STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
Michael W. Sole, *Secretary*

LAND AND RECREATION
Robert G. Ballard, *Deputy Secretary*

FLORIDA GEOLOGICAL SURVEY
Jonathan D. Arthur, *State Geologist and Director*

Special Publication No. 28 (Revised)

HYDROGEOLOGICAL UNITS OF FLORIDA

By

Rick Copeland, Sam B. Upchurch, Thomas M. Scott, Clint Kromhout,
Jonathan Arthur, Guy Means, Frank Rupert, and Paulette Bond

Published for the

FLORIDA GEOLOGICAL SURVEY
Tallahassee, Florida
2009

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PREFACE

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Tallahassee, Florida
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The Department of Environmental Protection, Land and Recreation, Florida Geological Survey (FGS), is publishing as its Special Publication No. 28 (Revised), Hydrogeologic Units of Florida.

The original document was first published in 1986. However, because of the tremendous increase in hydrogeologic knowledge in Florida in recent years, and because of the critical need to find new groundwater resources in the state for the projected increased population, there is an important need to address the issue of consistency of nomenclature within the hydrogeologic community in Florida. This document will assist both governmental agencies and the private sector regarding the proper and consistent use of hydrogeologic terms throughout the state.

Jonathan D. Arthur, Ph.D., P.G.
State Geologist and Director
Florida Geological Survey

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HYDROSTRATIGRAPHIC UNITS OF FLORIDA

by
Rick Copeland (PG #126), Thomas M. Scott, Sam B. Upchurch, Clint Kromhout, Richard Green, Jonathan Arthur, Guy H. Means, Frank Rupert, and Paulette Bond

INTRODUCTION

Background and Purpose

In 1986, the Florida Geological Survey (FGS) published the first guidelines for naming Florida's aquifers and confining systems (Southeastern Geological Society Ad Hoc Committee, 1986). These guidelines have served Florida well for 20 years but they concentrated on the most productive aquifers. Florida's explosive growth has resulted in a need for developing expanded water sources, including less productive aquifers that were not emphasized in the 1986 guidelines. This report presents an updated set of guidelines for naming aquifers which changes the focus to all strata that are capable of producing water to a well and that have potential for public or private supply. Specifically, the 1986 guidelines established three hydrostratigraphic systems:

- The surficial aquifer system
- The intermediate aquifer system or intermediate confining unit
- The Floridan aquifer system

The sub-Floridan confining unit was identified as lying below the Floridan aquifer system. The intermediate confining unit of the intermediate aquifer system or intermediate confining unit became the hydrostratigraphic unit that was often described as separating the surficial aquifer system and Floridan aquifer system. The terminology utilized for both units emphasized their role as confining strata.

Today, the more permeable portions of the intermediate aquifer system or intermediate confining unit are being exploited as a water source in areas where it had previously been considered to consist of low-permeability strata. In parts of Florida, the Lower Floridan aquifer system is being used for water supply (Miller, 1988). In addition, the Lower Floridan aquifer system and permeable units within the sub-Floridan confining unit systems are being utilized for water storage and/or wastewater injection targets (Bush and Johnston, 1988) (Hickey and Vecchioli, 1886). These uses reflect the demands of a growing population with limited conventional water supplies. As the uses expand into traditionally unused aquifer targets, a growing awareness has developed that the confining units are not consistent aquitards and that there is a need for revised thinking as to how Florida's hydrostratigraphic systems function and should be utilized. Therefore, an *ad hoc* committee of hydrogeologists has developed revisions to Florida's hydrostratigraphic nomenclature. The committee will be discussed later. This report presents the revisions developed by the committee.

STATEMENT OF NEED

Aquifer and Confining Unit Function

In 1923, Meinzer defined an aquifer as:

> "A rock formation or stratum that will yield water in sufficient quantity to be of consequence as a source of supply is called an 'aquifer' or simply a 'water-bearing formation,' 'water-bearing stratum' or 'water bearer'" (Meinzer, 1923, pp. 52-53)."

Meinzer was evidently struggling with the concept of an aquifer from the context of the wide range of capabilities of water-bearing strata throughout the nation. As part of the discussion in his 1923 text, Meinzer (p. 53) went on to indicate that an aquifer "...supplies water to wells and springs," and that it, "contains gravity ground water." He also added:

> "Few, if any, formations are entirely devoid of gravity ground water, but those that do not contain enough to be practical sources of water supply are not considered to be aquifers; they are not called water-bearing formations. Hence it may happen that in a region underlain by strong aquifers, a formation yielding only meager amounts of water may not be classed as water-bearing; whereas in a region nearly destitute of available water a similar formation may be a recognized aquifer tapped by many wells."

Obviously, Meizner recognized that the term aquifer would be applied to geologic horizons that are the <u>most</u> effective in producing water to wells.

Florida's aquifer nomenclature system (Southeastern Geological Society Ad Hoc Committee, 1986) made the distinction that Meizner considered in 1927. That is, hydrostratigraphic horizons that are typically capable of producing large quantities of water to wells are identified as aquifers and aquifer systems and those strata that are significantly less efficient at producing water are termed confining units. The Southeastern Geological Society Ad Hoc Committee (1986) described confining units in the intermediate aquifer system or confining unit as follows:

> "In places poorly-yielding to non-water-yielding strata mainly occur and there the term 'intermediate confining unit' applies. In other places, one or more low to moderate-yielding aquifers may be interlayered with relatively impermeable confining beds; there, the term 'intermediate aquifer system' applies" (Southeastern Geological Society Ad Hoc Committee, 1986, p. 5).

Clearly, the Southeastern Geological Society Ad Hoc Committee anticipated that the strata of the intermediate aquifer system or confining unit could be developed in some areas as low to moderate productivity aquifers.

Use of the terms aquifer or confining unit has resulted in several unfortunate, widely held assumptions since the Southeastern Geological Society Ad Hoc Committee revised the stratigraphic nomenclature for Florida in 1986. The primary assumptions regarding the 1986 nomenclature have to do with the function of "confining units" as defined in the 1986 publication. There are also some assumptions that appear to have been caused by terminology are:

- The intermediate confining unit is not suitable for water supply
- Where present, the intermediate confining unit minimizes sinkhole risk
- Where present, the intermediate confining unit reduces the vulnerability of the underlying Floridan aquifer system to contamination from the overlying surficial aquifer system
- The sub-Floridan confining unit is an adequate confining unit for separation of underground injection targets and the "underground source of drinking water" as specified by state and federal law

Since none of these assumptions are universally true and, as water and wastewater management becomes more and more challenging as a result of population growth, there is a need to find and exploit the exceptions to these assumptions. The current report proposes changes to Florida's hydrostratigraphic nomenclature that will clarify potential uses for the aquifers and confining units and encourage awareness of the errors that may develop in the absence of a clear understanding of the ability of the hydrostratigraphic horizons to produce water or minimize flow of water and contaminants.

For example, the presence of clay-rich strata within the intermediate confining unit at shallow depths has been utilized as a justification for the siting of landfills. Subsequent investigation of similarly sited landfills (e.g., Upchurch et al., 1995) has, in many cases, led to detection of contaminants in strata below the alleged confining unit. This is because the clay-rich strata are either penetrated by karst features, such as sinkholes, or contain lenses and beds of limestone, dolostone, or sand and gravel that create pathways for contaminant movement.

Similarly, recharge estimates to the Floridan aquifer system have been misinterpreted when the intermediate confining unit is present and overlies the Floridan aquifer system (e.g., compare the recharge potential in central Alachua County as shown by Stewart (1980) and Aucott (1988)). This misinterpretation is often due to the fact that borehole data used to characterize the subsurface are typically from sites in upland areas rather than the bottoms of nearby sinkholes.

Finally, in the realm of sinkhole investigations, the presence of the "Hawthorn confining unit" has been argued by many to indicate a significantly lowered risk of sinkhole activity. While significant thicknesses of plastic clay do resist raveling of cover materials into voids in the underlying limestone or dolostone, one should not assume that there are not any: (1) penetrations or (2) permeable zones in the clay that might allow for sinkhole development.

All of the above assumptions have some validity as long as there is an understanding that Florida's "confining units" may be perforated by karst features and may have permeable strata imbedded within them.

CHANGES IN WATER USE

The revisions to Florida's hydrostratigraphic nomenclature stem, in part, from a change in needs for water supply. Chapter 373.1962(3) Florida Statutes encourages the use of alternative water supply sources as part of water supply planning in Florida. With the high current population growth rates, the projected continued growth, along with the recent droughts, it has been determined by several water management districts that there is a need to expand the sources of groundwater as much as possible. In addition to alternative sources of water, such as desalination plants, aquifer storage and recovery facilities, above-grade reservoirs, water reuse, and water conservation, it has been determined that the surficial aquifer system, and permeable strata within the immediate aquifer system or confining unit, constitute viable, though less productive, aquifers. These should be used whenever possible, to minimize adverse impacts on the Floridan aquifer system (Southwest Florida Water Management District, 2006). This paper recognizes that even where lower permeability aquifers exist, there is a potential for vertical water movement through the strata and for the presence of smaller aquifers within the larger body of sediment.

Need for Revising Hydrostratigraphic Nomenclature

The 1986 nomenclature system created a hierarchy of hydrostratigraphic units for use in Florida, including aquifers, aquifer systems, and confining units. With the identification and utilization of regional and sub-regional horizons within the major aquifer systems that either confine or produce water and with the increased utilization of local aquifers, there is a need to refine the hierarchical system of aquifer and confining system naming in Florida. This should assist in appropriate utilization of water-producing zones and confining beds and assist in management and permitting activities by state and local government.

Previous Work

Meizner's (1927) insight into how one defines aquifers foreshadowed the complications that have arisen as our knowledge and utilization of water-bearing strata has increased. The present terminology for identifying aquifers and related confining and "semi-confining" beds is an artifact of the complex and rich history of the search for water throughout the world. Areas that generally only have low permeability strata which produce low quantities of water are termed aquifers, or an aquifer. Regions, such as the Gulf Coastal Plain, where highly productive limestone aquifers exist, do not recognize similar water-bearing strata as aquifers. Furthermore, the nomenclature used to identify these different water-bearing strata and their properties has been very inconsistent.

Attempts at developing hydrostratigraphic nomenclature can be divided into two efforts:

- Development of naming conventions
- Categorization of aquifers as to origin or function

Naming Conventions

The North American Commission on Stratigraphic Nomenclature developed a process for naming of rock (lithostratigraphic) and time (chronostratigraphic) units in the early 1960s. Since 1961, methods for assigning stratigraphic names to soils (pedostratigraphic units), igneous and metamorphic rocks (lithodemic units), magnetic properties (magnetostratigraphic units), fossil content (biostratigraphic units), strata bounded by unconformities (allostratigraphic units), and other types of stratigraphic units have been developed. To date, however, a uniform code of hydrostratigraphic nomenclature has not been published by the Commission (North American Commission on Stratigraphic Nomenclature, 2005).

There are fundamental properties of lithostratigraphic units (North American Commission on Stratigraphic Nomenclature, 2005) that can be applied to groundwater systems as well. These are:

- The unit must have sufficient areal extent and thickness to be mappable
- The unit must have easily identifiable physical (lithologic) properties
- The fundamental unit (a formation in stratigraphy) is formally named for a locality where a type section can be observed
- Formations can be grouped according to similarities in origin or rock type into groups and subdivided into members providing that the mappability criterion is preserved

While hydrostratigraphic terminology could be adopted according to rules that are similar to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005), there have been few attempts to do so. Two exceptions are by Laney and Davidson (1986) and the American Society for Testing and Materials (ASTM) (2004) and both will be discussed later. This is, in part, because of the history of naming aquifers after diverse criteria. Examples are: (1) place names (Biscayne aquifer of southeastern Florida), (2) lithologic properties (sand-and-gravel aquifer of northwestern Florida), (3) areas of extent (Floridan aquifer of the southeastern United States), (4) formation names (Tamiami aquifer of the intermediate aquifer system in southwestern Florida), and (5) ability to produce water. An example of the latter is permeable zones PZ1, PZ2 etc. (Southwest Florida Water Management District, 2005), but also referred to as permeable zones Zone 1, Zone 2 etc. (Knochenmus, 2006). These are all examples of inconsistent nomenclature.

In addition, there has been some difficulty in developing naming conventions because of perceptions of hydraulic performance. That is, an aquifer with relatively low permeability or limited areal extent may be considered an aquifer in the absence of other, potable water sources in one area and the same horizon might not be considered an aquifer in areas where high quality water can be developed from a highly productive aquifer. This is the case for permeable zones within the Hawthorn Group in Florida. Both the Southwest Florida Water Management District and the South Florida Water Management District encourage development of permeable zones within the Hawthorn Group in southwestern Florida because water in the Floridan is either saline or at risk of salt-water intrusion (Southwest Florida Water Management District, 2005; Wedderburn et al., 1982). Similar strata occur elsewhere in the Hawthorn Group of Florida (Scott, 1988; Scott, 1991) but they are not considered as being viable aquifers. As a result, naming conventions differ from north to south in Florida.

Categorizations

For the most part, hydrostratigraphic nomenclature development has focused upon determining what constitutes an aquifer and an aquitard (e.g., Meinzer, 1927; Poland et al., 1972), or the lithologic framework of the aquifer (Catalan Water Agency, undated; Wexford County Council, undated). Ronneseth and Wei (2005) have developed an aquifer classification system for the Province of British Columbia. Over 640 aquifers have been identified in the province. These have been identified and grouped based on attributes in order to develop a database for management and protection activities. Hibbs and Darling (2005) have attempted to classify aquifer systems in intermontaine basins of the Trans-Pecos area of west Texas and northern Chihuahua. They proposed a classification system based on details of the regional flow system.

SECOND AD HOC COMMITTEE ON FLORIDA HYDROSTRATIGRAPHIC UNIT DEFINITION

Considering the issues mentioned above, the FGS, along with assistance of the U.S. Geological Survey (USGS), formed the Second Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition (CFHUD II). It held its first meeting in Altamonte Springs on August, 13, 2003, a second meeting in Gainesville on December 7, 2005, and a third meeting in Gainesville on August 7, 2007.

Second Ad Hoc Committee

The second committee consisted of the following individuals:

Rick Copeland, Florida Geological Survey, Florida Department of Environmental Protection, Chairman
Jon Arthur, Florida Geological Survey, Florida Department of Environmental Protection
Kris Barrios, Northwest Florida Water Management District
Terry Bengstson, South Florida Water Management District
Michael Bennett, South Florida Water Management District

Marian Berndt, U.S. Geological Survey
Ron Ceryak, Suwannee River Water Management District (retired)
Jim Clayton, Southwest Florida Water Management District

Kevin Cunningham, U.S. Geological Survey
Jeff Davis, St. Johns River Water Management District
Rich Deuerling, Florida Department of Environmental Protection (deceased)
Dave DeWitt, Southwest Florida Water Management District
Tony Gilboy, Southwest Florida Water Management District
Jeff Herr, South Florida Water Management District
David Hornsby, St. Johns River Water Management District
Brian Katz, U.S. Geological Survey
Mike Knapp, HydroDesigns Inc.
Lari Knochemus, U.S. Geological Survey
Clint Kromhout, Florida Geological Survey, Florida Department of Environmental Protection
Gary Maddox, Florida Department of Environmental Protection
Jerry Mallams, Southwest Florida Water Management District
Jon Martin, University of Florida
Brian McGurk, St. Johns River Water Management District
Harley Means, Florida Geological Survey, Florida Department of Environmental Protection
Patty Metz, U.S. Geological Survey
Jim Miller, U.S. Geological Survey (retired)
Tom Missimer, Missimer Groundwater Sciences, Inc.
Louis Murray, U.S. Geological Survey
Doug Munch, St. Johns River Water Management District
Tom Pratt, Northwest Florida Water Management District (deceased)
Ron Reese, U.S. Geological Survey
Chris Richards, Northwest Florida Water Management District
Emily Richardson, South Florida Water Management District
Tom Scott, SDII Global Corporation, Inc.
Tom Seal, Florida Department of Environmental Protection
Karin Smith, South Florida Water Management District
Rick Spechler, U.S. Geological Survey
Dan Spangler, University of Florida (retired)
Sam Upchurch, SDII Global Corporation, Inc.
Warren Zwanka, St. Johns River Water Management District

The members of CFHUD II considered using the guidelines of American Society for Testing and Materials (2004). However, the committee ultimately believed that the work of Laney and Davidson (1986) represents the best guidelines for addressing those issues not directly covered in this document. It is hoped that the decisions of CFHUD II, along with the guidelines of Laney and Davidson, will assist in standardizing hydrostratigraphic naming and mapping procedures within the state. If the North American Commission on Stratigraphic Nomenclature includes hydrostratigraphy as one of their stratigraphic categories, it is anticipated the applicable elements will be adopted for use in Florida and will take precedence over the methods presented in this document.

MAJOR ISSUES AND CHANGES

The members of CFHUD II reached agreement on several major issues. One issue was not changed while several others were made relative to the first Ad Hoc Committee guidelines.

Regional, Sub-Regional and Local

Three terms of significant interest are used in specifying the lateral extent of hydrostratigraphic units. They are regional – an extent approximating the size of or larger than a water management district; sub-regional – an extent encompassing an area of a few counties but smaller than a water management district; and local – an extent encompassing an area smaller in size than a few counties. Note the word "few" and the typical size of a county were not defined. The definitions have not changed from the original guidelines.

Spelling of Groundwater

The first guidelines for naming Florida's aquifer systems, aquifers and confining units (Southeastern Geological Society, 1986) did not address the spelling of one of the most important terms related to hydrostratigraphic nomenclature - groundwater. This is unfortunate because over the past 20 years, numerous publications regarding nomenclature have spelled groundwater several different ways: (1) ground water as a noun, (2) ground-water as an adjective, (3) ground water as a noun and as an adjective, and (4) groundwater as a noun and as an adjective. In an effort to standardize spelling, the CFHUD II reviewed the literature and decided to use the term as one word, "groundwater", both as a noun and as an adjective.

Hydrostratigraphic Versus Hydrogeologic

Both terms are acceptable, but the term hydrostratigraphic is preferred.

Confinement

Except where the uppermost aquifer is under unconfined conditions, Florida's aquifers are under variable degrees of confinement. Confined aquifers are bordered above and below by relatively impermeable units that, to some degree, confine the aquifer. The Committee believes that the term "semi-confinement" should only be used as an informal term.

Capitalization

In 1986, there was no formal method for defining hydrostratigraphic units. For this reason the first Ad Hoc Committee chose not to formalize the names through capitalization. It was hoped that a formal procedure would eventually be developed for the definition and mapping of hydrostratigraphic units and capitalization could be addressed at that time. Unfortunately, a formalization process never occurred in Florida or in the nation and, since 1986, some authors capitalized the names while other did not.

In an effort to address standardization, CFHUD II decided to adopt the concept held by the North American Commission on Stratigraphic Nomenclature (2005). That is, an aquifer is still considered to be an informal unit. Thus, hydrostratigraphic units are not to be capitalized. However, proper names, along with their direct adjectives, are to be capitalized if a proper name is included as part of the hydrostratigraphic unit name. For example, for the term “Lower Floridan aquifer system,” the words “Lower” and “Floridan” are capitalized, while the words “aquifer” and “system” are not. Likewise, the words in the term “intermediate confining unit” are not capitalized.

Text and Poster

The text that follows discusses the major issues addressed and agreed to by CFHUD II. A poster accompanies this text which is a synopsis of the discussion below.

MAJOR HYDROSTRATIGRAPHIC UNITS OF FLORIDA

This publication describes Florida’s hydrostratigraphy on a regional basis. Except for the Biscayne aquifer and the sand-and-gravel aquifer, it does not address the description of sub-regional and local aquifers and confining units. CFHUD II encourages organizations and individuals to fully describe and map the extent and thicknesses of sub-regional and local aquifers and confining units using the guidelines suggested in this publication. Table 1 compares hydrostratigraphic names used in the original FGS Special Publication 28 (Southeastern Geological Society, Ad Hoc Committee, 1986) to those used in this document, FGS Special Publication 28 (Revised).

The generalized relationships among Florida’s regional hydrostratigraphic units and the major stratigraphic units of Florida, in the panhandle, northern Florida and southern Florida are presented in Figure 1. Figure 2 is a map of Florida, along with counties. Figure 3 is a generalized geologic map of Florida. Also found on the figure are the locations of seven cross sections.

The cross sections (Figures 4-10) depict the relationships between Florida’s stratigraphy and corresponding hydrostratigraphy throughout the state. The purpose is to assist the reader in understanding the regional hydrostratigraphic units. Figure 1, plus Figures 4-10, can also be found in the accompanying compact disk (CD). The CD allows the reader to print the figures in larger formats if needed. Symbols displaying lithology patterns, as displayed in the cross sections (Figures 4-10), are taken from the U.S. Geological Survey (1999).

Table 1. Florida's regional hydrostratigraphic units comparing terminology usage in 1986 to current usage. (Abbreviations for revised terminology are included.)

Special Publication 28 (Revised)	Special Publication 28 (1986)
surficial aquifer system (SAS)	surficial aquifer system
Biscayne aquifer (BA)	Biscayne aquifer
sand-and-gravel aquifer (SGA)	sand-and-gravel aquifer
intermediate aquifer system or intermediate confining unit (IAS/ICU) intermediate aquifer system (IAS) intermediate confining unit (ICU)	intermediate aquifer system or intermediate confining unit
Floridan aquifer system (FAS)	Floridan aquifer system
Upper Floridan aquifer (UFAS)	
Middle Floridan confining unit (MFCU)	
Lower Floridan aquifer (LFAS)	
undifferentiated aquifer systems and confining units (UAS/UCU)	sub-Floridan confining unit

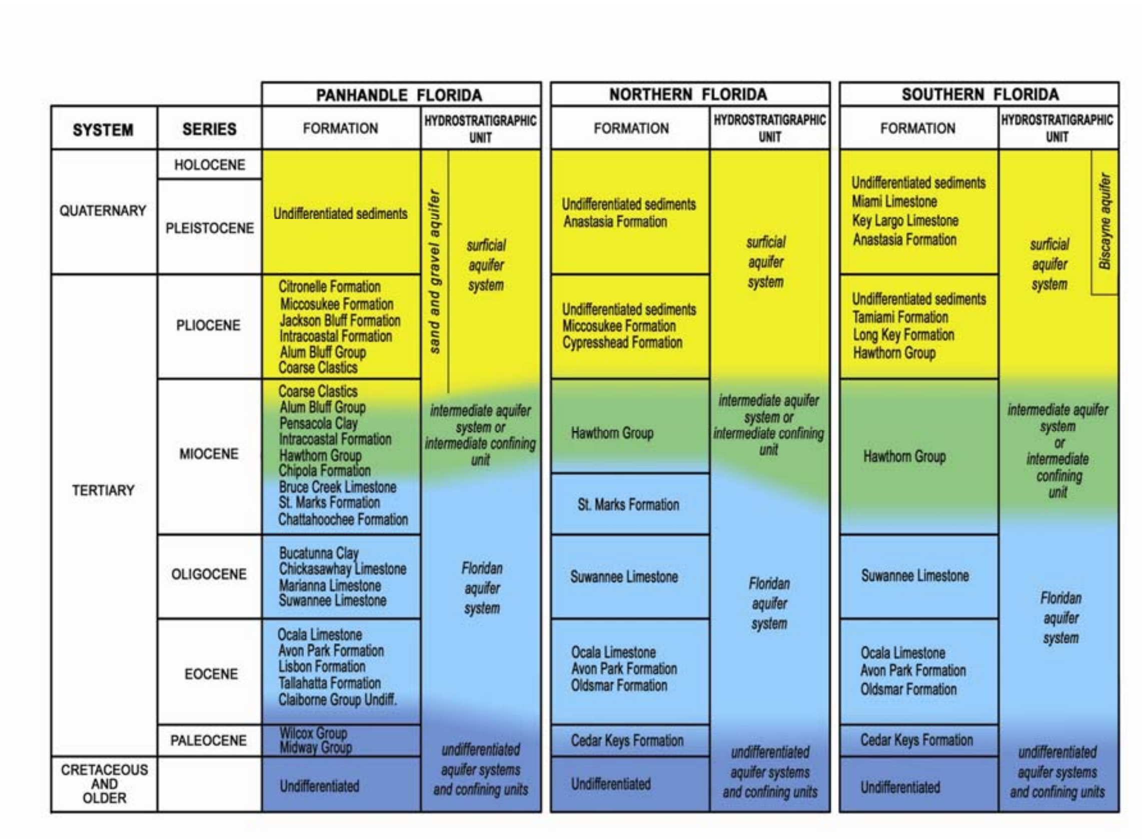


Figure 1. Generalized relationships among the regional hydrostratigraphic units and the the major stratigraphic units in the panhandle, northern, and in southern Florida. (Yellow – surficial aquifer system; Green – intermediate aquifer system or intermediate confining unit; Light Blue – Floridan aquifer system; Dark Blue – undifferentiated aquifer systems and confining units)

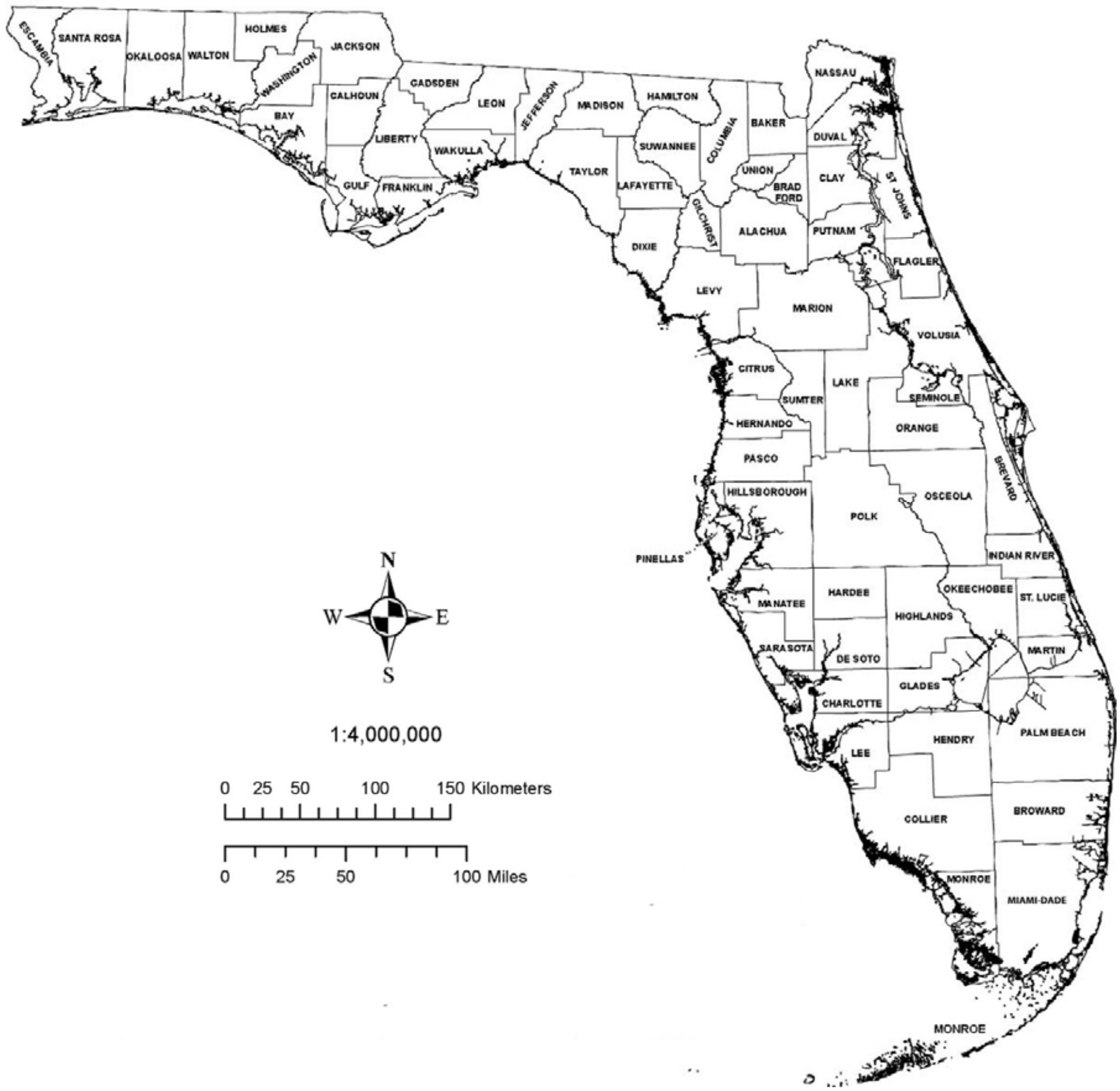


Figure 2. Florida with counties.

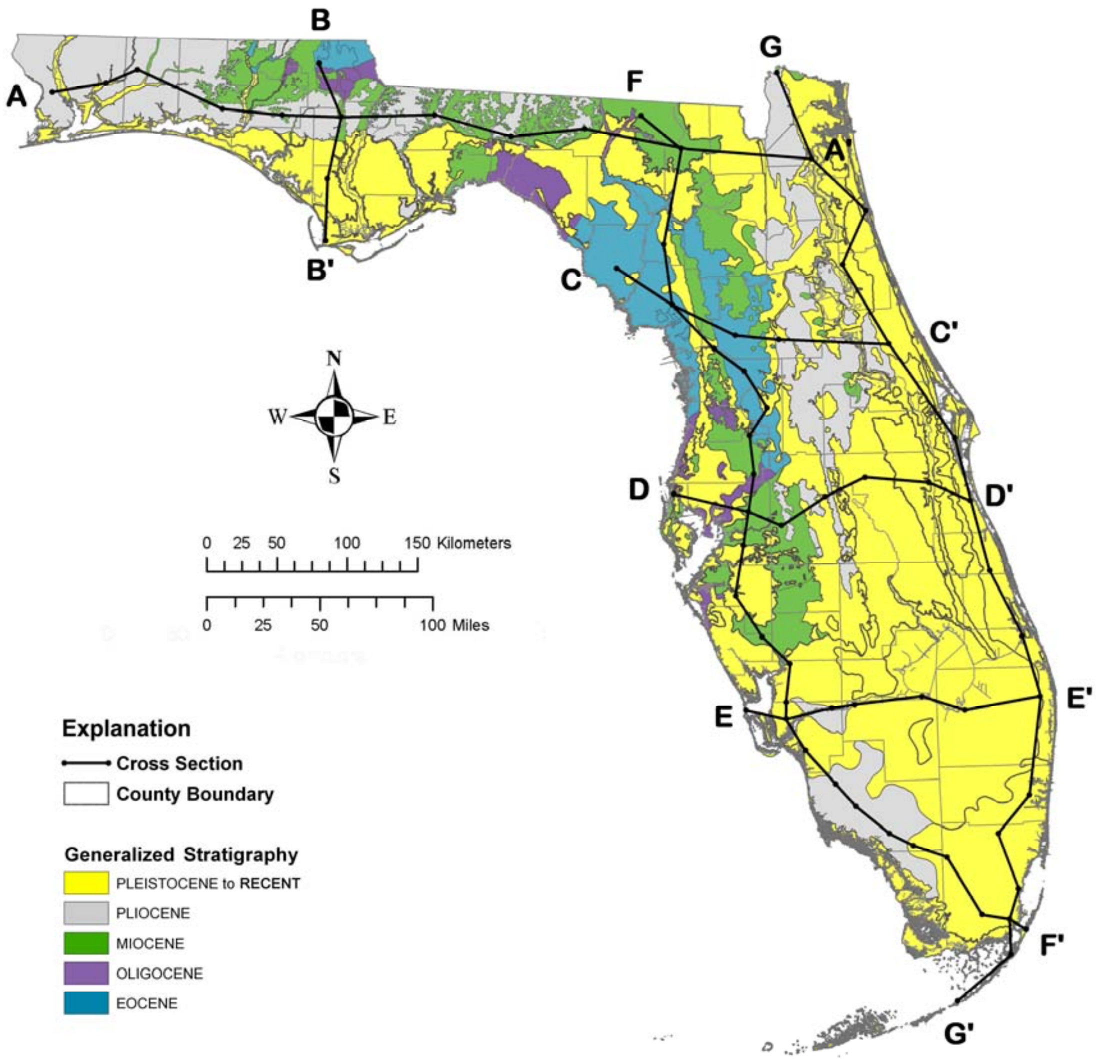


Figure 3. Geologic map of Florida with cross section locations
(Modified from Scott et al., 2001)

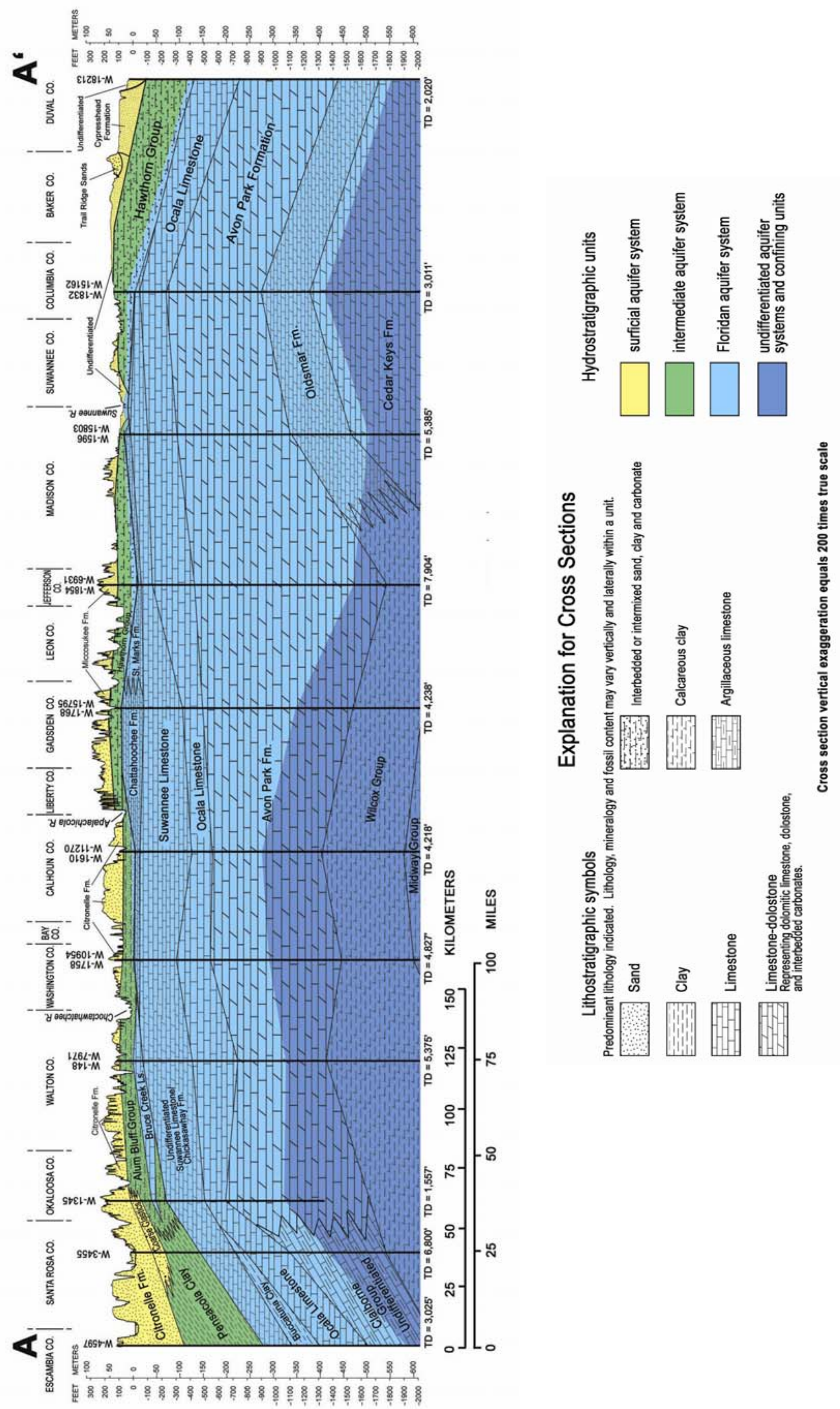


Figure 4. Cross section A-A'.

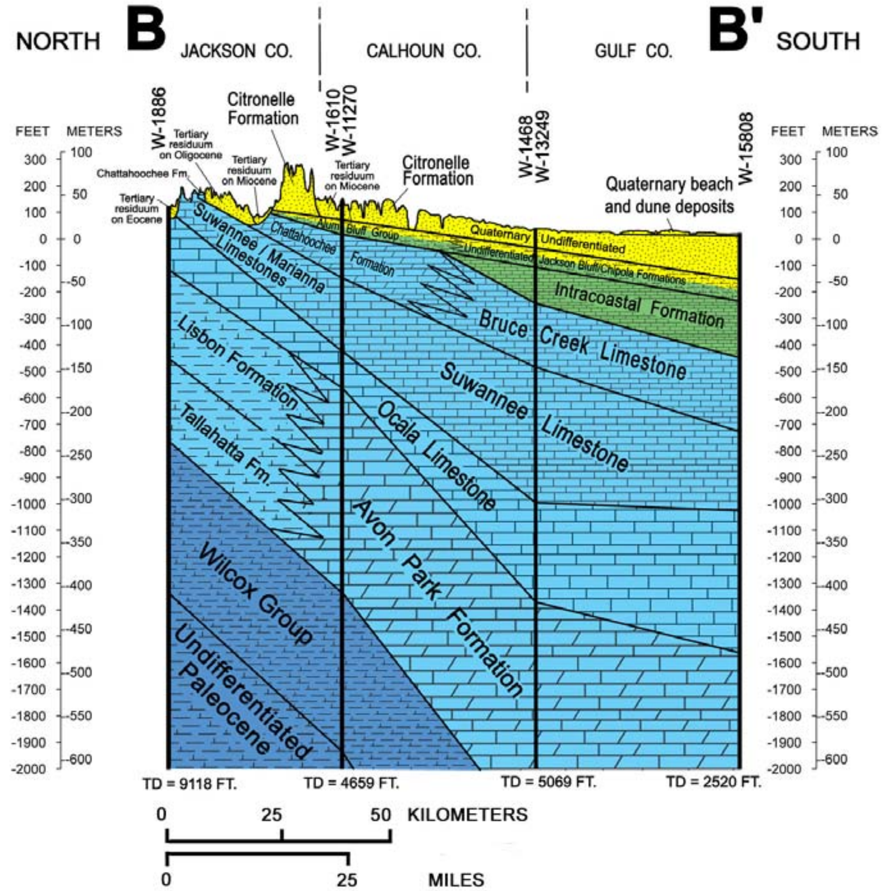


Figure 5. Cross section B-B'.

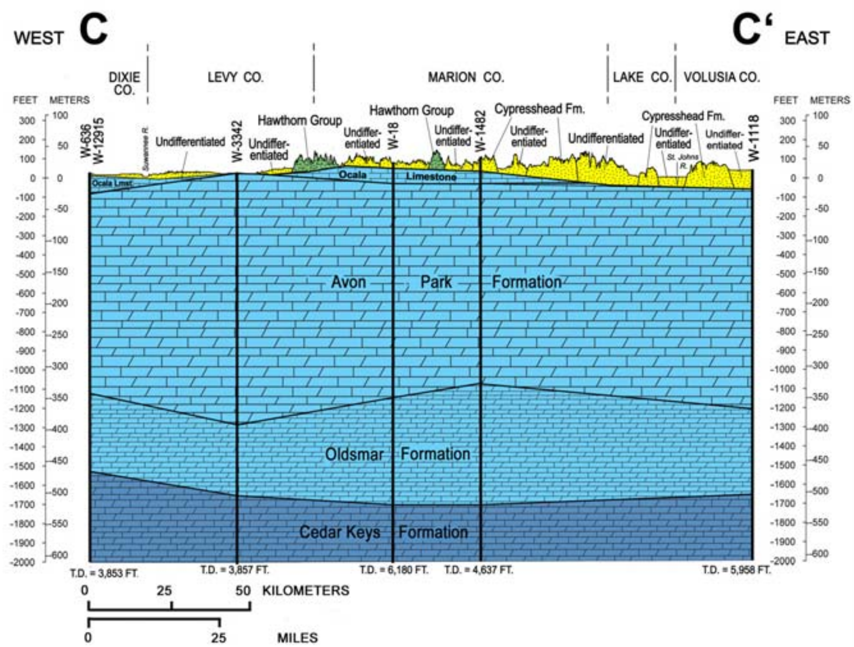


Figure 6. Cross section C-C'.

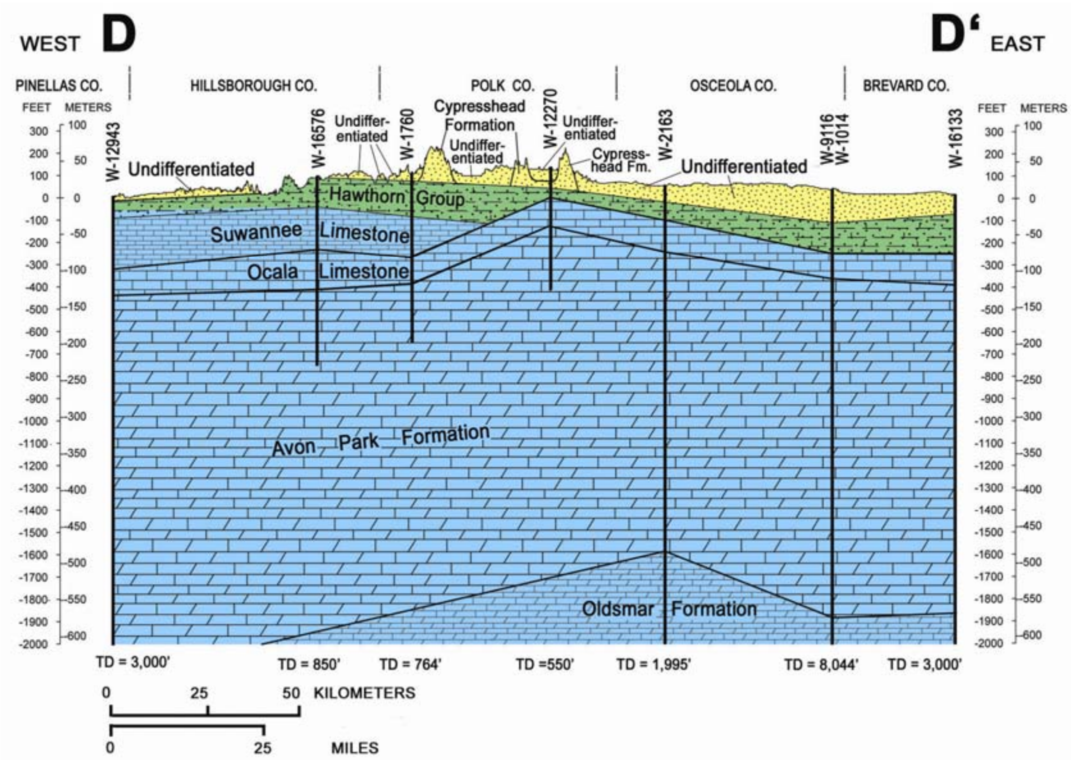


Figure 7. Cross section D-D'.

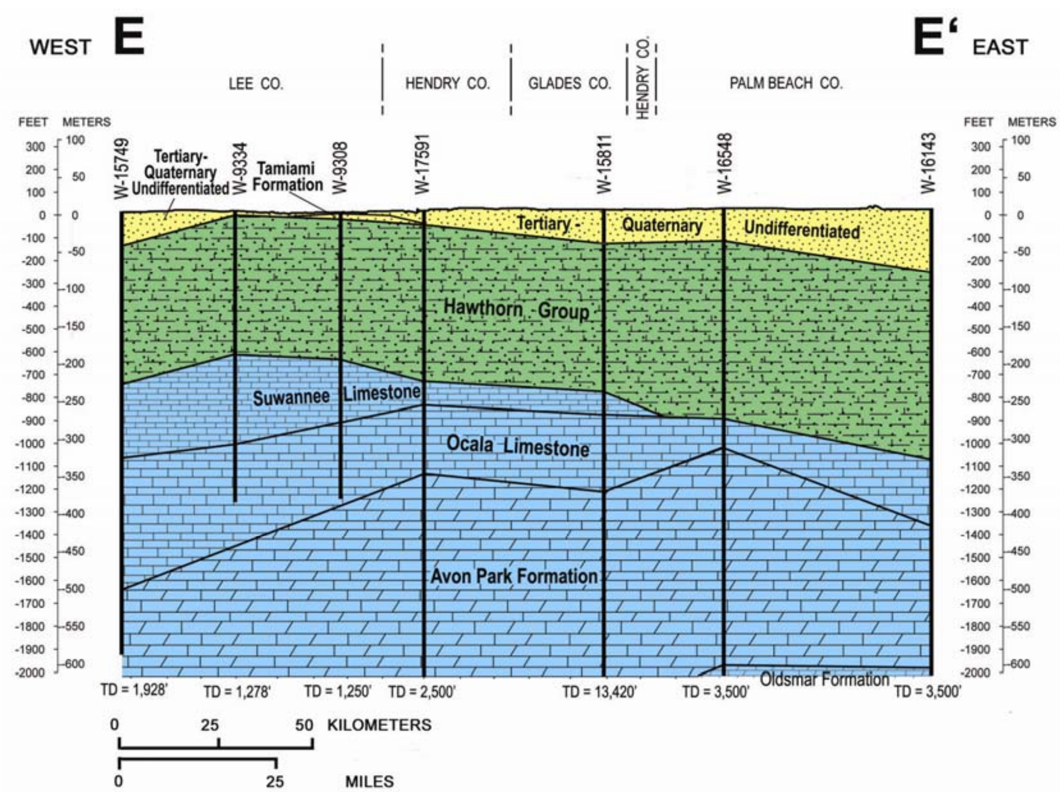


Figure 8. Cross section E-E'.

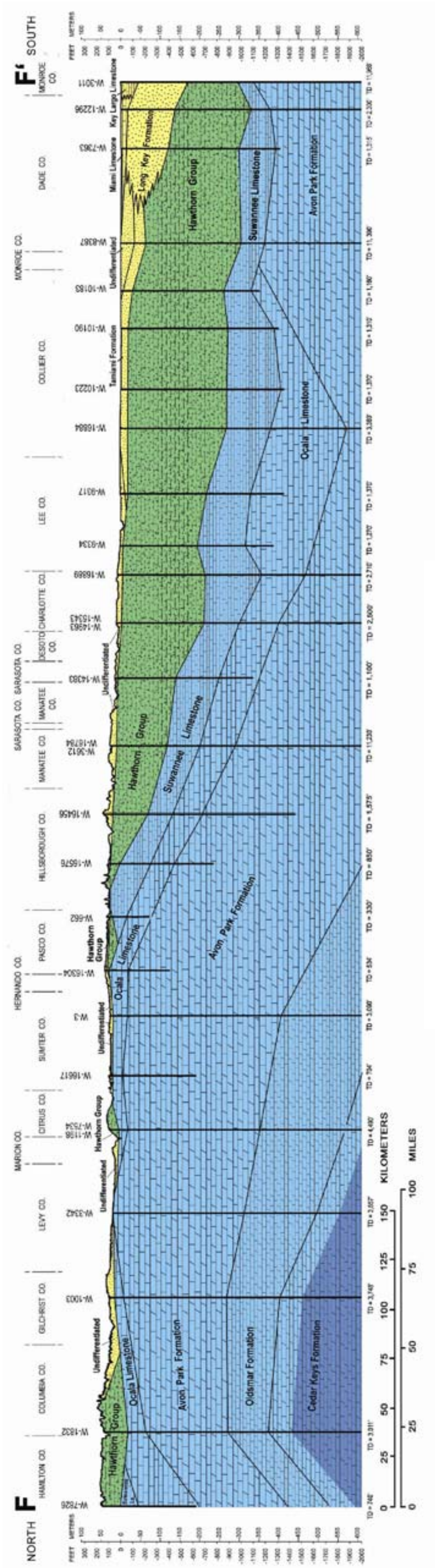


Figure 9. Cross Section F-F'.

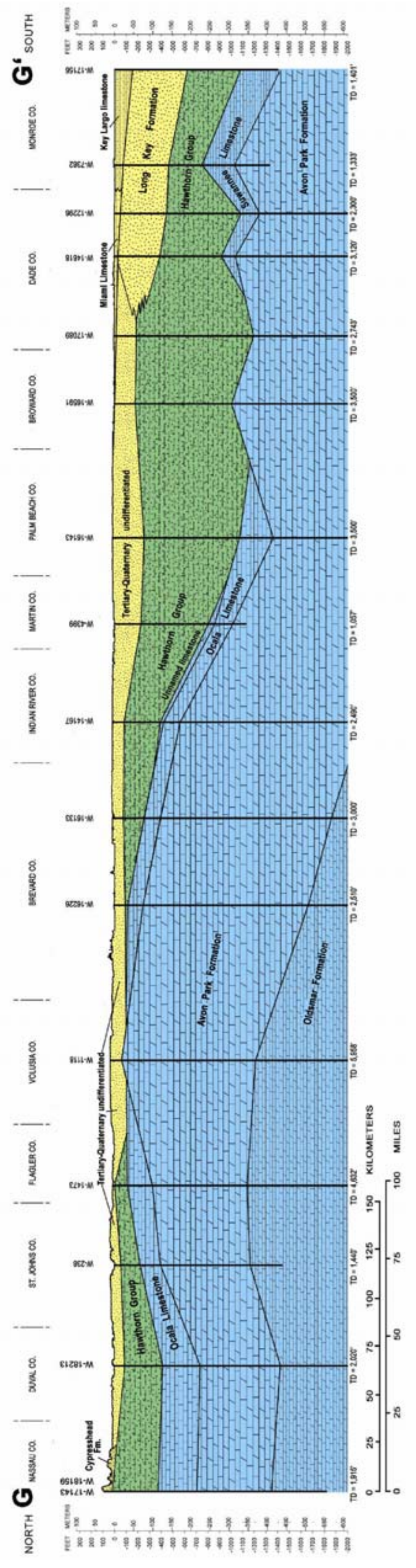


Figure 10. Cross Section G-G'.

Surficial Aquifer System

The permeable hydrostratigraphic unit referred to as the surficial aquifer system is contiguous with land surface and is comprised principally of unconsolidated to poorly indurated siliciclastic deposits. It also can include well-indurated carbonate rocks, other than those of the FAS. Sediments making up the SAS belong to all or part of the Miocene to Holocene Series. The SAS contains the water table and water within it is under mainly unconfined conditions; however, beds of low permeability may cause locally-confined conditions to prevail in its deeper parts. The lower limit of the SAS coincides with the top of laterally extensive and vertically persistent beds of much lower permeability. The lower permeable beds are considered to be part of the IAS/ICU or the ICU. A schematic is depicted in Figure 11.

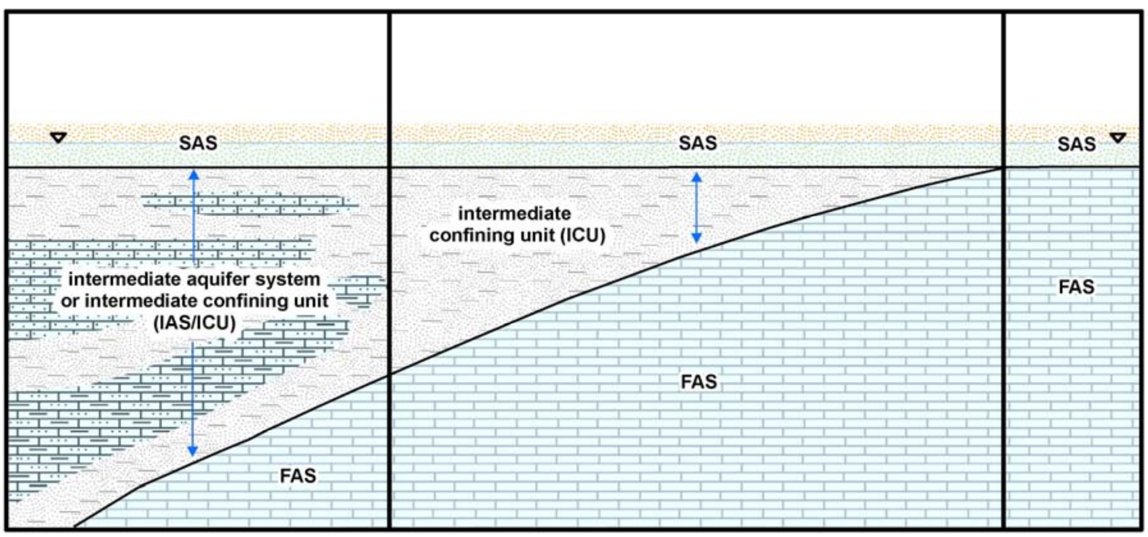


Figure 11. Generalized cross section of Florida's three uppermost aquifer systems. Note that no direction is implied.

There is one exception regarding the lower limit of the SAS (Figure 11, right). In portions of Florida where only a veneer (≤ 10 feet) of surficial sands directly overlie the carbonates of the FAS, the overlying surficial sands are considered to be part of the FAS and not the SAS. If a significant thickness (>10 feet) of surficial sands directly overlies the carbonates of the FAS, then the sands are considered to be part of the SAS. CFHUD II acknowledges the delineation at 10 feet is subjective. However, it also recognizes that in some places in Florida, the upper surfaces of the carbonates of the FAS are directly overlain by just a few feet of sand and are well connected hydraulically to the FAS. Depending on the rainfall conditions, the water table can reside in the carbonates or in the sands. Because of heterogeneity within the sands, the probability of the existence of significant "semi-confining"/confining material within the sands increases as the sands thicken. If the sand unit 10 feet or less thick, there is a reasonable probability that the sands are not separated hydraulically from the carbonates of the FAS.

Within the SAS one or more aquifers may be designated based on lateral or vertical variations in water-bearing properties. For example, in a portion of southwestern Florida, centered in Lee and Collier Counties, the SAS is composed of two distinct mappable aquifers separated by “semi-confining” to fully confining clays and carbonate muds (Missimer and Martin, 2001). In those parts of the state where all or part of the SAS constitutes a major source of supply, aquifers within it have been given distinctive names such as BA in southeastern Florida and the SGA in western panhandle Florida. The term surficial aquifer system replaces terms such as the "water-table aquifer," "nonartesian aquifer," "shallow aquifer," "sand aquifer," etc., that were previously applied in the literature to this hydrostratigraphic unit.

Intermediate Aquifer System or Intermediate Confining Unit

This unit includes all rocks that lie between and collectively retard the exchange of water between the overlying SAS and the underlying FAS. It can be referred to as the IAS, the ICU, or the IAS/ICU, depending on whether the system behaves predominantly as an aquifer system, a confining unit, or both (Figure 11). These units generally consist of fine-grained siliciclastic deposits intercalated with carbonate strata belonging to all or parts of the Oligocene and younger Series. The aquifers within this system contain water under confined conditions. The top of the IAS/ICU coincides with the base of the SAS and on a local scale with land surface. The base of the IAS/ICU is hydraulically separated to a significant degree from the top of the FAS. For the most part, the sediments comprising the IAS/ICU are the Hawthorn Group (Scott, 1988; Scott, 1991). However, in the panhandle the IAS/ICU is often includes the Alum Bluff Group, the Pensacola Clay, the Intracoastal and Chipola Formations, and may extend into the Jackson Bluff Formation. The terms: (1) intermediate aquifer system, (2) intermediate confining unit, and (3) intermediate aquifer system or intermediate confining unit replace previously used names such as the "secondary artesian aquifer(s)" and "shallow artesian aquifer(s)."

Floridan Aquifer System

The thick, predominantly carbonate, sequence comprising the FAS includes all or part of the Paleocene to Lower Miocene Series and functions regionally as one or more water-yielding hydraulic units. The FAS is present throughout the state and is the deepest part of the active, fresh, groundwater flow system in Florida.

The top of the FAS (Figure 11) usually contains a degree of hydraulic separation from overlying rocks. It generally coincides with the top of the vertically persistent permeable carbonate section and, less commonly, siliciclastics that have significant hydraulic separation with the permeable carbonates. Where overlain by either the intermediate aquifer system or intermediate confining unit, the FAS generally contains water under confined conditions (Figure 11, left and middle). Where overlain directly by sands, the top of the FAS is generally is under unconfined, but due to vertical variations in permeability, its deeper zones contain water under confined conditions. Where highly permeable sands directly overlie the FAS, the water table generally exists within the sands (Figure 12, left). Occasionally sands overlie the FAS but the water table lies within the carbonates of the FAS (Figure 12, right). As previously stated, if the sands are greater than 10 feet thick, they are generally considered to be part of the SAS. Otherwise, they are generally considered to be part of the FAS. Nevertheless, if site specific hydrologic data demonstrates a high degree of hydraulic connectedness between the SAS and the FAS, the data pre-empt the 10 feet SAS thickness guideline.

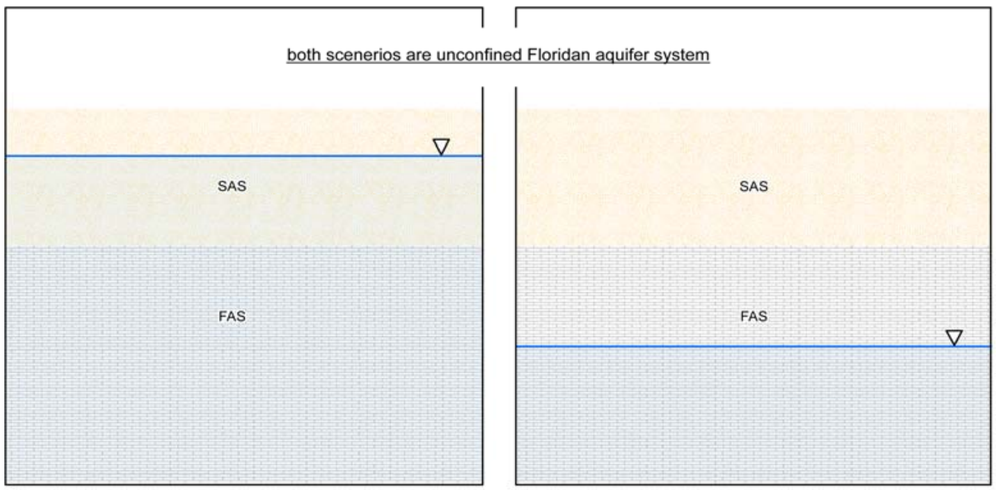


Figure 12. Surficial sands directly overlying the Floridan aquifer system.

Generally, the top of the FAS coincides with the top of the Suwannee Limestone (where it is present) or the top of the Ocala Limestone. In the panhandle, the top of the aquifer system may be the Bruce Creek Limestone, the Chattahoochee and St. Marks Formations, the Chickasawhay Formation, or the Marianna Limestone. In small areas of central peninsular Florida, and in southeast Florida, where the Suwannee and Ocala are missing, the Avon Park Limestone forms the top of the FAS. In portions of southwest Florida, the Tampa Member of the Arcadia Formation of the Hawthorn Group represents the top of the FAS (Arthur et al., 2008). Finally, in a small portion of southeast Florida, an unnamed limestone unit (Armstrong et al., 1985; Weedman et al., 1995) forms the uppermost unit of the FAS.

The base of the FAS in the panhandle is at the gradational contact with fine-grained siliciclastic rocks belonging to the Middle Eocene Series. In peninsular Florida, the base coincides with the appearance of the regionally persistent sequence of anhydrite beds that lie near the top of the Paleocene Cedar Keys Formation. The base of the FAS may also occur within the Eocene Oldsmar Formation or the Eocene Avon Park Formation where porosity is occluded by pore-filling anhydrite or thin evaporate beds.

Within the FAS, one or more aquifers (e.g. LFAS and UFAS) may be designated based on vertical variations in water-bearing properties. Similarly, at least one confining unit (i.e. MFCU) is recognized. The MFCU name is simply a modification of the middle confining unit described by Miller (1988). Miller mentioned that it consists of a series of units, both permeable and impermeable, that collectively are mapped as the MFCU. The LFA, the MFCU, and the UFA are mappable units located throughout most, but not all, of the extent of the FAS (Miller, 1988). The term Floridan aquifer system replaces the terms "Floridan aquifer" and "principal artesian aquifer" that previously have been applied to this hydrostratigraphic unit.

Since the (Miller, 1988) paper, there have been re-interpretations of the MFCU. For example, Arthur et al. (2008) mentioned that the number of sub-units of the MFCU varies from region to region. They also presented examples of inconsistent nomenclature usage pertaining to the MFCU, especially across water management boundaries. Over time, these and other issues regarding both the FAS and the MFCU will need to be addressed. Hopefully, the guideline presented in this paper will assist in resolving those issues.

Undifferentiated Aquifer Systems and Confining Units

The UAS/UCU units are strata of varying permeability that lie below the FAS. These systems and units are poorly defined because of inadequate data. From what is known, only broad statements regarding the uppermost sediments can be made. These sediments are of low permeability and they limit the depth of active groundwater circulation in Florida. In peninsular Florida, the uppermost unit is comprised mainly of a sequence of anhydrite beds interlayered with low permeability carbonate rocks belonging to the Paleocene and older Series. In the panhandle of Florida, the uppermost unit consists of fine-grained siliciclastic deposits belonging to the Middle Eocene and older Series. The uppermost unit is marked by the sharp permeability contrast with the more permeable carbonates at the base of the Floridan aquifer system.

CALL FOR THE DEVELOPMENT OF A NATIONAL CODE OF HYDROSTRATIGRAPHIC NOMENCLATURE

FHUD II considered preparing a draft Code of Hydrostratigraphic Nomenclature for use in Florida, as well as the entire North America. However, it quickly became apparent that, without the oversight of a well respected national entity, efforts by CFHUD II regarding specific nomenclature and mapping issue in Florida would not necessarily be accepted elsewhere. The development of a code of hydrostratigraphic nomenclature and mapping procedures is long overdue for the United States and other nations in North America. With this in mind, CFHUD II supports the formation of a national committee to develop a code of hydrostratigraphic nomenclature and mapping procedures. Note that the North American Commission for Stratigraphic Nomenclature has indicated an interest in establishing such procedures, but has not adopted them at the current time.

AQUIFER EXTENT AND UTILIZATION

Historically, Florida has steadily become more and more dependent upon its groundwater resources. In addition, it is anticipated that Florida will have no choice but to commence a search for new sources of groundwater in order to meet its future demands. For these reasons, the purposes of this section are to: (1) display the areal extent of each fresh-water aquifer system, (2) show where the state's aquifer systems are currently being used in significant quantities, and (3) suggest areas of the state where future groundwater supplies might reasonably be found.

Recall that Figure 2 depicts the locations of Florida's counties. For this report, for a county, significant groundwater use is considered to be greater than five percent of its total groundwater use. Total groundwater withdrawals by aquifer system by county for the year 2000 were obtained from Marella and Berndt (2005) and Marella (2006). The authors indicated that in 2000, the total amount of groundwater abstraction per county varied greatly, ranging from a minimum of less 1.8 millions of gallons per day (mgd) (Monroe County) to 541.6 mgd (Miami-Dade County). Table 2 displays the percentage of the total groundwater withdrawals for each county of the state by aquifer system. The table is a modification of the work of Marella (2006). Using Marella's work, Table 3 depicts the aquifers systems used significantly by water management district and by county. Currently, the IAS is used significantly only in parts of southwest Florida.

Figure 13 displays the extent of SAS including the sand-and-gravel aquifer in northwestern Florida and the Biscayne aquifer in the southeastern portion of the state. Where the two aquifers are present on the countywide scale, they are utilized more than either the FAS or the IAS. The SAS (Figure 14) is used extensively throughout southern Florida. The SAS is also utilized significantly in northeastern Florida in Flagler, St. Johns, and Nassau Counties. In the panhandle, in addition to the SGA, the SAS is currently utilized significantly in Gulf County. Miller (1988) indicated that because of the permeable nature of SAS sediment, rainfall easily percolates downward to the water table. From there, groundwater either moves laterally to points where it is discharged into surface streams or vertically downward to recharge either the FAS or the IAS. In portions of the state where there is no other source of groundwater, and the SAS is sufficiently thick, the SAS can potentially supply water for industrial, agricultural, or municipal use. Nevertheless, the sediments making up the SAS are often thin and discontinuous and, for these reasons, groundwater in the SAS is utilized primarily for domestic use. Because of its discontinuous nature, the SAS probably has limited potential for increased water use in the future.

Figure 15 displays the extent of the IAS/ICU and where the IAS is used significantly. In the portion of Florida where the IAS is not considered present, the sediments comprising the ICU often do exist. The only portion of the state where the IAS is currently being used significantly is in southwestern Florida. Nevertheless, since the IAS/ICU exists over much of the state, it will likely become a significant source of future groundwater use.

Figure 16 displays the aerial extent of the FAS in Florida where it is being used significantly. On a coarser scale, it extends from South Carolina to Mississippi. In Florida, it exists beneath the entire state and is the most widely utilized aquifer system. The top of the aquifer system dips to the west in extreme northwestern Florida and to the south in southern Florida. With depth, the groundwater becomes highly mineralized. Figure 16 indicates that the FAS is significantly used everywhere except in the extreme northwestern and southern portions of the state.

Table 2. Percentage of total groundwater withdrawals by county and by county and by aquifer system, 2000

[Modified from Marella and Berndt (2005) and Marella (2006)].

County	%FAS	%IAS	%SAS		County	%FAS	%IAS	%SAS
Alachua	99.3	0.0	0.7		Lee	16.1	27.1	56.8
Baker	96.7	0.0	3.3		Leon	99.1	0.0	0.9
Bay	98.4	0.0	1.6		Levy	98.6	0.0	1.4
Bradford	96.7	0.0	3.3		Liberty	97.3	0.0	2.7
Brevard	86.1	0.0	13.9		Madison	98.7	0.0	1.3
Broward	< 0.1	0.0	99.9		Manatee	96.7	3.3	0.0
Calhoun	97.9	0.0	2.1		Marion	97.6	0.0	2.4
Charlotte	20.4	75.4	4.2		Martin	13.3	0.0	86.7
Citrus	97.7	0.0	2.3		Miami-Dade	0.7	0.0	99.3
Clay	98.2	0.0	1.8		Monroe	86.7	0.0	13.3
Collier	2.2	57.2	40.6		Nassau	93.7	0.0	6.3
Columbia	97.3	0.0	2.7		Okaloosa	99.6	0.0	0.4
De Soto	88.8	11.2	0.0		Okeechobee	79.9	0.0	20.1
Dixie	97.7	0.0	2.3		Orange	99.7	0.0	0.3
Duval	97.2	0.0	2.8		Osceola	97.6	0.0	2.4
Escambia	0.0	0.0	100.0		Palm Beach	2.4	0.0	97.6
Flagler	83.8	0.0	16.2		Pasco	99.7	0.0	0.3
Franklin	99.1	0.0	0.9		Pinellas	99.9	0.0	0.1
Gadsden	97.9	0.0	2.1		Polk	96.1	3.5	0.4
Gilchrist	99.2	0.0	0.8		Putnam	98.8	0.0	1.2
Glades	36.4	3.4	60.2		St. Johns	88.9	0.0	11.1
Gulf	82.9	0.0	17.1		St. Lucie	58.1	0.0	41.9
Hamilton	99.8	0.0	0.2		Santa Rosa	29.3	0.0	70.7
Hardee	90.3	9.7	0.0		Sarasota	67.5	32.4	0.1
Hendry	0.1	64.0	35.9		Seminole	99.7	0.0	0.3
Hernando	99.7	0.0	0.3		Sumter	98.3	0.0	1.7
Highlands	85.0	14.9	0.1		Suwannee	99.0	0.0	1.0
Hillsborough	98.7	1.2	0.1		Taylor	99.8	0.0	0.2
Holmes	96.6	0.0	3.4		Union	96.2	0.0	3.8
Indian River	84.7	0.0	15.3		Volusia	99.7	0.0	0.3
Jackson	98.5	0.0	1.5		Wakulla	100.0	0.0	0.0
Jefferson	99.2	0.0	0.8		Walton	99.8	0.0	0.2
Lafayette	99.1	0.0	0.9		Washington	96.8	0.0	3.2
Lake	99.5	0.0	0.5					

Table 3. Significant groundwater withdrawals by aquifer system by water management district, by county, 2000
[Modified from Marella and Berndt (2005) and Marella (2006)].

Northwest Florida Water Management District				Suwannee River Water Management District				St. Johns River Water Management District			
County	**FAS**	**IAS**	**SAS**	**County**	**FAS**	**IAS**	**SAS**	**County**	**FAS**	**IAS**	**SAS**
Bay	Y			Alachua	Y			Alachua	Y		
Calhoun	Y			Baker	Y			Baker	Y		
Escambia			Y	Bradford	Y			Brevard	Y		Y
Franklin	Y			Columbia	Y			Clay	Y		
Gadsden	Y			Dixie	Y			Duval	Y		
Gulf	Y		Y	Gilchrist	Y			Flagler	Y		Y
Holmes	Y			Hamilton	Y			Indian River	Y		Y
Jackson	Y			Jefferson	Y			Lake	Y		
Jefferson	Y			Lafayette	Y			Marion	Y		
Leon	Y			Levy	Y			Nassau	Y		Y
Liberty	Y			Madison	Y			Orange	Y		
Okaloosa	Y			Suwannee	Y			Osceola	Y		
Santa Rosa	Y		Y	Taylor	Y			Putnam	Y		
Wakulla	Y			Union	Y			St Johns	Y		Y
Walton	Y							Seminole	Y		
Washington	Y							Volusia	Y		

Table 3. (continued)

Southwest Florida Water Management District				South Florida Water Management District			
County	**FAS**	**IAS**	**SAS**	**County**	**FAS**	**IAS**	**SAS**
Citrus	Y			Broward			Y
Charlotte	Y	Y		Charlotte	Y	Y	
De Soto	Y	Y		Collier		Y	Y
Hardee	Y	Y		Glades	Y		Y
Hernando	Y			Hendry		Y	Y
Highlands	Y	Y		Highlands	Y	Y	
Hillsborough	Y			Lee	Y	Y	Y
Lake	Y			Martin	Y		Y
Levy	Y			Miami-Dade			Y
Manatee	Y			Monroe	Y		Y
Marion	Y			Okeechobee	Y		Y
Pasco	Y			Orange	Y		
Pinellas	Y			Osceola	Y		
Polk	Y			Palm Beach			Y
Sumter	Y			Polk	Y		
Sarasota	Y	Y		St. Lucie	Y		Y

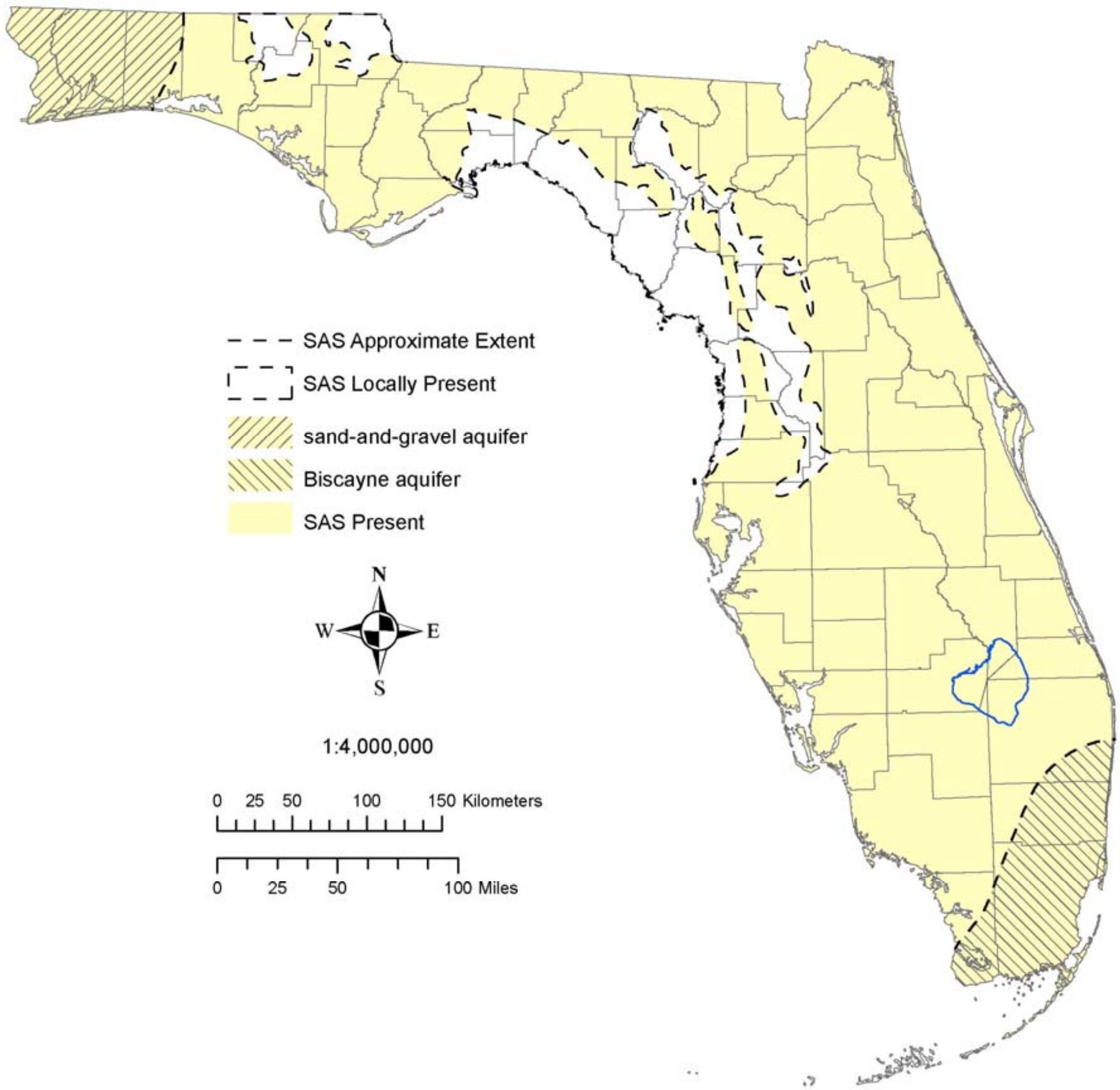
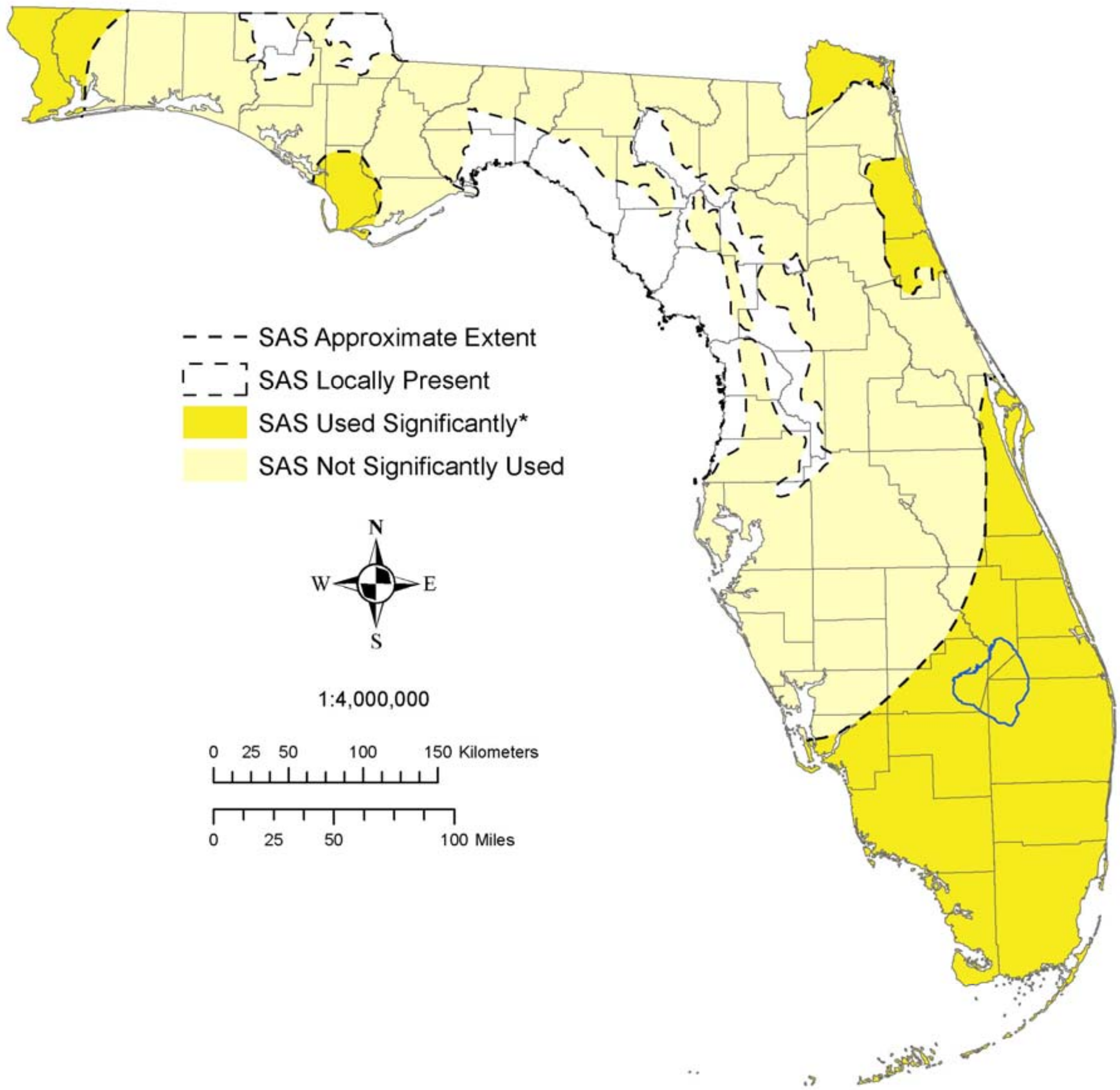


Figure 13. Extent of the surficial aquifer system, including the sand-and-gravel aquifer and the Biscayne aquifer.



* Significant is greater than 5% of county groundwater use, based upon 2000 data from Marella and Bendt (2005)

Figure 14. Areal extent of surficial aquifer system and where it is used significantly.

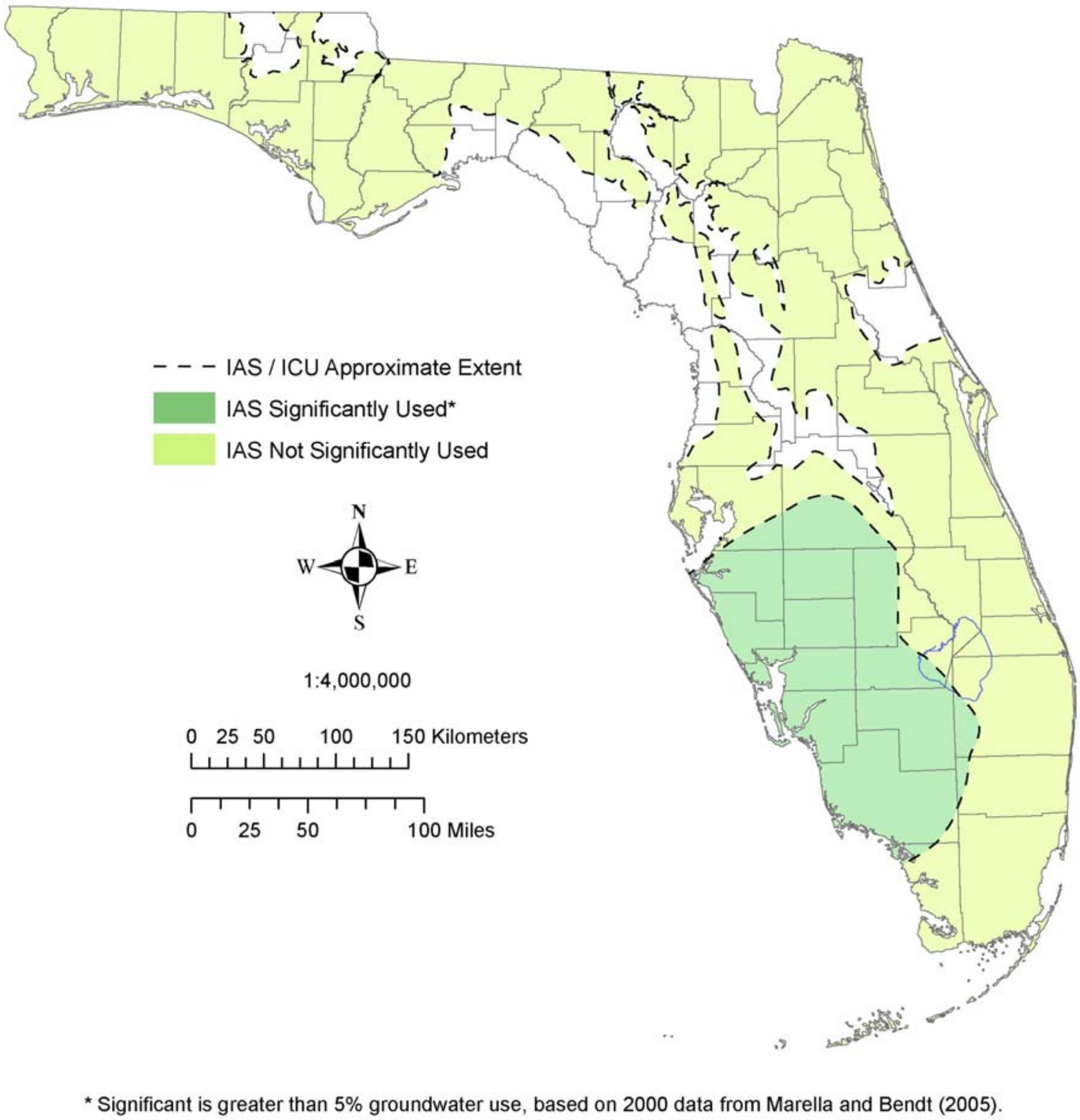


Figure 15. Areal extent of the intermediate aquifer system or the intermediate confining unit and where the aquifer system is used significantly.

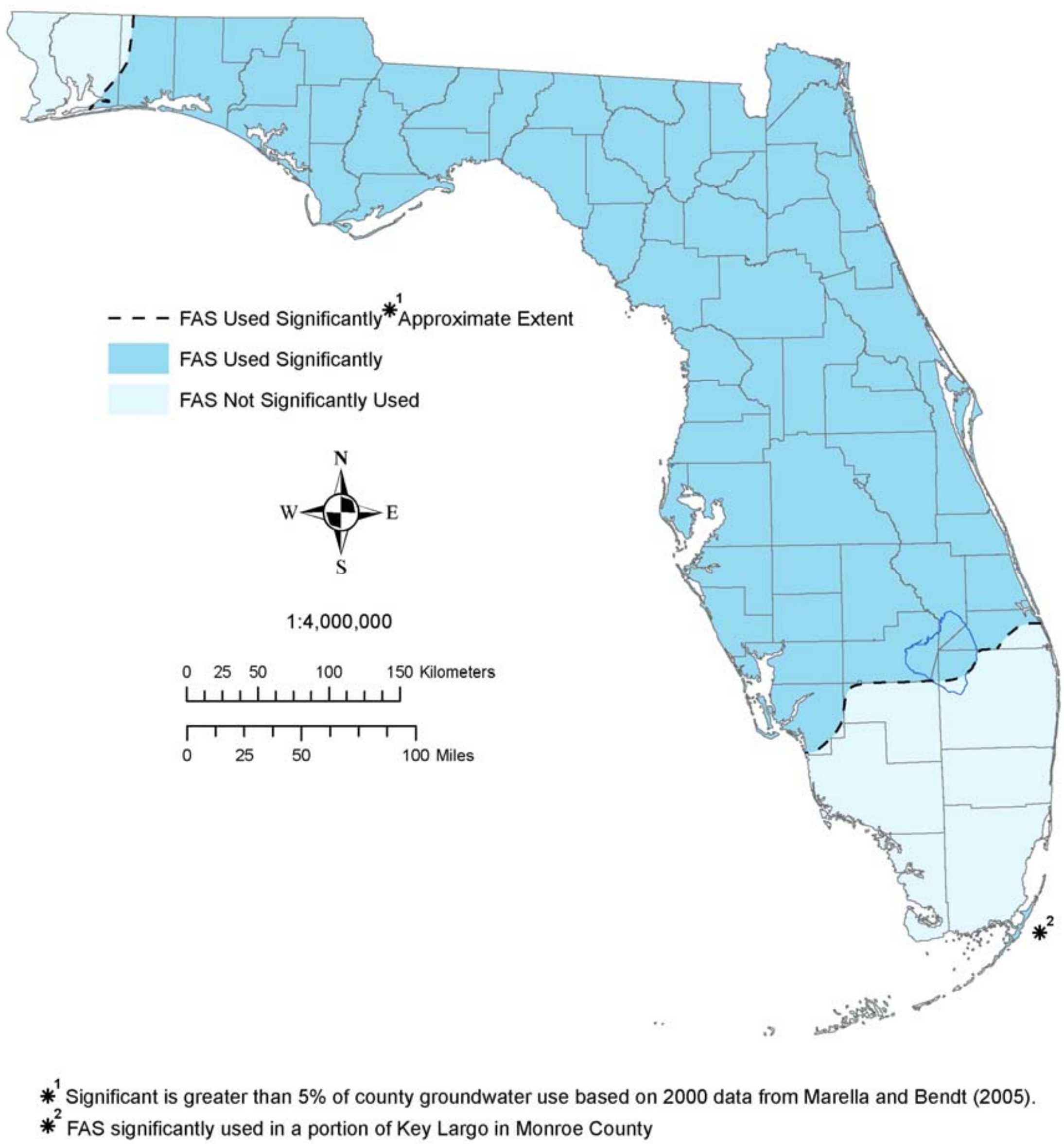


Figure 16. Areal extent of the Floridan aquifer system and where it is used Significantly.

In closing, consider the following. An aquifer is considered to be "a body of rock that contains sufficient saturated permeable material to conduct groundwater and to yield significant quantities of water to wells and springs" (Neuendorf et al., 2005). Comparing the areal extent of each aquifer system to the areas where the aquifer systems are currently being used significantly (Figures 14, 15, and 16) can assist in determining new areas of the state that can potentially be used for future groundwater supplies. However, it should also be understood that a potential also exists of encountering: (1) low permeabilities; (2) low quantities of groundwater; and (3) highly mineralized groundwater. Any one of these issues may limit their usage.

GLOSSARY

Unless otherwise stated, the terms are in this glossary are from Neuendorf et al. (2005). It should be note that *italicized* phrases are found in the glossary.

aquifer – A body of rock that contains sufficient saturated permeable material to conduct *groundwater* and to yield significant quantities of water to wells and springs.

aquifer system – A heterogeneous body of intercalated permeable and less permeable material material that functions regionally as a water yielding hydraulic unit and may be comprised of more than one aquifer separated, at least locally, by *confining units* that impede groundwater movement but do not greatly affect the hydraulic continuity of the system (Modified from Poland et al., 1972).

aquitard – See *confining unit*.

artesian – See *confined*.

confine – To restrict in movement (Barube and Boyer, 1985).

confined – An adjective referring to *groundwater* under hydrostatic pressure.

confined aquifer – An aquifer bounded above and below by *confining beds* or *confining units*.

"confiner" – An informal term for *confining unit*. Its usage is discouraged.

confining bed – See *confining unit*.

confining unit – A body of relatively impermeable or distinctly less permeable material above and/or below by an aquifer.

gradational – A description of a series of gradual, successive stages or systematic progressions (Modified from Barube and Boyer, 1985).

groundwater – That part of the subsurface water that is in the saturated zone.

hydraulic conductivity – The volume of water at the existing *kinematic viscosity* that will move in a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In contrast to *permeability*, it is a function of the properties of the liquid as well as the porous medium.

hydrostratigraphic unit – A body of rock distinguished and characterized by its porosity and permeability. It is unified and delimited on the basis of its observable hydrologic characteristics that relate to its interstices.

indurated – Said of a rock or soil hardened or consolidated by pressure, cementation, or heat.

intercalated – Said of layered material that exists or is introduced between layers of a different character (Modified from Neuendorf et al., 2005).

kinematic viscosity – The ratio of the viscosity coefficient to density at room temperature.

local – An area of less than a few counties (CFUHD II).

mappable – A physical feature that can be proportionally represented in one, two, or three dimensions. The area or space mapped must be significant relative to the scale of mapping (CFHUD II).

nonartesian – See *unconfined*.

permeability – The property or capacity of a porous rock, sediment, or soil for transmitting a transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure and is a function only of the medium.

porosity – The percentage of bulk volume of rock or soil that is occupied by interstices, whether isolated or connected.

regional – An extent approximating the size or larger than that of a water management district (CFUHD II).

retard – To slow the progress of, impede, or delay (Barube and Boyer, 1985).

"semi-confined" – An informal term for a body of rock that is relatively less permeable than the material that it borders. These units have little or no horizontal flow. They can store groundwater and transmit it slowly from one aquifer to another. (Modified from Southwest Florida Water Management District, 2005).

siliciclastics – Pertaining to clastic non-carbonate rocks that are almost exclusively silicon-bearing, either as forms of quartz or as silicates (Modified from Neuendorf et al., 2005).

stratigraphic unit – A stratum or body of rock recognized as a unit in the classification of the Earth's rocks with respect to any of the many characters, properties, or attributes that rocks may possess.

strata – Plural of *stratum*.

stratum – A tabular or sheet-like body or layer of sedimentary rock, visually separable from other layers above and below.

sub-regional – An extent encompassing a few counties (for this publication) (CFUHD II).

system – A major interval in a category of hydrostratigraphic classification (CFHUD II).

transmissivity – The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to the product of *hydraulic conductivity* and aquifer thickness.

unconfined – Groundwater that is not *confined* under pressure beneath a *confining bed*; it has a *water table*.

water table – The surface between the saturated zone and the unsaturated zone; that surface of a body of *unconfined* groundwater at which the pressure is equal to that of the atmosphere.

zone – A minor interval in a category of stratigraphic or hydrostratigraphic classification.

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