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Hydrological Connectivity Between a Geographically Isolated Wetland and the Upper Floridan Aquifer

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HYDROLOGIC CONNECTIVITY BETWEEN A GEOGRAPHICALLY ISOLATED WETLAND AND THE UPPER FLORIDAN AQUIFER

A Thesis

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Abstract

The Upper Floridan Aquifer is the primary source of freshwater for the majority of the southeastern United States. Increased stress on the Upper Floridan Aquifer due to irrigation has resulted in questions about the sustainability of the aquifer. Baker County, Georgia, has a high density of geographically isolated wetlands and of center pivot irrigation wells that are used to meet the demand for irrigation water. These wetlands respond to changes in precipitation and evapotranspiration, in the water level in surface streams, and in the water level of the Upper Floridan Aquifer. Understanding how the response of the wetlands has changed over time will increase our understanding of the hydrologic connectivity of the wetlands to the Upper Floridan Aquifer. Using water levels recorded in monitoring wells in and near Pond 51 (P51), a wetland within the Jones Center at Ichauway, water level data from a nearby surface stream and from the upper Floridan Aquifer, and local precipitation data, the hydrologic connectivity P51 was investigated. Similarities between changes in water level in nearby stream, the wetland, and the upper Floridan aquifer suggest that these water bodies are connected across the hydrological landscape. In addition, the changes in the water level in the wetland exhibited the highest correlation with changes in the water level in the aquifer.

Introduction

In a hydrologically connected landscape, geographically isolated wetlands (GIWs) are nodes that store, receive, and transmit water throughout the landscape ((Cohen et al., 2016) (Figure 1)). An understanding of how GIWs respond to changes in precipitation and stream flow can reveal details about the temporal flow dynamics within a landscape. Investigation of temporal changes in flow behavior and in the stage of water in GIWs can expose anomalies that may be indicative of external stresses that are imposed on the hydrological landscape.

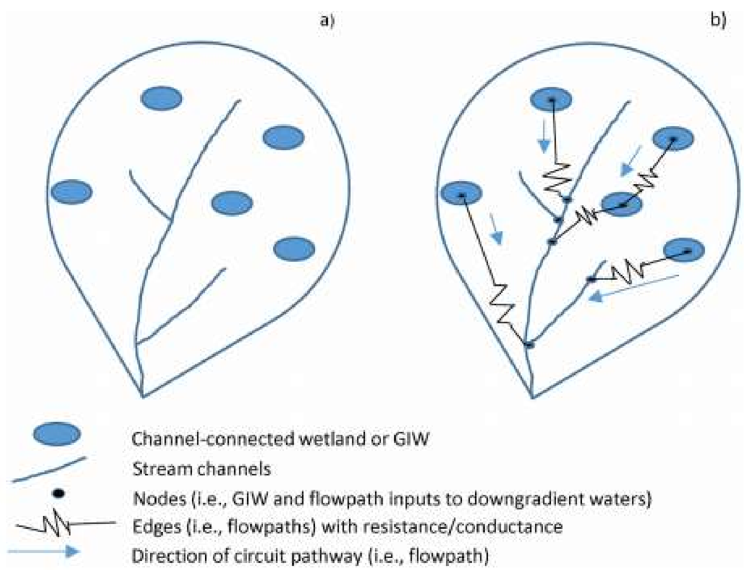

Figure 1. Conceptualized surficial flow dynamics of a watershed (panel a) and integration of GIWs and subsurface flow to the hydrologic network (panel b) (Rains and others 2016).

In karst regions, the role that groundwater plays in the hydrological landscape must be included as water-filled sinkholes (GIWs) are common in many notable karstic areas, such as the Mammoth Cave area in Kentucky (Brown, 1966), the Salem Plateau in Missouri (Harvey, 1981), and in the Dougherty Plain in Georgia (Gordon, 2011). In karst regions, the linkages between surface waters and groundwater are clear (White, 1988). However, Cohen and others

(2016) do not articulate the role of groundwater in maintaining hydrologic connectivity in a karstic landscape.

Blood and others (1997) noted three hydrologic behaviors between GIWs, groundwater, and precipitation. These behaviors were: 1) when the elevation of the groundwater in the Upper Floridan Aquifer was below 38 meter above sea level (m asl), the GIWs were dry; 2) when the elevation of the groundwater in the Upper Floridan Aquifer was above 41.5 m asl, the stage in the GIWs responded to changes in precipitation and evapotranspiration; and 3) when the elevation of the groundwater in the Upper Floridan Aquifer was between 38.0 and 41.5 m asl, the stage in GIWs was correlated with the elevation of the groundwater in the surrounding surficial aquifer and in the underlying Floridan Aquifer. This earlier work showed hydrologic connectivity between precipitation, groundwater, and GIWs; however, the connectivity to surface streams was not investigated. Blood and others (1997) also noted that “with the projected doubling of Floridan aquifer withdrawals in the next twenty years, special consideration should be given to the impacts that such withdrawals will have” on GIWs. The goals of this study are to document whether the projected increase of groundwater withdrawals occurred and to reassess the three hydrologic behaviors noted by Blood and others (1997) with a focus on the roles of surface water and of groundwater on controlling stage in the GIWs.

Study Area

The study area is the Jones Center, a 117 km^2 property in Baker County, Georgia, within the Dougherty Plain (Figure 2). The Jones Center is owned by the Robert W. Woodruff Foundation and is managed for ecological and conservation research and education. The Dougherty Plain is a mantled karst terrain within the southeastern U.S. Coastal Plain. The Dougherty Plain is relatively flat and is littered with dozens of GIWs (depressions surrounded by slightly elevated uplands) that likely formed as collapse features in the limestone (Martin et al., 2012) The unconsolidated mantle consists of white sand and reddish clay, between 0-30 meters (100 ft) thick, overlying the Ocala Limestone ((Beck, 1986) (Beck, 1984)). The karstic Ocala Limestone is the groundwater reservoir (artesian in many locations) that is the primary aquifer of the region (Fanning and Trent, 2009).

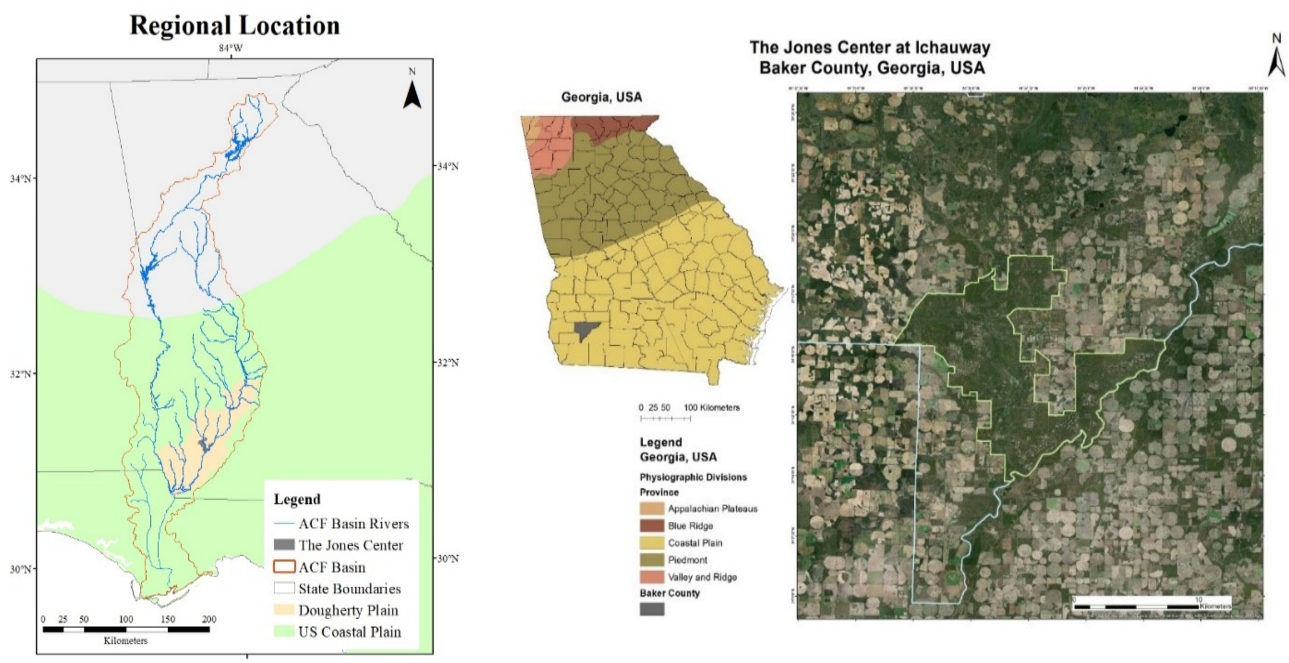

Figure 1. Map views of the ACF basin, Georgia, and a portion of Baker County showing the Jones Center. Credit: Joseph Honings.

The Jones Center is surrounded by farmland that makes up a vast portion of the southeastern coastal plain. Groundwater extraction via center pivot irrigation wells is widely practiced in the area (Figure 2). Withdrawals from the UFA in Baker County as of 2000 exceeded 38 million gallons per day (Marella, 2014). Surrounding counties of Mitchell, Decatur, and Miller counties also withdraw quantities of groundwater that are similar to the amount withdrawn in Baker County. Mitchell County withdrew 29 million gallons of water per day, Decatur County withdrew 50.52 million gallons per day, and Miller County reported 30.25 million gallons of water of water withdrawal per day in 2000 (Marella and Berndt 2005).

The Jones Center is on the thin and unconfined portion of the Floridan aquifer ((Miller, 1990)Miller, 1990). The karstic Ocala limestone is an Eocene aged carbonate rock that is the uppermost bedrock formation underlying the Dougherty Plain. Recharge to the UFA has been presumed to be from infiltration of precipitation through the overlying unconsolidated material and through sinkholes and swallets (Torak and Painter, 2006). The unconfined nature of the aquifer allows direct interaction between surface water and groundwater (Miller 1990). Thus, surface water throughout the Dougherty Plain is connected to the UFA allowing exchange between groundwater and surface water through sinkholes, springs, and other dissolution pathways (Opsahl et al., 2007). In addition, the secondary porosity of the Ocala limestone allows for connection between surface and groundwater resources in the region (Hicks et al., 1987). The most common examples of surficial and groundwater connectivity are the streams that are incised into and through the unconsolidated sediments resulting in swallets and the sinkholes that expose the underlying Ocala limestone (Hicks and others 1987).

The Jones Center and the Dougherty Plain contain dozens of GIWs that are key features for developing and sustaining the ecological diversity of the region and are home to various flora and fauna native to the area. One of the GIWs on the Jones Center's property that has been intensively monitored is P51 (Figure 3) thought to be a cover-subsidence sinkhole (Tihansky, 1999).

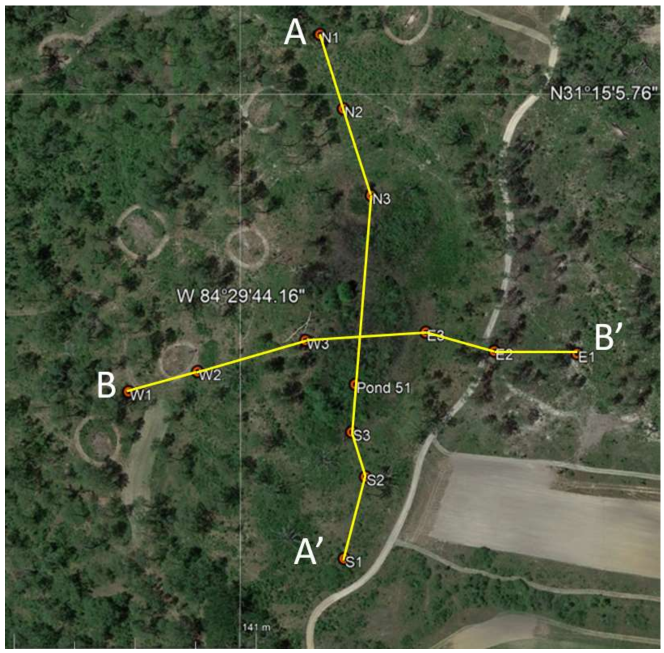

Figure 3. Aerial view of P51 area, showing locations of the piezometers. Additionally transects of cross sections A and B are included. Image courtesy of Google Earth.

As P51 exhibits a similar habit with many of the other GIWs found at the Jones Center, thus, P51 serves as a proxy to provide insight to the general structure of other GIWs at this location. From January 2006 until March 2016, P51 was the subject of a water level monitoring effort. Additionally, 12 piezometers were installed around P51, three in the North direction, three east, three west, and three south. The water levels in these piezometers were also monitored from January 2006 until March 2016.

Methods

Data Collection

Twelve piezometers are aligned along two transects surrounding P51 and another piezometer was in the deepest area of P51 (Figure 3). To investigate the connectivity of this mantled karstic landscape, the data that will be used were collected using an hourly sampling interval over a 10-year period from March 2006 to January 2016. [The data were collected using automatic data loggers, were archived at the Jones Center for future analysis, and were provided to the Wicks Research Group for this work.] In addition to the automatically collected data, physical measurements using a water level indicator were made by Jones Center scientists and recorded on several dates throughout the data collection period. These physical measurements provided data that could be used to calibrate the immense number of data collected by the automatic data loggers. In the physical measurements, a few of the readings were recorded as “dry”.

In addition, data from a nearby USGS groundwater well monitoring, USGS well 10H009, were accessed for the period July 1998 to May 2020. Another surficial element of the hydrological cycle is Ichawaynochaway Creek. USGS gaging site 02355350 is a stream monitoring site within the Jones Center property in close proximity to P51. Daily precipitation data were collected at USGS stream gauging station 02355350 that is within the Jones Center’s property. Data collected were stream gage data, including max gage height, average gage height, mean discharge, and precipitation on a daily basis.

Analysis

Preliminary assessment of the data from the date loggers revealed “flat spots”. These “flat spots” are inferred to be the response of the data loggers to dry conditions (in a sense “null readings”). This inference was supported by aligning the data from the physical measurements with the data from the data loggers. On dates when personnel recorded “dry conditions” in a piezometer, the data collected from these data loggers were removed from the dataset. Additionally, the lowest recorded values from the data loggers were also removed from the dataset. These steps were taken to reduce bias in the dataset.

Temporal changes in Pond 51, the 12 piezometers surrounding P51, the USGS well, precipitation data, and in the elevation of the surface stream were analyzed. Monthly averages of the data were investigated for seasonal trends (wet and dry periods) and annual trends. Piezometer levels in both wet, dry, and in between seasons were used to observe changes in the flow directions around P51. The averages of monthly data are used throughout the study and were plotted as contour plots and cross-sectional views.

Results and Discussion

Temporal changes in groundwater withdrawals

For the majority of the industries operating and for the people living in the southeastern United States, water is supplied by the pumping groundwater from the Floridan Aquifer. In 2000, daily withdrawals from the aquifer exceeded 4.02 billion gallons, making the Floridan Aquifer one of the most productive aquifers in the world (Marella, 2014). Nearly 2 billion gallons of water per day are withdrawn from irrigation wells that are used to support agriculture, livestock, and landscape management. From 1950 to 2000, a 500 percent increase in the amount of water withdrawn (from 90 million gallons per day in 1950 to 1,949 million gallons per day in 2000) was recorded, with irrigation being the main use and demand for water (Marella and Berndt 2005). Over 90 percent of this withdrawal comes from the uppermost portion of the Floridan aquifer, the UFA (Marella and Berndt 2005).

Temporal changes in groundwater-surface interactions

The water level data for P51 display both seasonal and long-term fluctuations (Table 1). The month with the highest average water level in P51 is April with an average elevation of 46.00 m above MSL, while the month with the lowest average water level in P51 is November with 45.37 m above sea level. These months are indicated as the wettest and driest months and were used to compare seasonal differences in the water levels in P51 and the surrounding piezometers. Using monthly data averaged over the course of data collection, 2006-2016, the wet and dry months observed in the data have been mapped to show a general overview of

hydraulic head in P51 and the surrounding wells (Table 1.Month to month averages of water level relative to mean sea level in P51. The green value represents the average wettest month, and the red value represents the average driest month to be used for comparison.).

Table 1.Month to month averages of water level relative to mean sea level in P51. The green value represents the average wettest month, and the red value represents the average driest month to be used for comparison.

Month	Average	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
January	**45.62**	-	45.48	45.40	45.74	45.95	45.26	45.19	45.26	46.12	46.02	45.75
February	**45.77**	-	45.71	45.61	45.75	46.23	45.59	45.22	45.69	46.13	46.05	-
March	**45.95**	-	45.75	45.85	45.83	46.21	45.71	45.56	46.37	46.22	46.06	-
April	46.00	-	45.66	45.81	46.50	46.06	45.71	45.54	46.29	46.40	46.00	-
May	**45.80**	45.36	45.37	45.53	46.33	46.04	45.43	45.45	46.12	46.47	45.87	-
June	**45.62**	45.19	45.19	45.21	46.14	45.80	45.19	45.36	46.05	46.32	45.78	-
July	**45.53**	45.19	45.19	45.19	45.93	45.52	45.19	45.19	46.25	46.08	45.61	-
August	**45.49**	45.19	45.24	45.35	45.73	45.32	45.19	45.19	46.42	45.81	45.42	-
September	**45.45**	45.19	45.20	45.65	45.57	45.20	45.19	45.19	46.47	45.63	45.22	-
October	**45.38**	45.19	45.19	45.43	45.50	45.19	45.19	45.19	46.26	45.53	45.17	-
November	45.37	45.24	45.19	45.37	45.44	45.19	45.19	45.19	46.10	45.45	45.36	-
December	**45.47**	45.25	45.22	45.64	45.72	45.19	45.19	45.21	46.09	45.70	45.53	-

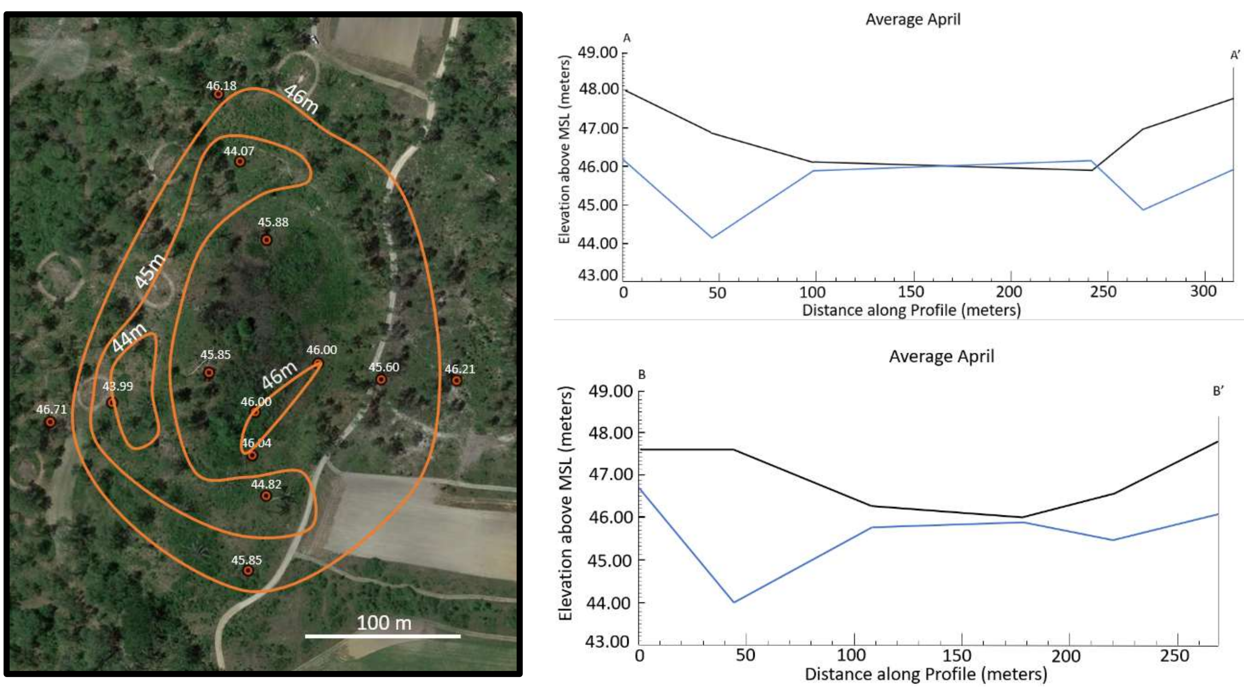

Figure 4. Contour map and cross sections of hydraulic head in P51, utilizing water levels from the average April (wet season) along with the elevation profiles of the transect (black) and the potentiometric surface (blue).

The overall trend of the P51 area in the wet season (April) shows water levels in the closest piezometers (N3, W3, S3, and E3) to be within 0.15 m of the water level in P51 (Figure 4). The center piezometers in each direction (N2, W2, S2, and E2) have the lowest observed water levels of the area in their respective directions and range from 0.12 m to ~2.0 m below the water level of P51. The distal piezometers (N1, W1, S1, and E1) display values that are generally higher than the water level observed in P51 with the exception of S1 that is 0.15 m below the average water level. During the wet season, the potentiometric surface has a saddled shape. The wet season displays water levels in P51 that are higher than the water levels in the wells in the surrounding area; potentially indicating that the wetland is recharging the nearby surficial water and underlying aquifer.

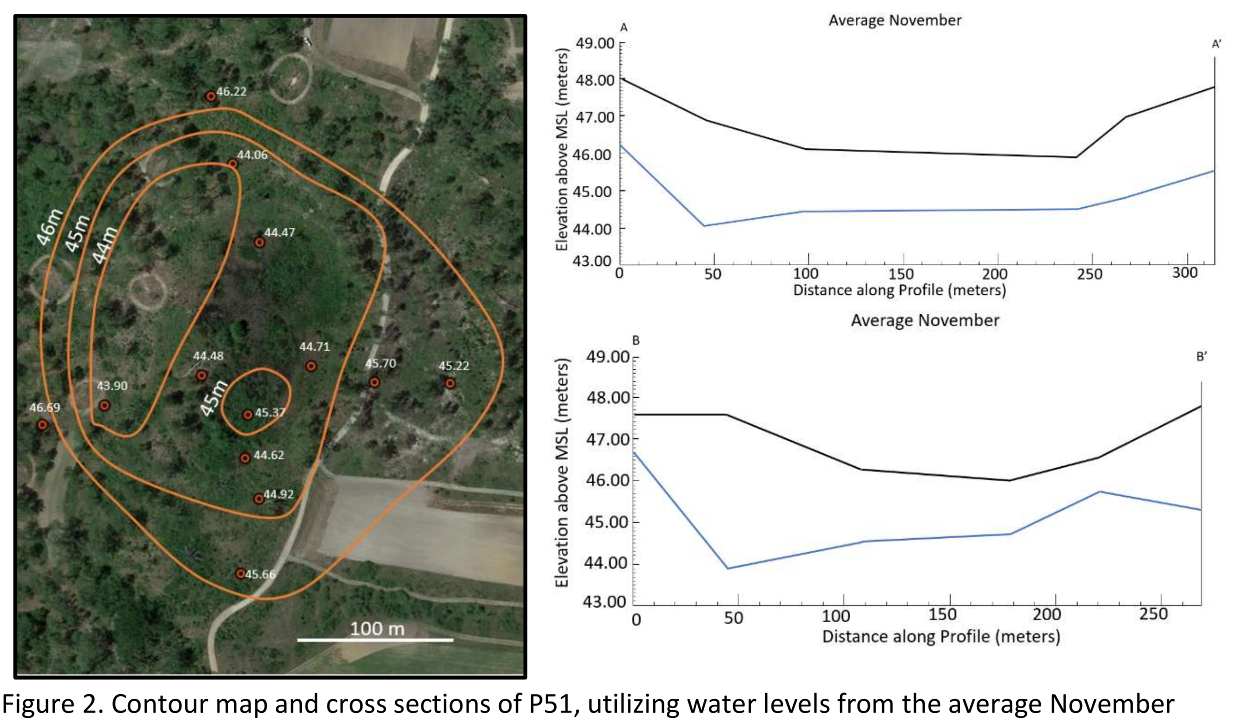

Figure 2. Contour map and cross sections of P51, utilizing water levels from the average November (dry season) along with the elevation profile of the transect (black) and the potentiometric surface (blue).

In the average dry season (November) the water level of P51 is ~45 m asl, 0.63 m lower than that observed in the average wet season (Figure 5). The proximal piezometers (N3, W3, S3, and E3) all display elevations lower than P51 ranging from 0.29 m to 0.9 m below P51. The central piezometers (N2, W2, S2, and E2) have variability in their difference to P51. N2 has a value 1.31 m below P51s water level, W2 has a water level 1.5 m above, S2 has a level 0.45 m below, and E2 has a value 0.33 m above P51. The potentiometric surface is lower during the dry period than during the wet period and the saddle-shape is not apparent. The lower water level in P51 during the dry season suggests that recharge of the wetlands by groundwater is unlikely during dry periods. Precipitation at the Jones Center fluctuations as does its availability for surface runoff or as a source of recharge to wetlands and the UFA and surficial water table (Figure 6).

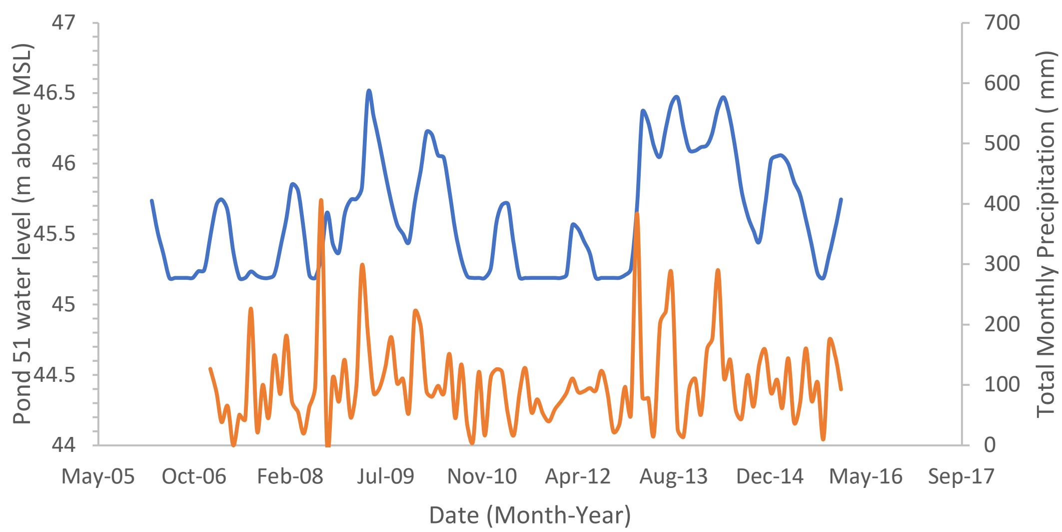

Figure 6. A comparison between P51's (blue) water level relative to mean sea level (MSL), and daily total precipitation recorded by a nearby rain gauge (orange).

Additional surface hydrological features are present in the Dougherty plain of southwest Georgia (Figure 7). At the Jones Center a tributary of the Flint River, Ichawaynochaway creek passes through the region and may potentially influence the hydrological landscape. USGS stream monitoring site 02355350 lies on the Jones Center property and monitors the stage and discharge of Ichawaynochaway Creek at this location. The relationship between the Jones Center wetlands and the nearby Ichawaynochaway creek is unclear and understanding any influence on one from the other may be important to understanding the hydrologic landscape as a whole. The data for site 02355350 collected by the USGS has been formatted to match the reference point for P51 and the UFA, meters above MSL. By plotting the changes in creek stage over time against the changes in P51's water level, there is possibility to uncover any relationship between the two. Comparing trends in the water level in P51 and the creek stage in Ichawaynochaway creek, it is visible that the creek, on average has a water level approximately 13 m lower than that of P51. Both P51's water level and the stage of Ichawaynochaway creek were on a linear upward trend from May 2006 to January 2016.

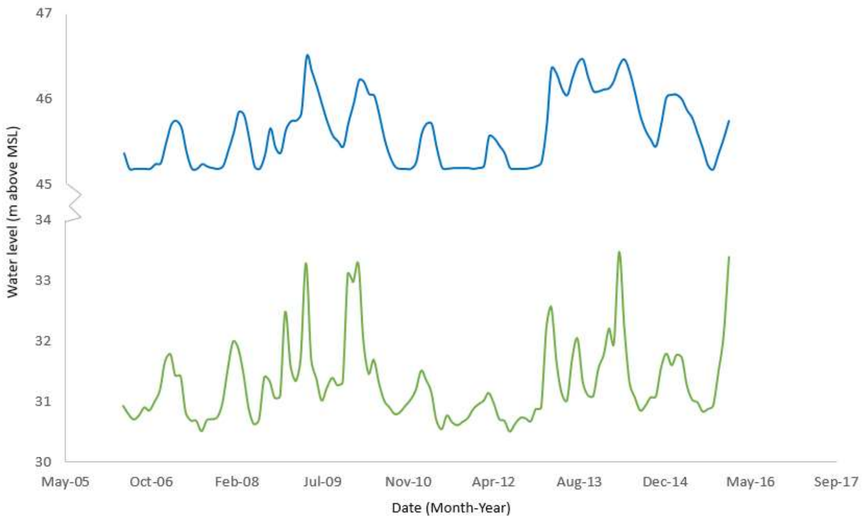

Figure 7. A comparison of water level between the creek stage observed in Ichawaynochaway Creek (green) and P51 (blue) over the duration of data collection.

Comparison to Blood and others (1997) work

Blood and others (1997) research on wetlands at the Jones Center indicated that the relation between the wetlands water levels and the water level in the UFA was the strongest. P51 may exhibit a similar relationship to the underlying aquifer, and it is worth investigating if this relationship is visible during the data collection period for this research (Figure 8).

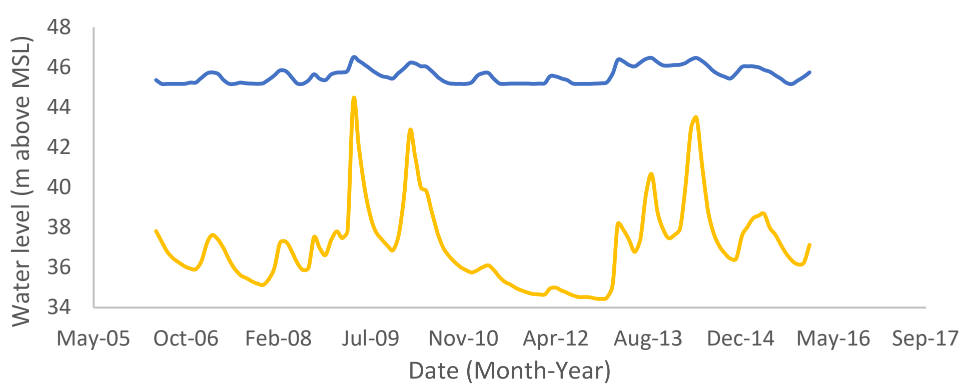

Figure 8. Plot of the water levels recorded in P51 (blue), and the UFA (yellow) relative to mean sea level MSL over the duration of data collection.

Quantifying the relationship between P51 and the other hydrological landscape elements at the Jones Center provides a more in depth look at potential causal relationships. Looking at cross plots between P51 and each of the three landscape elements discussed previously (precipitation, Floridan Aquifer, and Ichawaynochaway Creek) reveal real measurable correlations between these elements. The relations between the water level in P51 and in Ichawaynochaway Creek or the upper Floridan Aquifer or total precipitation had R^2 values of 0.39, 0.69, and 0.03, respectively (Figure 9).

Blood and others (1997) found that when the water level in the UFA dropped below 38m the wetlands at the Jones center were generally dry. In an effort to explore this distinction, a separate cross plot of the UFA and P51 was made where the data was broken into three groups with the level of water in the UFA being the defining parameters. The groups were: below 38 m, between 38 m and 41 m, and above 41 m. When looking at this data from this perspective, Blood and others (1997) observation of the wetlands being dry when UFA water level is below 38 m is visible in this data. In the below 38 m series, the majority of the data points have the water level in P51 to be at or near the indicated dry value. Additionally, the R^2 value, when the UFA water level is above 41 m asl has the highest R^2 value, 0.53. Blood and others (1997) found that the UFA water level was the single best indicator of wetland water level when the UFA water level was below 41.5 m asl, and precipitation-evapotranspiration above 41.5 m asl, the data used in this study show that linear correlation between P51 and the UFA is higher than precipitation at all values of the UFA water level. Blood and others (1997) observation of higher UFA water levels reflecting increased precipitation is visible here as well.

When segmenting the cross plots based on UFA water level, when the UFA was above 41m there is the highest correlation between P51 and precipitation (0.26).

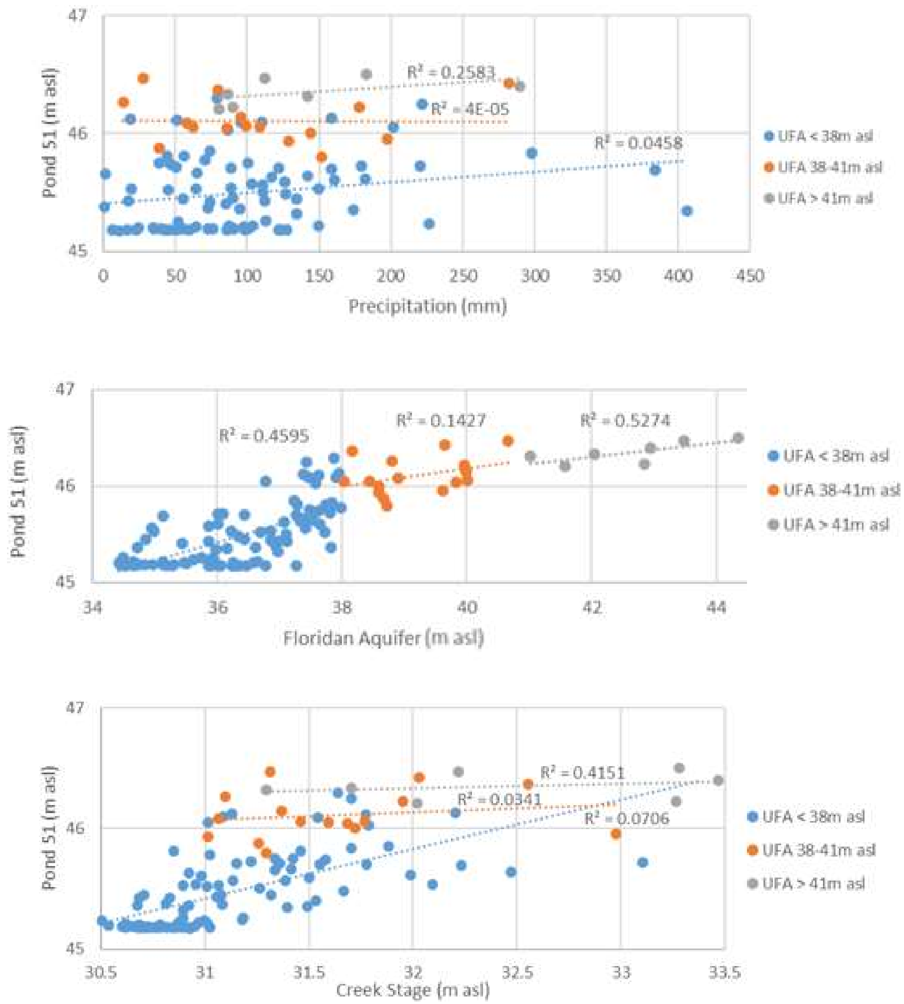

Figure 9. Cross plots displaying quantified correlation between P51 and, precipitation, the UFA, and Ichawaynochaway Creek.

Summary

The 2017 Census of agriculture county profile for Baker County[1], GA provides information on recent Floridan aquifer withdrawals from agricultural irrigation. The census indicates that as of 2017, 26,240 acres of farmland within Baker County are irrigated, with the primary source of water being the UFA. Of the acreage used for growing crops in Baker County, the primary crops are peanuts and cotton. Peanuts have a growth season generally from late March to August, and a coinciding irrigation season. Cotton crops in the Baker County area have a season from late April to early October. Blocking off a yearly season from April to October for the peak of irrigation may provide context to changes observed in the UFA and identify trends in P51. Overlaying the irrigation season for Baker County, GA's most widely cultivated crops on top of the data mentioned previously in this section (P51, Ichawaynochaway Creek, UFA, and precipitation) allows for visualization of the times the hydrologic landscape is under the most stress from anthropogenic influences (Figure 10).

[1] https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Georgia/index.php; accessed March 18 2022

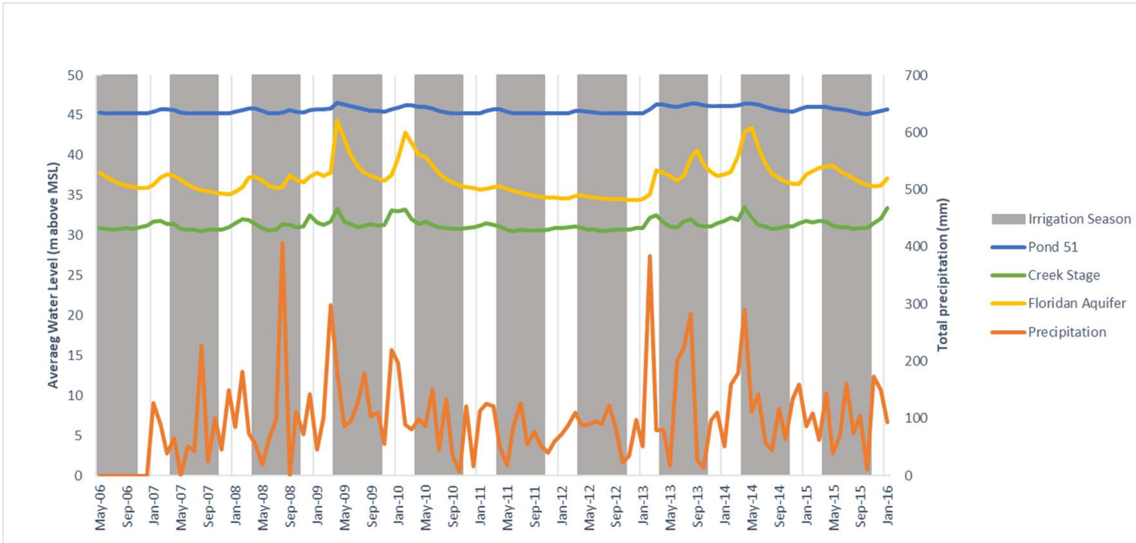

Figure 10. A combination plot showing the different potential influences on subsurface hydrology in the Jones Center and Dougherty plain region.

Conclusions

P51 and other similar wetlands at the Jones Center are perched. Similarities between water level trends in Ichawaynochaway creek, P51, and the UFA suggest that they are connected in the hydrological landscape. Similar to Blood and others (1997) this study found that the water level in the UFA is the most closely correlated element of the hydrological landscape to P51. The perched nature of P51 and the surrounding piezometer heads suggests that the pond itself is not a recharge zone (at least very quickly) but possibly that the cover collapse sinkhole that formed the depression is recharged outside of P51s perching. The disconnect between the lowest water level in P51 and the highest recorded water level in the UFA leads me to believe that P51 may recharge the Floridan aquifer but upward springing of the aquifer is highly unlikely. Springs in the banks of Ichawaynochaway creek suggest subsurface water flowing toward the creek and the deeper incision into the Ocala Limestone promotes a “path of least resistance” for subsurface water entering the UFA (visibly more correlation between creek stage and aquifer than pond and aquifer). Drastic changes in the Floridan Aquifer are much more subtle in P51s water level and temporal correlations between the two also reflect decreases in precipitation, the low relief in the area inhibits much surficial flow outside of the creek so precipitation is assumed to be the primary recharge mechanic. Ichawaynochaway creek’s water level more closely resembles the habit of the UFA and is more likely directly impacted by changes in the aquifer’s level. Ichawaynochaway creek provides faster recharge in higher amounts due to the incision through the residuum, however the inward flow of subsurface water into the wetlands more than likely contribute to recharge as well, smaller

amount of recharge, but with the over 120 wetlands in the Jones center property, these GIWs may play more of a role in Aquifer recharge than previously thought.

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Vita

Nicholas David Priehs, born in Port Huron, Michigan, studied at Grand Valley State University, where he received his bachelor's degree in geology. Following his time at Grand Valley State University, he enrolled in the Department of Geology and Geophysics at Louisiana State University to study geographically isolated wetland hydrology and anticipates graduate with his master's in geology in the spring of 2022. He currently works as a field geologist for Atlas in Novi, Michigan, where he is utilizing the skills acquired throughout his education for environmental remediation.