SUBMISSION BY NORMAN HOPKINS AND DAVID HOPKINS

Groundwater Flows Affecting Crystal River/Kings Bay - a Case Study by Norman Hopkins and David Hopkins

Executive Summary

After Crystal River/Kings Bay was classified as an Outstanding Florida Water (OFW) and is subject to the State of Florida Antidegradation Policy, requiring water quality standards to be held to levels as at 1st March, 1979, water quality has degraded significantly since that time.

Studies over the years have determined that most of the water entering Kings Bay is groundwater which has traveled underground before being discharged from springs into the Bay. Contaminants simply permeate the porous karst terrain into the groundwater as it flows within the Floridan Aquifer System.

Research was undertaken and computing algorithms developed to determine those natural groundwater flow paths most likely to deliver groundwater to the spring vents of the Kings Bay system. Two underground tributary systems of the OFW were identified trending northeast-southwest and southeast-northwest into Kings Bay.

Goals for the protection of the OFW from pollutants delivered via the springs on those paths were deduced and listed according to best management practices recommended by state departments. Protection measures put in place by municipal and county authorities would reduce the quantity of pollutants being discharged from the springs, reinforcing measures advocated by the Southwest Florida Water Management District.

Groundwater Flows - a Case Study
by Norman Hopkins and David Hopkins

Situation

Following a petition of local citizens, the then Florida Department of Environmental Regulation (now FDEP), on October 28, 1982, submitted a report to the Environmental Regulation Commission (ERC) on The Proposed Designation of the Crystal River as an Outstanding Florida Water (OFW).

Subsequently, with effect February 1, 1983, the ERC approved the petition designating Crystal River/Kings Bay an OFW (Chapter 62-302.700(9) FAC). Ambient water quality of the system, against which the state Antidegradation Policy was to be applied, was defined as that existing on March 1, 1979 (Chapter 62-302.700(8) FAC). Nevertheless, water quality studies conducted since that time have shown degradation to have taken place.

Evidence of Degradation

This picture taken on 3 June 2010 by Harley Means of FGS, shows the blue Hunter Spring (upper right) toward the narrows by the park area. The green algae covering the remainder of Hunter Spring Run evidences serious water quality degradation. As of writing this extensive algal bloom, which has the appearance of Diatom or Microcystis had not been specifically identified.

In August, 2006, teams from the University of Florida led by Thomas K. Frazer reported under contract to the Southwest Florida Water Management District on water quality and vegetative evaluations of the coastal rivers of Citrus County, and adjacent Gulf Coast waters. Confirming local anecdotal observations of water quality degradation. the conclusion to the report on the three rivers asserted degradation and that similar results were likely for the Crystal River/ Kings Bay and lower Withlacoochee rivers. Extracts follow:

The teams reported that, Groundwater nutrient enrichment presents a potentially serious ecological issue for much of central Florida. Because of the occurrence of the large aquifer systems and highly permeable karst geology, there are numerous locations and multiple pathways by which nutrient-enriched ground water can permeate and mix with the surface waters. Springs, for example, provide a direct conduit for nutrient-enriched ground water to move from the aquifer to surface waters. As nutrient-laden ground water enters the surface water system, largely via the springs, there is potential for adverse ecological changes to occur downstream. Increases in stream nutrient concentrations/loads, for example, have been linked to changes in autotrophic community composition, vegetative biomass, and an increase in nuisance species (Wong and Clark 1976; Mace et al. 1984; Wright and McDonnell 1986a, 1986b). Such changes can, in turn, affect shifts in community structure and alter food web dynamics (see Hershey et al. 1988; Peterson et al. 1993). In extreme cases, the ecological health and integrity of a system may be severely compromised as a consequence of increased nutrient inputs.

Concerns over the potential effects of increased nutrient delivery to the rivers was raised nearly a decade earlier when Jones et al. (1997) reported elevated nitrate concentrations within ground water emanating from the springs, and complexes of springs, that feed each of those systems. At that time, however, there were few quantitative data available that would allow scientists or water resource managers to determine whether or not the ecological character of these specific river systems had been or might be affected by an increase in nitrate. Frazer et al. (2001a) subsequently provided the first quantitative assessment of the Homosassa, Chassahowitzka, and Weeki Wachee rivers. (see also Hoyer et al. 2004). However, they also reported significant statistical relationships between nitrate and soluble reactive phosphorus and submersed aquatic vegetation and periphyton growth on macrophytes in both the Homosassa and Chassahowitzka rivers and indicated that additional nutrient inputs to these rivers could lead to changes in the vegetative community. These changes , in combination, were legitimate reasons for concern. Increased nutrient delivery, loss of native macrophytes and increased periphyton loads are symptomatic of eutrophication related phenomena.

It stands to reason with more than 90% of the water in Kings Bay having been discharged from the springs that the contaminants in that water must have accumulated as the water flowed underground before issuing from the springs. The emphasis upon springs as the principal source for the degradation is especially relevant to Crystal River/Kings Bay which is almost entirely fed from springs.

Groundwater Flows

The following is taken from Florida geological Survey Bulletin 66.

In order to fully understand the water quality of Florida's springs, a rudimentary understanding of the origin and chemistry of Florida's groundwater is needed. Most people are aware that Florida is surrounded on three sides by salt water. Many are unaware however, that salt water 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 of the rocks under the ocean, salt water existed in their intergranular pore spaces. Gradually over geologic time, sea level was lowered relative to its position when the carbonate sediments were deposited. Through compaction and downwarping 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.

As sea level lowered, the central portion of the Florida Platform was exposed to the atmosphere. Over time, rainfall percolated downward and eventually replaced the upper portion of salt water in the carbonates with a fresh water "lens." Today, the "lens" is generally deepest in the central portion of the state and becomes narrower toward Florida's coastline. The lens is over 2,000 feet thick at its maximum (Klein, 1975). It should be understood that the base of the lens is transitional rather than a sharp boundary. Groundwater in the deeper portion of the lens, and along our coasts, is mixed and has relatively high concentrations of saline indicators such as sodium (Na), chloride (Cl), and sulfate (SO_4).

Water discharging from Florida's springs has its ultimate 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 where it recharges our aquifers. During its travel downward from land surface to the water table, and while water resides within Florida's aquifer systems, many factors affect the water chemistry.

Residence time is the length of time that water is in contact with a particular portion of an aquifer system (Upchurch, 1992). 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 several days to thousands of years depending on the nature of the flow system (Hanshaw et al., 1965).

A second factor affecting ground-water chemistry is its 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 *(Surficial Aquifer System)*, result in low residence times for chemical reactions. 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 *(Floridan Aquifer system)*, reactions between rock and water become more probable and the TDS content of the water increases as a result of continued rock-water chemical reactions. Because of its residence time and flow path, spring water quality is typically reflective of the interactions of the major rock types of the source aquifer and water within it.

A third factor that is of particular interest is intergranular porosity (pores through which water passes between the individual rock matrix grains). Even though Florida's karst features suggest the existence of large, secondary cavernous pores spaces, most of the pores tend to be small (Upchurch, 1992). Fortunately, whenever the pore throats are very small, they act as filters for microbes, small organic substances, and clay minerals. In general, this results in very clean groundwater that is extremely desirable for both drinking water and recreational purposes. Unfortunately, some contaminants originating from our land use activities are not always removed and contaminate groundwater.

Dr. Robert O. Vernon had written in 1951, published as Florida Geological Survey – Bulletin 33.

A proportion of surface water is continually evaporated and transpired back into the atmosphere, part runs off as streams or collects in basins as ponds or lakes, part permeates under ground to enter voids in rocks to flow downhill eventually to the sea. Water contained in the voids in the rocks is subsurface water and that which completely saturates the rock is groundwater. If the top surface of the groundwater is free to fluctuate upwards and downwards the water is under water-table conditions. If the groundwater surface is overlain by a formation that contains few voids, or poorly connected voids or small enough voids to restrict the flow of water, the water is confined and under artesian conditions.

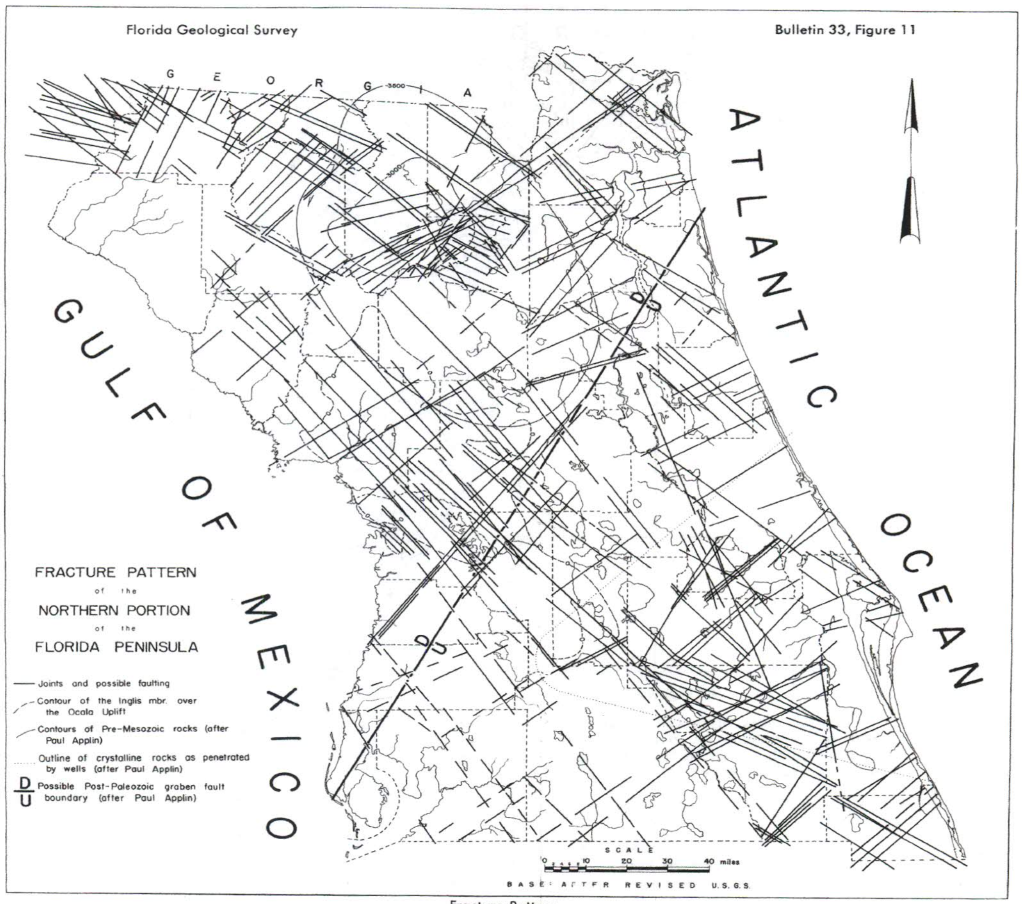
He also wrote, (on page 43): Limestone is as a rule jointed vertically and bedded horizontally and openings along these joints and beds provide easy avenues of travel for water. The ultimate source of all Florida's ground water is from the rain and precipitates from the atmosphere. As the rain water falls through the air it becomes charged with carbon dioxide gas that combines with water to form carbonic acid. On the ground humic acids from rotting vegetation is added. These are the common solvents of limestone. ... As it moves through pores and open spaces in the limestone it acts as a slow solvent to increase the size of the openings and to connect them to form a continuous system of channels. As these channels are expanded by solution, cave systems are developed horizontally and one system may lie over another and may be connected by vertical tubes and rooms."

He continues (on page 44), to discuss the formation of sinkholes by cave collapse near the surface and how solution pipes are created by upward artesian pressures to form springs or seeps at the ground surface, which in turn may continue to expand in size over time.

He emphasizes (on page 240): ...since all fresh water in Citrus county is derived directly from atmospheric precipitation falling locally and on adjacent counties, conservation of groundwater resources requires that water consumed does not exceed that which is readily available from streams, lakes and wells and that this usage be small enough to maintain normal storage of waters on the surface and in the ground. Otherwise, lake levels lower, and well and stream flows decrease".

Although the literature describes natural transport of chemicals within the aquifer, the increased urbanization over the years has introduced contaminants from fertilizers and mineral elements from vehicle exhausts into the groundwater flows which contribute to the degradation of water quality.

Prior to Dr Vernon's writing, faulting was not previously recognized in Florida. He mapped fracture patterns from their physiographic expressions shown on mosaics and contact prints of aerial photographic stereo pairs, having verified them with geologic and core hole sections and surface observations. He further verified their positions with reasoning of the geologic movements taking place some millions of years earlier in the Tertiary period when the Florida land mass was given form. (See Bulletin 33, Figure 11, on the next page).



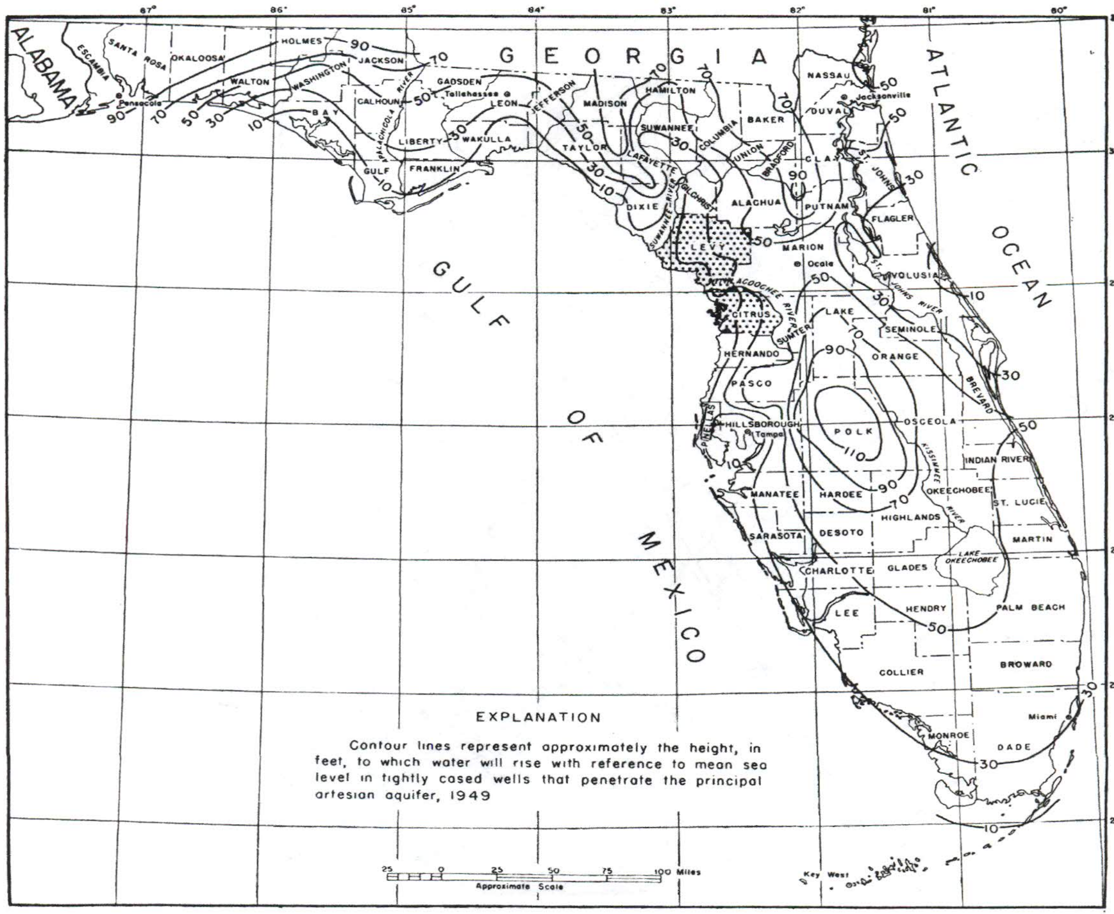
Fracture Pattern.

That fractures existed and conveyed water underground from place to place as been accepted for a long time. How they came into being, whether by tectonic forces or by lower sea levels over geologic time divides geologists today. Vernon, from his extensive down to earth surveys, drew attention to the pattern of fractures evident in Citrus and Levy counties trending generally southeast-northwest. Alongside those trending northeast-southwest intersecting at large angles and irregularly spaced along the flanks of what he termed the Ocala uplift -now termed, Ocala platform.

The identification by this Foundation of the southeast-northwest fracture conduits to the spring vents in the south part of Kings Bay are consistent with Vernon's rationale.

In Bulletin 33, Figure 40, on the next page, Vernon depicts artesian (or, piezometric) water flows of Florida. Data was constructed by measuring water levels in wells penetrating into the aquifer, referring the measurements to sea level and locating the wells on a map of Florida.

The imaginary surface by joining points of equal pressure with smooth lines called contours is known as the piezometric surface. Water is added to the aquifer from rainfall and leaves it as it is pumped out or runs down to the sea. The direction of flow is perpendicular to the contours, from areas where the piezometric surface is higher to areas of lower pressure. Areas where water is being added to the aquifer are referred to as recharge areas, and relatively low contours are referred to as discharge areas where water leaves the aquifer by leakage, springs or wells.



Piezometric Surface of Florida, 1951

Robert O. Vernon, *Geology of Citrus and Levy Counties, Florida* (Tallahassee, FL: The Florida Geological Survey, 1951)

Note: The existence of Florida's Hydrologic Divide depicted on page 10 of the Water Resources Atlas of Florida, showing a line snaking from Cedar Key to new Smyrna Beach would restrict both surface and groundwater flows towards Citrus County to those flowing southward from the northern part of Putnam County.

Faulkner, writing twenty two years after Vernon in the U.S. GEOLOGICAL SURVEY Resources Investigations Report, I-73, relates that he and others have observed that most caverns and solution channels in the limestone are oriented along near-vertical fractures having trends of fracture systems mapped at the surface. The logical inference is that water moving through the aquifer tends to follow the line of least resistance or greatest permeability, which in this case is along the fractures. In general, the greatest solution of limestone at shallow depths below the water table takes place where the greatest amount of water moves through. Thus cavities are developed as the walls of fractures are dissolved away by recently recharged ground water with a high carbon dioxide (CO_2) content. Faulkner explores the relationship of the fracture and fault system to the subsurface drainage system and emphasizes the importance of lineament indications of the presence of conduits governing direction and routes of groundwater flows. He encourages (p110), use of various remote sensing methods, such as aerial infrared and color photography, should be investigated and utilized where possible to aid in the delineation of certain stratigraphic and structural characteristics of the area, the knowledge of which may help to further define routes of preferential ground-water flow, and thereby aid in preventing pollution of water in the aquifer.

Thus two factors contribute to the routes taken by groundwater flows. First, the general patterns of piezometric flows, and second, the concentration of such flows and modification to their route when they join waters flowing in fracture conduits. Patterns of piezometric flow may vary with season and periods of drought or plenty, as aquifer head levels change opening or closing available channels through the rock. On the other hand, fracture conduits which have existed millions of years do not change their position. They only enlarge with the passage of time so long as acid charged waters flow into them, or accumulate sediments or material particles over time which affect the permeability and rates of flow in the conduits.

In the SJRWMD Special Publication SJ2007-SP4, Fifty-year Retrospective Study of the Ecology of Silver Springs, Florida, Knight (2006), observes:

> "Water quality and biological conditions at the Kings Bay Spring Group, headwaters of the Crystal River in Citrus County, were summarized by the Southwest Florida Water Management District (2005). In their evaluation they reported average nitrate nitrogen concentrations of about 0.165 mg/L in Tarpon Hole and 0.291 mg/L in Hunters Spring. Numerous ecological impairments have been identified in Kings Bay, apparently partially in response to elevated concentrations of nitrogen. These observations include loss of water clarity, increased populations of benthic algae and especially Lyngbya (also see Cowell and Botts 1994), increases in occurrence of unconsolidated sediments, and loss of desirable rooted submerged aquatic plants (particularly Vallisneria). Increasing salinities in Kings Bay may be a result of declining spring flow due to increasing groundwater withdrawals. In turn these increased salinities may have resulted in reduced SAV biomass, triggering a self-reinforcing cycle of increased growth of phytoplanktonic algae, decreased water clarity, and reduced light needed by SAV. Decreased water clarity and increased benthic algal dominance were observed at Silver Springs during the past fifty years. The Kings Bay research offers a possible clue to the effects of declining submerged macrophyte plant communities on these changes."

People and land-use practices are currently the leading cause of water pollution, harmful to humans, wildlife and the environment.

Polluted runoff occurs when rain runs off impervious surfaces such as rooftops, paved streets, highways, and parking lots. As water runs off these surfaces, it can pick up pollution such as: oil, grease, toxic chemicals, bacteria, excess fertilizer nutrients, pesticides, soil, trash, and animal waste. From whence, the water can flow directly, into a local stream, bay, lake, an underground tributary, or waterway. Clearance of trees and shrubs greatly assists this phenomenon. (See page 86 and 87, of Jones(1994). Of course, increasing impervious areas increases evaporation rates (See, Water Resources Atlas of Florida,1998, pages 148 and 149) reducing quantities of rainwater feed to aquifers and conduit flows. Thus depleting water deliveries to connected waterways, exacerbating salt water intrusions and ecologic system change, stimulating more harmful algae growth and degrading their water quality.

In addition, the large impervious surfaces in urban areas increase the quantity of peak flows of runoff, which in turn cause hydrologic impacts such as floods, scoured stream beds, channels, in-stream sedimentation, loss of fish and wildlife habitat and stimulates harmful toxic algal blooms. Sandy or gravelly soils allow rapid infiltration of contaminated stormwater into aquifers used for drinking and domestic water supply.

Untreated stormwater is not safe to drink nor swim in. It can contain toxic metals such as cadmium, molybdenum, arsenic, and lead, organic compounds, bacteria, and viruses. Polluted stormwater is the cause of many beach closures for health reasons.

Diodoto (1999) described:

> In south Florida, linear features (photolinears) are detected and identified based primarily upon indicators such as aligned solution depressions, surface ponds, vegetation, and variations in soil tone (Trainer and Ellison, 1967, Parizek, 1975). Doline (sinkhole) development can be expected to follow orientation of photolinears, as these represent areas of higher permeability and porosity.

Permeability and Porosity

Porosity is the percentage ratio of the volume of void spaces to the total volume of material in a given space. It represents the relative storage capacity of that space. Permeability is a measure of the ease with which fluids will flow though such a space where the voids are interconnected to allow fluid to flow.

Vernon explained the formation of holes in limestone rock formations, which have the capacity to store groundwater and, as the holes (both small and large) are interconnected, to facilitate piezometric flows. Flow rates are conditioned by material occupying the rock voids together with the water, and thus flow rate is a function of porosity and permeability both for groundwater matrix flows and flows in fracture conduits having suitable porosity.

Rock fractures significantly affect rates and direction of groundwater flows, as Faulkner has emphasized. Fractures may be completely void, both small and extremely large spaces, or have accumulations of material in them. Fractures may collect a variety of material into the fracture space as piezometric flows join along the whole length of the fracture, or a number of associated fracture paths. Rates of flow in fracture conduits vary according to porosity, permeability and head pressure within the FAS.

The composition of the material accompanying water in the rock or fracture voids affect ra te of flow through the rock or fracture space. The shapes, sizes, and degree to which granular materials are packed together affect both porosity and permeability properties in rock formations and fractures. In addition, of course, the intrinsic fluid viscosity and pressure also influence the rates of flow.

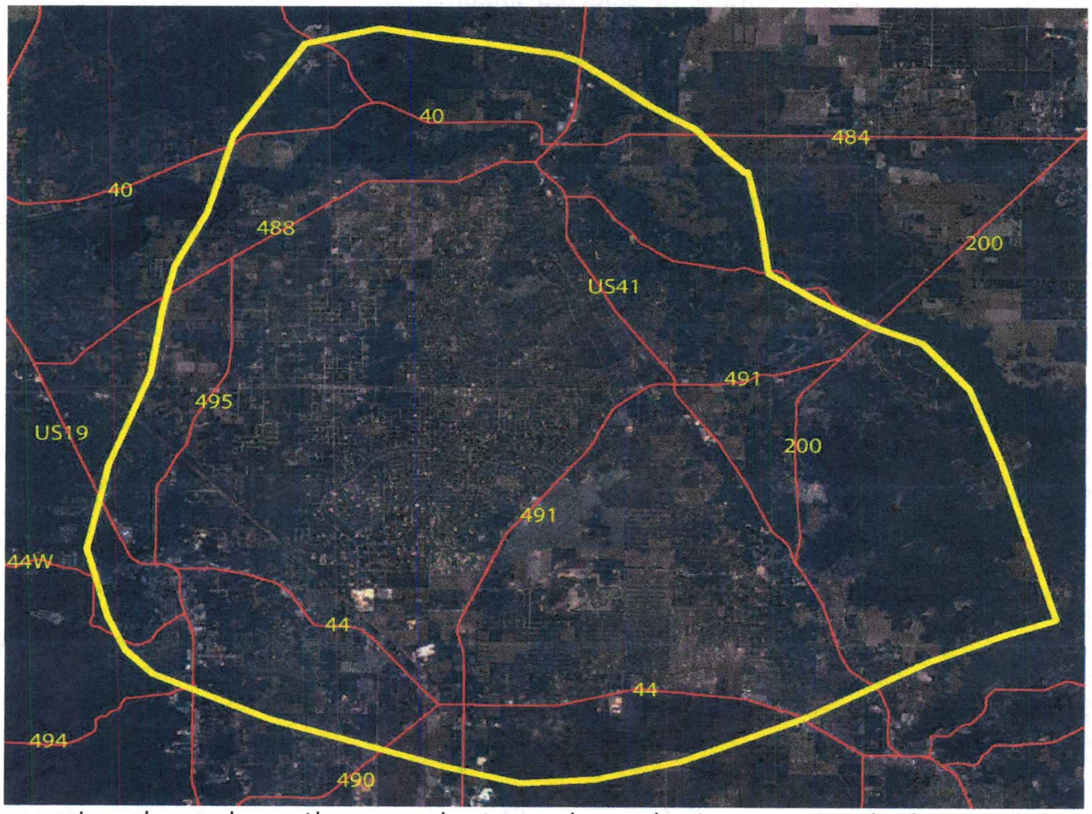
Ground/Surface water balance

Vernon discussed the relationship between groundwater under artesian conditions (Floridan aquifer system) and water under water table conditions (Surficial aquifer system). He and Faulkner also discussed how waters fed from underground flows appear at the surface. Surface waters become streams, rivers, lakes and wetlands which have flow paths controlled by topography rather than the head pressures and conduits. Surface waters are exposed to interaction with the atmosphere and saltwater tides. Lake evaporation rates locally in Citrus County average some four feet per year into the atmosphere (Water Resources Atlas of Florida, page 33). In addition, trees and plants transpire water to the atmosphere at more modest rates.

A Climatic Water Budget can be derived to illustrate the balance at the surface represented in inches by: PRECIPTATION (from the atmosphere) EQUALS (EVAPORATION + TRANSPIRATION – WATER SHORTAGE (historical)) + SURPLUS(moisture) + STORAGE_DELTA (soil water change). Such budget information is used to indicate water deficiency, water surplus, soil water recharge, and soil moisture utilization – that is a measure of the recharge amount of water percolating into the ground minus any amount taken up by plants, used or transpired.

This water balance is a vital component of environmental health, local and global climate and weather, impacting agriculture, livestock, marine and fresh water fisheries, recreation and quality of life. In the Water Resources Atlas of Florida, page 149, and depicted in the Effect of Covered Surfaces on Runoff, man's creation of impervious areas for roads, parking, buildings, clear cutting forests and the like diminish waters naturally fed back into the atmosphere by up to one tenth, reduce ground infiltration by up to three tenths and increase run off by at least four times – gathering a rich supply of pollutants on its way before eventual release into aquifer waters.

RESEARCH



The mapping above shows the groundwater recharge basin, or springshed area of the Kings Bay springs, as over printed in yellow on satellite topographical imagery (with the principal roads shown in red). Data was taken from the FDEP database, courtesy of the Southwest Florida Water Management District. Base data was derived from piezometric (artesian) flow mapping similar to those used by Vernon. Rain falling upon Citrus and surrounding Counties accumulating in this springshed is the principle source of water discharging from springs into Kings Bay. The area is described as poorly confined karst terrain having a high permeability, allowing liquid contaminants to drain directly into the FAS waters and attendant conduit systems.

Searches to locate aerial photographs or derived lineaments with respect to Citrus County in the vicinity of Crystal River/Kings Bay, as used by Vernon or Faulkner, were unfruitful, as were examination of historic archives for Citrus County (in person), and various state and university departments (with help from librarians).

Reports of work undertaken by the US Army Corps of Engineers were discussed with Army Corps project managers, and a GIS department manager. Telephone discussions were held with persons of Florida Geological Survey and United States Geological Survey and with members of Consulting organizations. Most helpful discussions with scientists of the Southwest Water Management District over a period of many months led to reviews of documentation and other material.

Eventually, a photograph of a mylar sheet of lineaments for the whole of Florida was obtained, prepared by The Remote Sensing Section, State Topographic Office, Florida Department of Transportation, in 1973. Several weeks later a 30 x 30 inches (approx) mylar was obtained from a state archive of the same set of photo lineaments containing four registration marks. A mosaic made with sixteen (16) Multispectral images taken by the NASA/GE Earth Resources Technology Satellite from an altitude of 570 miles, between Oct'.72 and Apr.'73, was also obtained having matching registration marks with those on the mylar.

A procedure was devised by the Foundation to orient and register the mosaic and the mylar in order to compute latitude and longitude of selected lineaments. A region encompassing Citrus County and part of Levy County was prepared and checked for accuracy within the constraints of the mylar and verified against the mylar superimposed over the mosaic, both physically mounted and in the computer. (Since that time a source of digitized photographs used to create the mylar has been discovered).

Lineament latitude and longitude data were calculated and entered to a database of Google Earth and there combined with data of sinkhole locations. Lastly, latitude and longitude data of spring vents, as supplied by the Southwest Florida Water Management District, for the chosen and adjacent areas were added.

Kings Bay/Crystal River Tributary Flows

Crystal River/Kings Bay is said to be the largest estuarine water body in the United States having its water sourced almost entirely from springs, and probably also in the world. The groundwater issuing from the springs originates from the Floridan aquifer system flowing under artesian pressure as they are complemented by faster flowing waters in fracture set conduits. It is the flow from fracture sets which contributes to higher the rates of flow from some of the springs in Crystal River/Kings Bay.

The upper image on the next page shows photo lineaments derived from the aerial survey conducted in 1972/3, confirming findings of Vernon (1951), and Faulkner (1973). The paths of the lineaments have been affirmed by computed Latitude and Longitude of lineaments, selected with coincident sinkhole and spring vent locations auto-plotted from official database information. The dark red SE to NW line represents the fracture indicated by Dr Vernon's research (probable joint with parallel fracture sets extending to the SW shown as indicated by Vernon - Bulletin 33,Fig. 11 - as purple lines). The circles show spring positions (those for Crystal River/Kings Bay are shown on the lower image). The blue lines are those lineaments with affirming physical features, as opposed to the white lines with have no known qualifying features. Some offshore spring vents are also shown.

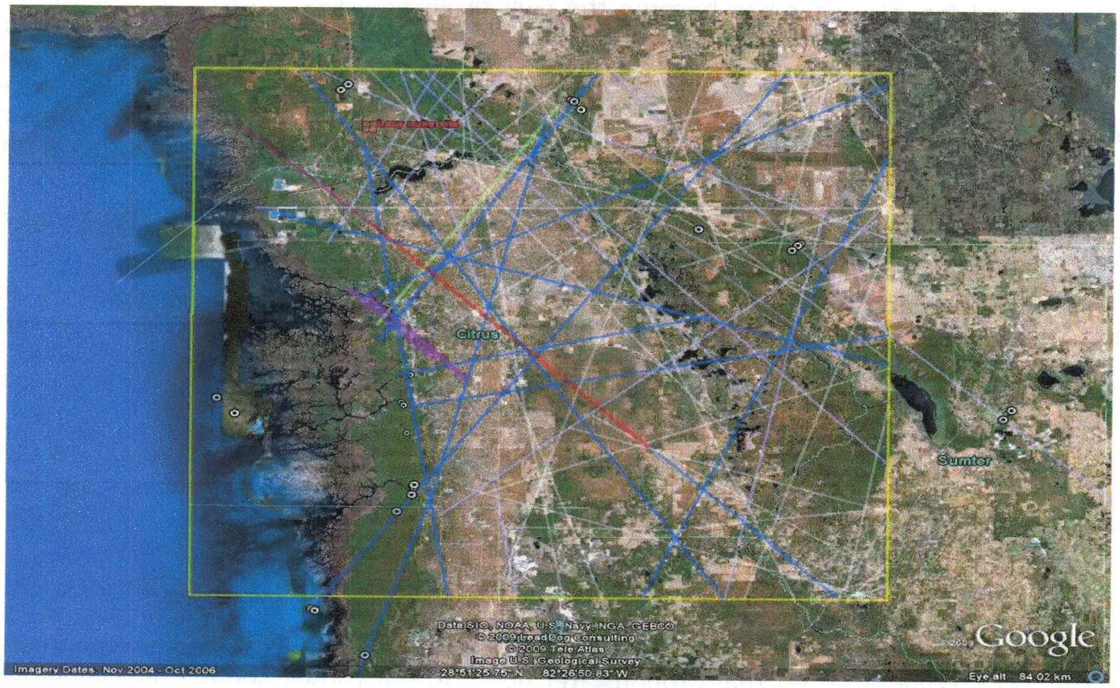
The NE to SW light green and parallel blue line which connects from the Rainbow River area is suggested as a second fresh water tributary path. The light green line passing through two Kings Bay springs and two sink holes (not shown), together with the parallel blue line passing through a number of spring vents in Kings Bay and six sink holes located on it's path, tends to support the second significant tributary path of the river system.

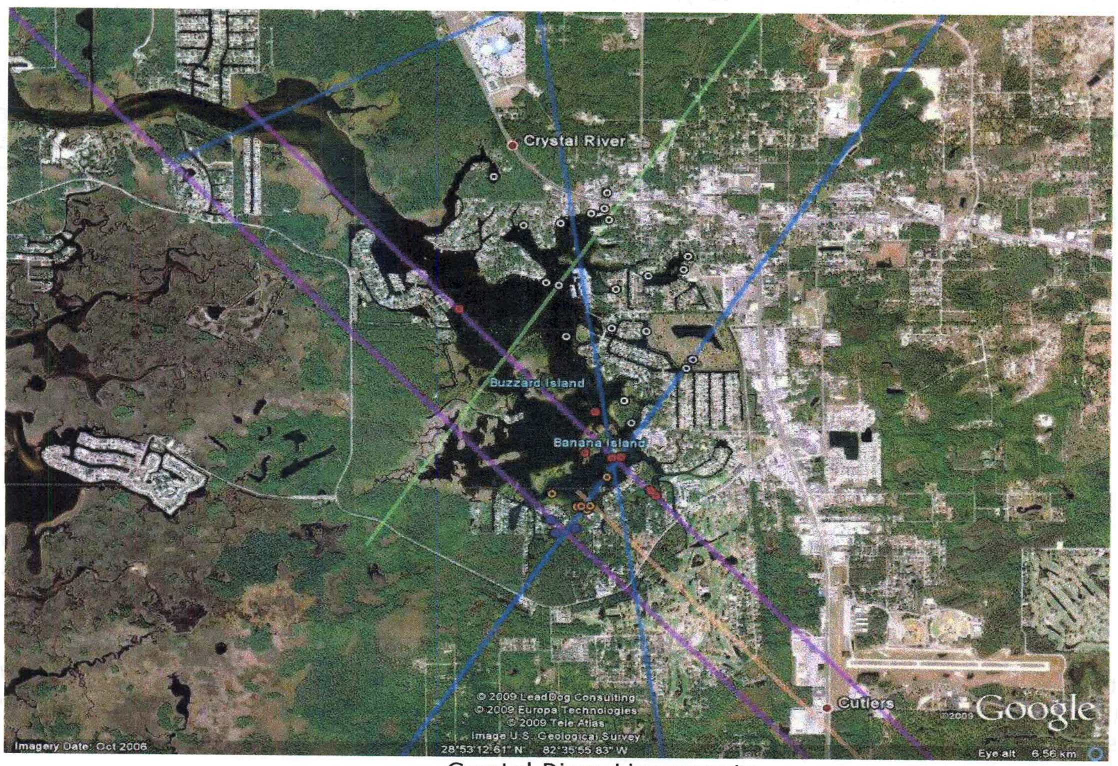
On the lower image on the following page, the SE to NW purple lines (parallel to the Vernon fracture line, shown in dark red in the upper image) encompass a major tributary underground flow, delivered from fractures into Kings Bay from spring vents.

This pattern of lineaments predicates two separate water sources serving the south-west and north-east portions of the bay. In USGS Open File Report 96-230, (1996), Hammett, et al, observe that surface waters do not intermingle between the north-east and south-west portions of the bay. The lineaments (probable conduits) from the north-east appear to intersect those from the south east. Specific conductance readings of spring vents which are lowest in the group laying to the north-east of Kings Bay with values up to 500µS/cm, and highest from those vents to the south-west of the bay with Values up to 12900µS/cm, with graduating values in between according to SWFWMD data. Since the surface waters have no interaction it suggests that mixing could be happening beneath the Bay waters.

Of further interest is the location of cave systems in the Withlacoochee Forest, Citrus Tract, positioned coincident with a photo lineament of the 1972, DOT aerial survey. This suggests that the caves are probably surface representations of a deeper fracture. Although the particular caves are dry today they were probably once expressions of aquifer conduit flow. The direction of the lineament indicates a path into the recharge basin of the King's Bay springs.

Citrus County Lineaments





Crystal River Lineaments

Note that explanation of these two graphics is given on the previous page

When these fractures (suggested by lineaments) were formed, the western shore of the land mass would have extended far into what has become the Gulf of Mexico, say, 50 to 150 miles(USGS FlaSH data). Hence fractures would not stop at US19 but extend westwards, to either deliver fresh water as conduits breached the seabed, or, allow for salt water to be pumped under the sea according to extant tidal or weather surge pressures. The reason lineaments did not show on the mylar could be because areas west of US19 were not surveyed or were too wet to register lineaments in a discharge zone. A black and white 1970s GIS map of the region did not reveal any lineament data nor did a 2008 infrared photograph.

So far, the principal sources of information cited relating to lineaments and fractures, are those of Vernon (1951), Faulkner (1972), and the FDOT (1972/3) aerial survey data.

A further important source of information is that of Gregg W. Jones and Dr. Sam B, Upchurch et. al. (1994), Origin of Nutrients in Ground Water Discharging from Kings Bay Springs. Notwithstanding that the Vernon (1951) report is not cited as a reference, and no mention is made of particular fracture conduit flow paths, nor reference made to vehicle exhaust sources of groundwater pollutants, it is a very thorough analysis of hydrology and geochemistry.

> The discussion of hydro-chemical facies from well samples, on pages 44 through 49 and Figures 18 and 19, of Jones(1994) reveals an east-west connection between the Tsala Apopka lakes region and Kings Bay Springs, as a sub-regional flow system passing under the central area of Citrus County which was not reflected in the aerial survey data.
>
> The note on page 25, of Jones (1994) describes the nature of fractures and photo-linears, according to co-located sinkholes (Littlefield et al. 1984), as "major conduit systems for groundwater flow". Figure 30, on page 81, of Jones(1994) illustrates potentiometric (peizometric) travel times for that groundwater flow corridor (under conduit flow conditions travel times would likely be shorter). However, there is no evidence in the aerial data of a fracture conduit on that path, possibly due to the depth of the overburden of the Brooksville Ridge.
>
> Moreover,. The choice of the 15% porosity factor is seen as a conservative stretch of the Travel Time computation. Especially for the southeast-northwest tributary flow, as predicated on page 80, of their report. Personal data from SWFWMD 2010, reports nitrate concentrations in Kings Bay (0.28 – O.35mgL) markedly lower than those seen in the Rainbow River (1.8 mgL).
>
> Emphasis is also given to degradation of water quality in the protected waterway of Crystal River/Kings Bay on page 66, of Jones(1994), when considering Total Nitrogen, as follows.
>
> > "Since transformations between nitrogen species are rapid and complex, it is often best to consider total nitrogen. Total nitrogen concentrations represent the summation of all of the previously discussed analytes.
> >
> > The distribution of total nitrogen (Figure 25a and b) ties several of the pathways previously discussed together. The high nitrogen concentrations that have resulted from leakage from Lake Tsala Apopka are well represented. The east-west, northeast-southwest, and north-south corridors are also strengthened. These corridors correspond with principal directions of fractures and lineaments and suggest that there is a long-term supply heading for the springs. The high in the western portion of the City of Crystal River is contoured with the springs, suggesting a connection."
>
> Attention is drawn on page 110 (item 14) in Jones(1994) to an increased nitrogen feed into Kings Bay, say, by the year 2014. The Lyngbya growth recently observed in the Three Sisters Springs complex may herald an early arrival of that feed.

The following paragraphs, were suggested by USACE as a good summary on fracture-trace mapping principles by Diodato (1999):

Photolinear analysis is a type of remote sensing analysis wherein investigators map linear features (photolinears) observable on aerial photographs or other remotely-sensed images. The use of photolinears for ground-water well siting was pioneered by Lattman and Parizek (1964). For linear features of geologic origin, lineaments are defined as those photolinear features greater than one mile in length, whereas fracture traces are the same type of feature having a total length of less than one mile. The width of these zones of fracture concentration can vary from a few to tens of meters. In general, longer lineaments tend to have wider surface expressions of the zone of fracture and wider zones of fracture concentration at greater depths. Because the fracture trace is the surface expression of the vertical zone of fracture concentration, Parizek has suggested the "fracture zone trace" might be a more appropriate descriptive term (Parizek and Diodato, 1995).

Zones of fracture concentration in soluble rocks such as carbonates and evaporates can lead to enhanced dissolution of these rocks due to accelerated chemical and physical weathering. In the case of rocks prone to karstification. White (1999) has determined that the development of karst conduits begin when fracture apertures reach about one centimeter.

In south Florida, linear features (photolinears) are detected and identified based primarily upon indicators such as aligned solution depressions, surface ponds, vegetation, and variations in soil tone (Trainer and Ellison, 1967, Parizek, 1975). Doline (sinkhole) development can be expected to follow orientation of photolinears, as these represent areas of higher permeability and porosity.

Legal Issues

According to the Institutes of Justinian, a Roman codification of customary law, Book II.I.1., "By the law of nature these things are common to all mankind – the air, running water, the sea, and consequently the shores of the sea."

The English common law recognized similar principles of ownership, but vested it in the sovereign, held in trust for the use and benefit of the public.

As applied in the United States, this public trust embraced all tidal waters and all navigable waters, and is incorporated in the Florida Constitution (Article X, Section 11), subject to certain exceptions, only when in the public interest, regarding sale and private use. Owners of land abutting a water body, Riparians, share rights with the public and each other. If a body of water is navigable or tidal, riparians share a right with the public and each other to navigate, fish and swim. They also control use of their land to gain access to the water.

However, since 1856, (*Chatfield v. Wilson*, 28 Vt. 49, 54 [1856]), "The secret, changeable and unknowable character of underground water in its operations is so diverse and uncertain that we cannot well subject it to the regulations of the law, nor build upon it a system of rules, as is done in the case of surface streams ".

This arcane and somewhat arbitrary principle has bedeviled relations between land owners wanting to exploit resources in a manner they see as their right, and the environment as it serves the interest and needs of the general public. It has encouraged both legislation and litigation, especially in regard to wetlands conversions, which has cost untold millions of tax dollars and degraded water resources immeasurably.

People and land-use practices are currently the leading cause of water pollution, harmful to humans, wildlife and the environment.

Florida State Law

Florida state law regards wetland as "Isolated" unless connected by surface water flows. There is finite risk of decisions being taken that would result in degrading water quality of protected waters, contrary to law.

Antidegradation Policy

The Florida Antidegradation Policy (Sections 62-302.300 and 62-4.242, F.A.C.) recognizes that pollution that causes or contributes to new violations of water quality standards or to the continuation of existing violations is harmful to the waters of the state. Under this policy, the permitting of new or previously un-permitted existing discharges is prohibited where the discharge is expected to reduce the quality of a receiving water below the classification established for it. Any lowering of water quality caused by a new or expanded discharge to surface waters must be manifestly in the public interest (that is, the benefits of the discharge to public health, safety, and welfare must outweigh any adverse impacts on fish and wildlife or recreation). Further, the permittee must demonstrate that other disposal alternatives (for example, reuse) or pollution prevention are not economically and technologically reasonable alternatives to the surface water discharge.

Florida Law Commentary

Notwithstanding that "Waters" are defined whether or not flowing underground through pores or conduits, (Sections 62-520,200(21) FAC.), the following interpretations have been given by FDEP by e-mail exchange.

1. Classification of a surface water as an Outstanding Florida Water does not extend that classification to adjacent groundwater. Florida law treats surface water and groundwater as two separate things even when groundwater flows directly into a surface water.

2. Wetlands whose only connection to other state waters is via groundwater flow are considered "isolated", as state law does not recognize such connections.

3. The 9th CC of Appeal decision, to the effect in the normal sense of the word that a Tributary flow from a source into a waterway may be underground or on the surface, relates to determining whether or not a wetland is subject to regulation by the U.S. Army Corps of Engineers under the Federal Clean Water Act. It has no bearing upon Florida law.

4. The ERP rules (for SFWMD see rule 40D-4.301) state that in order to receive a permit an applicant must provide reasonable assurance that, among other things, the project will not adversely affect the quality of receiving waters such that the water quality standards set forth in Chapters 62-4, 62-302, 62-520, 62-522 and 62-550, F.A.C., including any antidegradation provisions of paragraphs 62-4.242(1)(a) and (b), subsections 62-4.242(2) and (3), and Rule 62-302.300, F.A.C., and any special standards for Outstanding Florida Waters and Outstanding National Resource Waters set forth in subsections 62-4.242(2) and (3), F.A.C., will be violated. Rules 62-520 and 522 are the groundwater rules.

5. The ERP regulates all wetlands whether they are connected to other state waters or not. In considering whether or not to issue an ERP, consideration would be given to the impact of that activity on groundwater and if that groundwater directly flows to a surface water that is an OFW then consideration would be given to the impact on the OFW.

If we really care about conserving Florida's water resources, when faced with risk of degrading water quality of a protected United States waterway, or diminishing a scarce fresh water resource, as as a condition precedent for issuing any permit to proceed even under Florida state law, the proposed developer should be required to prove conclusively that the venture will not act to the detriment of the public interest.

United States Federal Law

Clean Water Act of 1972 (federal law administered by USACE, supervised by EPA).

Congress intended The Clean Water Act (CWA) to apply to "all waters of the United States". Waters of the United States embraced among other things, tributaries of various waters, adjacent wetlands, and intrastate waters with linkages to interstate commerce.

However, the act has been weakened by two Supreme Court decisions.

1. In 2001, the United States Supreme court in a 5 to 4 decision held in Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers — the SWANCC case - that non-navigable, intrastate waters are not protected by the Clean Water Act.
2. In June, 2006, the United States Supreme court in the case referred to as Rapanos/ Carabell handed down a plurality decision with four justices opining that the jurisdiction of the CWA should only apply to "relatively permanent, standing, or continuously flowing" waters, or wetlands immediately adjacent to such waters. Justice Kennedy voted with the plurality to remand the case to the lower court, but disagreed with the plurality's reasoning and rendered his own explanation. Justice Kennedy's opinion focused on whether the specific wetlands at issue possess a "significant nexus" with navigable waters.

Among numerous court decisions following the SWANCC and Rapanos decisions, the Ninth Circuit Court of Appeal, on August 6, 2007, handed down their decision in the Russian River case. The decision affirmed the wetland significant nexus (JK), and that Tributary flow into a navigable-in-fact United States waterway may be surface or underground (according to normal use of the word "Tributary") and flows could be intermittent (due to seasonal or drought influences). Although this principle is reflected in Florida state law, it is not being vigorously applied.

The Clean Water Restoration Act of 2009, currently in U.S. Congress, would seek to restore longstanding safeguards to all the nation's water resources by replacing the word "navigable" with "waters of the United States" throughout the CWA, to include all "isolated" waters, headwater streams, small rivers, ponds, lakes and wetlands, and remove any doubts introduced by the Supreme Court decisions.

Federal Law Commentary

It would appear that federal law outweighs state law today in regard to isolated waters, when such waters (flowing above or below ground) connect with tributaries of a navigable-in-fact United States waterway, which may include wetlands in "significant nexus". However, it is noted that under the significant nexus test, a party seeking to invoke the court's jurisdiction had to present evidence of a hydrologic connection. Rapanos, 126 S. Ct. at 2250-51 (Kennedy, J., concurring). That connection may suffice in some but not all cases to show "some measure of the significance of that connection for downstream water quality."Id. at 2251.86/

A question is raised as to the meaning of significant nexus. It is conceivable that evidence of hydrologic connection could not be obtained in every case. In a case where a United States navigable-in-fact waterway was protected by law against degradation of water quality, and being supplied with water by a tributary (flowing above or underground), and any pollutant discharge into the tributary sufficient to degrade water quality in the waterway, then the tributary and waterway would be classed as a significant nexus. However, should a wetland be adjacent to the tributary and filter run off into the tributary, would that wetland possess significant nexus with the waterway, and be a connected wetland? [Currently excluded under Florida state law].

It is important to know the course of underground water flows in order to frame decisions which safeguard our precious underground water resources, as they continue to be consumed at higher rates than they are created by rainfall. That said, for purposes of a court proceedings would evidence of a hydrologic connection be necessary in addition to any fracture set analysis or any other reasoning ?

If it were possible to ascertain hydrologic connection by sampling water at say, well A, and sampling water discharged from say, spring vent B, and should the water from both sources have sufficiently similar characteristics, then it could be concluded that the water sources were connected. However, in reality, it is not so simple. A conduit flow occurs when the properties of porosity and permeability of the conduit space are such as to allow fluid to flow in the conduit. (See Porosity and Permeability above).

In view of the different treatments prescribed by state and federal law, and having in mind the principal of Supremacy of Law, it would seem that the only way to achieve harmony would appear to be for the law to be clarified by a binding court decision.

Nevertheless, recognizing that the physical complexities may inhibit the determination of significant nexus in advance of a given industrial or commercial building venture, obligation should rest upon a potential developer to respect the public interest. Faced with risk of degrading water quality of a protected United States waterway, or diminishing a supply of a fresh water scarce resource, the proposed developer should be required to prove that the venture will not act to the detriment of the public interest, as a condition precedent for issuing any permit to proceed.

Recommended Goals for Protection for the OFW

Following advice in the November, 2002, document, "Protecting Florida's Springs - Land Use Strategies and Best Management Practices", and in the 2008 Guidebook of Springs Protection, goals to be achieved should include the following:

1. Restore water quality in Kings Bay to levels prescribed as at 1 March 1979.
2. Verify the revealed tributary flows by peer review.
3. Delineate protection zones for the tributaries and associated spring vents.
4. Establish protection criteria for the delineated zones and their groundwater paths.
5. Define and harness enforcement programs required by the Florida Antidegradation Policy.
6. Define and implement water quality restoration programs for the OFW.
7. Develop a dollar/value function model and a Water Budget for Citrus County to assist in framing public interest decisions affecting the OFW.
8. A key issue for elevating any ERP process to federal level would appear to rest upon determination of linkage between threatened wetlands and the OFW surface water body of Crystal River/Kings Bay by way of the southeast-northwest trending tributary.

Notes

The preemption or supremacy doctrine derives from the Supremacy Clause of the Constitution (Article VI) which states that the "Constitution and the laws of the United States... shall be the supreme law of the land... anything in the constitutions or laws of any State to the contrary notwithstanding." This means that any federal law and even a regulation of a federal agency trumps any conflicting state law. However, the application of this principle is not always easy as many issues arise which are considered implied and not expressly stated in the language of any given rule of law.

Furthermore, Section 307 of the Coastal Zone Management Act, 1972, (CZMA) contains the Federal consistency requirements, which apply to federal activities, development projects, permits and licenses, and support to state and local governments. In the CZMA, Congress created a federal and state partnership for management of coastal resources, codified in the state's coastal management program. The processes established, to ensure compliance with the state's federally approved coastal management program, is called a consistency determination for federal activities and development projects and a consistency certification for federal permits and licenses and federal support to state and local agencies.

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