Hydrologic Connections between Trail Ridge and the Okefenokee Swamp and the Potential Effects of Mineral Sands Mining on the Okefenokee and the St Marys River

Dr. C. Rhett Jackson, John Porter Stevens Distinguished Professor of Water Resources, UGA, 8/29/22

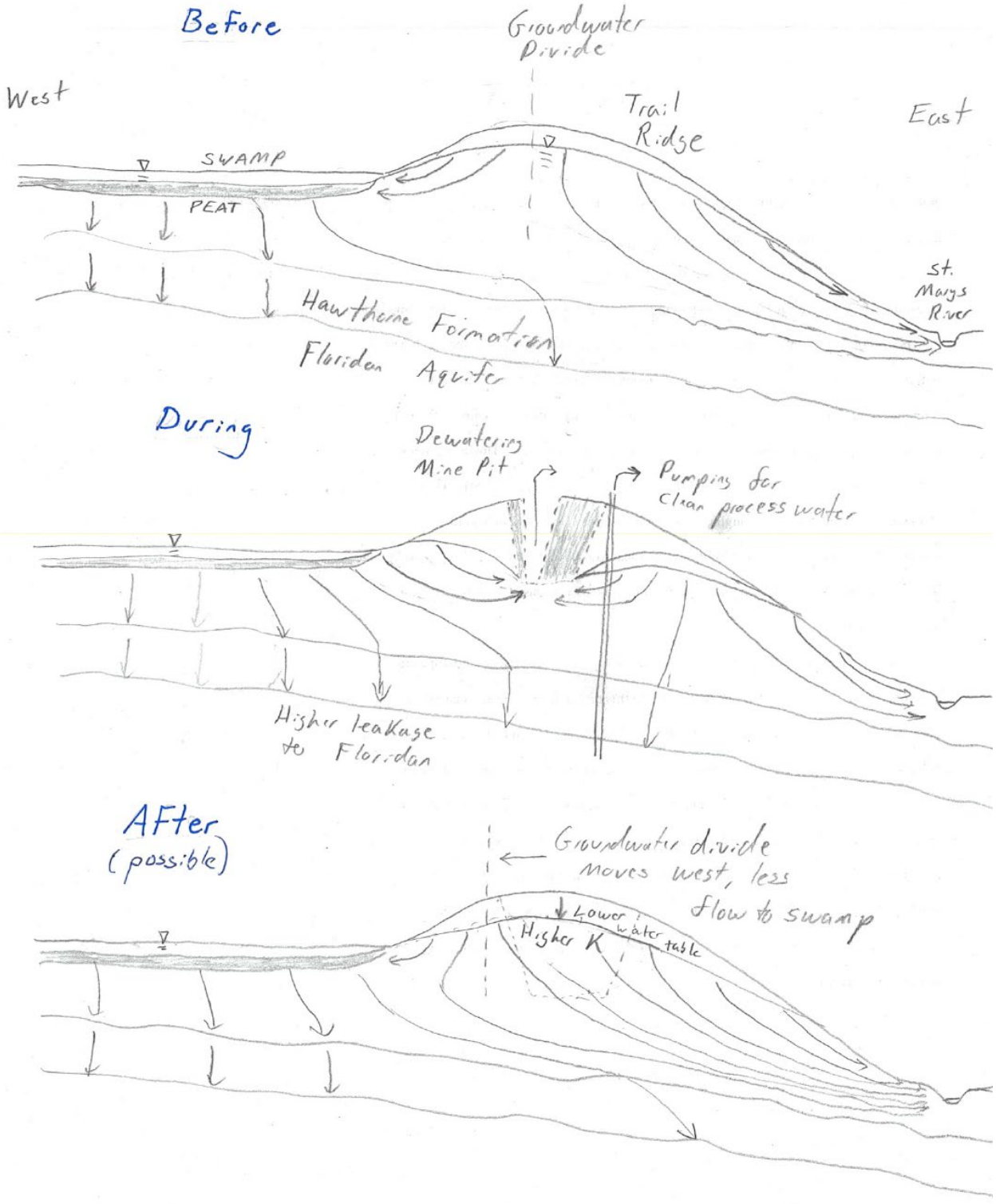
An important question about mineral sands mining on Trail Ridge is whether such mining will affect the hydrology of the Okefenokee Swamp. The schematic below summarizes water flows before, during, and after mining, illustrating how mining is likely to affect the water budget of the swamp, and, by extension, how it might increase the frequency of severity of drought periods in the swamp environment.

BEFORE. The ancient Okefenokee Swamp sits in a wide shallow depression west of Trail Ridge. Rainfall incident upon the swamp contributes 80% of swamp water, with the rest coming from small streams flowing from the west and northwest. The swamp is the headwaters of both the Suwannee River to the southwest and the St Marys River to the southeast. The St Marys flows south until it flows east through the only notch in the 160km Trail Ridge and then flows back north to Folkston along the east side of Trail Ridge. From west to east, there is a large drop in water levels from the swamp to the St Marys. *Trail Ridge acts as an earthen dam which prevents surface water movement from the swamp directly to the east where it wants to go*. The swamp is underlain first by peat deposits, and then by the Hawthorne formation of weathered limestones and clays which moves water slowly. The Hawthorne sits atop the Floridan aquifer, a porous and highly productive aquifer that can move water quite quickly. Water levels in the swamp are 70-80 feet higher than well levels in the Floridan, so some water percolates downward from the swamp, through the Hawthorne, and into the Floridan. There are no measurements of the hydraulic characteristics of the Hawthorne, so the amount of vertical flow through the formation is unknown.

The surficial water table in Trail Ridge is higher than the swamp to the west and much higher than the St Marys to the east, so groundwater in Trail Ridge has a divide: water to the west of the divide flows to the swamp, and water to the east of the divide flows to the St Marys valley and tributaries draining the ridge.

DURING. The mine will create a moving, 50-foot-deep pit, 1-2 acres in area, from which sands will be temporarily removed to extract the approximately 1.5% of valuable mineral sands with the remaining 98.5% returned to the pit. The pit will move back and forth across Trail Ridge as sands are excavated and returned. *The pit has to be continually dewatered by pumping as the mining progresses. The bottom of the mining pit is much lower than the water table feeding the Okefenokee to the west, and the lowest parts of the pit are lower than the swamp itself, so water will flow into the pit from both the west and the east, not only reducing flows to the swamp but also drawing water out of the swamp (supplementary material)*. The mine will also put two wells in the Floridan aquifer to pump 1.44 million gallons per day (MGD) of clean process water. *Process water pumping will reduce pressures in the Floridan aquifer below the swamp, increasing the rate of percolation of swamp water through the Hawthorne and into the Floridan*.

AFTER. This is hard to predict without detailed 3D modeling and the hydraulic characteristics of the replaced sands – it depends on the specific geometry of the pits after reclamation. The following things are certain: *the sands returned to the mining pit will be homogenized, no longer layered as they were before mining. The homogenized sands will move water faster than the original sand formation. This will lower the overall water table height in Trail Ridge and make it difficult to establish replacement wetlands on Trail Ridge after mining (the mine site is currently over 50% wetlands)*. If the replaced sands are geometrically balanced across the original groundwater divide, flows to the swamp will not change. If, however, the replaced sands are better connected to the steeper groundwater system to the east, the groundwater divide will move west of its original position. This will have the net effect of reducing flows from Trail Ridge to the swamp and commensurately increasing flows from Trail Ridge to the St Marys.


Before
Groundwater Divide
West
Trail Ridge
East
SWAMP
PEAT
St. Marys River
Hawthorne Formation
Floridan Aquifer
During
Dewatering Mine Pit
Pumping for clean process water
Higher leakage to Floridan
After (possible)
Groundwater divide moves west, less flow to swamp
Lower water table
Higher K

Why does dewatering the pits pull water that would otherwise go to the swamp?

I.E. The basic hydrogeology of wells and holes in the ground

When you go to the beach and dig a hole up the beach from the water line, the hole fills with water to the same level as the ocean water (actually slightly higher than the ocean water). If you try to empty the hole with a bucket, you notice that it just keeps filling with water. This is a basic property of holes dug below the water table, and this is the principle behind wells.

A well is simply an engineered hole in the ground. You drill and install your well, and water enters the well and equilibrates with the water table around the well. You pump the well, and water enters the well from the surrounding aquifer to replace the water you have taken out. In a poor aquifer, water enters the well slowly. In a productive aquifer, the well refills rapidly after pumping. In hydrologic science, we have well-accepted and tested equations for predicting inflow to a well based on the well diameter, the depth of drawdown, and the aquifer properties.

From the hydrogeologic investigations, we know that the water table is near the surface of Trail Ridge, and thus the 50-foot deep mining pit is essentially a large hole that will be about 45 feet below the pre-mining water table. The November 7, 2021 mining plan indicates that the pit will be dewatered when first excavated and will also be dewatered after interruptions to mining. The plan makes vague statements about water entering the pit during mining, but makes no calculations of this normal inflow. However, based on what we already know about wells and holes in the ground, we know that the continual inflow will be substantial. *The mining pit will essentially act as a large diameter well with a water level approximately 45 below the water table in Trail Ridge. Following the basic principles of holes and wells, it will need continual pumping to keep it from filling with water. This is a basic law of hydrogeology, there is no way to stop the hole from filling with water, and if the mine operators don't want a hole full of water, they have to pump out water at the same rate it flows in*.

Groundwater will be pulled into mining pit from all directions. Pumped wells create what hydrologists call a "cone of depression" meaning that the water table slopes from all directions to the well, creating a cone in the water table. Wherever this cone overlaps with areas that previously directed groundwater to the swamp, that contribution to the swamp is lost. *Pit dewatering will necessarily reduce groundwater flows to the swamp*.

What will the mine do with all the pumped water?

As of summer 2022, the mining permit documents have been very vague on this point. If the mine wants to discharge these waters to streams, it needs a waste water discharge permit to do so, but they haven't applied for one.

If the mine does not discharge this water to streams, they have to evaporate the water, but the climate in south Georgia is not conducive to evaporating the water. Specifically, the annual rainfall at the mine site is approximately equal to the atmospheric potential for evapotranspiration. During the winter and spring, rainfall is greater than potential evapotranspiration. Only in summer and early fall would the mine be able to evaporate more water than falls as rain. *The mine will either have to discharge processing water and pit dewatering waters or suspend operations for most of the year*. The site water budget would only allow the mine to operate for a few months a year, and even then only with evaporation pits substantially larger than the pits shown in the mining plan.

As an example of this water management problem, the Southern Ionics mine near Winokur, Georgia also attempted to manage a zero discharge system, but were unable to do so. They eventually had to get an NPDES discharge permit and construct a treatment system for the discharged water. This treatment system flocculates and settles solids, controls pH, and manages the resulting sludges from the settling ponds in order to clean the discharge water sufficiently before discharge to surface waters.

What effects might the mine have on the hydrology of the swamp?

Here I provide rough estimates of the effects of the Twin Pines Minerals, LLC proposed mineral sands mining on Trail Ridge on the water budget and streamflows of the Upper St Marys River system where it is gaged by the USGS at Moniac (USGS Gage 0228500). Flows in the Upper St Marys are highly correlated with water levels in the southeastern portion of the swamp (Hyatt, 1984; see endnote), so river flows at this gage are a surrogate for swamp water levels in the southeastern section of the swamp draining to the St Marys. I will caveat these estimates given the minimal hydrogeologic information available to make these estimates more accurate and more precise. The proposed Twin Pines Minerals, LLC mining operation will affect the water budget of the basin in three ways:

1. *Dewatering the mine pit will remove groundwater from the surficial aquifer, water that otherwise would have supported streamflows and water levels in the upper St. Marys basin*. Sheet 7 of the November 7, 2021 mining plan indicated the active pit will be dewatered during operations so that only 1.5 feet of water are standing at the bottom of the pit. To maintain this water level against seepage from the surrounding aquifer, pumping will be required. *Essentially, the mine pit will act as a large-diameter well drawing from the surficial aquifer*. Professor of Hydrology Todd Rasmussen has used standard well calculations to estimate average withdrawals of 1.0 MGD (1.55 cubic feet per second) to dewater the pit.

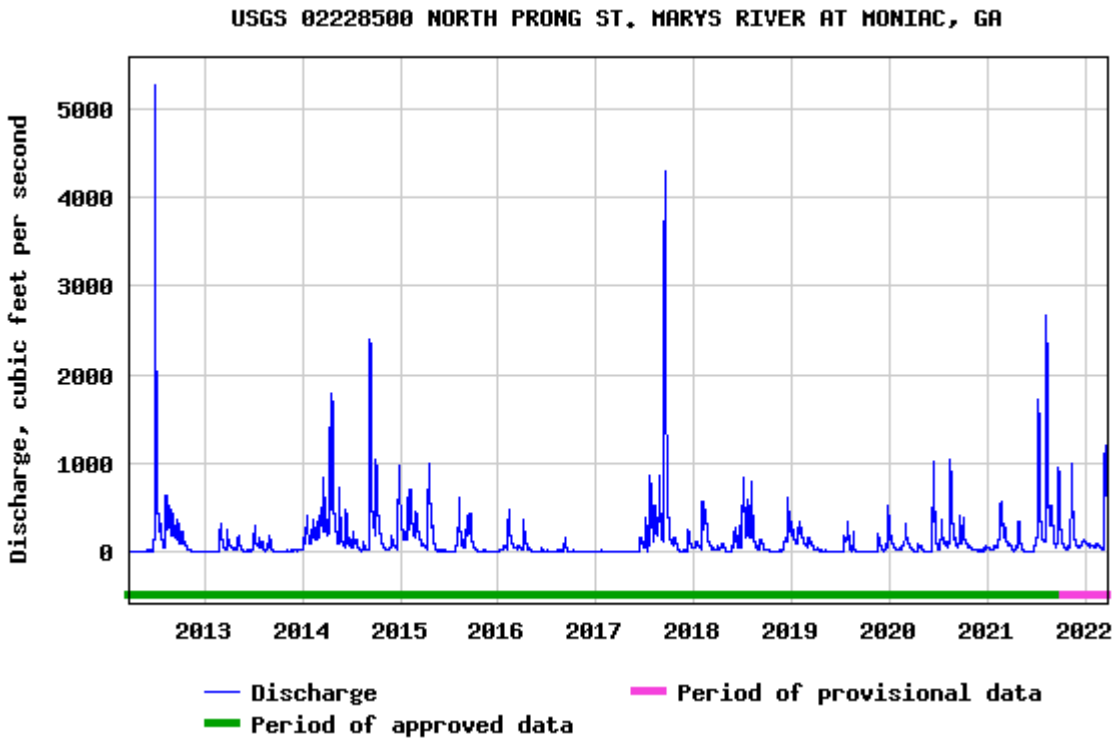
2. The mine proposes to withdraw 1.44 MGD (2.23 cubic feet per second) of clean process water from the Floridan Aquifer below the mine. *Process water withdrawal will reduce the hydraulic head in the Floridan aquifer beneath the St. Mary's basin, increasing vertical percolation from the surficial aquifer to the Floridan*. *No pumping studies have been conducted to support Twin Pines' contention that the confining layer between the aquifers is essentially impermeable and this downward flow can be neglected*. Other hydrogeologic information indicates there is connection and a downward hydraulic gradient between the surficial and Floridan aquifers in this area. Specifically, examination of the time series of hydraulic heads monitored in the Floridan below the swamp shows that hydraulic heads in the Floridan is generally 21 to 25 meters less than hydraulic heads in the swamp and also shows that hydraulic heads in the Floridan below the swamp are highly variable (up to 5-7 meter inter-annual variation) and responsive to dry periods at sub-annual timescales (USGS Monitoring Well 27E004, Station 304942082213801, located at Stephen Foster State Park). Since the swamp is surrounded by commercial timber lands, with no irrigation, this is not likely to be a pumping effect. It is a long way to the nearest center pivot systems. Additionally, stable isotope signatures of Floridan aquifer waters in the region show an anomaly beneath the swamp (Plummer 1990). This anomaly in the 18O signatures is consistent with inputs of swamp water subject to high evaporative fractionation.

3. The mining operation will remove the layered soils and geologic strata on Trail Ridge and return them to the pit as a mix. Mixing layered materials like this always increases the bulk hydraulic conductivity of the aquifer. In other words, it makes it easier for water to move through the materials, all other things being equal. As the water levels of the basin are much higher on the swamp side of Trail Ridge than the ocean side of Trail Ridge, groundwater moves through Trail Ridge from the upper St Marys basin to the

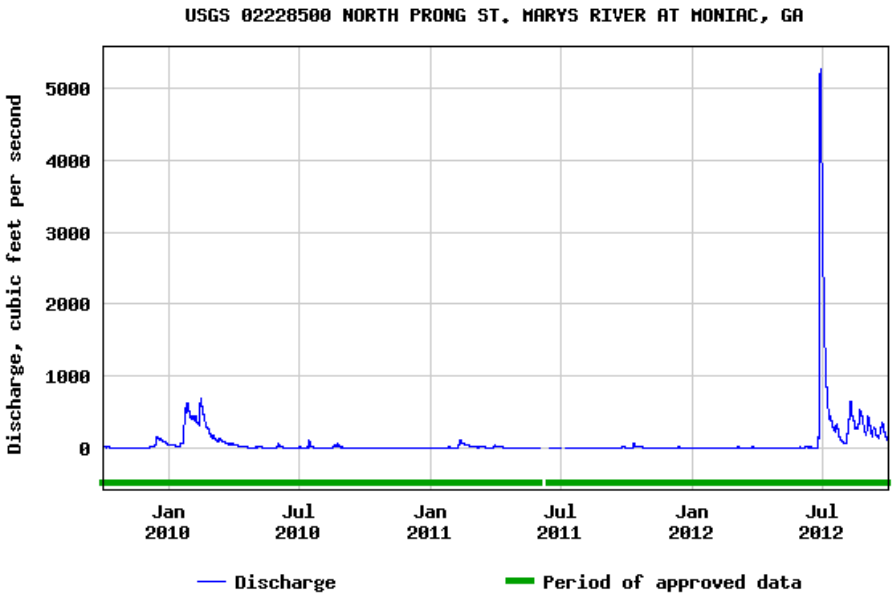
lower St Marys basin. *The mine is likely to increase the eastward flow of water underneath the mine, moving the groundwater divide westward and reducing groundwater flows to the swamp*. Again, insufficient hydrologic analyses have been conducted to estimate this increased flow through Trail Ridge. *Furthermore, the mixed sands will lower the water table in Trail Ridge, making it harder to reestablish wetlands and intermittent streams on the surface*.

We have one solid number of withdrawal from the surficial aquifer (1.55 cfs from pit dewatering), plus additional percolation from the surficial aquifer to the Floridan aquifer and additional lateral flow through Trail Ridge. Let's first estimate that the total loss from the Okefenokee basin is 3.0 cfs. Is that a lot? *The potential water loss from the swamp is enough water to supply a city of 25,800 residents, assuming a typical water usage of 75 gallons/person/day*. We can also compare it to the average and median flows of the upper St. Marys river, which are 143.1 and 42.0 cfs, respectively. Compared to the average of 143.1 cfs, 3.0 cfs does not seem like a lot, but 3.0 cfs is 7% of the median flow. Let's take a look at the flow behavior of the St. Marys river to put 3.0 cfs in perspective.

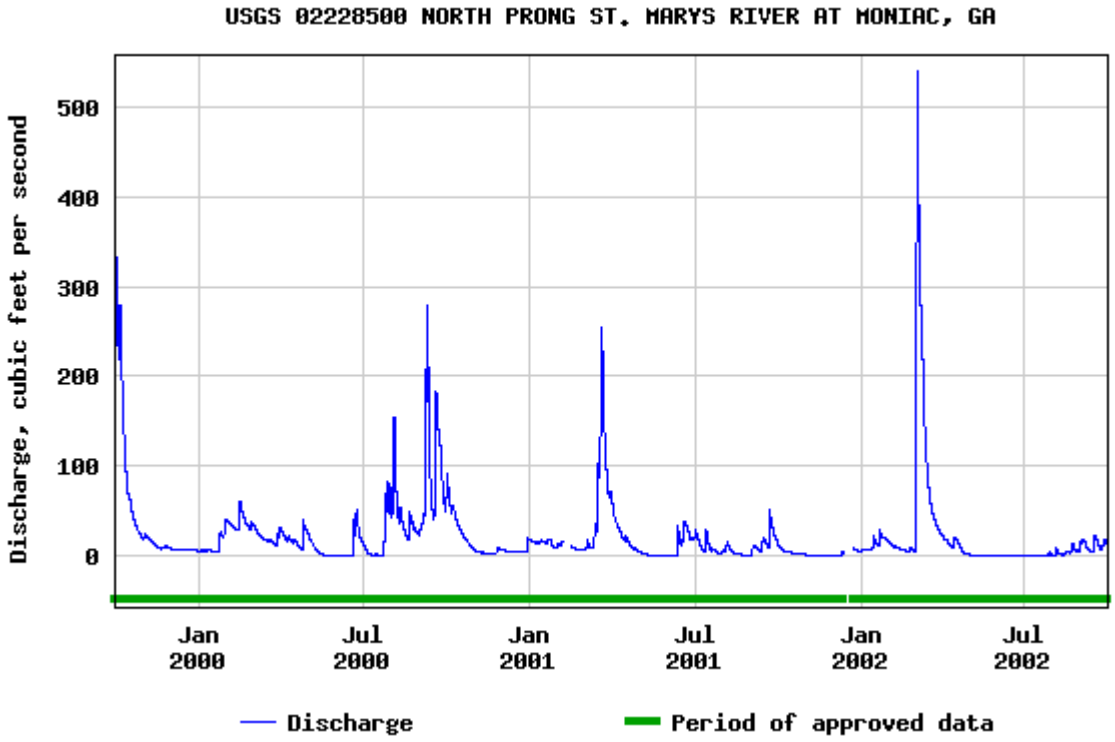
The Okefenokee Swamp is sensitive to droughts. The upper St. Marys river has wet periods and dry periods, and the river commonly dries up (zero flow) during dry periods (see hydrograph below). That is why the median flow is so much lower than the average. The southeastern portion of the Okefenokee Swamp, the part that feeds the upper St. Marys basin, is fed largely by precipitation. The upper St. Marys river receives very little baseflow support from the surficial aquifer. Consequently, the upper St. Marys basin is very sensitive to periods of low rainfall, and the river frequently goes dry.



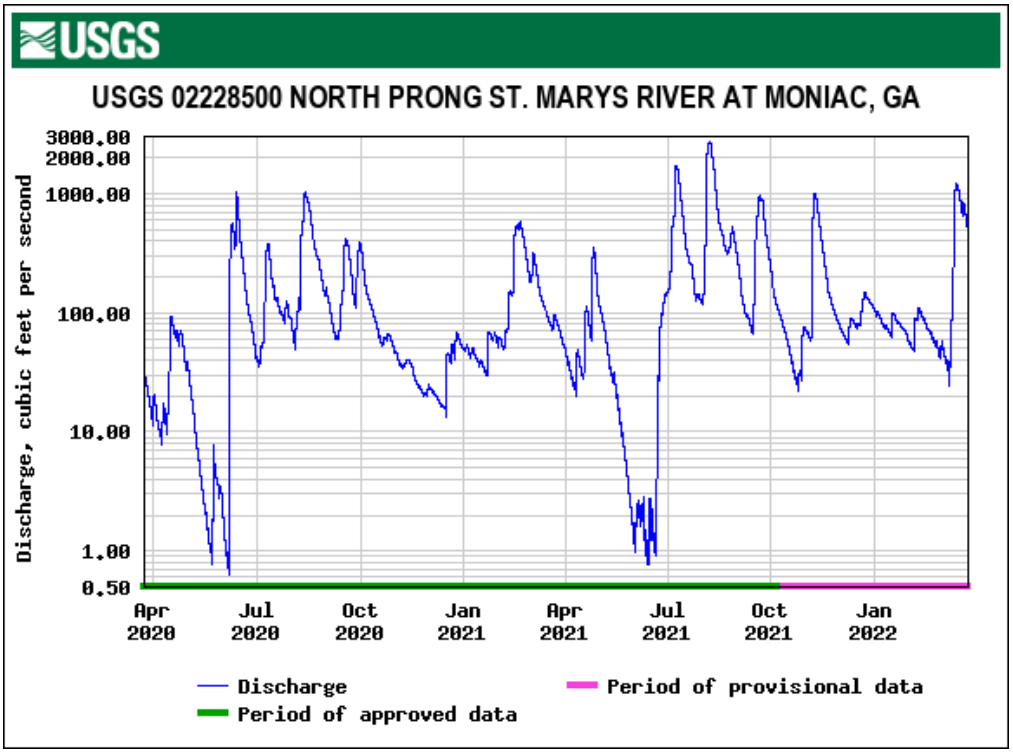
If we look at a drought period, like the 2009-2012 drought, we see the river rarely flows (below).



In the less severe drought of 2000-2002, we see frequent periods of zero flow lasting weeks or months.



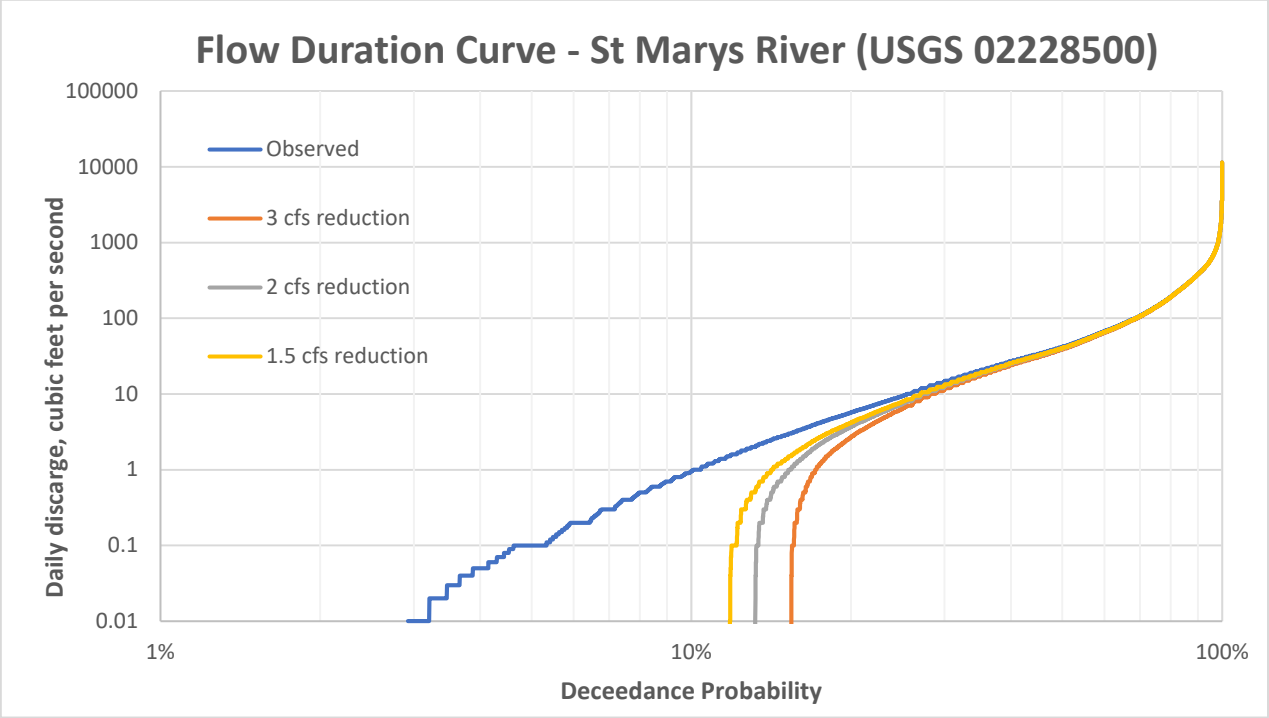
In a wet period, like the last two years, we don't see the river going dry, but we do see periods of very low flows of less than two cfs.



Considering the nature of flows in the upper St. Marys basin, we see that a loss of three cubic feet per second from the system could have substantial effects on the frequency and duration of extremely low flows (including zero flows) and correspondingly affect water levels in the southeastern portion of the swamp draining to the upper St Marys river.

We can use a flow duration curve to assess the effects of a various streamflow losses on the aggregate hydrologic behavior of the St Marys River and the swamp. A flow duration curve simply plots the fraction of time, through the entire flow record, that flows are either greater than or less than a given flow. The flow duration curve below plots the deceedance probability of all flows in the record, in other words it shows the fraction of time that flows are less than a given flow. Analysis of this flow duration curve, with and without the subtraction of 3.0, 2.0, and 1.5 cfs shows that reducing flows by 3 cfs would quintuple the amount of time that the river flows are less than 0.01 cfs and nearly double the amount of time flow was less than 1 cfs. A reduction of only 1.5 cfs in St Marys flows would still triple the amount of time flows are less than 0.01 cfs and increase by 50% the amount of time flow was less than 1 cfs. There would be corresponding effects on the frequency of very low swamp water levels. In essence, this analysis shows that ***the proposed mine can be expected to make the swamp drier in dry periods and also to make dry periods last longer. Drought frequency and severity, along with fire risk, would increase.***

This graph plots the data on log scales on both axes. This is done because of the wide variance in the range of the data, and the log scales allow the reader to see differences when flows are very low and the deceedance probabilities of these flows are very small.



What other social and ecological effects might the mine have on the Okefenokee Swamp?

Trail Ridge itself contributes to the biodiversity of the regional swamp ecosystem, particularly because of its high density of depressional wetlands and intermittent streams. The surface of the proposed mining site is over 50% wetlands (Jackson et al. 2021). The sandy upland soils on Trail Ridge also provide habitat for gopher tortoises and indigo snakes. Wetland restoration on the mining site will not be required by the federal government, as the United States Army Corps of Engineers determined that these wetlands did not fall under the jurisdiction of the Clean Water Act using the Navigable Waters Protection Rule in place at the time of application. This rule has since been invalidated by two federal district courts, but prior jurisdictional determinations applicable to the Twin Pines property currently remains in place. EPD could require wetland restoration as part of the mining permit requirements, but *previously mined sections of Trail Ridge in Florida show little wetland restoration and poor forest regeneration*. The State of Georgia has no state laws specifically protecting freshwater wetlands.

The mine will diminish the value of the swamp as a dark sky attraction for stargazing. The Okefenokee Swamp is a noted dark sky site that attracts stargazers and amateur astronomers from far away. The Stephen Foster State Park is a designated dark sky park. Even with these notable dark skies, light domes are currently visible over Jacksonville and Valdosta from the swamp. Bright lighting to support night operations at the mine would degrade the night sky quality and diminish the recreational value of the swamp.

Summary. The proposed Twin Pines Minerals, LLC mineral sands mine on Trail Ridge will have significant hydrologic and other impacts on the Okefenokee Swamp and St Marys River.

1. The combination of mine pit dewatering, deep aquifer pumping, and homogenization of currently layered sands will divert groundwater that would otherwise flow to, and replenish, the swamp. The water table under Trail Ridge will drop as a consequence of homogenizing the sands.

2. Accordingly, the mine can be expected to make the swamp drier in dry periods and also to make dry periods last longer. Drought frequency and severity, along with fire risk, would increase.

3. The mine will generate significant volumes of wastewater that it will not be able to handle under its currently proposed, zero-discharge design. Similar mineral sands mining projects in the area have failed to acheive zero discharge and have had to discharge to local water bodies. It is almost a certainty that the Twin Pines project will have to discharge to St Marys tributaries.

4. Dredging and filling of over 320 acres of isolated wetlands on Trail Ridge, with little to no potential for successful restoration, will damage the greater Okefenokee ecosystem.

5. The mine will diminish the value of the swamp as a dark sky attraction for stargazing.

References and notes

Hyatt, Robert Allen. 1984. Hydrology and Geochemistry of the Okefenokee Swamp Basin. PhD Dissertation, University of Georgia.

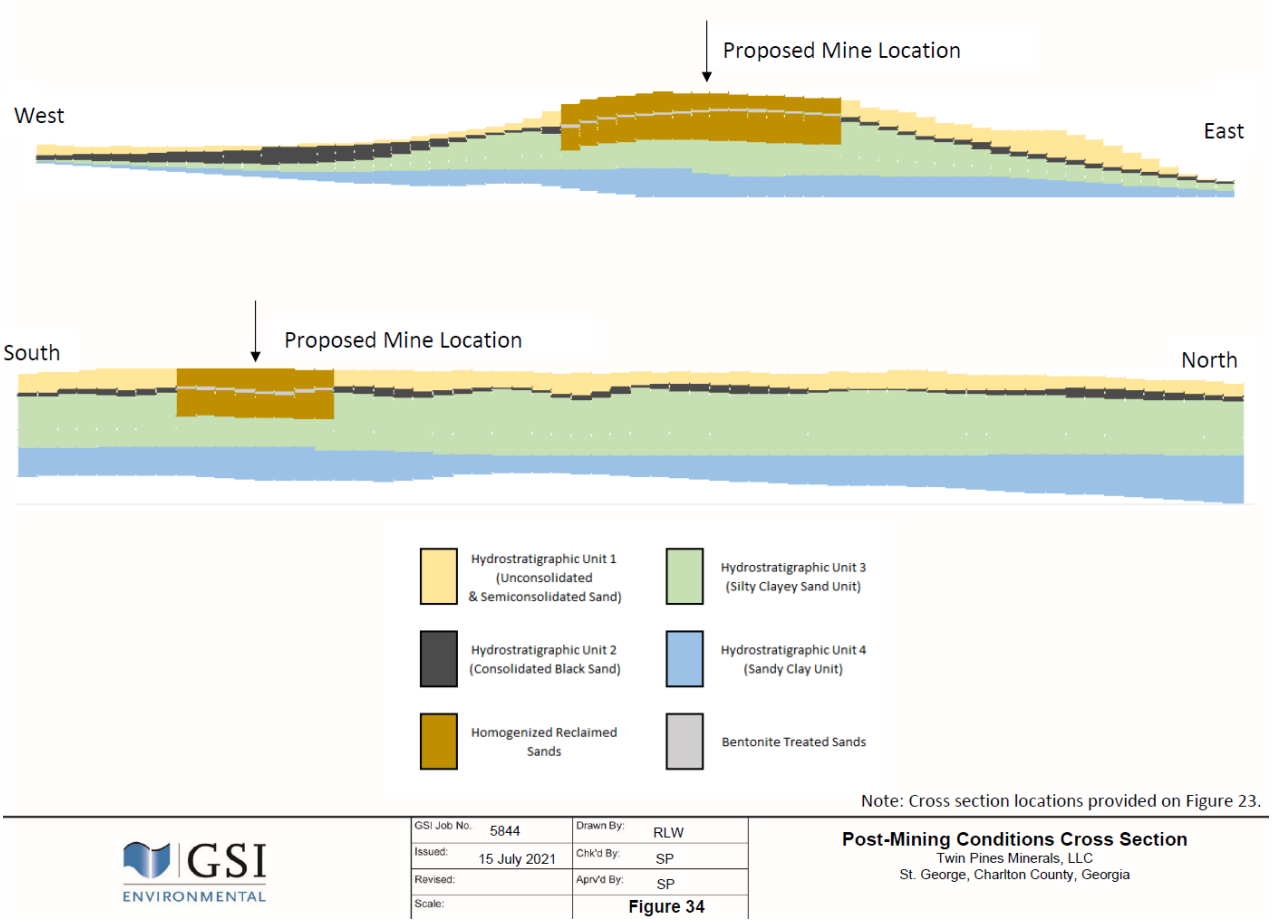
Hyatt modeled flows in the St Marys River at Moniac based on water levels in Sapp Prairie in the swamp measured by the USFWS. Water levels in Sapp Prairie explained 81 percent of the variation in streamflows, indicating the high correlation between river flows and swamp water levels.

Jackson, C.R., C. Sytsma, L. Sutter, and D.P. Batzer. 2021. Redefining Waters of the US: a Case Study from the Edge of the Okefenokee Swamp. Wetlands 41:106. DOI:10.1007/s13157-021-01512-8

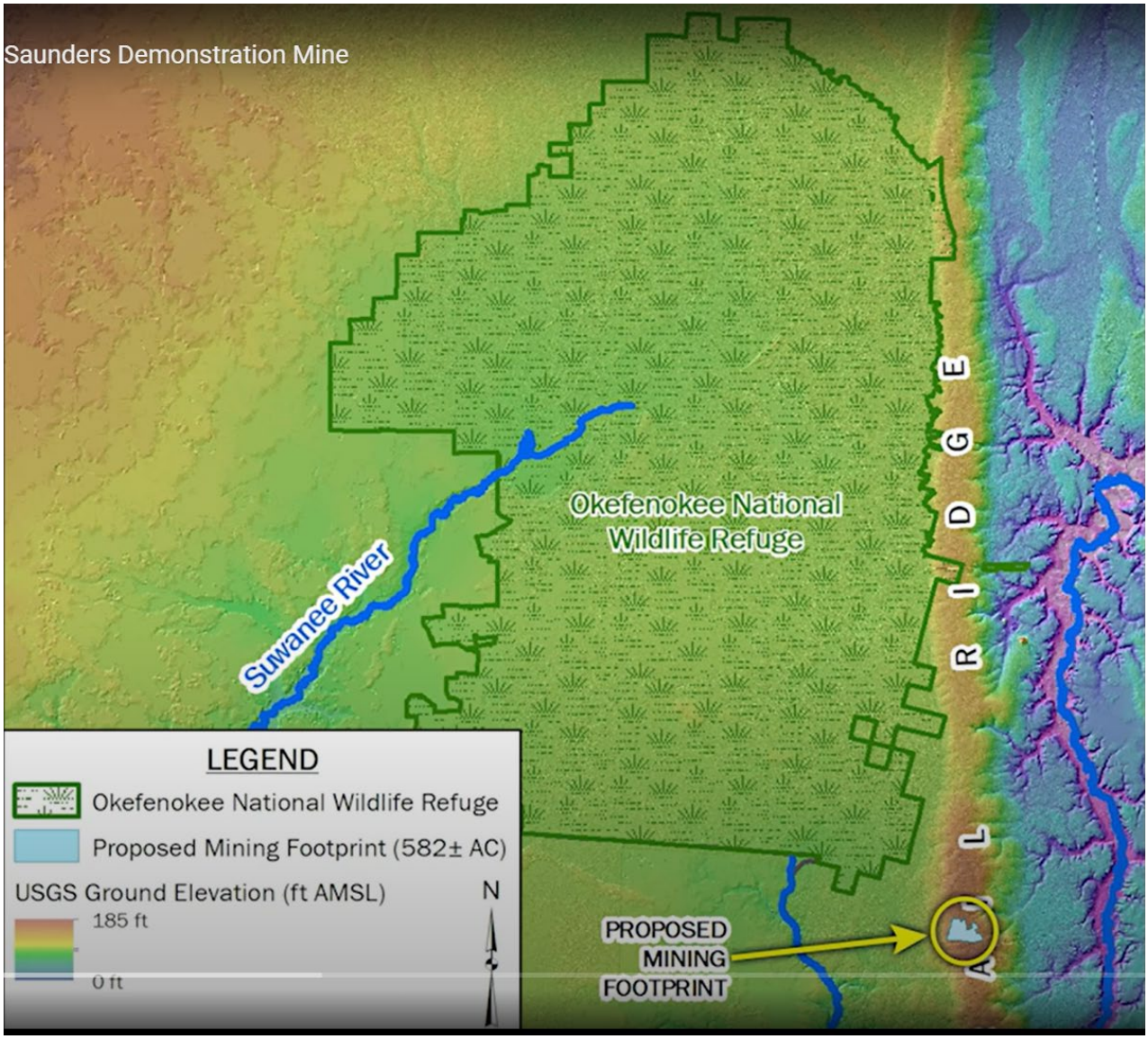
Plummer, LN. 1993. Stable Isotope Enrichment in Paleowaters of the Southeast Atlantic Coastal Plain, United States. Science 262:2016-2020.

L. Neil Plummer of the USGS measured stable isotopes (18O and D) along three well transects from above the Gulf Trough to the Atlantic ocean and used 14C, dissolved N, and Argon to age the waters. He found anomalous 18O enrichment in the wells beneath the swamp. Plummer attributed this enrichment to a large local pluvial event, but a simpler explanation of the anomaly would be that evaporatively -fractionated swamp water percolated into and mixed with Floridan water. Plummer's hypothesis was based on an assumption of disconnection between the swamp and the Floridan.

Supplementary materials



Top: West-East Cross section through Trail Ridge showing the mining pit with respect to the topography. From GSI Environmental modeling report in support of the mining permit application.



LiDAR hillshade mape of the swamp and Trail Ridge showing how Trail Ridge effectively dams the swamp and keeps it from flowing into the much lower St Marys River to the east and how the swamp serves as the headwaters of the Suwanee and St Marys Rivers. Map also shows the St Marys tributaries draining Trail Ridge in the vicinity of the mine site and connecting the surficial wetlands to the river. From Twin Pines Minerals, LLC information video ("Twin Pines Minerals – Saunders Demonstration Mine") on the mine website: [Twin Pines Minerals, LLC – Charlton County (twinpinesmineralscharlton.com)]