$	0.00001432					
$\beta_2 = r/B_2$	0.00000529					
$\beta^2 = \beta_1^2 + \beta_2^2$	0.00000000					
β	0.00001527					
$\beta\varepsilon_1 = re/B_1$	0.63888905					
$\beta\varepsilon_2 = re/B_2$	0.23592542					
$\beta\varepsilon^2 = \beta\varepsilon_1^2 + \beta\varepsilon_2^2$	0.46384001					
$\beta\varepsilon$	0.68105801					
$\ln(r_e/r)$	10.706					
$K_0(\beta)$	11.206					
$K_0(\beta\varepsilon)$	0.680809207					
$I_0(\beta\varepsilon)$	1.119365277					
$I_0(\beta)$	1					
$\delta 1 = T1/T2$	0.136363636					