<u>Research Paper: Naturecoast Water Systems, June, 2011</u>

<u>Abstract</u>

Since 1994, the quantity of groundwater discharged from springs into Kings Bay has dropped by one third from 630 million gallons per day (mgd) to some 410 mgd. Among reasons for this are drought, pumping, increased evaporation rates fro roads and buildings and reduced porosity in flow pathways resulting from increased sedimentation from the slowing flow.

According to FGS Bulletin 69 this correlates with increased degradation of water quality in our protected surface waterways which, if it were the only consequence, is itself serious indeed.

When viewed as the underlying reason for reduced potentiometric aquifer levels in relation to our fresh water (potable) resources it could become deadly serious.

When we reflect upon contamination of the region's freshwater "lens" by radionuclide fall out accumulations from nuclear power generation plants situated in areas of unconfined aquifer systems; the disturbance of the "lens" systems by digging deep into them and grouting huge areas for reactor vessel foundations; digging deeper still for mining activities associated with the nearby proposed Tarmac, Kings Road mine together with associated toxic run off from a thousand trucks a day traversing roadways adjacent to the protected waterways; coupled with any additional pumping from the aquifer systems consequent upon the ongoing *(mis-)*calculation of Minimum Flows and Levels (MFL), the seriousness rises to suicidal proportions for Citrus County.

Simply put, we are consuming more potable water than is being replenished to us naturally. We have the wake-up call.

EXECUTIVE SUMMARY

The waters administered by the Southwest Florida Water Management District (SWFWMD) are all south of Florida's Hydrologic Divide such that the sole source of recharge to the aquifer and its fresh water "lens" system is rainfall.

The rainfall for Citrus and Levy Counties, 1915-1996, averaged about 52 inches a year with evapotranspiration directly returning some 42 inches to the atmosphere. Exposed water bodies and impermeable surfaces evaporate water into the atmosphere at much higher rates (up to 64 inches per year) which further reduce volumes available for aquifer recharge.

The systems depicted by the FGS Bulletin 66 indicate a unified water source for the spring systems which supply virtually all of the fresh water flowing out of the coastal rivers of the Nature Coast.

Environmentally, these Ghyben-Herzberg lens systems are crucially important not only to healthy stream flows and the biotic health of the protected waterways but also to the region's potable water supply. The lens system assures the water supply only so long as its lens' mass remains sufficient to inhibit mixing of non-potable water from lower aquifer systems. Florida Geological Survey have advised that the lens' depths have reduced since last being surveyed by Howard Klein et. al., in 1975 but is not due to be determined again for some time to come.

Klein reported upon areas of the east coastal and southern regions of Florida which had become completely denuded of the potable water lens due to over-pumping. Moreover, the 2010 report to SWFWMD by Vanasse Hengen Brustlin, Inc. graphically illustrates the discharge of non-potable water from spring vents fed from a contaminated lens system co-located with an underground tributary into the southern section of Kings Bay.
Periods of drought, returns to the atmosphere, high rates of pumping, and lateral underground infusions from the Gulf of Mexico (Fretwell and

Causseaux,1983), seek to reduce the mass and precipitate the mixing. **To preserve the integrity of this vital potable water lens systems an absolute standard would appear to be warranted and rigorously enforced, say, at the theoretical tipping point plus a fifty percent margin.**

For example, fall out from reactor air emissions, of certified carcinogenic radionuclides, onto the region's poorly confined aquifer systems will seriously hazard public health in local communities. Over the life of the plant accumulations in groundwater systems will have exceeded federal drinking water standards many times over. Furthermore, massive excavation and pressure grouting of the lens systems to seal off to a depth of 100 feet in order to de-water the foundation structures for the two nuclear reactors proposed for Levy county will radically disrupt and hazard the region's potable water resource. It will be further exacerbated should the excavation of the Tarmac /Kings Road mine be permitted by the United States Army Corps of Engineers (to a depth of 120 feet over an area of 2,757 acres).

BACKGROUND

David Suzuki, wrote in "Betraying Nature" of 8 April, 2009, an essay, published in "the Big Picture", 2009, by David Suzuki and Dave Robert Taylor.

> *"One of the hallmarks of science is that experiments must be repeatable. So when performing experiments, we remove all the confounding factors that could influence or confuse the results.* ***But nature doesn't work that way.*** *Nature does not operate in a vacuum. Interconnections among the various parts of the natural world are what actually drive it. When we pull it apart, we lose context, and that can mean everything."*

Like all biotic systems, time itself has conditioned the global fabric of our own existence within the reach of nature's complex of interrelating natural systems and changing periods of day, night and the seasons. A mathematical modeler, to assist understanding, has first to establish that the system addressed is capable of worthwhile examination as a separate entity and remain representative of the total universe of data and influences that man barely understands. Anything less is merely a "pulling apart" resulting in loss of contextual meaning, exposing ecosystems to risk of unintended consequences of human endeavors.

Environmental Issues

Environmental issues both impact and are impacted by people. There is no single ecologic factor that acts alone in any environment.

The fresh water "lens" of the regional aquifer systems is the sole source of potable water of the region. It is recharged exclusively by rainfall which percolates readily into the underground aquifer systems. [See Figure 1.](The illustration Figures are collected in Annex B).

Anthropogenic pollutants percolate down from the land surface into the aquifer systems reducing water quality of the lens. When the lens depth is reduced below a required threshold, for example, when pumped withdrawals, for domestic, agricultural or industrial uses, combine with the natural discharges via spring vents and have exceeded the regional rainfall accumulations, concentrations of chlorides and dissolved solids are allowed to well up from deeper aquifer systems and add to the degradation of water quality in the lens, [See Figure 2.] A description of the Ghyben Herzberg relation is given in Annex C to this paper

A recent study by Vanasse Hangen and Brustlin, Inc, showed graphically just how prone are these systems serving Kings Bay to anthropogenic changes from pumping and pollution. [See Figure 3.] Increasing saltiness levels of spring discharges over prior years had already induced ecological changes, as marine and exotic species of aquatic vegetation out-competed native fresh water species. Yet just a single isolated year of near average rainfall was sufficient to reduce by half measurements of specific conductance (saltiness) of water being discharged from Kings Bay springs.

When depths of the potable water lens were last determined by Howard Klein et. al. in 1975, in MS 42 (revised), "potable water" was defined as having fewer than 250 mg per liter of chlorides and no more dissolved solids than 500 mg per liter. Klein attributed to pumping activities the lack of potable water lens along the east coast of Florida, at comparable parallels of latitude to those of Citrus and Levy counties. [See Figure 4.] The Florida Geological Survey (FGS) advise that depths recorded by him of this "Ghyben-Herzberg lens" at the time will have reduced since then. Fretwell & Causseaux in their 1982 FGS publications reported their findings of penetration of chloride concentrations originating from the Gulf of Mexico which also were affecting the the extent of the potable water lens.

Annex A

Community Health - Radioactive Water

Background Levels

Rays of energy from outer space entering the earth's atmosphere cause some hydrogen atoms there to adopt a second neutron. This isotope of hydrogen is called tritium. According to the IATA, 1981, tritium has a radioactive half life of 12.43 years. All three isotopes of hydrogen have a single proton in their nucleus. Atoms of protium (ordinary hydrogen) has no neutron in its nucleus and is stable, deuterium has one neutron in its nucleus and is stable. Tritium with two neutrons in its nucleus is unstable and ejects Beta particles (essentially high-energy electrons). Since the number of protons determines chemical bonding, tritium behaves like ordinary hydrogen and replaces it in water molecules producing radioactive water. (Hoffman Tritium Study).

Incorporated in water molecules in precipitation from the atmosphere, tritium ultimately reaches the land or sea surface. From where it readily cycles through the hydro-logic and biologic components of the biosphere, including our ground-water aquifer reservoirs.

There are several sources of tritium in addition to the above. Since the early 1960s, when the atmospheric testing of thermonuclear weapons raised background levels by several orders of magnitude (100 times), Background levels have receded to twice the level preceding the weapons testing period. All nuclear electric power plant reactors emit tritium into water and the atmosphere. Progress Energy and Nuclear Regulatory Commission documents simply refer to the fact that all reactors emit tritium and the EPA monitors levels.

The standard unit of measure, a tritium unit (TU), is a set ratio of tritium atoms to hydrogen atoms in a substance, for example, water. In terms of radioactivity, one TU is equivalent to 3.19 picocuries per liter (Clark and Fritz, 1997). In SI units, one tritium unit is about 0.118 bequerels per liter (Bq/L), where the bequerel is one unit of disintegration per second. Tritium decays naturally over time of about 120 years to become helium.

Tritium is classified by the EPA as a human cancer causing agent. We can take this agent into our bodies by breathing, through the pores in the skin, and by eating or drinking contaminated fluids or food. EPA sets a fairly tight limit on drinking water under the Safe Drinking Water Act, at 740 becquerels per liter. The Beta particles do not normally penetrate the skin.

All living organisms can be harmed by the beta particles emitted from tritium, which can sever chemical bonds and damage cells, affecting DNA structures and subsequent generations. Effects upon microorganisms are probably not known. By extension, so also are consequences upon dependent ecologic systems and species, on which our marine food web and the livelihood of so many depend. The difficulty in constructing a test environment involving Beta radiation has led to a lack of essential documentation.

Scientific Uses

Ratios of tritium to helium in ground water can give an accurate measure of age (and possible source) of that water. Both tritium and helium are relatively inert gases. The method separates helium derived from tritium from helium derived from natural sources. The tritium/helium method is based on the radioactive decay of tritium relative to helium. Apparent age estimates from the tritium/helium method can be extremely accurate (within months) for groundwater containing high tritium concentrations (waters recharged since 1963). Unlike the chlorofluorocarbon dating method, tritium/helium is a valid technique for sites contaminated with organic compounds.

Use of Tritium as an aid to water age assessment – data on natural tritium concentrations in water in the upper part of the Floridan aquifer were collected from December 1966 to November 1968 to evaluate tritium as a radioactive tracer. Some useful information on recharge characteristics resulted. In very general terms, an appreciable concentration of tritium is an indicator of younger water.

The natural production rate of tritium in the atmosphere is considered constant, but nuclear weapons tests as late as the early 1960's raised the tritium level to many times the normal level. The level declined after the tests but has not returned to normal, estimated by L. L. Thatcher as about 6 TU along the Atlantic Coast (Stringfield, 1966, p. 150).

During the 2-year sampling period in the Floridian Aquifer study area, one or more samples were collected at each of 26 different observation stations. Bimonthly samples were collected and analyzed from ten of the stations, including Rainbow and Silver Springs, Ocala Caverns, and seven wells.

Samples collected irregularly from four wells in the confined part of the aquifer, mostly in the Oklawaha River valley, contained zero to only traces of tritium, indicating complete or nearly complete decay of originally contained tritium. This supports interpretations from other geologic and hydrologic data that the water was old and not subject to direct recharge being in a confined aquifer system. On the other hand, all samples collected east of the river valley in the unconfined part of the aquifer had appreciable concentrations of tritium, thus supporting the belief that much of that area was subject to direct recharge. Each of the samples had more than twice the presumed normal concentration of 6 TU in rainfall, but far below peak concentrations measured in rainfall in Ocala in 1963 after the large thermonuclear tests in late 1962, thus suggesting that the high concentrations in the ground water from 1963 recharge had already passed.

The weighted average tritium concentration for 1963 precipitation in Ocala was 620 TU (Stewart and Galsworthy, 1968, p. 281). Concentrations in ground-water samples collected west of the Oklawaha valley during the 1966-1968 sampling period ranged from 13 to 174 TU while rainfall in Ocala ranged from 20 to 158 TU. The concentration in eleven samples collected at Rainbow Springs averaged about 49 TU with a high of 85 TU in May 1967 and a low of 38 TU in March 1968. Silver Springs water during the same period averaged about 47 TU with a high of 150 TU in May 1967 and a low of 25 TU in July 1967. This compares with a count of only 4.2 TU in Silver Springs water in January 1961 (Stringfield, 1966, p.150). The average concentration in the seven wells sampled bi-monthly during 1966-68 was about 80 TU, and rainfall at Ocala for the same period was about 60 TU.

Ever since the record highs in precipitation in 1963, there has been a general decline in tritium concentration, although seasonal peaks and troughs continue to occur as they would under normal conditions. A similar decline apparently occurs at most groundwater observation stations. A correlation is suggested between many of the concentration curves for the groundwater stations and the curve for precipitation. A lag of a month or two is apparent from the rainfall peaks to the peaks in several of the ground-water curves. Correlation of the curves is very much complicated by variable recharge characteristics and by differential rates of groundwater movement in the area. Much remains to be done to properly integrate and fully evaluate the tritium data, but in the meantime the tritium data provide a useful tool for recognition of some differences in recharge conditions from one place to another within the study area.

The Proposed Nuclear Plant for Levy County

The amount of tritium estimated for the discharges from the two nuclear plants proposed for Levy County is given in Appendix J, to the USNRC DEIS report, NUREG-1941.

A Progress Energy document avers, "Tritium is a byproduct of generating electricity at nuclear power plants. All nuclear plants release tritium into both the water and air. The U.S. Environmental Protection Agency (EPA) regulates the acceptable level of tritium concentrations in groundwater and drinking water".

Other Progress Energy documentation indicates the intention to take between 100 and 130 million gallons of water a day from the Cross Florida Barge Canal. Of that amount 40% (say 50 million gpd) would be emitted to air and 60% (say 60 million gpd), at elevated temperatures, piped alongside the Barge Canal to vent to the Gulf waters using the existing outlet from the Crystal River Energy Complex.

Both sources of discharge carry radioactive tritium among other nuclides. Local precipitation would return tritium to people, soils and groundwater cumulatively every day. Ejection to the Gulf waters would pollute water and offshore sea grass meadows, with unpredictable consequences to plants and wildlife including the protected manatee species which regularly forage there. Citrus and Levy Counties draw domestic drinking water supplies from wells into the unconfined aquifer systems exposed to fallout effluent from the proposed Levy nuclear reactors. Potentiometric flows from the site , and concentration of flows within identified fracture sets would appear to imperil domestic and drinking water supplies from aquifer systems serving populations of both Citrus and Levy County. See also the "Braidwood and Dresden Nuclear Power Plants" as a Foundation News Item (March 2, 2009).

Comments submitted to the Nuclear Regulatory Commission on behalf of the Amy H Remley Foundation arising from the DEIS review meeting on 23 September 2010, are reproduced below.

"Tritium. Before licensing any LNP plant, the public needs to be apprised of how, in what quantities and into which areas harmful radionuclides are to be released and accumulated in groundwater over the operating life of the plant for both gaseous and liquid effluent pathways. Together with the calculated dosages resulting therefrom.

Concern about Tritium is expressed for several reasons:

- It cannot be denied that atmospheric deposits of tritium in water molecules accumulate in groundwater of a poorly confined aquifer system. Fifty or so years ago, measured amounts of tritium in ground water near Ocala had risen to exceed one hundred times normal background levels - due to nuclear events many thousands of miles away on the other side of the planet.
- All nuclear reactors including those proposed for Levy County and that at the CREC throughout their operating life continually release tritium (together with several dozen other radionuclides such as strontium and radio-iodine) (Pages, J-3 and J-7),
- Tritium abides in tritiated water molecules as hydrogen as explained in the USNRC Tritium Backgrounder,
- Tritium is a radioactive isotope of hydrogen and an EPA listed human cancer causing agent, emitting Beta particles until it degrades into helium after about 120 years,
- Furthermore, it is believed that the dosage models used in this DEIS only consider routine radiation releases and fail to account for either accidental releases or tritiated water accumulations in groundwater.
- Moreover calculated dosage limits also assume venting of a routine radiation release from "standard man's" contaminated bodily fluids within a few days,.
- The integrity of blowdown water piping to the CR site through a single wall PVC pipe without leak detection causes concern, especially as it will be subject to regular daily seismic disturbances from mining activities.
- The statistics put forward by Mary Olson at the 23 September 2010 review meeting, indicating levels of human harm from radionuclide emissions and in high level wastes within the regulated standards, were simply staggering and quite unacceptable to civilized society. "

Annex B

Figures

Figure 1, illustrates that rainfall permeates down to join aquifer water underground. It is the sole source of water constituting the Ghyben Herzberg Lens of the regional aquifer systems, originating in consequence of a global complex of climatic, weather and hydrologic systems, Scientists term aquifers under Citrus and Levy counties as "poorly" confined - meaning that liquid is readily absorbed over most areas. Darker areas show where water falling upon the land percolates faster to join aquifer systems - 10 to 20 inches per hour.

Figure 1.

FLORIDA GEOLOGICAL SURVEY

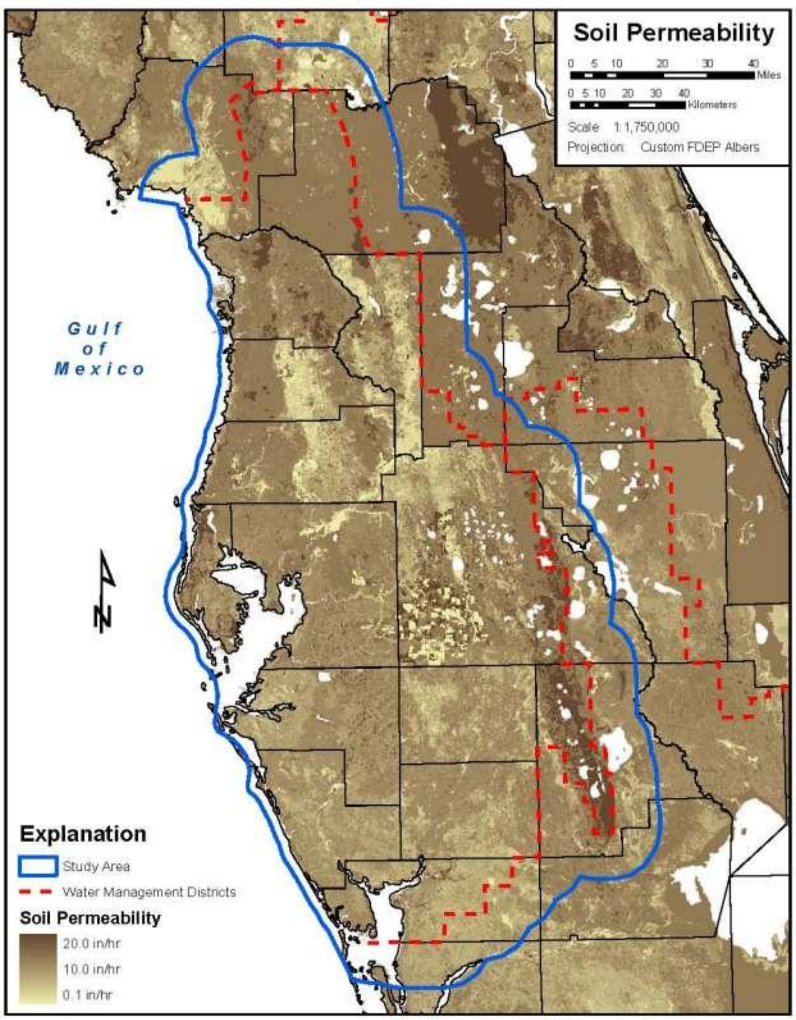

Figure 18. Soil permeability of study area (Arthur et al., in review); (data compiled on per county basis from U.S. Department of Agriculture, Natural Resource Conservation Service, 2002 and the Florida Geographic Data Library [www.fgdl.org]).

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Figure 2, represents the relative artesian pressure distribution within the the main - Floridan - aquifer system. The thin wavy lines join points of equal artesian pressures, as a contour would join points of equal land elevation. Water tends to flow from areas of higher to lower pressure at right angles to the "contours", to enter Citrus County from the SE and NE. (The flows are further influenced by conduit pathways of karstic features and fracture sets established over geologic time, as the path of least resistance is adopted by the combined flow). In particular the Nature Coast coastal river systems, being fed principally by spring discharges from the aquifer constitute a contiguous sub-system.

Figure 2.

FLORIDA GEOLOGICAL SURVEY

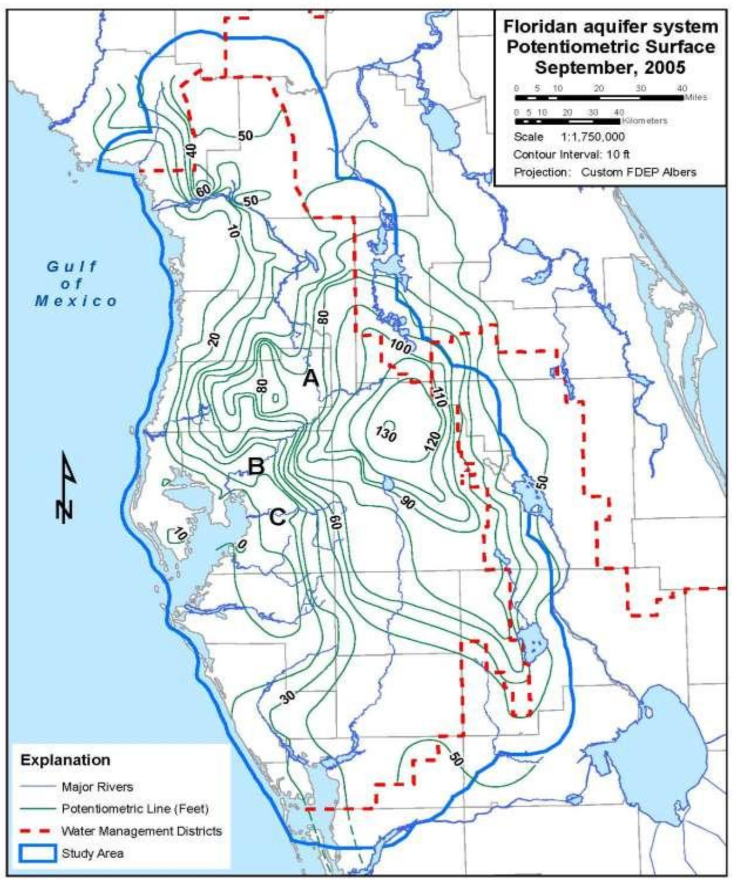

Figure 30. Potentiometric surface of the Floridan aquifer system, September, 2005 (from Ortiz, 2006); A – Withlacoochee River, B – Hillsborough River and C – Alafia River. See Figure 1 for additional river labels.

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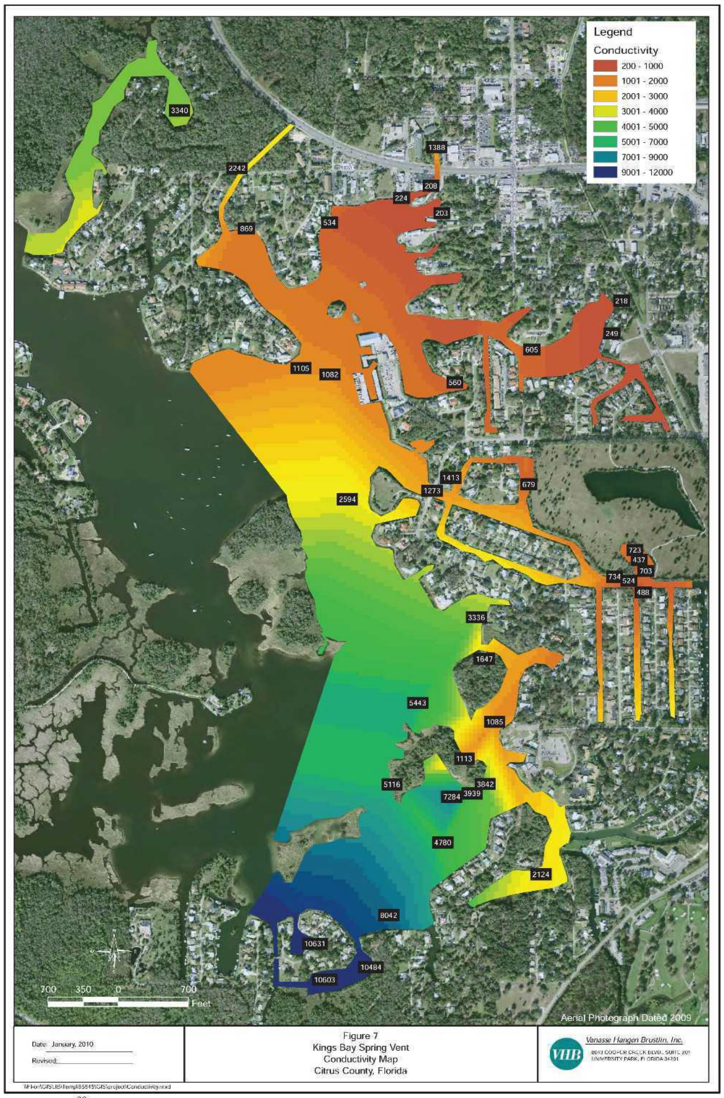
Sedimentation within conduit pathways influence porosity and permeability and condition rates of flow within them.

Figure 3, illustrates that periods of rainfall drought or plenty, together with pumping and pollution along underground tributary flows, have consequences upon salinity levels of water delivered from the spring vents. These show how the Lens water quality has been compromised over recent times which in turn has led to ecologic and species change in the surface water body.

Figure 3.



Kings Bay Saltiness

This figure shows the variation of saltiness across parts of Kings Bay. The darker blue in the SW indicates higher (saltier) conductance with the lower readings shown brown to the north. Conductance measurements recorded from the spring vent discharges, vary with seasonal rainfall amounts. The increased saltiness from the springs appears not to be due to intrusion of sea water from the Gulf, The principal underground tributary flows contribute to the phenomenon. Since 1994, the volume of water being discharged from Kings Bay springs has reduced by one third. The following is taken from FGS Bulletin 69, pages 9, and10, by permission:

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 irregularly shaped "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 (SO4).

Water discharging from Florida's aquifer systems and springs has its primary source from rainfall. Much of the rainfall reaching land surface flows overland to surface water bodies, evaporates, or is transpired by plants. However, a portion of the rainfall percolates downward through the sediments, or enters sinkholes, where it recharges the aquifers. During its travel downward from land surface to the water table, and during residence within Florida's aquifer systems, many factors affect the water chemistry.

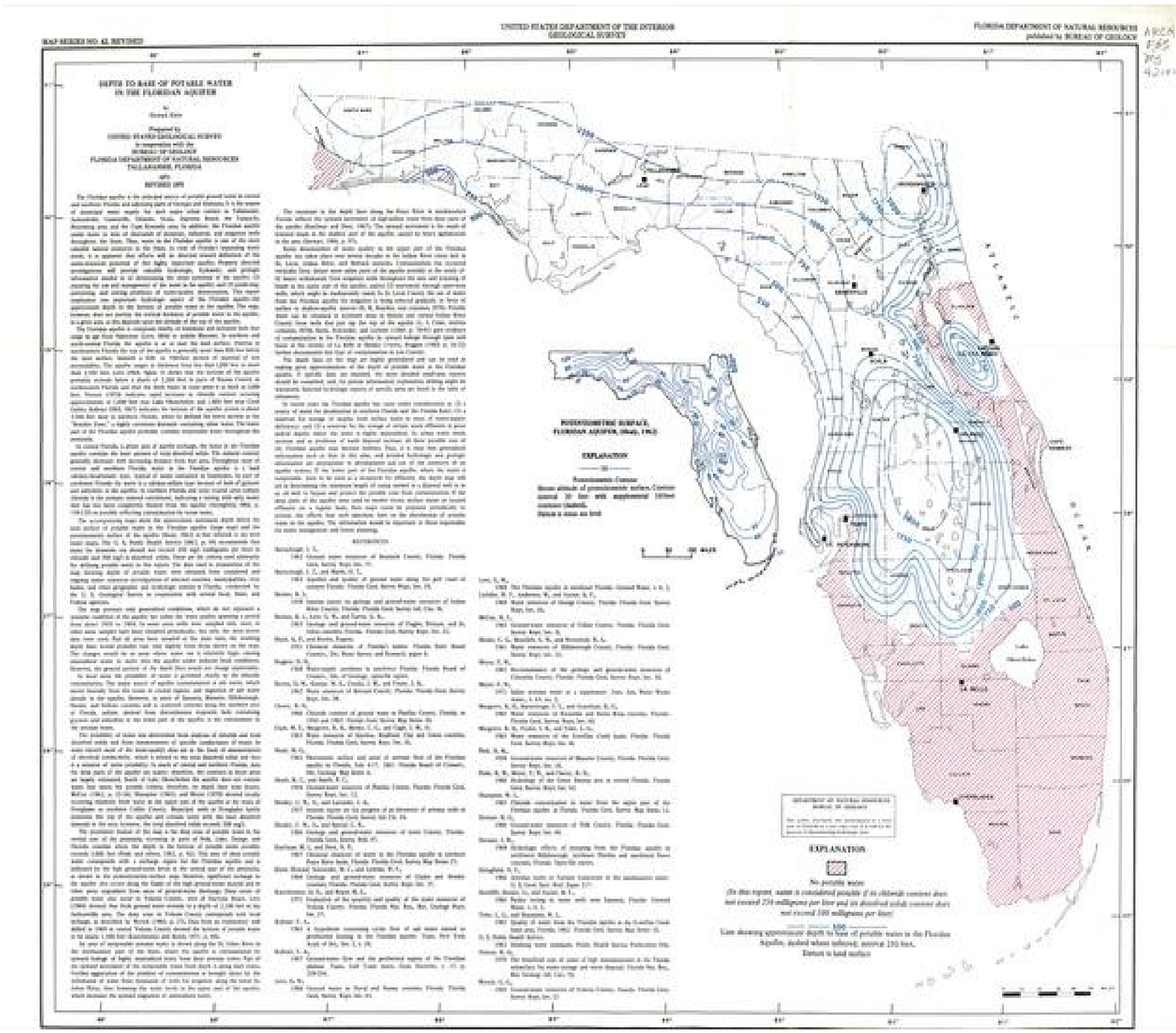
A long residence time may allow sufficient time for chemical reactions between the water and the aquifer rock. As such, water chemistry reflects the composition of the aquifer rock. Typical residence times range from less than several days (in secondary produced caverns and sinkholes) to centuries (Hanshaw 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 intergranular 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 are not always removed and our aquifers can become contaminated.

Figure 4, is an historic view of the fresh water "Lens" system and shows how over-pumping has reduced its depth and mass to allow upwelling of saltier water from lower levels to fatally compromise water quality. Saltier more mineralized water is held to greater depths by weight of a “lens” of fresh water above. FGS cautions that lens depths have diminished since Klein's work (c.1960/70s).

Figure 4.



“Potable water” defined by Howard Klein et al. 1975, as chlorides less than or equal to 250 mg/L, and dissolved solids less than or equal to 500 mg/L. Depths of lens given in feet relative to land surface datum. Klein attributes loss of potable water along Florida's east coast to pumping activities. Drought periods and pumping over the years have reduced aquifer levels and depth of the fresh water “lens”. The reduced mass of the lens allows saltier water to well up from deeper down.

Annex C

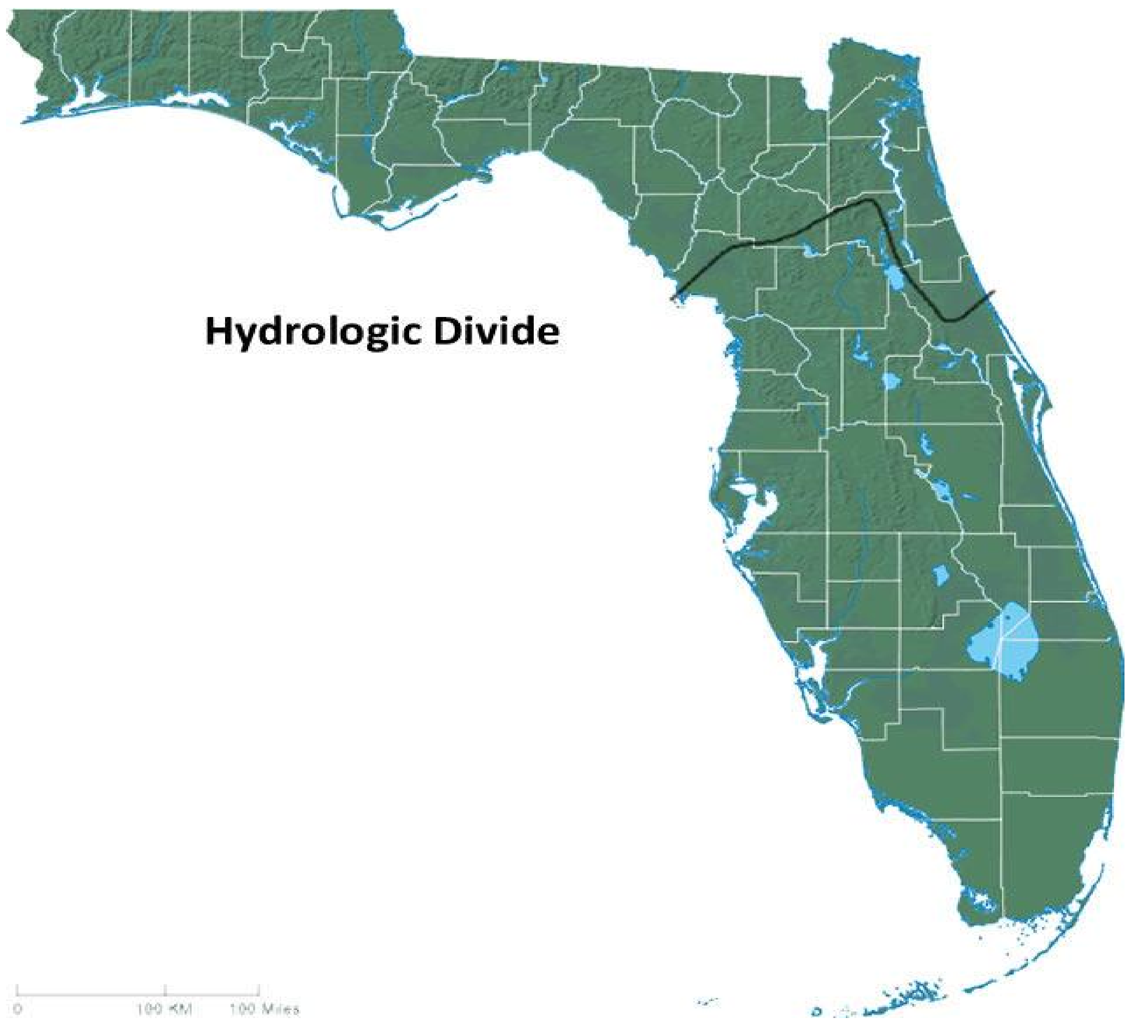
A Description of the Ghyben Herzberg Relation

(Taken from the Saltwater Intrusion page of the Amy H Remley Foundation Inc. website)

Saltwater Intrusion

"Water is life; without water, we have nothing. Without water, we die."

So said, Garald G. "Jerry" Parker, Sr. (1905—2000) known as the "Father of Florida groundwater hydrology". A renowned hydrologist, Parker also named the principal artesian aquifer the Floridan Aquifer. Perhaps his most significant legacy for us who reside in the region administered by the Southwest Florida Water Management District is his definition of the Hydrologic Divide of Florida which separates the geographic region where aquifer recharge is solely from rainwater from that to the north of the divide.



Aquifer recharge to the south of the hydrologic divide is solely from rainfall. For information, north of the divide some groundwater within the Floridan aquifer system is recharged from Georgia and some from Alabama. (Personal communication from Rick Copeland, 2011).

W. Badon-Ghijben (1888, 1889) and A. Herzberg (1901), derived analytical solutions to approximate the behavior of salt water intrusion. Today the relation is called the Ghyben-Herzberg relation and is of profound importance to regional environmental systems.

In West Central Florida three factors combine to ensure application of the Ghyben Herzberg relation to systems governing behavior of fresh water resources and salt water intrusion:

1. A consequence of the divide is that rainfall is the sole source of recharge to the aquifer systems,
2. due to the lack of an impermeable land cover to the aquifer systems, rainwater falling upon the land surface percolates readily down and accumulates over time in the aquifer rocks,
3. the bounding to the west by the Gulf of Mexico ensures a ready source for salt water intrusion postulated by that Ghyben Herzberg relation.
4. Note in particular that this discussion applies to unconfined aquifer systems. For confined aquifers an analogy can be made with the Ghyben-Hertzberg model, albeit the more complex;

The following is taken from FGS Bulletin 69, Page 9, and explains the origin of Florida's "lens" systems:

> "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.
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> Today, the irregularly shaped "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.
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> 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 (SO4). "

Salt water intrusion and the Ghyben Herzberg Relation

Saltwater intrusion happens when saltwater penetrates underground from the sea into the freshwater aquifer systems. This behavior is caused by sea water having a higher density than freshwater (due to carrying more solutes). Note also that elevation of the sea level due to warming of the sea increases pressure at depth and increases the tendency for the saltwater to intrude. Sea level rise also diminishes the fresh water depth above sea level increasing the tendency toward up-coning.

The pressure under a column of saltwater is thus greater than the pressure under a column of the same height of freshwater. When these two columns are connected at the bottom, then the pressure difference would cause a flow from the column of saltwater to the freshwater column until the pressures equalize.

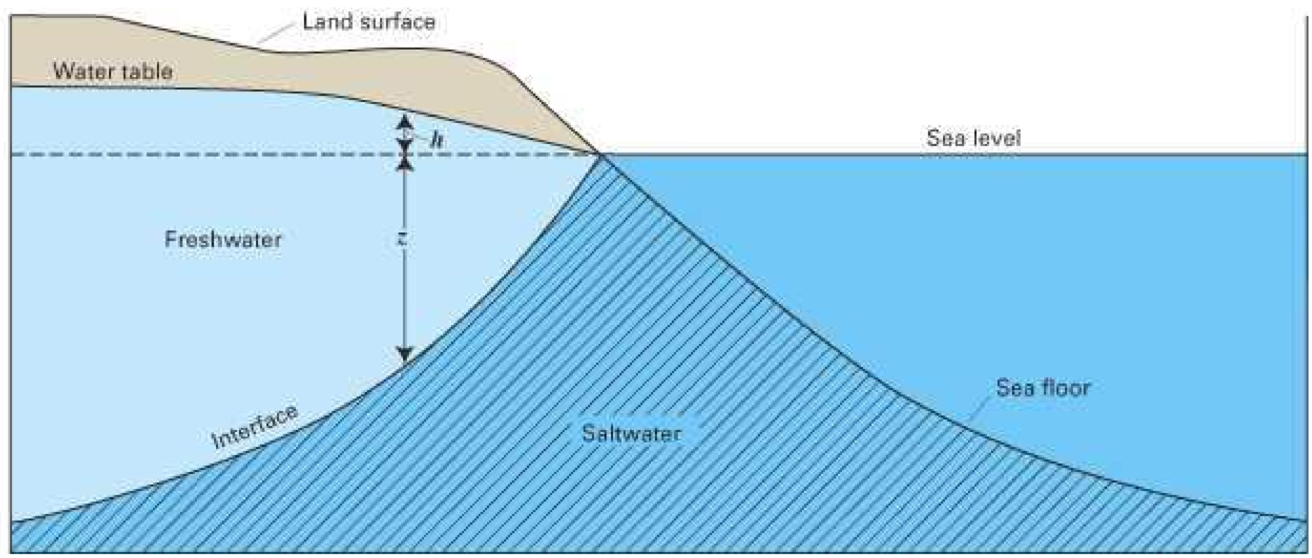
The mixing is inhibited only so long as the mass of the fresher water remains sufficient to resist the upwelling (up-coning) tendency of the saltier water from lower down.

Depletion of the mass of fresh water in an aquifer system above sea level reduces its relative pressure and intensifies the tendency for salt water to mix with the fresh water.

The flow of saltwater inland happens in the coastal areas. Further inland, the freshwater column is higher due to the increasing altitude of the land and enables the relative fresh and salt water pressures to equalize and stabilize the salt water intrusion.

The higher water levels inland have another effect of causing water to flow seaward, as freshwater flows out, in the lower parts saltwater flows in.

The Ghyben-Herzberg relation (Diagram from Wikipedia)



In the equation, $z = (\rho_f / (\rho_s - \rho_f))h$ where the thickness of the freshwater zone above sea level is represented as *h* and that below sea level is represented as *z*. The two thicknesses *h* and *z*, are related by ρ_f and ρ_s where ρ_f is the density of freshwater and ρ_s is the density of saltwater.

Freshwater has a density of about 1.000 grams per cubic centimeter (g/cm3) at 20 °C, whereas that of seawater is about 1.025 g/cm3. The equation can be simplified to $z = 40h$.

Thus the Ghyben-Herzberg ratio states, for every foot of fresh water in an unconfined aquifer above sea level, there will be forty feet of fresh water in the aquifer below sea level.

Environmentally, these Ghyben-Herzberg "lens" systems are crucially important not only to healthy stream flows and the biotic health of the protected waterways but also to the region's potable water supply.

The "lens" system assures the freshwater supply only so long as its lens' mass remains sufficient to inhibit mixing of non-potable water from lower aquifer systems.

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Moreover, the 2010 report to SWFWMD by Vanasse Hengen Brustlin, Inc. graphically illustrates the discharge of non-potable water from spring vents fed from a contaminated lens system co-located with an underground tributary into the southern section of Kings Bay.

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List of References

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