UTILIZING STABLE ISOTOPES (^{2}H, ^{18}O) AND RADIOCARBON (^{14}C) DATA TO BETTER UNDERSTAND THE HYDROGEOLOGIC FRAMEWORK OF THE FLORIDAN AQUIFER SYSTEM IN SOUTHWEST FLORIDA

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Date: 4/22/00

WS-21

Abstract

The hypothesis suggests that there may be vertical fractures and solution channels throughout the Floridan Aquifer System (FAS) that cause ground water from the upper and lower Floridan aquifers to interact with one another. The FAS is separated into three different hydrostratigraphic units, the upper Floridan aquifer, middle-confining unit, and the lower Floridan aquifer. This paper summarizes the hydrogeologic framework of the FAS underlying southwest Florida. Stable isotopes (^{2}H, ^{18}O) and uncorrected Radiocarbon (^{14}C) data were used to define two different water types within the FAS and the possible interaction between the two aquifers. The South Florida Water Management District (SFWMD) collected 42 samples from the Floridan aquifer at 16 sites. Plots of ^{2}H and ^{18}O were used to define the two different groundwaters that make up the FAS and to discover if there is any evidence of interaction between the two aquifers. Uncorrected ^{14}C data were used to verify the different groundwaters within the FAS by dating them and to show a generalized direction of flow in each hydrostratigraphic unit.

Introduction

1.1 Objective

A better understanding of the interaction of groundwaters is sought through the use of stable isotope (^{2}H, ^{18}O) and radiocarbon (^{14}C) data from the Floridan aquifer system of southwest Florida.

1.2 Location and Geomorphology of Study Area

The state of Florida is the above-sea-level part of a large peninsular landmass called the Floridan Plateau. The Plateau in south Florida is approximately 240 miles in width (Kohout, 1967). This platform is flanked on the west by abyssal depths greater than 12,000 feet in the Gulf of Mexico (Kohout, 1967). This platform is truncated on the east and south by the Florida Straits (Kohout, 1967). The study area is within the lower west coast region of south Florida, which includes Lee, Collier, Hendry and southern portions of Charlotte and Glades counties (Figure 1).

South Florida terrain is characterized by broad, flat, gently sloping and poorly drained topography (Klein et al, 1964). The topography of this area can be divided into two regions, the Immokalee Rise and the Big Cypress Swamp. These two features have not been appreciably affected by the deposition of post-Flandrian peat, lime mud, shell, or sand (White, 1970). The Immokalee Rise was built in Pamlico time as a submarine shoal that lies north of the Big Cypress Swamp, west of the Everglades and south of the Caloosahatchee Valley (White, 1970). The Big Cypress Swamp is a flat plain that slopes very gently to the south.

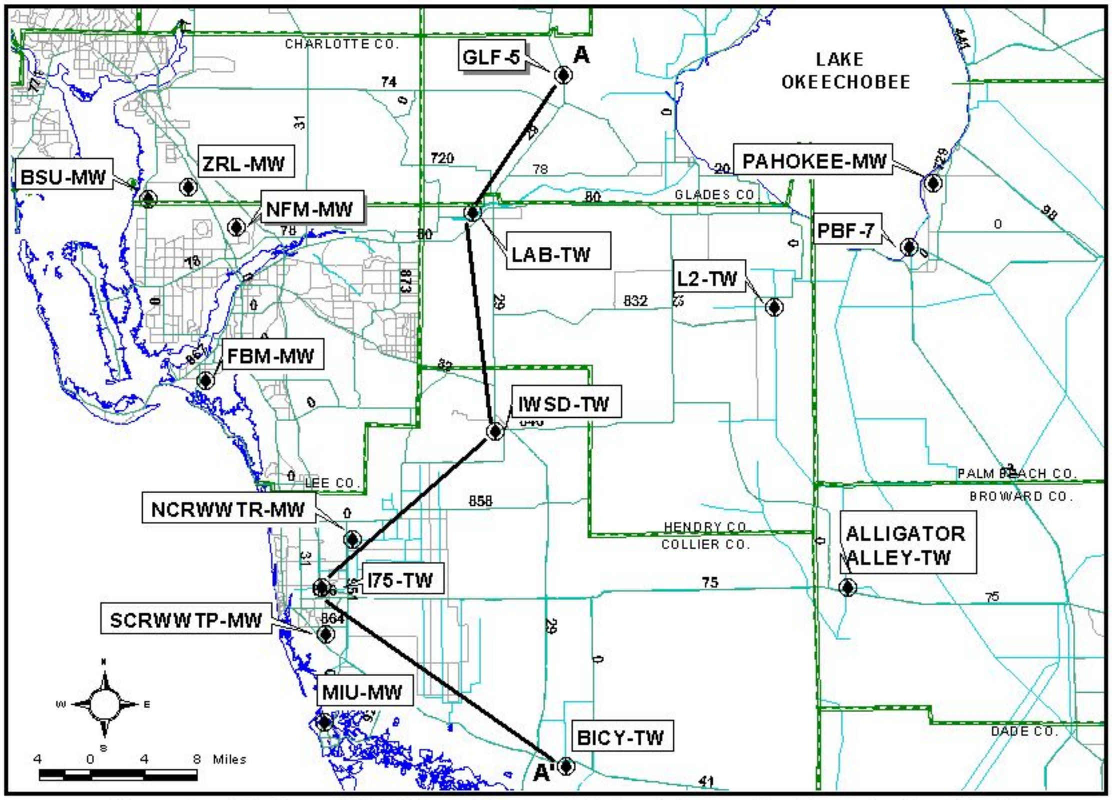

Figure 1. Site Map with Well Locations and Hydrostratographic Cross-Section (A - A')

The climate in this region is subtropical and the temperature rarely falls below freezing (White, 1970). This tropical climate that covers nearly all of southern Florida is referred to as a tropical savanna (savanna being a grassland with scattered trees) or tropical wet-and-dry climate (Henry et al, 1994). During the rainy season, conditions are similar to equatorial rainy climates, with frequent cloudy skies, warm temperatures, high humidity, and frequent afternoon thunderstorms (Henry et al, 1994). Conversely, during the dry season, conditions usually include abundant sunshine, much lower humidity, and often a lack of rain for several weeks or even months (Henry et al, 1994).

1.3 Well Descriptions

The stable isotope and radiocarbon data were obtained from eight Floridan aquifer system (FAS) test wells owned by the South Florida Water Management District (SFWMD) and eight FAS monitor wells operated by various Wastewater Treatment facilities within the review area. The location of these wells are shown on Figure 1.

Samples were collected at various depth intervals within the Floridan aquifer system. They were collected during open hole packer tests or from completed monitor wells. Appendix 1 lists the owners, well names, and intervals that the samples were collected from for this study.

2.0 Background

2.1. Hydrogeologic Framework

The Floridan Aquifer System is defined as a vertically continuous sequence of permeable carbonate rocks of Tertiary age that are hydraulically connected in varying degrees, and whose permeability is generally several orders of magnitude greater than that of the rocks that bound the system above and below (Miller, 1986). The Floridan aquifer in southwestern Florida is composed predominately of limestone with dolomitic limestone and dolomite. The Floridan aquifer system consists of the upper Floridan aquifer, middle confining unit, and lower Floridan aquifer. Table 1 shows the stratigraphic units and hydrostratigraghic designations for the Floridan aquifer system. Figure 2 shows a hydrostratigraphic cross-section from north to south (A – A', shown on Figure 1) with wells used in this study.

Table 1. Stratigraphic and Hydrogeologic Framework.

Series	**Stratigraphy**	**Hydrostratigraphy**	
Pleistocene/ Pliocene	Pamlico	Surficial Aquifer System	
	Ft. Thompson		
	Caloossahatchee		
	Tamiami		
Miocene	Hawthorn Group	Upper Confining Unit	
		Intermediate Aquifer System	
Oligocene	Suwannee Limestone/ Ocala Group	**Floridan Aquifer System**	Upper Floridan Aquifer
Eocene	Upper and Lower Avon Park		Middle Confining Unit
	Oldsmar Formation		Lower Floridan Aquifer
Paleocene	Cedar Keys Formation		Lower Confining Unit

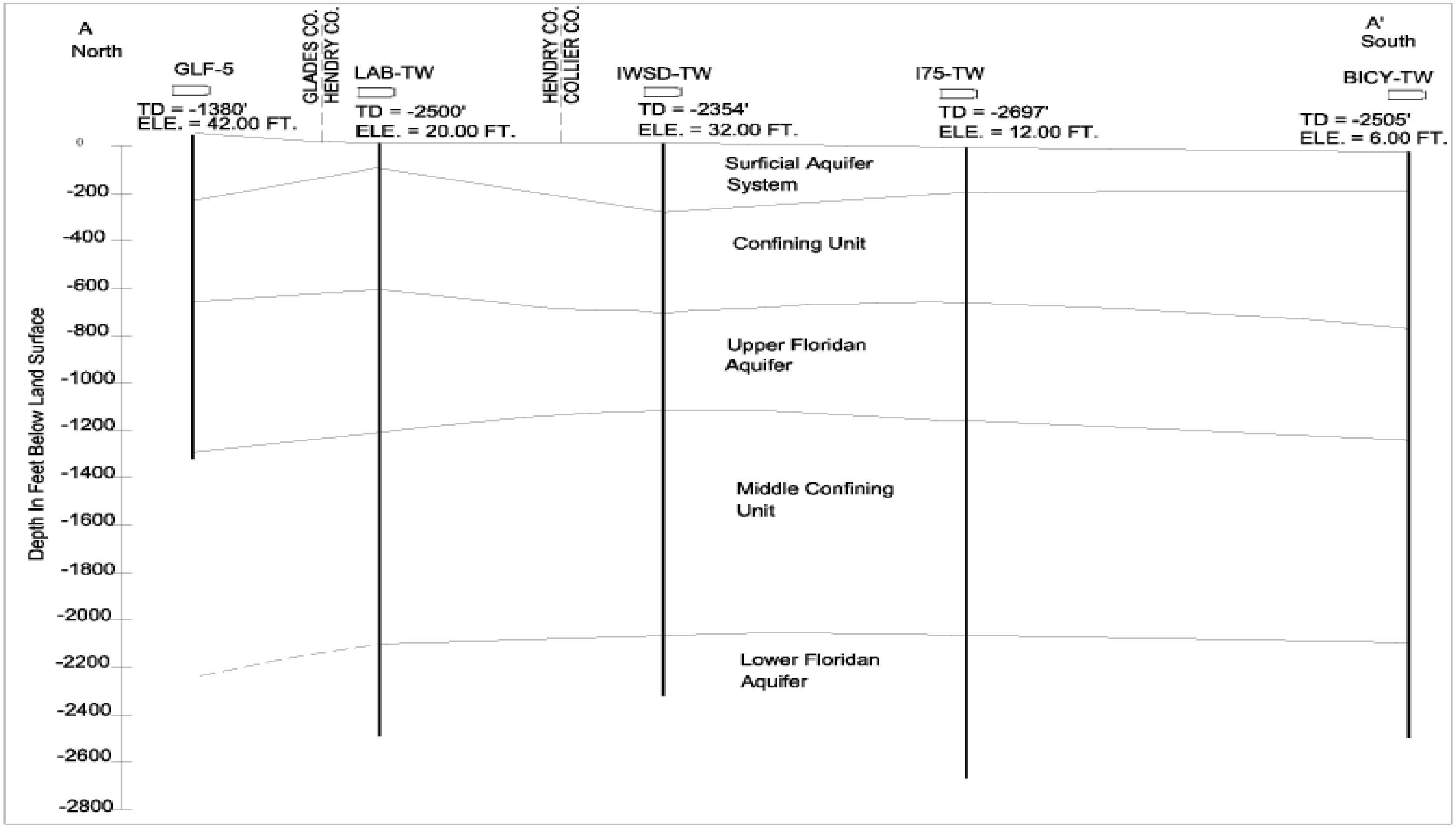

Figure 2. Hydrostratographic Cross-Section from A-A' through Southwestern Florida (Line of Cross-Section Shown in Figure 1.)

The upper Floridan aquifer in southwestern Florida chiefly consists of permeable zones in the lower Hawthorn Group, Suwannee Limestone, Ocala Group and the upper part of the Avon Park Formation. Generally the upper Floridan aquifer consists of several thin water-bearing zones of high permeability interlayered with thick zones of much lower permeability (Reese, 1994). The most transmissive permeable zone is found at the top of the upper Floridan aquifer and is associated with the unconformity at the top of the rocks of Eocene age (Reese, 1994). The lithologic and hydraulic properties of most of the rocks in the lower part of the upper Floridan aquifer are similar to those of the middle-confining unit of the Floridan aquifer system (Reese, 1994). The salinity and temperature of the upper Floridan aquifer generally increases with increasing depth. However, temperatures along the southeastern coast are lowest (about 70.0 ^{0}F) owing to heat transfer to the Atlantic Ocean (Straits of Florida) (Sproul, 1977) and (or) to heat transfer to cooler saltwater in the Lower Floridan aquifer (Kohout, 1965)

The middle-confining unit of the Floridan aquifer system consists chiefly of the lower part of the Avon Park Formation. The unit has relatively low permeability, and it generally separates the brackish ground water of the upper Floridan aquifer, from the ground water that closely resembles seawater in the lower Floridan aquifer (Meyer, 1989). Hydraulic connection between the upper and lower aquifer is inferred from sinkholes and fractures that transect the middle-confining unit (Kohout, 1965, 1967). Ground water movement in southern Florida is estimated to be primarily upward from the lower Floridan aquifer through the middle-confining unit, then horizontally toward the ocean through the Upper Floridan aquifer (Kohout, 1965, 1967). Salinity varies greatly at the top of the middle-confining unit as the upward moving saltwater is blended with seaward-flowing freshwater in the upper Floridan aquifer (Meyer, 1989).

The lower Floridan aquifer consists of the Oldsmar Formation and the upper part of the Cedar Keys Formation. Ground water in the lower Floridan aquifer is compared closely to the chemical nature of modern seawater. There are three permeable dolostones units within the lower Floridan aquifer that are separated by less permeable limestones (Meyer, 1989). The transmissivity of the lower dolostone (locally called the Boulder Zone; Miller, 1986) is slightly higher than the overlying dolostones (Meyer, 1989). The high permeability in the Boulder Zone is due to the cavernous porosity and extensive fracturing present (Reese, 1994). In southwestern Florida, drilling data suggests that the dolostones are hydraulically connected, although head data and aquifer tests to confirm this interpretation are lacking (Meyer, 1989). There is a pronounced temperature anomaly present in the lower Floridan aquifer; the geothermal gradient is reversed at a depth below 3,000 feet below sea level. Temperatures increase generally from the Straits of Florida inland toward the center of the Floridan Plateau (Meyer, 1989), and, as previously mentioned, Kohout (1965) hypothesized circulation of cold seawater inland from the Straits of Florida through the lower part of the Floridan aquifer system driven by geothermal heat flow. In this paper, data from the uppermost dolostone unit will be integrated.

2.2 Stable Isotopes and Radiocarbon

The analysis and interpretation of stable isotope data will improve the understanding of the regional ground water circulation patterns and geochemical process within the Floridan aquifer system. It can also help to better define ground water origin, subsurface residence time, flow rates, mixing process, as well as recharge and discharge areas. Stable isotope data often provides a strong complement to information gained from more traditional means of evaluation such as potentiometric head monitoring and ground water flow modeling. These data can be particularly useful because they provide additional criteria linking water chemistry with mineral mass transfer, which can ultimately be used to better understand the geochemical processes within the Floridan aquifer system.

Deuterium (^{2}H) and oxygen-18 (^{18}O) are two stable isotopes commonly used in hydrologic studies. These stable isotopes do not undergo radioactive decay, but because of the difference in mass between them and the more common isotopes of their respective elements, protium (^{1}H) and oxygen-16 (^{16}O), they react differently with other atoms and molecules as they move through the hydrologic system (Swancar and Hutchinson, 1992). The higher mass of ^{2}H and ^{18}O causes them to bond more tightly in molecules (including water), thus requiring more energy to break the bonds when these molecules participate in chemical reactions (Swancar and Hutchinson, 1992). Consequently, these two isotopes become enriched in the reactants of chemical reactions requiring higher energy levels (Swancar and Hutchinson, 1992).

Mixing within regional groundwater flow systems has the effect of averaging the isotopic composition of ^{2}H and ^{18}O in various groundwaters from different recharge environments. The isotopic composition of deep or well-mixed groundwater in such cases converges on the mean weighted value of all recharge contributions (Clark and Fritz, 1997). Such regional scale mixing can be observed in deep groundwater as well as in shallow but confined systems with a long subsurface flowpath (Clark and Fritz, 1997). In such cases, stable isotopes are used as indicators of regional flow rather than to identify discrete areas of recharge (Clark and Fritz, 1997). Stable isotopes in this study, such as oxygen and hydrogen ratios are used to indicate local recharge as well as to date the groundwater.

Carbon-14 (^{14}C) has a half-life of 5,730 years, making it a useful tool for dating waters as old as 50,000 years. There are some complications in the behavior of ^{14}C during recharge, so the “absolute” age of groundwater cannot be determined reliably (Drever, 1997). Although, if the ^{14}C concentration is measured at several points along a flow line within an aquifer, the differences in age between the points and the flow velocity can then be determined (Drever, 1997). There are some other complications within the Floridan aquifer system for the dating of groundwaters. This may be do to the presence of vertical fractures and dissolution channels that could cause the ascent of deep-seated brines mixing with the groundwaters of a different origin. Also, the dissolution of carbonate minerals may add no detectable ^{14}C (dead carbon) to the water, giving it an inaccurate old age (Drever, 1997). The contribution of the stable carbon ratio $^{13}C/^{12}C$ is a good potential tracer and is used in determining more accurate ^{14}C dates within the Floridan aquifer (Drever, 1997). Uncorrected ^{14}C will be used to help determine the age of the groundwaters, where the groundwaters may be originating and suggested flowpaths within each hydrostratigraphic unit.

3.0 Previous Investigations

Numerous regional and local aspects in hydrogeology of the Floridan aquifer system in southern Florida have been reported. Applin (1944) wrote a paper on regional subsurface stratigraphy and structure of Florida and southern Georgia. Applin (1944) used geologic and paleontologic data to delineate structural and lithologic controls within the Floridan aquifer system. Kohout (1965, 1967) hypothesized the cyclic flow of salt water related to geothermal heating in the Floridan aquifer. He suggested that cold, dense seawater flows inland through the cavernous dolomite in the deep part of the aquifer, where it becomes progressively heated by geothermal heat flow. The reduction in density produces an upward convective circulation which brings seawater into contact with freshwater. Stringfield (1966) reports on the Tertiary Limestone of the southeastern United States concerning their stratigraphy and water bearing properties. Meyer (1971, 1974, and 1989) used geologic, isotopic and hydraulic data to describe the hydrogeology and the flow characteristics in the Floridan aquifer system of southern Florida. Thayer and Miller (1984) analyzed the stratigraphy and petrology of core samples in central Florida. This study aided them in determining the origin of pore systems, the effects of diagenesis and dolomitization on porosity and permeability within the Floridan aquifer system. The diluted salt water flows seaward and discharges out through the upper part of the aquifer. Reese (1994 and 1998) studied the vertical variations in water quality (salinity) in the Floridan aquifer system and related these variations in water quality to the local hydrogeologic framework of southern Florida.

There have also been Ph.D. dissertations completed on the structure, lithologic, and diagenetic controls of the Floridan aquifer system. The investigations helped in defining origins for the formations and what sort of structural and lithological features control flow in the Floridan aquifers system. Cander (1991), Hammes (1992), and Missimer (1997) are some that have completed dissertations on these subjects.

The use of isotopes as tracers in studies of groundwater movement in the Floridan aquifer system began in the early 1960's (Meyer, 1989). These studies began with estimates of groundwater velocities using ^{14}C in the upper part of the aquifer system in central Florida by Hanshaw and others (1965). Plummer (1977) in the same area, examined transient changes in water chemistry in relation to the earlier ^{14}C ages, and new ages (slightly younger) were assigned to Hanshaw samples on the basis of mass-transfer reaction coefficients. Hanshaw and Back (1971), in studies of the origin of dolomite in the Floridan aquifer system, used stable isotopes (^{13}C, ^{18}O) to distinguish between marine (primary) dolomite and nonmarine (stoichiometric) dolomite. Meyer (1989) analyzed naturally occurring isotopes of carbon, oxygen, and uranium in south Florida to assess their potential as tracers of groundwater movement within the Florida aquifer system.

Other investigations have been done using naturally occurring uranium isotopes as tracers of groundwater movement in the Floridan aquifer system. These studies began in the early 1960's using the alpha-activity ratio of $^{234}U/^{238}U$ and uranium concentrations to infer circulation patterns. These investigations were done by Kaufman et al (1969), Osmond et al (1974), Osmond and Cowart (1977), and Cowart et al (1978).

4.0 Methodology

4.1 Data Collection

In order to evaluate if there is interaction between the upper and lower Floridan aquifers, the South Florida Water Management District (SFWMD) collected 42 samples from the Floridan aquifer at 16 sites. These samples were obtained from 8 Floridan aquifer system (FAS) test wells owned by the SFWMD and 8 FAS monitor wells operated by various Wastewater Treatment facilities within the review area. They were collected during open hole packer tests or from completed monitor wells. Figure 1 shows the sample locations and Appendix 1 lists the owners and sample depths. Some wells had more than one sample taken from different intervals within the same hydrostratigraphic association. Averages were taken from these samples where this occurred and are designated in Appendix 1. All monitor wells and packer intervals were purged until three bore volumes had been evacuated, or until the water chemistry stabilized as indicated by temperature, pH, and specific conductance measurements.

These samples were collected in two-liter nalgene bottles and sent to the Environmental Isotope laboratory at the University of Waterloo (Ontario, Canada) for stable isotope analysis (^{2}H, ^{18}O, and ^{13}C). All ^{14}C results were determined by Rafters Radiocarbon laboratory at the Institute of Geologic and Nuclear Sciences (New Zealand) by tandem accelerator mass spectrometry.

4.2 Analysis and Reporting

Deuterium (^{2}H) determinations were performed on hydrogen gas produced from water reduced on hot Manganese using the procedures outlined by Coleman et al (1982) and Drimmie (1991). A short narrative of the procedure is provided as follows. A sample is introduced to the evacuated reaction vessel containing prepared manganese. The water is frozen and the vessel re-evacuated. The vessel is heated to 512 degrees C which releases hydrogen of identical isotope concentration to that of the original water. The precision for this technique should be +/- 2.0 per mille. Saline groundwater samples (conductivity 10,000 micro mho) must be distilled to dryness at a minimum of 250 degrees C or separated by Azeotropic distillation before analysis for deuterium.

Results were then recorded and standard corrections using the international reference materials V-SMOW (Vienna Standard Mean Ocean Water and SLAP (Standard Light Antarctic Precipitation) from the International Atomic Energy Agency. The reporting of the hydrogen ratio in natural water is as follows:

Del ^{2}H per mill = $[(R_{\text{Sample}} – R_{\text{SMOW}} / R_{\text{SMOW}}] \times 1000\ ^{o}/_{00}$

Where R= ^{2}H/^{1}H ratio and SMOW (standard mean ocean water) is the referenced standard.

Oxygen (^{18}O) values were determined by CO_2 equilibration using standard procedures outlined by Epstein and Mayeda (1953) and Fritz (1987). A short narrative of the procedure is as follows. The standard procedures for oxygen isotopes entails equilibration of CO_2 with water in a temperature controlled bath, with continuous shaking for a minimum of 3 hours but should be carried out overnight. A minimum of 60 hours is required for brines that are prepared in special vessels with manual stopcocks. Preparation and extraction of the CO_2 (Moser, 1977) shall be done on a fully automated system attached to a VG MM 903 mass-spectrometer.

Quality control was maintained by placing the lab water standard (de-ionized water kept in stock bottle and calibrated to VSMOW and SLAP) at the beginning of each rack and at the end of the run. Standard corrections will then be performed based on the current laboratory/VSMOW/SLAP calibration.

Results were recorded and standard corrections using the international reference materials V-SMOW (Vienna Standard Mean Ocean Water) and SLAP (Standard Light Antarctic Precipitation) from the International Atomic Energy Agency. The reporting of the stable oxygen ratio in natural water is as follows:

Del ^{18}O per mill = $[(R_{\text{Sample}} – R_{\text{SMOW}})/R_{\text{ SMOW}} \times 1000\ ^{o}/_{00}$

Where R = ^{18}O/^{16}O ratio and SMOW (standard mean ocean water) is the referenced standard.

Carbon (^{13}C**)** determinations were performed on carbon dioxide produced from dissolved inorganic carbon (DIC) treated with phosphoric acid using methods described by Drimmie et al (1990). A short narrative of the procedure is as follows. From dissolved inorganic carbon (DIC) is performed by treatment with phosphoric acid (H_3PO_4) for ^{13}C (by mass spectrometry) and/or ^{14}C (by tandem accelerator mass spectrometry) isotope analysis. This system may also be used for converting carbonates to CO_2 (^{13}C only).

Water samples were acidified under vacuum and the released CO_2 will be purified using cold distillation. The CO_2 was then transferred into mass spectrometric vessels and analyzed on a MM-903, PRISM, or equivalent for d^{13}C DIC with respect to PDB. For carbon-13 DIC analyses, there are no international water standards available therefore; the mass spectrometers will be calibrated using IAEA and NIST primary carbonate standards. The reporting of the carbon ratio in natural water is as follows:

Del ^{13}C per mill = $[(R_{Sample} - R_{PDB})/R_{PDB}] \times 1000\ ^{o}/_{00}$

Where R = $^{13}C/^{12}C$ ratio and the standard is the carbon isotope ratio derived from the CO_2 liberated from belemenite of the Coastal Plain Cretaceous Peedee Formation of South Carolina.

The activity of "modern carbon" is defined as 95 % of the ^{14}C in the 1950 NBS oxalic acid standard. Del ^{14}C is defined as the relative difference between the absolute standard activity and the sample activity correct for age.

Del $^{14}C = (A_s/A_{abs} - 1) * 1000\ ^{o}/_{00}$

Where A_s is the activity of the sample and A_{abs} is the activity of the standard.

The conventional radiocarbon age (C^{14} Age) is calculated in the following manner: $t = -8033 \ln (A_{sn}/A_{on})$

Where A_{sn} is the normalized sample activity and A_{on} is the normalized oxalic acid activity (count rate).

4.3 Results

Appendix 2 lists the analytical results. The analytical results were compiled, reviewed and interpreted as follows:

Plots of ^2H and ^{18}O (Figure 3) indicate two different types of water within the Floridan aquifer system; this is consistent with findings in previous studies (Meyer, 1989; Swancar and Hutchinson, 1992). The lower Floridan aquifer values plot close to 0.0 $^{0}/_{00}$, which indicates the isotope composition of ocean water. The isotopically heavier values may also suggest that the source of the lower Floridan aquifer is ocean water migrating in from the Straits of Florida. The upper Floridan aquifer values are isotopically lighter than ocean water. These values, shown in

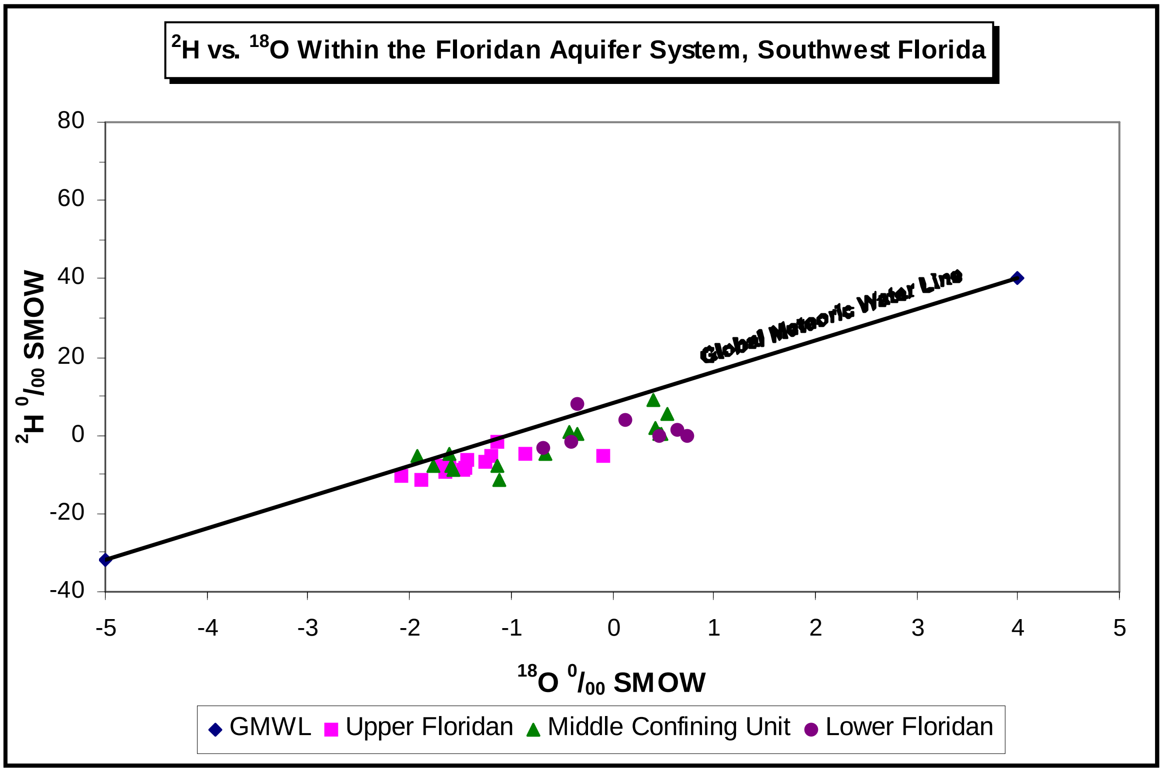

Figure 3. Floridan Aquifer System ^{2}H-^{18}O stable isotope compositions plotted with the Global Meteoric Water Line (GMWL). See sample locations in Figure 1.

Figure 3, parallel the Global Meteoric Water Line (GMWL), which suggest the source of the water is precipitation from recharge areas in central Florida. The stable isotope composition of the middle-confining unit, as shown on Figure 3, is distributed more or less evenly among isotopically light and heavy values that fall along the GMWL. This may suggest the evidence of interaction between the upper and lower Floridan aquifers, within the middle-confining unit. This could also support Kohout's (1965) theory of "cyclic flow" or to the presence of vertical fractures and solution channels throughout the Floridan aquifer system.

Uncorrected ages of ^{14}C are posted beside the sampling locations as shown on Figures 4,6, and 8. Contouring, using the kriging method was applied to suggest a direction of flow within the Floridan aquifer system. Figures 5, 7, and 9 show potentiometric head data (collected Nov-1998) posted beside SFWMD monitor wells to give support to the ^{14}C findings. Potentiometric head data was contoured using the kriging method to suggest a direction of flow within each unit. The direction of flow may not be entirely accurate, due to the spatial distribution and the limited amount of data within the southwest Florida region. Uncorrected values of ^{14}C were used in this study, resulting in age values varying by + or – 10,000 years.

Upper Floridan Aquifer

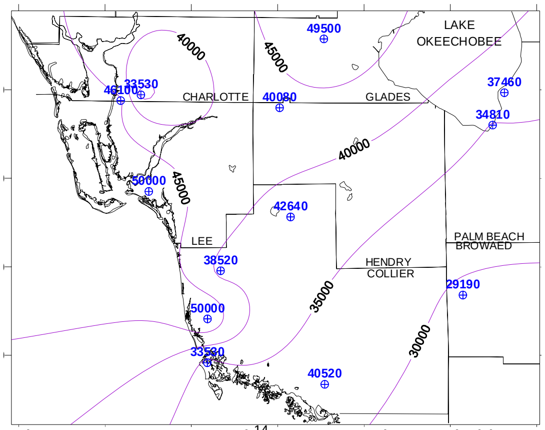

Figure 4. Uncorrectected ^{14}C ages, southwest Florida.

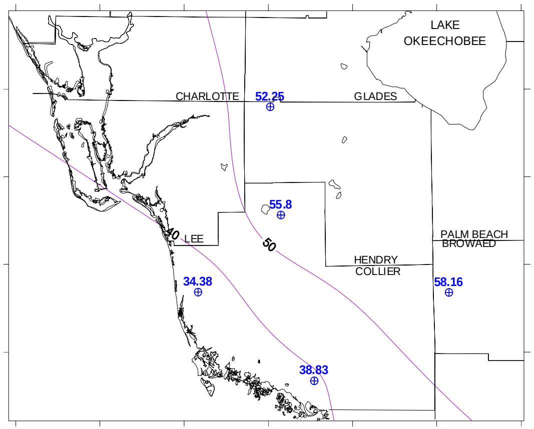

Figure 5. Head data and potentiometric surface, southwest Florida.

Middle-Confining Unit

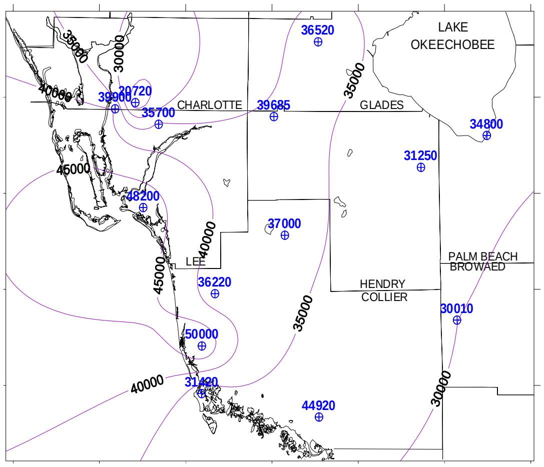

Figure 6. Uncorrectected ^{14}C ages, southwest Florida.

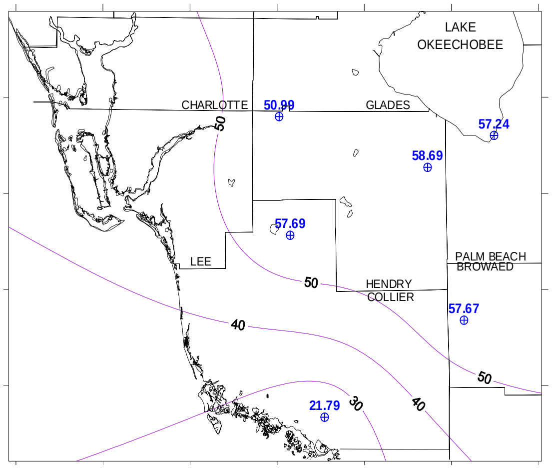

Figure 7. Head data and potentiometric surface, southwest Florida.

Lower Floridan Aquifer

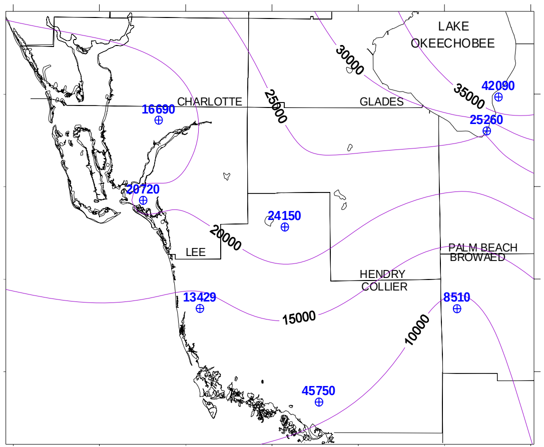

Figure 8. Uncorrectected ^{14}C ages, southwest Florida.

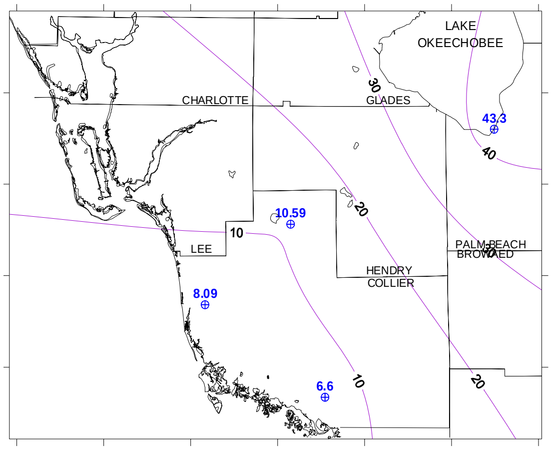

Figure 9. Head data and potentiometric surface, southwest Florida.

The upper Floridan aquifer, middle-confining unit, and lower Floridan aquifer are all shown individually to depict a better representation of the age and the suggested direction of flow within each hydrostratigraphic unit.

The upper Floridan aquifer, as seen in Figure 4, shows the age of the groundwaters increasing in a west-northwest direction. This may suggest a flow direction out into the Gulf of Mexico. The potentiometric head data (Figure 5) suggests a flow direction to the west-southwest direction. The slight shift in direction between these two figures may be due to the limited data available, although both figures still show a general flow direction out into the Gulf of Mexico. Kohout (1965) also indicates flow towards the Gulf of Mexico in this region. Kohout theorized that the lower Floridan groundwaters are migrating in from the Straits of Florida and being driven up by geothermal heat into the upper Floridan aquifer, then out to the Gulf of Mexico in this region. Cowart et al (1978), and Meyer (1989) support Kohout's theory on "cyclic flow" and suggest the same direction of flow on their analysis of the upper Floridan aquifer using stable isotopes and radiocarbon data. Kaufmann and Bennett, on their paper titled "^{14}C Activity and Cyclic Flow in the Floridan Aquifer" (in review), offer a different theory based on radiocarbon data. In their paper, it is suggested that the age range of the upper Floridan aquifer correlates with low sea level stands during the last Ice Age, which may have ameliorated or induced aquifer recharge from precipitation.

As shown by the values on Figure 6, the groundwaters of the middle-confining unit show slightly younger ages than the upper Floridan aquifer. The ^{14}C ages in the middle-confining unit suggest the same direction of flow as the upper Floridan aquifer. The potentiometric head data (Figure 7) suggest the same direction of flow as Figure 5 in the upper Floridan aquifer. The middle-confining unit data suggest a general flow direction out into the Gulf of Mexico. The limited data available in this region may cause the slight shift in flow direction between Figures 6 and 7. This general flow pattern is supported by Kohout's (1965) theory of water entering the Floridan aquifer system from the east through the Straits of Florida and migrating west out into the Gulf of Mexico.

The lower Floridan aquifer, as suggested on Figure 8, has the youngest groundwater ages of all three hydrostratigraphic units. The general direction of flow appears to be towards the west, with waters moving into the lower Floridan aquifer from the east-northeast and south through the Straits of Florida. The potentiometric head data (Figure 9) suggests a general flow direction to the west with water originating from the east-northeast. Water migrating into the lower Floridan aquifer from the south (Figure 8), through the Straits of Florida is not supported by previous studies. Kohout (1965), Cowart et al (1978), and Meyer (1989) all suggest ocean water moving into the Straits of Florida from the east and migrating generally to the west, as suggested in Figure 9. The ^{14}C data in this study does suggest ocean water to be migrating in from the south; however more data would be required to confirm this. One possible explanation for an influx of ocean water from the south into the lower Floridan aquifer could be related to the location of this study area on the Floridan Plateau. The Floridan Plateau axis parallels southwest Florida west from the shoreline in the Gulf of Mexico, and the Straits of Florida truncates the plateau to the south of the study area, just off the shore of the Florida Keys. This region, being closely located to the Florida Keys, could allow younger ocean waters to migrate into the lower Floridan aquifer from the south.

5.0 Summary

This paper presents a hypothesis that there may be vertical fractures and solution channels throughout the Floridan aquifer system (FAS) that causes ground water from the upper and lower Floridan aquifers to interact with one another. Stable isotopes (^{2}H, ^{18}O) and radiocarbon (^{14}C) data was used to help better understand the complexity of the FAS.

Stable isotopes (^{2}H, ^{18}O) and radiocarbon data were used in this study to determine if there are two different bodies of water and to show if there is evidence of interaction between these two different groundwater systems. The ^{2}H and ^{18}O plots do show evidence of two different bodies of water within the FAS and may suggest interaction in some parts of this region between the upper and lower Floridan groundwaters. Radiocarbon (^{14}C) data was applied in this study to show the ages of the groundwaters and the generalized direction of flow in the three hydrostratigraphic units. The uncorrected ages of ^{14}C data does show evidence of two different groundwaters in the FAS and the data may suggest a generalized direction of flow within each unit. Because of the spatial distribution and limited data in southwest Florida these findings might not be entirely accurate. In time, we may have a better understanding of the FAS in southwest Florida do to additional research being conducted by government, state and local agencies.

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APPENDICES

Appendix 1.

OWNER	WELL NAME	MONITORING INTERVALS DEPTH FT. (bls.)	HYDROSTRATIGRAPHIC ASSOCIATION
SFWMD	L2-PW1	1400-1810	Middle Confining Unit
SFWMD	I75-TW	2300-2350	Lower Floridan Aquifer
SFWMD	IWSD-TW (Avg.)	790-910, 1065-1165	Upper Floridan Aquifer
SFWMD	IWSD-TW	1700-1880	Middle Confining Unit
SFWMD	IWSD-TW	2100-2354	Lower Floridan Aquifer
SFWMD	LAB-TW (Avg.)	670-840, 1145-1270	Upper Floridan Aquifer
SFWMD	LAB-TW (Avg.)	1140-1460, 1650-1720	Middle Confining Unit
SFWMD	BICY-TW (Avg.)	838-980, 1195-1295	Upper Floridan Aquifer
SFWMD	BICY-TW (Avg.)	1550-1785, 1790-1910	Middle Confining Unit
SFWMD	BICY-TW (Avg.)	2260-2500, 2260-2505	Lower Floridan Aquifer
SFWMD	GL-5B	710-928	Upper Floridan Aquifer
SFWMD	GL-5C	1350-1390	Middle Confining Unit
SFWMD	PBF-7	775-890	Upper Floridan Aquifer
SFWMD	PBF-7 (Avg.)	1267-1396, 1633-1762	Middle Confining Unit
SFWMD	PBF-7	1913-2020	Lower Floridan Aquifer
SFWMD	G-2618 (Alligator Alley Well)	1104-1164	Upper Floridan Aquifer
SFWMD	G-2617(Alligator Alley Well)	1648-1726	Middle Confining Unit
SFWMD	G-2296(Alligator Alley Well)	2447-2811	Lower Floridan Aquifer
North Collier County WWTP	CO-2318U	910-1146	Upper Floridan Aquifer
North Collier County WWTP	CO-2318L	1815-1930	Middle Confining Unit
South Collier County WWTP	SCCWWTP-MZU	850-910	Upper Floridan Aquifer
South Collier County WWTP	SCCWWTP-MZL	1820-1950	Middle Confining Unit
Marco Island Utilities	MIU MW2	1000-1089	Upper Floridan Aquifer
Marco Island Utilities	MIU MW1	1490-1600	Middle Confining Unit
North Fort Meyers WWTP	NFM-MZ2	1318-1422	Middle Confining Unit
North Fort Meyers WWTP	NFM-MZ1	1939-2004	Lower Floridan Aquifer
Fort Meyers Beach WWTP	FMB-MZU	1170-1270	Upper Floridan Aquifer
Fort Meyers Beach WWTP	FMB-MZL	1568-1650	Middle Confining Unit
Fort Meyers Beach WWTP	FMB-IW	2319-3000	Lower Floridan Aquifer
Zemel Road Landfill	ZRL-UMW	1341-1415	Upper Floridan Aquifer
Zemel Road Landfill	ZRL-DMW	1795-1830	Middle Confining Unit
Florida Water Services	BSU-MZU	1207-1287	Upper Floridan Aquifer
Florida Water Services	BSU-MZL	1832-1868	Middle Confining Unit
Pahokee WWTP	Paho-MZU	946-1147	Upper Floridan Aquifer
Pahokee WWTP	Paho-MZL	1915-2008	Lower Floridan Aquifer

Appendix 2.

Identifier	Depth Interval ft. (bls)	Del-^{18}O $^{0}/_{00}$	Del-^{2}H $^{0}/_{00}$	Del-^{13}C $^{0}/_{00}$	^{14}C (pmc)	Uncorrected ^{14}C Age
LAB-MZ#1, PT#3 (Avg.)	670-1270	-1.60	-7.71	-2.58	0.68	40080
GL-5B	710-928	-2.08	-10.46	-4.28	0.21	49500
PBF-7 PT#5	775-890	-1.45	-8.36	-4.34	1.31	34810
IWSD MZ#2, PW#2 (Avg.)	790-1165	-1.69	-7.77	-2.21	0.67	42640
BICY-MZ#2, PT#3 (Avg.)	838-1295	-1.26	-6.60	-2.40	0.68	40520
SCCWWTP-MZU	850-910	-1.19	-5.53	-3.05	0.17	50000
CO-2318U (NCCWWTP)	910-1146	-1.14	-1.53	-3.70	0.82	38520
Paho-MZU	946-1147	-1.64	-9.33	-0.82	0.94	37460
MIU MW2	1000-1089	-0.08	-5.17	-3.00	1.53	33530
G-2618(Alligator Alley-TW)	1104-1164	-1.88	-11.36	-2.00	2.63	29190
FMB-MZU	1170-1270	-1.46	-8.79	-1.89	0.09	50000
BSU-MZU	1207-1287	-1.43	-6.24	-3.72	0.32	46100
ZRL-UMW	1341-1415	-0.85	-4.54	-3.57	1.53	33530
LAB-MZ#2, MZ#3 (Avg.)	1140-1720	-1.11	-11.35	-1.49	0.72	39685
PBF-7 PT#2, PT#3 (Avg.)	1267-1762	-1.61	-4.60	-2.98	1.32	34800
NFM-MZ2	1318-1422	-1.14	-8.06	-1.85	1.17	35700
GL-5C	1350-1390	-1.92	-5.36	-4.14	1.05	36520
L2-PW1	1400-1810	-1.56	-8.74	-2.89	2.03	31250
MIU MW1	1490-1600	-0.35	0.28	-3.80	1.99	31420
BICY-MZ#3, PT#5 (Avg.)	1550-1910	0.47	0.53	-1.29	0.38	44920
FMB-MZL	1568-1650	0.48	0.18	-1.71	0.18	48200
G-2617(Alligator Alley-TW)	1648-1726	-1.76	-8.08	-1.77	2.37	30010
IWSD MZ#3	1700-1880	-1.59	-7.90	-2.31	0.99	37000
ZRL-DMW	1795-1830	-0.42	0.97	-3.56	7.54	20720
CO-2318L (NCCWWTP)	1815-1930	0.40	9.00	-1.77	1.09	36220
SCCWWTP-MZL	1820-1950	0.55	5.33	-1.18	0.00	50000
BSU-MZL	1832-1868	0.43	2.05	-3.24	0.70	39900
PBF-7 PT#4	1913-2020	-0.69	-3.07	-2.46	4.28	25260
Paho-MZL	1915-2008	-0.66	-4.83	-3.98	0.53	42090
NFM-MZ1	1939-2004	-0.41	-1.67	-4.32	12.45	16690
IWSD MZ#4	2100-2354	0.12	3.72	-2.88	4.92	24150
BICY-MZ#4, PT#4 (Avg.)	2260-2505	0.73	0.06	-0.85	0.27	45750
I75 MZ#4	2300-2350	0.65	1.16	-1.78	19.70	13429
FMB-IW	2319-3000	0.47	0.02	-2.93	7.54	20720
G-2296(Alligator Alley-TW)	2447-2811	-0.35	8.05	-1.84	34.47	8510