Continued problems with the assessment of the hydrologic effects of the proposed TPM LLC mineral sands mine and a recommendation for an independent expert panel.

Dr. C. Rhett Jackson, John Porter Stevens Distinguished Professor of Water Resources, UGA.
3/27/2024

Preface: Approximately 10 months after the close of the public comment period on the draft Mining Land Use Plan, Georgia EPD (EPD) posted a large number of voluminous new documents supporting a revised land use plan and stating that TPM's groundwater model and EPD's analysis indicate that the mining plan will cause no significant harm to swamp hydrology. These new documents include a 64-page memo from TPM's hydrologic consultant and modeler, Dr. Sorab Panday of GSI. In short, I found no new information refuting the critical technical comments from myself and Bureau of Interior hydrologists. Here, I briefly recap the principal hydrologic issues, why the consumptive groundwater withdrawals by the mine will increase drought frequency and severity in the swamp, and why the TPM groundwater model does not address the relevant questions. Finally, I recommend that EPD charge an independent panel of hydrologic experts to review the issues and the criticisms and provide guidance to EPD. Relative to the EPD's and TPM's responses to public comments, my response will be short – less than 6 pages.

I. The Tyranny of the Water Budget – why Twin Pines planned operations will definitely affect the Okeefenokee swamp levels and the St. Marys River flows during droughts.

Watersheds don't make or destroy water – they take water in, temporarily store it, and send water out, either as evapotranspiration, streamflow, or groundwater flow. A watershed water budget is just like a no-interest bank account – you have income, a balance, and outlays, but a no-interest bank account neither creates nor destroys money. Taking $100 from either your income or from your balance or adding it to your bills, all have the same effect on your balance and your finances. Taking a fixed amount of water from the Okefenokee swamp or taking it from swamp inputs will affect the swamp water budget the same way. This principle of conservation of mass and energy underpins physics, chemistry, all natural sciences, and all hydrologic analyses. It isn't debatable, hence the tyranny of the water budget.

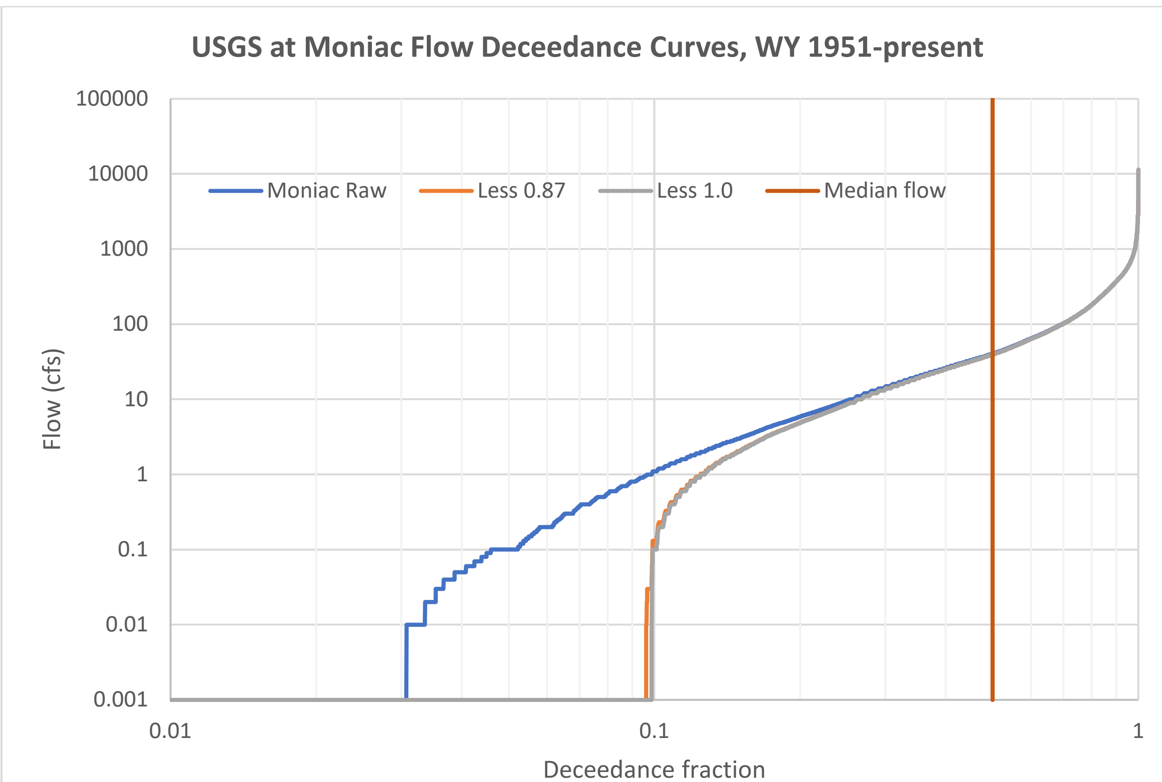
The planned extraction and evaporation of surficial groundwater that seeps into the mining pit will directly rob water from the swamp water budget. In water resource management, we differentiate two types of water uses, consumptive and non-consumptive. Consumptive uses take water from the watershed water budget, either by sending it to the atmosphere or exporting it to another basin. The well-known groundwater declines in the Central Valley of California and the Oglalla Aquifer are the result of consumptive use – farmers pumping groundwater and sending it to the atmosphere as evapotranspiration from crops. There are no processes that replace this water, so groundwater storage in the watershed continually declines and streamflows decrease. Conversely, taking a shower or flushing the toilet are non-consumptive uses. The water is returned to the river from the water reclamation facility.

Groundwater and surface water are always connected. This is fundamental to Georgia water policy. Baseflows in streams and rivers come from groundwater discharge to these bodies. If this weren't true, we wouldn't have to worry about agricultural pumping from the Dougherty Plain or declining low flows in Ichawaynochaway Creek or Spring Creek. We can't have one set of hydrologic principles for Georgia farmers and a different set of principles for Twin Pines LLC.

The TPM water management plan estimates that 783 gallons per minute (gpm), equivalent to 1.128 million gallons per day (MGD) or 1.75 cubic feet per second (cfs) will need to be continuously pumped from the 500 ft x 100 ft x 50-foot-deep mining pit to remove groundwater seeping into the pit from the surrounding surficial aquifer. This is the TPM estimate, not my estimate, but the estimate does match that predicted by well equations calculated by other experts. The mining plan calls for evaporating all of this water, returning none of it to the watersheds. As Trail Ridge is a local hydrologic divide, half of this 1.128 MGD (1.745 cfs) of seepage water to the mine pit will come from east side of Trail Ridge, and the other half will come from the west from which it would have otherwise flowed to the swamp. If the TPM models don't show this loss, there is something wrong with the simulations, because the water budget is inviolate.

This consumptive use of groundwater from the watershed draining to the St Marys River portion of the swamp will continuously remove *0.87 cfs from the swamp water budget. This loss will be most noticeable* *during drought conditions, as it is this surficial groundwater seepage that helps sustain the swamp during droughts*. During normal or wet conditions, this water removal will have no significant effect on swamp hydrology. It is only during drought that it will matter, but that is precisely why and when it is important.

To estimate the effects of this consumptive groundwater withdrawal on the swamp, we can subtract 0.87 cfs from all historically recorded streamflows for the St. Marys River as it leaves the swamp, and compare the cumulative distribution of flows with and without the subtraction (see graph below). This is how EPD evaluates the effects of consumptive use applications around the state. We can see that the withdrawal has no effect on median flows, and it really doesn't change hydrograph behavior until flows drop below 10 cfs. However, *this relatively small withdrawal has very large effects during drought periods, and it would triple the duration of zero-flow periods (from 3% of the time to over 9% of the time). Essentially, robbing 0.87 cfs from the St. Marys compartment of the swamp will make drought conditions more frequent and more severe*. EPD has pretended this doesn't matter, but to do so, they have had to use a different method of assessing the consumptive use effects than they use for other consumptive use applications in the state. *Why does this method make sense everywhere else but not here? How does a 0.87 cfs reduction not matter if the flow is less than this value 7% of the time? (*See Appendix B, Letter from 13 southeastern hydrologists stating that the hydrologic effects of the mine should be assessed from the Moniac gage flows)



The above flow-deceedance curve shows the fraction of time that river flows are below any given level. As an example, for the raw flow data from the Moniac gage, the St Marys River flows are less than or equal to 1.0 cfs for 10 percent of the time (1/10 of the total flow period). This curve was created using the USGS-measured streamflow record for the Upper St Marys River as it leaves the swamp (USGS gage 02228500). The curve shows that the undisturbed river has no measurable flow for slightly more than 3% of the gage record, indicating the sensitivity of the swamp to drought. Previous analysis has shown that flows at this gage are highly correlated with US FWS-measured water levels in the swamp (Hyatt, PhD dissertation, Univ. of Georgia, 1984). The plot also shows flow-deceedance curves for a narrow range of consumptive water withdrawals from the swamp; 0.87 and 1.0 cfs. The 0.87 cfs loss equals half of the necessary pumping for mine pit dewatering, and this is the minimum potential effect of the mine. The larger withdrawal cases reflect an additional possible loss up to 0.13 cfs due to increased leakage from the swamp due to Floridan

Aquifer pumping by the mine. Unlike the pit dewatering, Floridan pumping will be episodic, but the mine documents estimate average consumption will be 0.43 MGD or 0.67 cfs. TPM documents argue that there will be no leakage from the swamp to the Floridan aquifer, but that is an assumption in the model. It is not based on data or modeling of leakage. Note: both axes are on log scales, which is done in hydrology when data vary by several factors of 10.

Dr. Panday's response says, "reduction in inflows due to mine pit dewatering is estimated to range, at most, from 0.07 cfs to 0.09 cfs, or between 17 and 21 million gallons per year." This statement defies physics. Is the watershed magically creating water to replace the 0.87 cfs they say they will remove from the pit? If this statement represents the model outputs, there is something wrong with the model because it violates a basic principle of watershed science.

The swamp is very drought sensitive (the St. Mary's does not flow from the swamp for 3% of the time over the long term), and the notorious swamp fires occur during droughts. *Massive wildfires regularly start in the swamp during swamp drought periods, most recently in 2007, 2011, and 2017.* Appendix C provides Google Earth Images showing the sensitivity of the swamp to drought conditions. *Any simulations that ignore drought conditions are not relevant to the issues at hand*. As discussed below, the simulations conducted by TPM have been conducted for average, steady-state conditions and thus ignore drought as it affects the swamp.

II. Problems with the boundary conditions – Twin Pines groundwater model

Appendix A provides a schematic and equations briefly describing the basics of a groundwater model. A groundwater model solves a differential equation called Richards Equation that says that water moves from high energy to low energy and that the rate of flow is proportional to the rate of change of energy over distance and also a soil/rock property called the hydraulic conductivity that itself is a function of the volumetric moisture content of the soil/rock. Richards Equation combines Darcy's Law for groundwater flow, the principle of conservation of mass, and the physics of the interaction of water with soils into one equation. The modeler divides space into little blocks called elements and assigns soil/rock properties to each element, and the equation describes the flow of water between all adjacent elements. The model uses matrix algebra to solve a large system of equations covering the whole domain. A dynamic model also breaks time into small chunks (the timestep) and solves the large set of equations for every timestep. Basically, the model converts a 4-dimensional (adding time as a dimension) calculus equation into a large set of algebraic equations that must be solved iteratively until the solution converges for each time step. Groundwater models can be run as steady state (with steady inputs and outputs, no change in storage, and no time variability of conditions) or dynamic (the system changes with changes in inputs, like rainfall and evapotranspiration). For obvious reasons, steady state models are much easier to run.

A groundwater model is set up to address a specific set of management questions, and the appropriateness of the model setup depends on the questions being asked. Three-dimensional Richards equation groundwater models are commonly used for predicting pollutant plume movement from landfills and chemical spills, for designing pump and treat systems for contaminated groundwater, for predicting long-term drawdown due to groundwater extraction for irrigation, estimating the potential for saltwater intrusion from coastal groundwater extraction, estimating drawdown effects on neighboring landowners, and predicting regional flow fields and baseflow contributions to rivers.

One of the problems with the TPM groundwater modeling is that it never states what questions the model is meant to address or specifies how the model simulations were designed to address those questions. TPM's consultants set up and ran a complicated groundwater model, but nowhere did they specify the questions intended to be addressed. I searched the July 2021 GSI modeling report for "?" and found none. I did the same for GSI's October 2023 Responses to Public Comments and found one question mark in a citation for another report. However, in groundwater modeling, the questions determine both what boundary conditions and what input/output conditions are appropriate.

As has been argued by me and by the Bureau of Interior hydrologists, the boundary conditions employed in the TPM groundwater model preclude the assessment of the most important questions. Below, I will try to explain why these boundary conditions and why the steady-state simulation render the model irrelevant to the questions at hand. First, I will define the questions as I see them, since the questions were never defined either by EPD or by GSI's modeling reports:

1. How would the groundwater removals (both mine pit dewatering and Floridan extraction) affect swamp inflows, water levels, and outflows during drought periods (e.g., when St. Marys River flows are below 3 cfs)?

2. How much would pumping of the Floridan aquifer affect downward hydraulic gradients and percolation to the Floridan aquifer under the southeast portion of the swamp?

3. How often, under what conditions, and where will process water ponds overflow?

4. What sensitivity analyses should be run with respect to the above questions?

Boundary condition effects on question 1. On the west side of the TPM model domain, which is essentially the edge of the swamp, the TPM modelers employed two types of boundary conditions: drain-package boundary conditions and held-head boundary conditions that hold water levels constant at one foot below the ground elevation. The drain-package boundary sets the hydraulic head equal to the ground surface elevation if the model predicts the water table rises to the ground surface and acts as a no-flow boundary otherwise. A held-head boundary conditions holds water levels constant, so no matter what happens on the inside of the domain, the water table will not move at the boundary condition. Furthermore, if hydraulic gradients are reversed, such that pumping on the inside of the domain lowers water levels below the held-head boundary, the model will keep adding water on the boundary to hold the head constant*. In other words, no matter what happens inside the model, the model cannot predict a drop in wetland water levels. It is precluded by the boundary conditions*. These boundary conditions preclude analysis of drought conditions, because under such conditions swamp water levels drop several feet.

I found GSI's presentation of boundary conditions on the west and east boundaries somewhat confusing because the drain-package boundary condition should only apply to the upper surface of the model elements. It isn't actually clear what boundary conditions apply to the edge of the domain in these locations. I assume it goes back to held-head, but the model description doesn't specify.

Boundary condition effects on question 2. The TPM model sets a no-flow boundary condition on the bottom of the model. This precludes the surficial aquifer from interacting with the Floridan aquifer below. *The stated prediction that pumping the Floridan aquifer will not increase downward flow from the swamp is not a model prediction. It is an a priori assumption. As designed, the model does not allow downward flow from the swamp*.

A strong downward hydraulic gradient from the swamp to the Floridan aquifer is evident from water levels in the USGS well at Stephen Foster State Park. Isotope data indicates that the Floridan aquifer at this location receives swamp water (Plummer 1993). We know that water moves from the swamp to the Floridan aquifer, but we don't know the rate and how this rate will respond to pumping in the Floridan. *There is no data on the conductivity of the confining layer, and no one has conducted pump tests to evaluate surficial aquifer responsiveness to pumping in the Floridan aquifer*. A low hydraulic conductivity has very different ramifications from a zero hydraulic conductivity. Impermeable layers are rare in nature, and we know one doesn't exist here.

Steady State Analysis of Average Climatic Conditions. The TPM groundwater model has been run in steady-state mode using average climatic conditions. The model does not actually include climate signals, rather, inputs to the system are based on USGS average recharge to groundwater in the region. *The simulations do not account for seasonality, inter-annual variation, or hydrologic extremes of droughts are hurricanes*. The inference that can be drawn is based only on average conditions. *Since the effects of the consumptive groundwater withdrawals will only be significant during drought periods, the model results are irrelevant to the effects of the consumptive groundwater withdrawals in drought periods*.

III. EPD's modeling of the Swamp as a Level Pool Reservoir of Water (Page 9 of the November 16, 2023 EPD Memo: "Summary of hydrologic analyses on Twin Pines Mineral's (TP's) Charlton County project")

As described in page 9 of EPD's November 16th 2023 memo on hydrologic analyses, EPD vaguely describes an attempt to estimate the water level effects of the loss of the mine pit dewatering water by modeling the swamp as a level pool reservoir. This modeling effort is problematic and unreliable for the following reasons. First, the swamp is not a level pool reservoir of water. Most of the swamp is an organic matrix that holds water. A quick look at an aerial or satellite photograph of the SE compartment of the swamp (see Appendix C) indicates that there is almost no open water in that portion of the swamp. Much of this portion of the swamp supports stands of trees and woody shrubs. To model this area of the swamp accurately, it is necessary to treat the swamp as a wet organic soil with high evapotranspiration rates. Such a model would require developing a "soil moisture release curve" that describes how much water the soil can hold against the water tensions (negative pressures) that develop when soils are unsaturated. EPD has not done this. Because of the moisture-holding behavior of soils and organic matter, a withdrawal of 1 inch of water from the system would translate into 4 or 5 inches of water table drawdown. For this reason, soil water cannot be modeled as open water. Furthermore, modeling of swamp water level behavior would also require modeling swamp evapotranspiration, as it is the major swamp outflow. EPD's description of their model does not indicate they have done this. It would also require checking model predictions against the water level time series in the swamp observed by the USFWS. EPD has also not done this. Furthermore, EPD has not demonstrated that their model reproduces either flows or water levels at the USGS Moniac gage. Nor has EPD reported the time period used for this modeling (which 12 years? Why these 12 years? Why not the whole record?) or the assumed inflows and outflows to the model. This modeling effort as described does not meet the basic standards or tenets of hydrologic modeling, nor does it pass any credible tests of modeling. With the information provided, it is impossible to judge the validity of its predictions.

Recommendation to Create an Independent Panel of Hydrologic Experts

GAEPD has relied on TPM's hydrologic analysis and dismissed substantive comments from myself and Bureau of Interior hydrologists without justification. To examine these conflicting evaluations of the hydrologic effects of the proposed mine, I recommend that EPD create an independent panel of hydrologic and groundwater monitoring experts to review the mining documents and the technical comments from myself and the Department of Interior scientists and to provide an independent assessment of the hydrologic issues associated with the mining proposal and the adequacy and appropriateness of the assessments provided by the mine consultants. There are many people who would be appropriate for such a panel, but as a start I would suggest the following scientists:

- Lynn Torak and Elliott Jones – retired USGS groundwater modelers who developed many of the USGS groundwater models for the Coastal Plain of Georgia
- Dr. Adam Milewski of the UGA Geology Department
- Dr. Rafael Bras, School of Civil and Environmental Engineering, Georgia Tech

All are very well-qualified and experienced hydrologists, and all have excellent reputations for their professionalism.

My suggested set of questions for the expert panel would be:

1. If the model is meant to estimate how much water levels would drop in the swamp during drought conditions, then:
    a. What is the appropriate western boundary condition?
    b. Under what climatic conditions should the model be run? Should the model be run as steady-state or dynamic?
    c. What model outputs would be useful for addressing this question?
    d. What does it mean if the model simulations do not show a reduction in groundwater discharges commensurate with evaporation of mine pit dewatering water?
2. If the model is meant to estimate whether pumping the Floridan aquifer will affect the swamp, what is the appropriate lower boundary condition?

3. What sensitivity analyses should be run with respect to the above questions?
4. Is flow-duration curve analysis (at the USGS St. Mary's Moniac gage) of the proposed consumptive water usage an appropriate way to estimate the effects of the evaporation of the water removed from the mining pit on low flows and drought conditions?
5. What is the likelihood of success of the Twin Pines' proposed system for evaporating 1.44 MGD?

Summary

1. Watersheds do not create or destroy water, so if 0.87 cubic feet per second of water from the swamp watershed are withdrawn from the mining pit and evaporated (along with 0.87 cfs from the St Marys River watershed), inflows to the swamp will decrease by 0.87 cfs. **This effect will be substantial during droughts, tripling the frequency of drought and increasing drought severit**y. The physics of the water budget are inviolate, and this analysis is based on the techniques that EPD uses to assess other consumptive use permit applications.
2. The TPM groundwater model simulates average conditions. It does not address issues associated with hydrologic extremes, either drought or large storm events. In other words, the model doesn't address any of the conditions during which problems are likely to arise.
3. The western boundary condition of the model holds swamp water levels constant at one foot below ground level, yet it is purported to predict how the swamp reacts to mining activities. As designed, the model cannot evaluate the potential for swamp levels to fall in response to reduced inputs.
4. The bottom boundary condition of the model does not allow downward water flow from the swamp to the Floridan aquifer. Geochemical evidence indicates they are connected yet the applicant has conducted no pump tests to quantify the connectivity of the aquifers. The model predicts no effects of pumping the Floridan because the models doesn't allow such pumping to affect the swamp.
5. EPD's modeling of water levels in the swamp does not meet any accepted standards for hydrologic modeling or documentation and the predictions cannot be assessed with the information provided.
6. A panel of outside hydrologic modeling experts is needed to review the modeling that has been completed and the criticisms thereof and to advise EPD on the sufficiency of the analyses to address the relevant hydrologic questions.

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

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

Note about my experience with groundwater modeling, groundwater flows, and hydrology: Although most of my scientific career has been based on field hydrologic studies, I am an expert in groundwater modeling. My doctoral dissertation consisted of modifying a Richards Equation code (the code was called VAM3DCG) to handle unusual groundwater flow problems in mountain environments and also using the modified model to conduct a large set of thought experiments on how the shape of the soil moisture versus pressure curve affects water pressure distributions in hillslopes. Coincidentally, the person who helped me modify the groundwater model was Dr. Sorab Panday, the Twin Pines modeler and also the groundwater modeler for EPD on ACF groundwater issues. At the time, Dr. Panday worked with Dr. Peter Huyakorn, the CEO of the company that developed VAM3DCG. Dr. Huyakorn had agreed to share his code and his company's expertise with my academic advisor for a research project on landslide initiation. I spent a week in their offices where Dr. Panday consulted with me on implementing curvilinear elements in the model and incorporating an option for a seepage face boundary condition (similar to the drain-package boundary condition now used in MODFLOW). It is a small world of people who conduct this type of modeling. In addition to my dissertation, I have written two journal articles using Richards Equation and a simplification thereof to investigate dynamic groundwater flows in unusual situations. I have also developed a simplification of Richards equation that allows estimation of the connectivity of shallow soil water in hillslopes to stream valleys and published two highly-cited papers on this simplification. One of my graduate students used this simplification to develop a novel type of groundwater model with moving boundary conditions. I have also co-authored a paper using a Richards Equation model to investigate the role of shallow lateral soil flow on base flow maintenance in mountain streams. Currently, I am working with a graduate student to develop a quasi-two-dimensional GIS-driven groundwater model based on the 1-D simplification of Richards Equation called the Dupuit equation.

My hydrologic experience is broad and deep. I began my career monitoring contaminated groundwater around landfills operated by the Los Angeles County Sanitation Districts. After earning my PhD, I conducted hydrologic modeling of the effects of basin development for King County, Washington. Then I spent three years consulting on water quality issues for timber companies and municipalities. I have been a teaching and research professor at UGA for over 26 years. My research focuses on how nonpoint source pollution is mobilized and transported to streams from human land uses, the effects of nonpoint pollution on aquatic ecosystems, and how we can efficiently reduce nonpoint pollution transport to streams. I have particular expertise in urban stream hydrology, the effects of silvicultural activities on sediment transport and water budgets and hydrographs, the interactions of riparian vegetation with channel morphology, stream thermal dynamics, and the hydrologic transport of nutrients. I am also a well-published and cited expert in the physics of shallow lateral subsurface flow in hillslopes. My work has been used in the development and application of stormwater management policies and forestry best management practices. Through my career I have collaborated with top scientists in hydrology and stream ecology. I have published 112 peer-reviewed journal articles and book chapters, mostly in prestigious journals in hydrology, geomorphology, and ecology. These works have been cited over 7960 times.

Pro Bono Analysis. As I have stated before, I have received no compensation, monetary or otherwise, for my analyses of the TPM LLC proposal to mine mineral sands on Trail Ridge. I have worked at the behest of no one but myself. All of the work I have done, reviewing permit documents, reading scientific papers on the hydrogeology of the swamp, preparing spatial analysis of wetlands on the mine site, analyzing hydrologic data, reading the Georgia surface mining law, visiting the swamp and the Mission Mine, writing a journal article, writing memoranda to EPD permitting staff, participating in public comment sessions, and answering questions from the public – has been performed out of professional interest in this resource management and policy question and out of a sense of duty to the citizens of Georgia who pay my salary at the University of Georgia.

Richards Equation for Groundwater Flow

$$\frac{\partial^2 (K_x(\psi) H)}{\partial x^2} + \frac{\partial^2 (K_y(\psi) H)}{\partial y^2} + \frac{\partial^2 (K_z(\psi) H)}{\partial z^2} = \frac{\partial \theta}{\partial t} + \text{inputs} - \text{outputs}$$

H = hydraulic head = $Z + \psi$

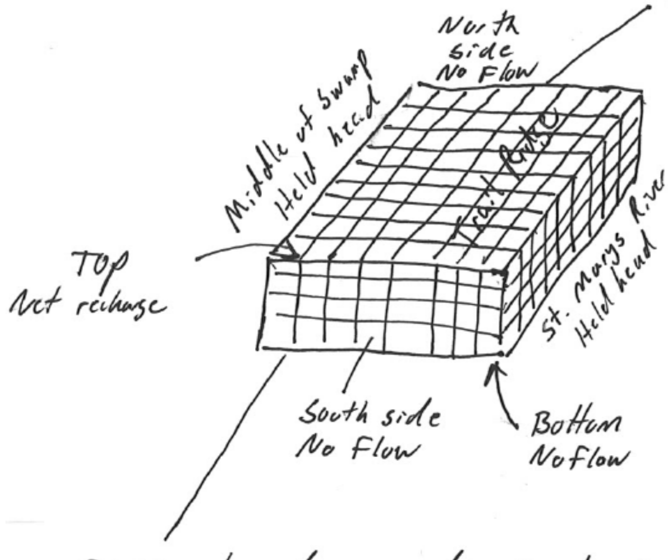
ψ = pressure head ; Z = elevation

$K(\psi)$ = hydraulic conductivity as a function of ψ

θ = moisture content (volumetric)

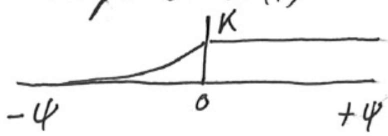
For a steady state analysis, $\frac{\partial \theta}{\partial t} = \emptyset$ and inputs & outputs are averages

This equation is discretized in space and time over a "domain" specified by the modeler

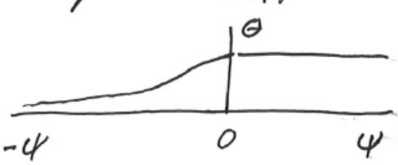


every "element" (block) must specify:

- saturated hydraulic conductivity
- shape of $K(\psi)$ curve



- shape of $\theta(\psi)$ curve



Every boundary node must specify either

- hydraulic head (i.e. prescribed head)
- water flow (i.e. prescribed flux)

if the prescribed flux = $\emptyset$, this is a "no-flow boundary"

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February 27, 2023

Georgia EPD and Interested Parties

Re: Appropriate streamflow data for assessing how the proposed TPM LLC mine groundwater withdrawals will affect Okefenokee Swamp Hydrology

We, the undersigned research hydrologists of southeastern universities, find that the appropriate USGS gage for assessing hydrologic effects on the Okefenokee Swamp of consumptive groundwater withdrawals by the proposed TPM LLC mineral sands mine is gage #02228500, North Prong of the St Marys River at Moniac, GA. Further, we find gage #02231000, St Marys River near Macclenny, FL, chosen by GA EPD, is inappropriate for such analysis.

The salient hydrologic question about the mine is the degree to which it will alter the hydrology and associated ecosystem benefits of the southeastern portion of the Okefenokee Swamp. The North Prong of the St Marys at Moniac exclusively drains the southeastern portion of the swamp plus its contributing areas from Trail Ridge, and previous research has demonstrated very high correlations between flows at this gage and swamp water levels monitored by the USFWS. The geographic position of this gage is ideal for analyzing potential effects to swamp hydrology of consumptive ground water withdrawals beneath Trail Ridge.

Conversely, the data from the USGS gage at Macclenny, FL are inappropriate for direct analysis of how consumptive groundwater withdrawals by the mine will affect the hydrology of the swamp. The Macclenny gage drains a basin that is 4.4 times larger than the Moniac gage. Three-quarters of the area draining to this gage is in relative highlands of north central Florida. The hydrologic inputs to this basin and the hydrologic behavior of this basin are in no way similar to that of the southeastern portion of the Okefenokee Swamp. Furthermore, the sheer size of the basin and its flows at this gage will mask the effects a fixed withdrawal would have where the river exits the swamp.

Conclusions drawn from consumptive flow removal from the Macclenny, FL gage data cannot be applied to the question of how the Trail Ridge groundwater withdrawals will affect the swamp. To assess this question, it is necessary to use flow data from the Moniac gage.

We thank you for your attention to this important matter. We know you agree it is critical to apply the best possible data to this resource management decision affecting Georgia.

Sincerely,

Signing for:

C. Rhett Jackson, John Porter Stevens Distinguished Professor of Water Resources, Warnell School of Forestry and Natural Resources, University of Georgia

Larry Band, Ernest H. Ern Professor of Environmental Science, School of Engineering, University of Virginia

Stephen Schoenholtz, Director and Professor, Virginia Water Resources Research Center, Virginia Tech University

Kevin McGuire, Professor of Hydrology, College of Natural Resources and Environment, Virginia Tech University

Daniel L. McLaughlin, Associate Professor of Hydrology, Department of Forest Resources & Environmental Conservation, Virginia Tech University

Diego Riveros-Iregui, Associate Professor of Watershed Hydrology, Department of Geography, University of North Carolina at Chapel Hill

Ryan Emanuel, Associate Professor of Hydrology, Nicholas School of the Environment, Duke University

Matt Cohen, Professor of Water Resources, School of Forest, Fisheries and Geomatics Sciences, University of Florida

Chris Anderson, Professor of Wetland Science, College of Forestry, Wildlife and Environment, Auburn University

Courtney Siegert, Associate Professor of Hydrology, College of Forest Resources, Mississippi State University

Luke Pangle, Associate Professor of Hydrology, Dept. of Geosciences, Georgia State University

James Reichard, Professor of Hydrogeology, Department of Geology and Geography, Georgia Southern University

Todd Rasmussen, Professor of Hydrology, Warnell School of Forestry and Natural Resources, University of Georgia

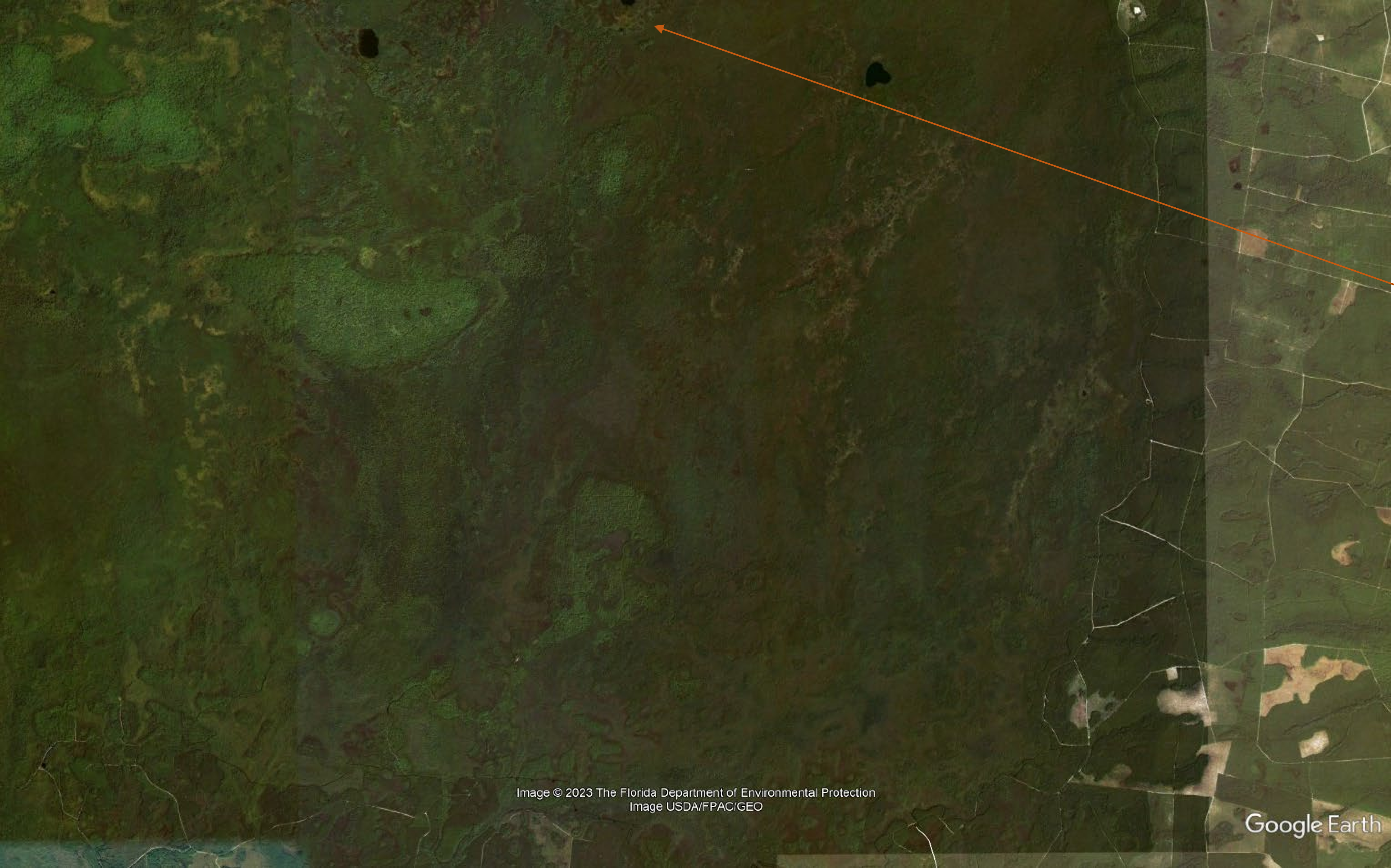
Temporal Dynamics of Okefenokee Swamp Wetness and Vegetative Condition, **Southeastern Corner of the Swamp nearest proposed TPM LLC mine**; Nine satellite images spanning 2005-2021

Illustrated with Google Earth Satellite imagery. Eye altitude between 10.5 and 10.9 mi.

Vegetation dynamics and variations in greenness are caused by changes in weather, water levels, and fires. Fires occurred in this portion of the swamp in 2007, 2011, and 2017. Note there are very few areas of open water in this portion of the swamp. *The swamp is a wet matrix of peat, organic matter, and plants, and, sometimes it's not wet*.

Images from the years of large fires, 2007, 2011, and 2017 are noticeably browner and drier.

C. Rhett Jackson, March 8, 2023



8/18/05

Eye altitude 10.54mi

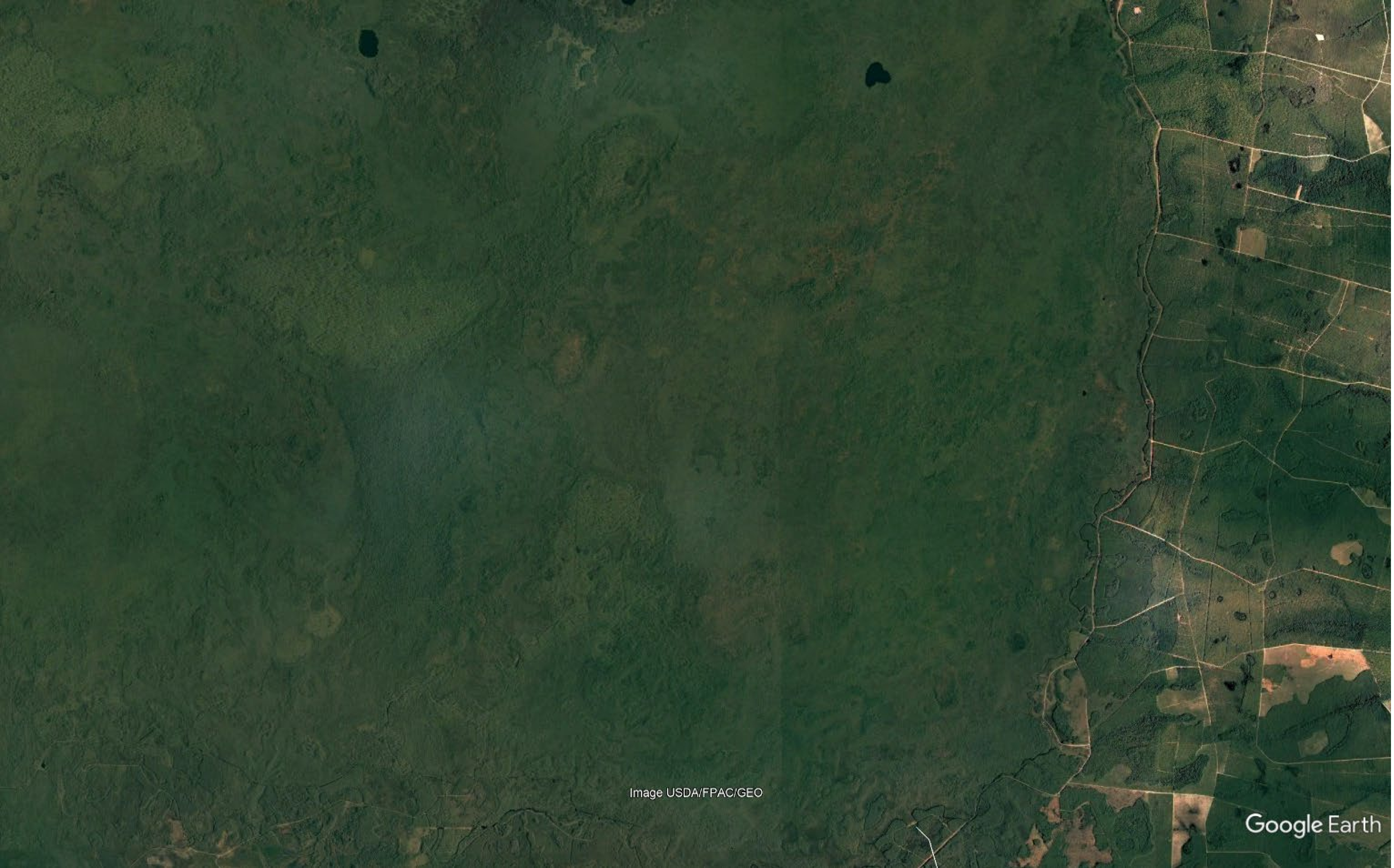
Monkey Lake

TPM LLC site

6/24/07

Fire year, this is 2 months after fire, which was patchy in this part of the swamp.

Eye altitude 10.54mi



6/24/09

Eye altitude 10.54mi

3/18/11

Fire year. This is 3 months before fire.

Eye altitude 10.54mi

3/27/13

Eye altitude 10.54mi

5/5/14

Eye altitude 10.63mi

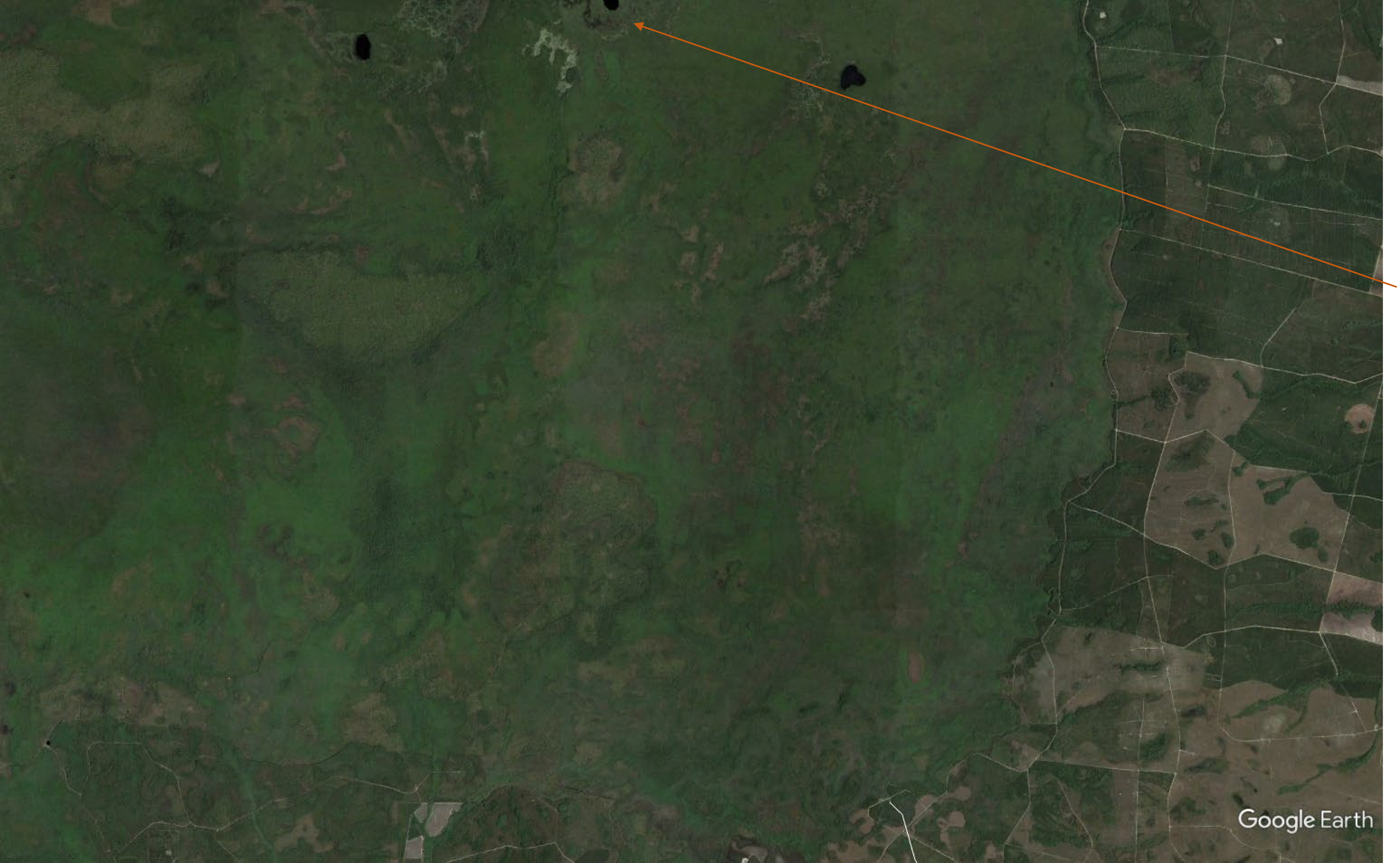
3/10/17

Fire year. One month before fire started.

Eye altitude 10.87 mi

3/6/18

Eye altitude 10.87 mi



4/12/21

Eye altitude 10.87 mi

Monkey Lake

TPM LLC site