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such, most nutrient concentrations observed in springs are localized and should be analyzed in relation to the corresponding springshed pxiv

nitrogen can be stored in the soils of Florida's springsheds (Bruland et al., 2008). pxiv

When rainfall conditions return to normal, the soils will release the nitrogen and concentrations in spring water will eventually increase. On a similar note, decreases in phosphorus in some areas may likewise not be a reflection of improved management. It is possible that the upward migration of older water, with different chemistry, reduced the phosphorus concentrations in many springs. If so, reduction of phosphorus could simply be a byproduct of mixing with deeper, higher pH water—not an improvement in water quality. This mechanism is discussed by Hem (1985) and by Odum (1953). They indicated that the solubility of phosphorous can be controlled by pH. p xv

Saltwater encroachment is the displacement of fresh groundwater by the advance of saltwater due to its greater density (Neuendorf et al., 2005). It can occur during a drought when recharge declines and the freshwater "lens" shrinks in size. Over geologic time, it can occur with sea-level rise. It can also occur when excessive groundwater pumping causes the advancement of saltwater. Freeze and Cherry (1979) use the term saltwater intrusion as the migration of saltwater into freshwater aquifers under the influence of groundwater development (pumping).

For this paper, we use the term intrusion to indicate a man-induced process and use the term encroachment to make no distinction between natural and man-made causes. p xvi

In order to make up for the drought, groundwater pumping increased, largely for irrigation (Verdi et al., 2006). Because an increase in groundwater pumping occurred during one of worst droughts, it is likely that human-induced saline intrusion took place and contributed to the increase in saline and rock matrix analyte trends. On a statewide scale, the extent and severity of the intrusion is difficult to quantify. However, within the northern portion of the SWFWMD, a water budget and a regional groundwater flow model indicated that the increase [0.3 cm/yr (+0.1 in/yr)] in groundwater withdrawals was less than 2.0% of the decline in recharge due to the decrease [18.3 cm/yr (7.2 in/yr)] in rainfall (Ron Basso, Southwest Florida Water Management District, personal communications). Nevertheless, intrusion should be a concern. If another drought of this magnitude occurs, depending on the amount of increased pumping, it could potentially have adverse affects on the long-term sustainability of Florida's groundwater resources. p xvii

It also noted that over the past 30 years many of Florida's springs experienced an increase in nuisance algae and invasive exotic aquatic plants. These plants tend to thrive on excess nutrients and decrease dissolved oxygen levels in spring runs.

Analyses for the 1991-2003 time frame indicated that trends in nutrient concentrations in Florida's spring-water increased in some springs, while they decreased in others. It is encouraging to note that there are some decreasing trends. The fact that nutrients (especially nitrate) tended to increase is an indication that some land-use management practices warrants reevaluation. But as noted previously, the relationship of these apparent decreasing trends may be related to diminishing spring flow. p xviii

Spring-water quality is sensitive to changes in spring flow and to aquifer water levels. They represent excellent natural sampling locations for monitoring saline incorporated into a statewide saltwater encroachment monitoring network. It is recommended that, to the extent practical, springs should be incorporated into a statewide saltwater encroachment monitoring network. The results of the spring monitoring could then potentially be e used to supplement well monitoring networks that are used for saltwater encroachment purposes p xix

Although the monitoring of springs and wells is critical for the sustainability of Florida's water resources, not all analytes of concern are sampled. Synthetic organic, other supplementary analytes (supplementals), as well as biological indicators, should be included on the monitoring lists. It should be understood that supplementals are expensive to collect and analyze, and for these reasons, they can only be sampled on a low frequency basis. It should also be noted that supplemental monitoring is often determined by site-specific issues. For example, pesticides may only be detected at certain times of the year or in certain locales, determined by land use conditions. Supplementals such as pesticides, synthetic organic compounds, and trace metals should occasionally be sampled. p xix

If one or more indices were developed, they have the potential to become very useful in informing the public about the status of our springs. However, in order to be viable, buy-in by both the public and scientific communities are essential. Hopefully, indices will be adopted in the future.p xxi

Over the past several decades, flows in Florida's springs are declining and water quality is degrading. The primary chemicals of concern are nutrients, including soluble forms of nitrogen and phosphorus. p 1

The springs provide a "window" into the aquifer, allowing for a measure of the health of the aquifer. Chemical and biological constituents that enter the aquifer through recharge processes may negatively affect the water quality in aquifers, as well as the flora and fauna of springs and spring runs. The declines in water quality can be directly attributed to Florida's increased population and changing land-use patterns (Florida Springs Task Force, 2000). p 3

.The springshed consists of all areas where water can be shown to contribute to the groundwater flow system that discharges from the spring of interest. p 6

Florida enjoys a humid, subtropical climate throughout much of the state (Henry, 1998). Rainfall, in the region of the major springs (Figure 1), ranges from 127 cm (50 inches) to over 152 cm (60 inches) per year. As a result of the climate and the geologic framework of the state, Florida has an abundant supply of fresh groundwater. Scott (2001) estimated that more than 8.3 billion cubic meters [2.2 quadrillion (2.2×10^{12}) gallons] of freshwater are contained within Florida's aquifers. However, only a very small percentage of freshwater is available as a renewable resource for human consumption p 7

As the acidic rainwater percolates downward to the FAS, it is made slightly more acidic by carbon dioxide from the atmosphere and organic acids in the soil. Once in the FAS, the groundwater dissolves portions of the limestone and enlarges naturally occurring fractures. The dissolution enhances the permeability of the sediments and forms cavities and caverns. Sinkholes are formed by the collapse of overlying sediments into the cavities. Occasionally, the collapse of the roof of a cave creates an opening to the land surface. See Lane (1986) for a description of sinkhole types common in Florida. p8

Natural Factors Affecting Groundwater and Spring-Water Quality

Most of the Florida land mass is a peninsula that is surrounded by saltwater. Relict saltwater also underlies the entire state. The reason for this is that the Florida Platform consists of carbonate rocks that were deposited in a shallow ocean. At the time of deposition, saltwater existed in their inter-granular pore spaces. Gradually over geologic time, sea level was lowered relative to its position when the carbonate sediments were deposited. Through compaction and down warping of sediments on both sides of the Platform, a series of complex fracture patterns developed. The patterns are often reflected at land surface and have actually influenced the pathways of many of Florida's streams.

Over geologic time, as sea level lowered, the central portion of the Florida Platform was exposed to the atmosphere. As rainfall percolated downward it eventually replaced the upper portion of saltwater in the developing aquifers with a freshwater “lens.” Today, the irregularlyshaped “lens” is generally thickest in the central portion of the state, where it is over 610 m (2,000 ft) thick (Klein, 1975). It becomes narrow toward Florida's coastline. The base of the “lens” is typically a transitional rather than a sharp boundary. Groundwater in the deeper portion of the “lens”, and along the coasts, is mixed with saltwater and has relatively high concentrations of saline indicators such as sodium (Na), chloride (Cl), and sulfate (SO_4). p 9

A long residence time may allow sufficient time for chemical reactions between the water and the aquifer rock. As such, water chemistry reflects the composition of the aquifer rock. Typical residence times range from less than several days (in secondary produced caverns and sinkholes) to centuries (Hanshaw et al., 1965).

A second factor affecting groundwater chemistry is flow path, which is the length and depth of the path that the groundwater follows as it flows through an aquifer (Upchurch, 1992). In general, shallow, short flow paths (which are characteristic of the SAS) result in shorter residence times for chemical reactions to take place. Consequently, the total dissolved solid (TDS) content is less than in longer flow-path systems. If the flow path is long (on the order of tens of kilometers), such as commonly occurs in the FAS, reactions between rock and water become more probable and the TDS content of the water would be greater as a result of continued rock-water chemical reactions. Because of the residence time and the flow paths of the groundwater within an aquifer, the quality of spring water is typically reflective of the interactions of the major rock types in the aquifer and the groundwater itself.

A third factor which is of particular interest is inter-granular porosity (pores through which water passes between the individual rock matrix grains). Even though Florida's aquifers have large, secondary cavernous pores spaces, most of the pores tend to be small (Upchurch, 1992). Fortunately, whenever the pores are very small, they act as filters for microbes, small organic substances, and clay minerals. In general, this results in naturally filtered groundwater that is very pure and desirable for both drinking water and recreation. Unfortunately, some pollutants not always removed and our aquifers can become contaminated.

Differences in Spring- and Well-Water Quality

The processes controlling the water quality in wells is very similar to those controlling spring-water quality with at least one major difference. Wells are often drilled to production zones as close to land surface as is economical. This is the situation for the wells used in this study, which are for the most part monitoring wells. Monitoring wells tend be shallow (median depth ≈ 80 feet (24 m) (Appendix C, online). Most water in these shallow wells represents young, recently recharged water. On the other hand, because springs are major discharge points, spring-water can be considered to be an integrator of water from the entire springshed.

Spring water is a mixture of young, shallow, freshly recharged water and older water from the deeper portions of the aquifer. For this reason, spring water tends to be older than the relatively shallow water found in the monitoring wells used in this study.

Indicators of Groundwater and Spring-Water Quality Problems
Spring water, while it resides in the aquifer, is considered to be groundwater. However, once spring water exits from the spring onto the earth's surface, it is considered to be surface water. Because of this change, the question arises whether regulators should apply groundwater or surface water quality standards to the water. Primary and secondary standards with maximum contaminant limits (MCLs) may exist for an analyte while the water is considered groundwater, but differ for surface water; or vice versa. p 10

Problems.
One of the more disturbing aspects about Florida's groundwater quality has been the documented steady increase of nitrate over the past several decades .p 11

Another groundwater quality concern is the influence of saline water. Several springs have concentrations of chloride (Cl; a saline indicator) exceeding the 250 mg/L threshold for drinking water. Springs with this type of water tend to be located along Florida's coast and along the St. Johns River.

The ultimate source of the saline indicators is from naturally occurring saline water within the FAS (Klein, 1975), or from sea water near Florida's coasts. When the concentrations of saline indicators are increasing, it may be the result of: (1) natural circumstances such as drought, (2) the consequent upconing of groundwater within the FAS, or (3) lateral intrusion of salt water due to increased groundwater pumping. p 11

Natural systems in general undergo two main types of change: cyclic and linear (A and B, top of Figure 8). Cyclic change is common in nature. Two common examples of cyclic changes include diurnal and seasonal changes. Natural changes can also be linear, moving conditions from one state to another without returning to the original state. The focus of this report is to document linear trends in water quality and quantity. It is also assumed that trends in certain analytes are most likely anthropogenic, rather than natural in origin p 17

Verdi et al. (2006) mentioned that a drought is a time of less-than-normal or expected rainfall. It can be thought of as a period of time when there is insufficient water to support the agricultural, urban or environmental needs of a society. They also stated that a hydrological drought is an extended period during which stream flow, lake, reservoir storage, and groundwater levels are below normal.

Referring to a drought, Jackson (1997) said, “In general, an extended period of dry weather or period of deficient rainfall that may extend over an indefinite number of days. There is not a quantitative standard to determine the degree of deficiency needed to constitute a drought. Qualitatively, a drought may be defined by its effect as a dry period of sufficient length and severity to cause at least partial crop failure or having impacted the ability to met normal water demand.” p 126

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Figure 56. Fresh groundwater wedge before and during a drought. Top – Saline transition water (hatched) and saline water surround Florida. During normal times, freshwater “lens” is thicker and spring flow is greater.
Bottom - Reduction in spring flow reflects freshwater “lens” decrease. Reduction draws in saline water, both laterally and potentially from below.

According to Marella and Berndt (2005), Florida's groundwater withdrawals for all water use categories (agriculture, public supply, commercial/industrial, recreation, domestic, and power generation) in 2000 exceeded 3.1 billion gallons per day. Of those categories, agriculture and public supply accounted for over 82 percent. If divided evenly amongst the population, in 2000, over 190 gallons per day (gpd) of groundwater were used by each person of the state.

Since Florida's population is growing by 730 people per day and each new person is using over 190 gpd, then the demand for groundwater increases by more than 135,000 gpd or by more 50 million gallons per year.

Because of the lack of precipitation, in an effort to make up for the lack of rain, the pumping of groundwater typically increased during droughts. Thus during Sequence C the drought, the increased population and the increase in consumption of groundwater each had a negative impact on both the quantity and quality of Florida's groundwater resources.

Groundwater Summary
Groundwater quantity and quality data indicates that during Sequence C, Florida suffered from natural saltwater encroachment during the drought. The ability to quantify the extent and severity of the encroachment problem on a statewide basis is not possible at this time due to lack of sufficient data. The drought caused a decline in recharge which in turn lowered the potentiometric surfaces in Florida's aquifers followed by a decrease in spring flow. This was exacerbated by: (1) the increased pumping of groundwater during the drought and (2) the increased demand for groundwater because of the increased population. The consequence of the drought and the increased pumping of groundwater was saltwater encroachment. It is indicated by decreasing trends in spring flow and increasing trends in the concentration of rock and saline indicators.

A return of normal rainfall should greatly help in reversing the process. In the future, spring monitoring and trend analyses should identify any changes. In addition, water conservation practices, along with minimum flows and levels (MFLs) (Florida Statutes,1983, Chapter 373.042) being established by the WMDs should mitigate the affect of future droughts. Nevertheless, the monitoring of population growth, pumping of groundwater, per capita water use, as well as water quality and quantity, are also needed in order to properly manage our water resources. p 134

<u>The King's Bay Springs Group</u> is the second largest system in Florida. Tarpon Hole and Hunter Springs are part of this group. Freshwater springs were located on the east side of the bay while springs with brackish water were found in the central and western portions. As of 2001, flow in the springs was only 75 percent of the historical average (Champion and Starks, 2001).

Water quality in the King's Bay Springs Group is tidally influenced. TDS and chloride concentrations change with tides. This suggests that, even at low tide, the springs are strongly influenced by the coastal transition zone. Most nitrate input was from inorganic sources, most likely inorganic fertilizers applied to golf courses and residential properties near the springs.Thus, the nitrates are indicative of a local flow system (Jones and Upchurch, 1994).

<u>Homosassa Springs Group</u>
The Homosassa Springs Group, in western Citrus County, had several springs with upward nitrate trends: Homosassa, Trotter Main, Pumphouse, and Hidden River Head. Like the King's Bay Group, the Homosassa Springs Group shows an influence from the coastal transition zone (Jones et al., 1997). Like the King's Bay Springs Group, Homosassa Springs Group nitrates were derived primarily from

inorganic sources of nitrate—inorganic fertilizers applied to residential and golf course turf grass near the springs. Again, the nitrates represent a local flow system.

Chassahowitzka Springs Group

Like the King's Bay and Homosassa Groups, Chassahowitzka Springs Group varies between fresh and brackish and is tidally influenced. TDS and chloride concentrations varied greatly, showing a coastal transition zone influence even at low tide (Jones et al., 1997). Nitrate concentrations were generally below 0.6 mg/L but varied among individual springs in the group. Mixing of coastal transition zone waters and variations in Floridan aquifer system nitrate concentrations were sources of variations. Most nitrate was derived from inorganic sources, such as inorganic fertilizers applied to residential and golf course grass near the springs (Jones et al., 1977) p149