DETERMINING BASELINE GROUNDWATER QUALITY FOR WATER RESOURCES MANAGEMENT: ALACHUA COUNTY, FLORIDA

By

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Abstract

Under a 1983 Florida law, the State of Florida has been mandated to set up a statewide-ambient groundwater quality monitoring network. Alachua County, seeking to set up its own background monitoring program in conjunction with the state program, has undertaken research to gather and evaluate existing data on wells and groundwater quality in the county, examine processes affecting water quality, and set up a preliminary ambient groundwater quality monitoring network. Hydrogeologic and geochemical processes pertaining to groundwater quality in a county exhibiting several aquifer types, discontinuous aquitards, fracture traces, and karst geology are examined. Existing wells are screened to establish a monitoring network, and data from this network evaluated to establish a groundwater quality baseline in the primary aquifer supplying potable water. County maps showing areal distribution of water quality parameters from this network are produced. Geochemical traverses are made to evaluate the influence of geologic and hydrogeologic factors on groundwater quality. Finally, areas most susceptible to groundwater contamination are delineated, and recommendations made as to future monitoring needs and groundwater management strategies.

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I. INTRODUCTION AND BACKGROUND

History

In the United States, with the exception of rural domestic supplies, surface water withdrawals for all uses typically far exceed groundwater withdrawal rates (Freeze and Cherry, 1979). In Florida, the situation is different, with 92% of Florida's total drinking water supplies coming from groundwater (Senate Committee on Natural Resources and Conservation, 1982). Alachua County, Florida, is unique in that 100% of its drinking water is withdrawn from underground supplies.

Prior to public awareness of problems of groundwater contamination, the focus of water resources management has centered on protecting surface waters from municipal and industrial discharges, and of potable water supplies from disease vectors. Groundwater, protected by layers of clay and filtering sands, was previously assumed to be relatively free from contamination that existed in surface waters. Typically, those groundwater analyses that were conducted tested mainly for hardness, pH, major ions, and pathogenic bacteria, primarily to indicate contamination of well water by domestic sewage and to indicate the suitability of groundwater for use in boilers. However, as more incidents of other types of groundwater contamination reached the press, and as laboratory analytical capabilities expanded, researchers began testing in the 1970's for longer lists of chemical compounds, including metals (other than iron) and manmade organic chemicals such as solvents, PCB's, and pesticides. One study in New Jersey has shown that groundwater is <u>at least as</u>

contaminated as surface water (Page, 1981). Monitoring data from other state studies indicate that the concentrations of synthetic organic compounds detected in public groundwater supplies can greatly exceed maximum concentrations of those compounds detected in surface water supplies for public consumption. Trihalomethanes and chlorinated hydrocarbon solvents are most frequently detected in groundwater supplies (Dyksen and Hess, 1982). Moreover, it was learned that groundwater does not have the same pathways for self-purification that are available to surface waters, and in the case of compounds that do not readily attenuate, such as certain solvents, contamination may spread throughout an aquifer and persist for decades, essentially removing the aquifer from consideration as a source of potable water.

In 1967, Florida passed its first environmental control legislation, the Florida Air and Water Pollution Control Act, officially recognizing the threat of pollution toward water supplies. This legislation called for setting water quality standards for the state, determining levels of water quality and sources of pollution, and establishing programs to require permitting and review of installations that are pollutant sources. With the passage of the Florida Safe Drinking Water Act of 1977, Florida took primary responsibility for its public water systems, adopting standards for public drinking water that met or exceeded federal primary and secondary drinking water standards. Private water supplies remained under the jurisdiction of the Florida Department of Health and Rehabilitation Services, which has set limits only on nitrates and coliform bacteria.

At present there is no federal program dealing specifically with the problem of groundwater contamination. The nature of the problem is such that no one piece of legislation could address it properly.

The Safe Drinking Water Act of 1974, the Resource Conservation and Recovery Act of 1976 (RCRA), the Toxic Substances Control Act of 1976, the Clean Water Act of 1977, and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) are the principal federal statutes that have been enacted which deal indirectly with groundwater protection.

The passage of the Florida Resource Recovery and Management Act of 1974 (amended in 1980), recognized the relationship between wastes and groundwater quality. It began to require the placement of monitor wells at certain sanitary landfills, and the collection and treatment of leachate. In addition, this law provided for restoration of waters of the state contaminated by hazardous waste.

Today, reports of cases of groundwater contamination are common. One 1982 estimate suggested the 200,000 point sources (septic tanks, landfills, pits, ponds, and lagoons) known at that time had contaminated over 2% of the nations usable groundwater (Pye and Patrick, 1983). The extent of contamination due to non-point sources such as feedlots and pesticide applications is not known. Since the passage of CERCLA, 750 hazardous waste sites nationwide have been evaluated through a ranking process and were found to constitute enough of a contamination problem to warrant inclusion on the EPA's National Priority List for immediate remedial action under the Superfund program (Elkins, 1985).

The threat to groundwater supplies in Florida is great due to high population densities, high rainfall, thin and highly permeable sandy soils, and shallow depths to the aquifers. Consequently, many of the Superfund sites are located in Florida. In addition, many public groundwater supplies in Florida have been found to contain one or more types of contamination, including supplies to large metropolitan cities such as Fort Pierce, West Palm Beach, Ft. Lauderdale, North Miami, Hollwood, and Tampa (FDER, 1982b). Most recently, it has been reported that at least 290 wells in the state have been found to contain unsafe levels of ethylene dibromide (EDB), which reached the groundwater after land application of the chemical to control nematodes in orange groves.

Alachua County, with its total dependence on groundwater resources for water supplies, has a significant history of groundwater problems. In the spring of 1964, a large number of reported cases of a viral infection among users of Gainesville city water were linked to contamination of the Floridan Aquifer underlying the city's well field by effluent released from sewage treatment plants (Davis, 1985). In 1983, contamination of surficial and secondary aquifers by chlorinated solvents, dumped by the D.O.T. into an unlined borrow pit 2.5 miles northeast of Gainesville, forced the closure of 49 private residential water supply wells (Dames and Moore, 1983). Most recently, private wells drawing water from the Floridan Aquifer south of Micanopy have been polluted by coliform bacteria, 14 private wells near two of the county's landfills have been found to contain chlorinated solvents believed to have come from the landfills, and 15 private wells in Gainesville have been found to contain ether, EDB, and other petroleum derivatives characteristic of contamination by gasoline leaking from underground storage tanks (ACDES, 1985).

Another site in Alachua County has gathered recent publicity due to its inclusion on EPA's Superfund list. The Cabot Carbon site in Gainesville, formerly a manufacturer of turpentine solvents, pine tars, and charcoal, has contaminated areal groundwater through years of seepage of water soluble phenolic compounds through the bottom of unlined waste lagoons. Subsequent destruction of the lagoons and haphazard burial of the wastes during construction on the site further contributed to the problem. In addition to increasing the groundwater contamination, this latter activity also caused the waters and sediments of Hogtown Creek, which drains 2/3 of Gainesville, to become contaminated with 37 different kinds of toxic compounds, requiring it to be posted as unsafe for recreational use. Recent studies have shown the soil and groundwater on the site to be heavily contaminated with phenols, terpenes, and condensed aromatics, several of which are on the EPA's priority pollutant list (Zoltek et al., 1982).

Just as the number of cases of groundwater pollution reaching the press had spread, so did awareness of the vulnerability of Florida's water resources to contamination. In 1983, the Florida Water Quality Assurance Act was passed, designed to upgrade existing legislation to further prevent contamination of potable groundwater supplies. Among other things, this legislation empowered the FDER to set up a statewide groundwater monitoring network to establish background water quality and detect contamination in aquifers before it reached wells from which drinking water is withdrawn.

Study Objectives

In order to help the state meet its legislative imperative, and to enable Alachua County administrators to more effectively manage their groundwater resources, it is the primary purpose of this research to design an ambient groundwater quality monitoring network and database to separate background water quality from that of affected areas, and to establish a baseline for detection of groundwater contamination in Alachua County. In addition, this study will explore the hydrogeology of the area, delineate areas most susceptible to contamination, and suggest alternative groundwater resource management options.

II. WATER RESOURCES OF ALACHUA COUNTY

Previous Research

Previous studies of the water resources of Alachua County are for the most part contained in publications of the USGS. Groundwater in Central and Northern Florida (Cooper et al., 1953), and Water Resources of Alachua, Bradford, Clay, and Union Counties, Florida (Clark et al., 1964) are the principal references. Assorted USGS map series publications covering the county area, and the yearly USGS Water Supply Papers or Water Resources Data publications provide additional information. Detailed geologic information is available from lithologic logs at the Florida Bureau of Geology, and through its publication titled The Geology of the Western Part of Alachua County, Florida (Williams et al., 1977). Twenty six 7.5 minute topographic quadrangle maps are available from the USGS which cover the entire county. Aerial photographs covering individual sections of the county are available from the county administration. In addition, local studies done by consultants provide information on specific aspects of local water resources.

Hydrology

Alachua County has a population of 151,369 (1980 census), occupies a land surface area of 892 mi^2, and is situated in the north central part of peninsular Florida known as the Central Highlands. It is bounded on the north by the Santa Fe River, on the east by Putnam County, on the south by Marion and Levy Counties, and on the west by Gilchrist County. The county is laid out according to the system of section, township, and range, but enough irregularly shaped tracts and grants exist to make the use of that system cumbersome. Many roads in the county follow section boundaries.

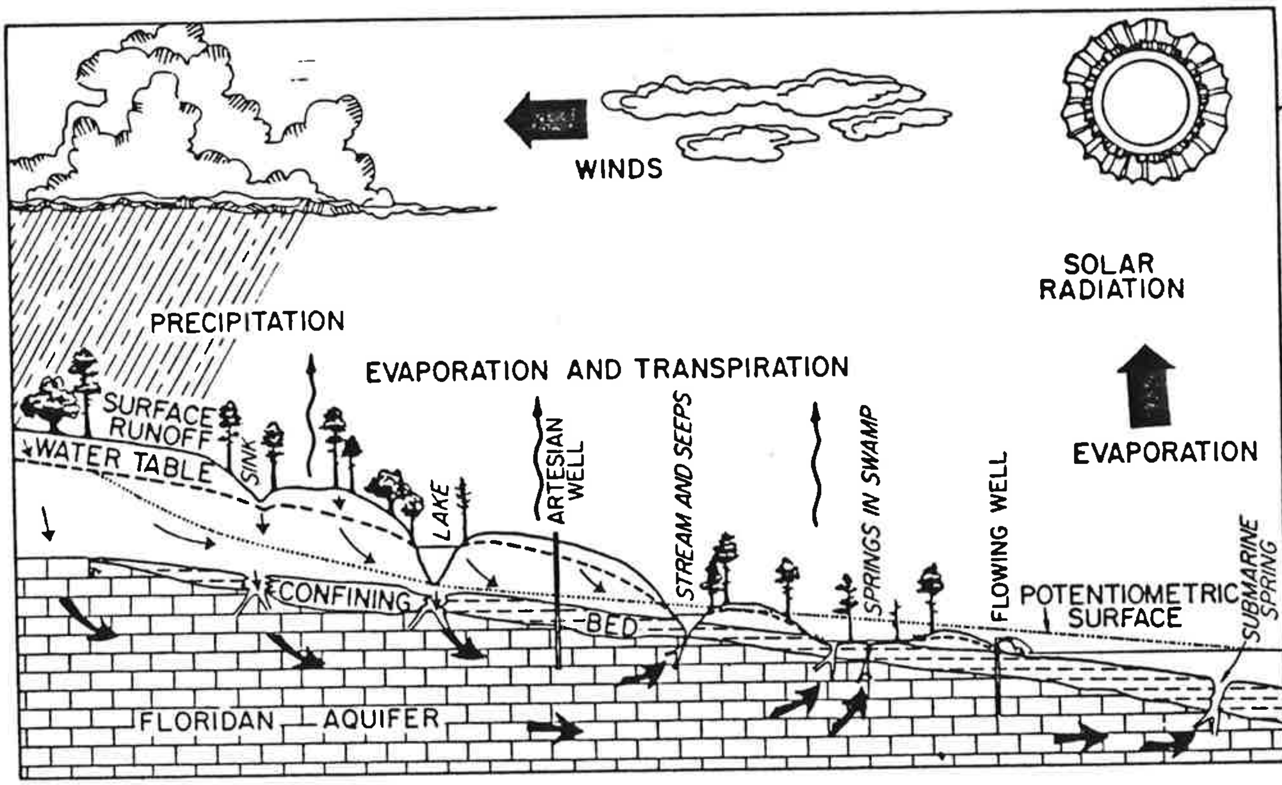
The climate of Alachua County is humid subtropical. The average annual air temperature at Gainesville is 70 F. The average precipitation is 52 in/yr., but can range from a low of 35 to a high of 77 in/yr., leading to drought or flood (Hughes et al., 1971). There are well defined wet and dry seasons due to the nature of the storm systems producing the rainfall. The period of greatest rainfall occurs from June through September, and is mainly due to convective storm activity (Clark et al., 1964; Cooper et al., 1953).

Precipitation that falls on the county returns to the atmosphere by evapotranspiration, runs off the land surface to lakes and rivers, and infiltrates to replenish the groundwater supply (fig. 1).

The USGS has delineated three hydrologic units or basins covering Alachua County which channel runoff to streams. Runoff as defined by the USGS includes not only overland flows that reach surface water bodies, but also that component of precipitation which infiltrates to groundwater and later emerges into surface streams. Since the USGS first designated the county's drainage basins, a complete topographic map series has become available. Using these maps, a revised set of basins can be drawn, which indicates less area contributing surface runoff to the Santa Fe River, and more area lying in that part of the county which exhibits little, if any, runoff.

Runoff over Alachua County is extremely variable, both with time and location. The Santa Fe River Basin contains areas wherein runoff ranges from 6-85 in/yr, while runoff in the Orange Creek basin, which drains southeast Alachua County to the Oklawaha River and eventually the St. Johns River, ranges from 5-15 in/yr (Clark et al., 1964;

Figure 1. **The Hydrologic Cycle**
(Rosenau et al., 1977)



Hughes et al., 1971). The high runoff of 85 in/yr to the Santa Fe River occurs west of High Springs, and is due to springs contributing base flow to the river in that area. The remaining area of the county is considered part of the Waccasassa River Basin, and although it exhibits no channelization for surface outflow, is considered to have 5-10 in/yr of runoff (Hughes et al., 1971). However, the presence of large numbers of active sinkholes in the region, and the absence of surface drainage features indicate that the probability of any runoff leaving the area is small. Although there are creeks present in this basin in the Gainesville and Alachua areas, they discharge into sinkholes and cease to be surficial paths of runoff.

Most runoff in the county occurs during the wet season, when rainfall exceeds evapotranspiration. Aside from the baseflow increases attributed to runoff, spatial variability in the runoff data is due to several factors. Topography plays an obvious role, with flat, poorly drained areas retaining much rainfall on the surface, allowing considerable evaporation to occur. These areas occupy much of the eastern half of Alachua County, where a shallow water table is present and close to the surface, and soil types usually fall into moderate to poorly drained categories. Hilly terrain allows little surface retention, and increased runoff occurs (such as in the area along the Santa Fe River north of Alachua). Well drained soils, especially in combination with karst features, allow more infiltration than evaporation, and there is subsequently less runoff. Much of the western part of the county falls into this category. Man's influence, especially that of urbanization, also affects runoff patterns (Kenner, 1966).

Values for actual evapotranspiration over the county are difficult to assess. Use of the Penman equation with its exacting data requirements is considered the best method of determining potential evapotranspiration (Jones et al., 1984), but an estimate of potential evapotranspiration in the form of average annual lake evaporation, which gives a general value for Alachua County of 46 in/yr (U.S. Dept. of Commerce, 1979), agrees well with estimates reached by other researchers (Visher and Hughes, 1969). However, potential evapotranspiration is the <u>maximum</u> amount of moisture that can be evaporated from land and vegetative surfaces under the assumption that availability of water will not be a limiting factor. Actual evapotranspiration will be less than potential. An estimate of actual evapotranspiration for the county using nomograms based on temperature distributions for the state and average water availability under normal conditions gives a value of 35 in/yr (Dohrenwend, 1977).

Infiltration is a useful parameter with which to estimate recharge. However, it is perhaps the most difficult element of the hydrologic water budget to determine, due to its dependency on antecedent soil moisture conditions, soil porosity or storage potential, soil clay content, vegetative cover, and land use. It can be calculated from the water budget when the other parameters are known or estimated, or indirectly, by methods used to estimate aquifer recharge. Aquifer recharge will be discussed in the section covering groundwater.

In a county such as Alachua where no surface inflow occurs, assuming no net change in surface water or groundwater storage, a simplified water budget formula using average annual values and spatially lumped parameters is appropriate:

$$I = P - ET_a - Q_o \quad (1)$$

where:
I = Infiltration (in/yr),
P = Precipitation (in/yr),
ET_a = Actual evapotranspiration (in/yr), and
Q_o = Runoff (in/yr).

This equation gives general estimates of potential infiltration in various parts of the county. For example, using an ET_a of 35 in/yr to get a rough estimate of infiltration in the karst areas of the county where there is no evidence of outflow, gives a potential recharge of 17 in/yr, or 8.1 $\times 10^5$ gal/mi^2-d. However, due to the variability associated with actual evapotranspiration, and lacking discharge data on small streams to separate out the baseflow component of the USGS runoff estimates, the budget method should be used only to estimate a range of values.

Topography and Physiography

Elevations within Alachua County, taken from USGS topographic maps, range from a low of around 25 feet MSL near Poe Springs on the Santa Fe River, to a high of around 195 feet MSL northwest of Gainesville.

Three major physiographic regions describe Alachua County (Pirkle, 1956b):

1. A plateau, covering most of the eastern and northeastern part of the county.
2. A western plains region of karst topography and occasional hills.
3. An area in the south central to southeast part containing flat bottomed lakes and prairies.

The region of Alachua County called the Northern Highlands Plateau (Williams et al., 1977) is a relatively high flat area of low relief characterized by cypress hammocks, pine flatwoods, and swampy areas of poorly drained soils. Its sandy, clayey soils are underlain by the Hawthorne formation, whose clays account for much of the standing water. Typical elevations range from 125 to 185 feet MSL. Surface drainage features exist where relief is significant. Generally, flow is to the Santa Fe River, which cuts across the plateau, or to Newnans Lake. This upland plateau originally covered the entire county with resistant units of the Hawthorne, but erosional processes, coupled with solution activities in deeper limestone units, have reduced its extent by nearly half. Occasionally, sinkhole development near the margin of the plateau is obvious, as at the "Devil's Mill Hopper", but generally solution activity in the interior is marked by low relief slumpage and erosional infilling due to thick overlying sediments.

The erosional border of the plateau, called the Northern Highlands Marginal Zone, is an escarpment of considerable relief marking the retreat of the resistant plateau. Elevations in this westward facing zone extend from 75 feet in the limestone plain to 190 feet on the plateau. This range is due to the erosional action of small streams coming off the plateau. Evidence of solutional activity in this zone is widespread, with numerous sinkholes and several caves present. On the University of Florida campus in Gainesville, this escarpment is evidenced by considerable relief. Sinkholes, and springs discharging the water table are also common on the campus.

The second major physiographic feature is the Western Valley or Limestone Plain. It is a subdued karst region occupying the area west of the escarpment, composed of near surface Crystal River Formation limestones overlain by a variable veneer of sediments. Relief on the plain itself is low, but occasional erosional remnants of Hawthorne sediments from the plateau which formerly covered the area form hills on the plain, causing relief to vary between 60-100 feet. The near level surface of the plain is believed to be due to marine terracing and planation due to Pleistocene seas (Williams et al, 1977).

The karst nature of the plain is strongly apparent. Numerous sinkholes and solution pipes in various stages of activity abound. The extent of solution activity marking the highly irregular surface of the Ocala Group limestones composing the valley floor is subdued by erosional infilling of cavities with overlying sediments. Logs of wells drilled into some of these solution features indicate depths of cavity and fill of over 200 feet (Pirkle, 1956a).

The widespread sinkhole activity is explained by the county's geomorphological history. The western plain occupies a position on the northeastern flank of a northwest-southeast trending anticline which formed in Tertiary times known as the Ocala Uplift. In addition to causing a slight northeast dip in sediments, this feature produced extensive fracturing and high angle faulting in the rigid limestones, both along the axis of the uplift and at right angles to it. As a result, this fracturing accelerated solution activities which express themselves at the surface as linear patterns of sinkhole development, lineaments, and joint controlled stream patterns such as exhibited by the Santa Fe River northwest of Alachua (Williams et al., 1977).

In the extreme southwest part of the county, sands of the Brooksville Ridge mark the western boundary of the Limestone Plain. Relief of these ridges and hills varies between 55 and 135 feet. These sands are thought to be remnant dunes from Pleistocene seas, transported and shaped by winds. Underlying this unit is an uneven mantle of clay, the Alachua Formation, covering the solution riddled surface of the Ocala limestones (Williams et al., 1977).

The third major region of Alachua County, called the Alachua Lake Cross Valley (Williams et al., 1977), occurs in the southern and southeastern parts of the county, and is characterized by shallow, flat bottomed lakes and level prairies. Relief is small, ranging up to 20 feet above the local piezometric surface which marks the base level to which this area has been reduced by solutional erosion. Water levels in the prairies occupying the area correspond closely with the water table, and fluctuate with groundwater levels and discharge rates of the sinks draining them. Paynes Prairie, for example, has on occasion become a large lake, even permitting traverse by freight steamer, as Alachua Sink became temporarily plugged (Pirkle and Brooks, 1959). Other lakes and prairies in this region are similarly constrained by solutional, subsurface drainage. Their water levels are affected by piezometric fluctuations and degree of bottom aquiclusion by clay and organic sediments. Although bottom sediments and surficial outflow features act to dampen water level fluctuations, control reverts to subsurface drainage when deposited aquicludes are breached by collapse or flushing due to sinkhole activity. Such activity in Orange Lake in 1955 drained more than two-thirds of the lake, and reduced the lake level by 11 feet (Pirkle and Brooks, 1959).

Tuscawilla Lake, in the area of Micanopy, is not a part of the Alachua Lake Cross Valley province due to its elevation above the local piezometric surface. It occupies a basin in an outlying erosional remnant of plateau consisting of the less permeable Hawthorne sediments.

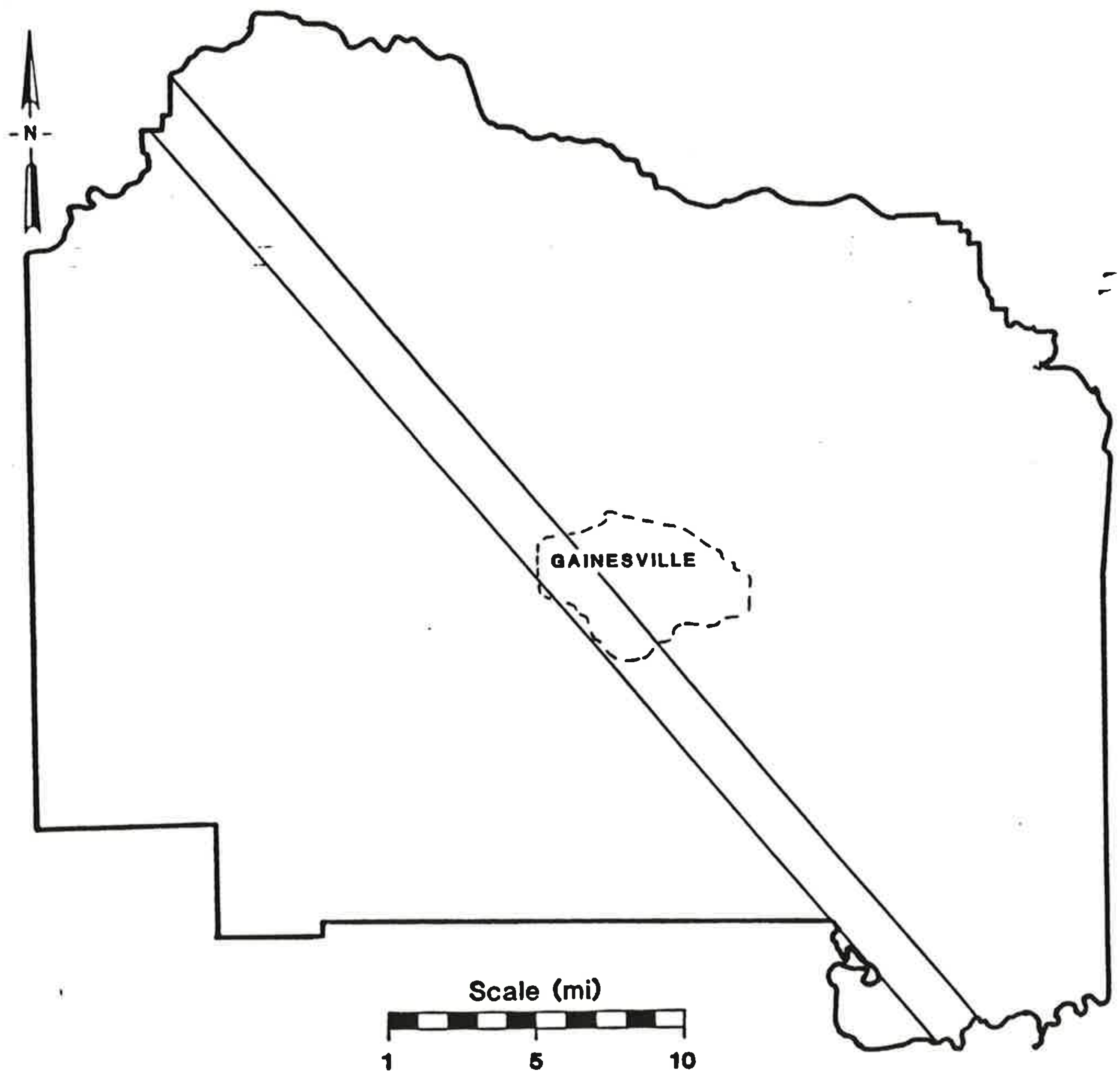
Alachua County exhibits strong evidence of a cross-county fracture zone with highly developed karst solution features (Williams et al., 1977). This lineation, due to fracturing of Ocala Group limestones during the time of the Ocala Uplift, extends in a northwest-southeast direction, and traverses the entire central part of the county (fig. 2). Solution activity along this joint pattern produces large numbers of active sinkholes and disappearing streams. The sinkhole draining Orange Lake, Alachua Sink, former sinks used for waste disposal in the area now known as Lake Alice, the Devils Millhopper sinkhole, sinks in Sanchez Prairie, and the sinking of the entire Santa Fe River underground at O'Leno State Park are all attributed to this fracture zone. No fewer than ten sinkholes swallow streams draining 70 mi^2 of the area near Alachua. Mapping of jointing in Warrens Cave near this zone indicates primary fracture strikes closely resemble lineation exhibited by surficial sinkhole patterns and stream channels (Williams et al., 1977).

Geology

Alachua County, like most of Florida, is formed from sedimentary processes taking place in relatively recent geologic time. A generalized map of the county showing representative lithologies appearing just under the soil zone is given by Knapp (1978). These surficial lithologic types generally coincide with subsurface geologic formations. A study of the geology of the western part of the county by Williams et al., (1977) resulted in a fairly detailed geologic map of the region (fig. 3).

The oldest formation appearing on the surface in the county is the Crystal River Formation of Upper Eocene age. This formation is the upper member of the Ocala group, the upper sequence of limestone

Figure 2. Cross County Fracture Zone (Williams et al., 1977)



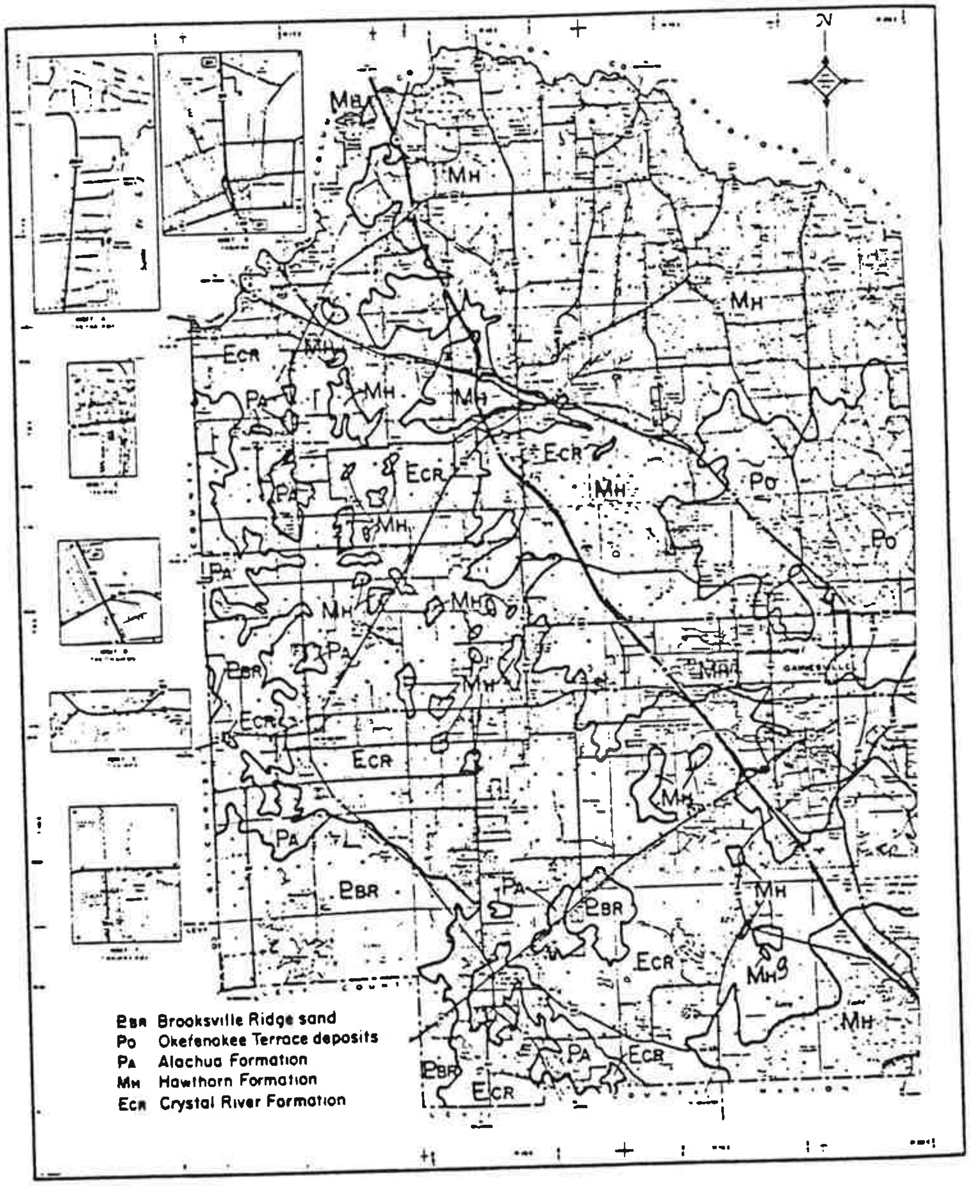


Figure 3. Geology of Western Alachua County, Florida (Williams et al., 1977).

formations which contain the Floridan Aquifer. The Crystal River is a soft, creamy white, chalky or granular coquinoidal limestone of marine origin containing foraminifers, echinoids, bryozoans, and molluscs. It varies from being well indurated with calcite to being soft, friable, or granular. Some dolomitization, and secondary silicification along fractures occurs in this formation. Solution along joints and fractures, along with a high secondary permeability, make this a highly transmissive unit. Caverns in this formation are common, and cavities as deep as 40 feet have been reported. Thickness of the Ocala Group ranges from near 80 feet in western Alachua County to 250 feet in the east. The formation has been extensively quarried in the limestone plain region of the county (Clark et al., 1964).

Erosional remnants of a once-continuous band of Oligocene sediments known as the Suwanee Limestone are found in the northwest section of Alachua County. This formation overlies the Ocala Group, and is characterized by cone shaped foraminifers and the echinoid Rhyncholampus Gouldii (Williams et al., 1977). It is composed of beds of hard to soft cream-colored dolomitic or coquinoidal limestone, containing silicified layers of chert or flint. Where present in the county, its thickness may range from 20-50 feet. Exposures of this formation consist largely of residual silicified boulders lying on top of the Crystal River Formation (Williams et al., 1977).

The Hawthorne Formation, deposited marine sediments of Miocene age, is the most extensive surficial formation in Alachua County. Where present, it unconformably overlies the eroded, irregular surface of Crystal River and Suwanee limestones. It is a highly variable formation, and can contain clay, quartz sand, clayey sand, sandy clay, phosphatic grains and pebbles, and soft to very hard limestone or dolomitic limestone. The two most common forms are a phosphatic, sandy, somewhat dolomitic limestone or a bluish or greenish clay containing varied amounts of sand and phosphate. The lenses of limestone, which may reach 20 feet in thickness, contain solution cavities similar to those in the Crystal River Formation. Thickness of the Hawthorne can range from a few feet to around 200 feet. In the Devil's Mill Hopper sinkhole, 115 feet of Hawthorne is exposed. Numerous shark teeth and marine vertebrate rib fragments, along with fossils of marine invertebrates, such as bioherms of Ostrea normalis and large heads of the colonial coral Siderastrea sideria, help characterize this diverse formation (Williams et al., 1977).

Upwelling currents rich in nutrients, and an abundant bird population in Miocene times account for the pervasiveness of phosphate throughout the depositional sequence of the Hawthorne sediments (Vernon and Puri, 1964). Phosphate has been mined from this formation near Hawthorne since before the turn of the century (Pirkle, 1956a).

Upper Miocene sediments, deposited over the Hawthorne and once continuous across the county, have been almost entirely eroded away. The Alachua Formation of Pliocene age, which partly underlies Brooksville Ridge sediments in the western part of Alachua County, is made up of erosional residues from these sediments, as well as from the Hawthorne, Suwanee, and Crystal River Formations. The Alachua Formation has terrestrial origins, as evidenced by the presence of scattered deposits of mammalian bones. Its lithology consists of blue to gray sandy clay which weathers yellow or red due to the presence of iron oxides. Residual silicified boulders from weathered parent formations may also be present. Phosphate, from the Hawthorne

Formation, is present as phosphatic sand, or as plates and boulders of secondary hard rock phosphate. Although generally less than 50 feet in thickness, it has been extensively quarried in western Alachua County (Williams et al., 1977).

Plio-pleistocene sediments found in Alachua County constitute the Okeefenokee Terrace deposits. These deposits, covering parts of central and eastern Alachua County, consist of sands intermixed with clays, marl, and organic material. Along with more recent deposits, they are thought to be related to a late Pliocene stand of sea level (Williams et al., 1977).

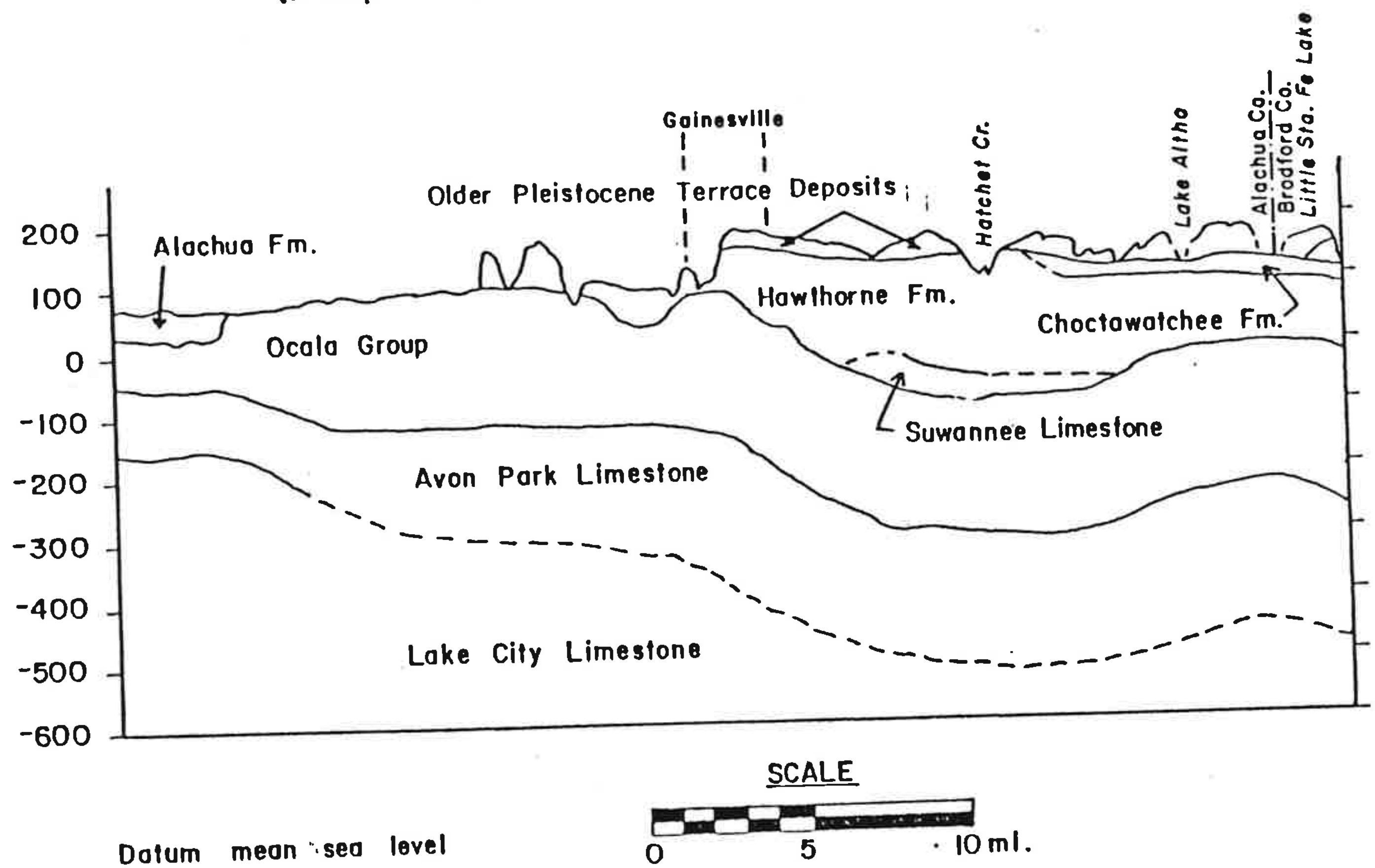
Fluctuations of a Pleistocene sea during stages of glaciation is thought to account for the Brooksville Ridge sands of extreme southwest Alachua County. These sands, derived from Late Miocene and Pliocene deposits, are relatively clean and well sorted quartz grains, reworked and transported into stabilized dunes and ridges by wind action (Williams et al., 1977).

A typical geological transect across Alachua County from west to east is illustrated in figure 4.

Surface Water

Surface water in Alachua County consists of lakes and ponds, streams, prairies, and springs. With the exception of Lake Alice, which is a polishing pond for effluent from the University of Florida STP in Gainesville, all surface water bodies in Alachua County are rated Class III by the Florida Department of Environmental Regulation (FDER). There are three major drainage divides in Alachua County, but only two of them deliver runoff to streams outside the county.

Figure 4. West-east Geologic Section in Alachua County, Florida (Adapted from Clark et al., 1964)



The Santa Fe River basin, of which approximately 150 mi^2 lie in Alachua County, drains the northern part of Alachua County.

The Santa Fe River begins in the flat swampy watershed surrounding Lake Santa Fe and flows westward, forming the northern border of the county, eventually discharging into the Suwanee River. Several tributaries to the Santa Fe River help drain the basin. The largest of these is Rocky Creek, near LaCrosse. Rhuda Branch, which empties into Sunshine Lake, is not included in this basin due to lack of outflow from Sunshine Lake, and the presence of sinkholes in the area. Lake Santa Fe, with a surface area of 8.3 mi^2, is the largest lake in the basin. A second major Lake is Lake Altho, near Waldo, which is connected to Lake Santa Fe by canal (Clark et al., 1964).

Flow in the Santa Fe River averages 58 $ft^3/_S$ at Graham, and 438 $ft^3/_S$ at Worthington Springs. The nature of the Santa Fe River changes as it passes onto the limestone plain near I-75. Although most inflow to prior reaches of the river was by tributaries, it was a stream "losing" water to groundwater. At this point however, the river becomes a "gaining" stream, with groundwater baseflow contributing most inflow to the river. This is evidenced both by the converging flow lines, from the potentiometric surface, and by the fact that several springs contribute flow along the river in this area. Since normal river levels are close to groundwater potentiometric levels in this area, periods of high water or flood may recharge considerable quantities to groundwater. Hydrographs of the Santa Fe River from gaging stations above and below the limestone plain show the effect of groundwater base flow contribution on total river flow (fig. 5). The entire river enters a sinkhole at O'Leno State Park and flows under-

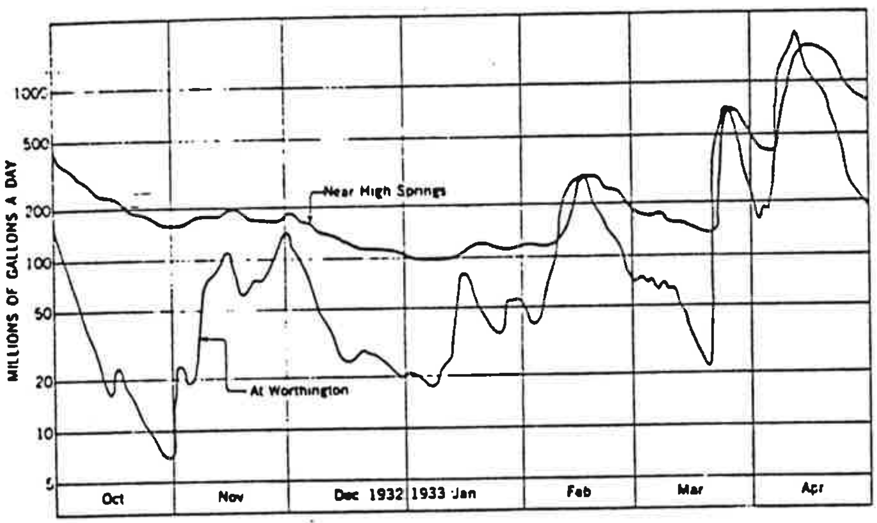


Figure 5. Hydrograph of Santa Fe River at Worthington Springs and High Springs, showing influence of base flow contribution on river flow (Cooper et al., 1953).

ground a distance of three miles before re-emerging north of High Springs. In a random water year, 1981-1982, measurements of flow as the river entered the sink and then re-emerged indicate that increase in flow due to groundwater contributions in that underground segment could easily range from 22% to over 300% (US Dept. of Interior, Geological Survey, 1982).

The Orange Creek basin covers an area of approximately 250 mi^2 in eastern Alachua County, and discharges to the Oklawaha River which empties into the St. Johns River. Newnans Lake, with a surface area of 11.5 mi^2, receives flow from Hatchet Creek, which drains the headwaters of the basin. Flow from Newnans Lake reaches Orange Lake by way of Prairie Creek (diked to prevent flow onto Paynes Prairie), Camps Canal, and River Styx. Lochloosa Creek drains eastern Alachua County south to Lochloosa Lake. Flow into Lake Lochloosa, with a surface area of 13.7 mi^2, eventually reaches Orange Lake by way of Cross Creek (Clark et al., 1964). Discharge from Orange Lake is around 117 $ft^3/_S$ in Orange Creek near Citra (US Dept. of Interior, Geological Survey, 1982).

Since the groundwater potentiometric surface is higher than the surface elevation of Newnans Lake (68 feet), some upward leakage may contribute to flow into the lake. Lake Lochloosa, with an average elevation of 58 feet, receives part of its inflow from springs, and may be similarly recharged. Orange Lake, with a surface area of 20.6 mi^2, appears to be more dependent on groundwater levels. The lake basin is situated in the top of the Ocala Group limestones, and is evidently hydraulically connected to the groundwater of those formations. During the drought of 1955, as groundwater levels fell, the lake surface area was reduced to about 5 mi^2 by lake waters draining into a sink in the lake bottom (Clark et al., 1964). Current evidence, in the form of scour patterns from aerial photographs, indicates some discharge from Orange Lake may occur by sinkholes in the southern part of the lake.

The remaining 500 mi^2 of Alachua County does not contribute surface flow to any system of stream channels, but falls into the category of karst terrain. All surface runoff in this region, exclusive of moisture that constitutes evapotranspiration, enters the groundwater regime either after a short overland flow to a sinkhole or by entering a sinking stream. These streams all originate on the highland plateau, and play an active role in the downcutting of the erosional scarp. In addition to several unnamed streams in the Alachua area, Turkey Creek, Blues Creek, Cellon Creek, and Mill Creek all empty into sinks along a fracture zone. An exception is Tumblin Creek, which enters into Bivens Arm, a low lying lake perched above the water table. Hogtown Creek, combined with its tributary Possum Creek, drains most of the Gainesville urban area, discharging an average 19.2 $ft^3/_S$ into Haile Sink near Arredondo (U.S. Dept. of the Interior, Geological Survey, 1982). Sweetwater Branch, which drains the southeast section of Gainesville, flows in a well defined stream channel during the dry season through Paynes Prairie and subsequently empties into Alachua Sink. A partial record station, established by the USGS in 1981, measured 18 $ft^3/_S$ of flow in Sweetwater Branch near the cattle bridge (U.S. Dept. of the Interior, Geological Survey, 1982). An average 5 mgd (3.2 $ft^3/_S$) of this flow is secondarily treated effluent from Gainesville Regional Utilities (GRU) Main Street 1 and 2 sewage treatment plant (Phelps, 1985). Both sinks are thought to be associated with fracturing of underlying limestones.

Several large prairies are found in this karst region south of Gainesville. The largest of these is Paynes Prairie, containing 12,000 acres. This prairie fluctuates between a lake and a wet lowland, depending on groundwater levels. Levy Lake, which has been drained by canals for agricultural purposes, and several smaller lakes and prairies are also found in this area. Watermelon Pond in southwest Alachua County west of Archer, is situated in the Brooksville Ridge. It is a lake, perched above the potentiometric surface of the Floridan on clays of the Alachua Formation.

Many abandoned lime quarries and phosphate pits in this basin have standing water. This water is the unconfined free water surface of the Floridan Aquifer, and is representative of the potentiometric surface in that area.

Groundwater

Three types of aquifers, or saturated subsurface zones occur in Alachua County. They fall into the categories of water table, secondary, or confined aquifer. Water table aquifers are unconfined; that is, their free water surface is at atmospheric pressure, and free to rise and fall. A confined, or artesian aquifer is usually found at considerable depth, is under pressure, and is overlain by a relatively impermeable material restricting the flow of water into or out of the aquifer. When a confined aquifer is penetrated by a tightly cased well, water in the well will usually rise above the base of the overlying confining layer. A secondary aquifer may occur anywhere between the water table aquifer and a lower confined aquifer.

Water table aquifers occur in shallow sands and clayey sands over much of the northeastern half of Alachua County, as well as in the sands of the Brooksville Ridge. These aquifers are usually underlain by relatively impermeable clays of the Hawthorne or Alachua Formations. A generalized map, constructed using lithologic logs, showing the occurence of these clay layers within 50 feet of ground surface is given by Healy and Hunn (1984). Water table aquifers receive their recharge from infiltrating precipitation, and in some cases from upward leakage of water from a lower confined aquifer through the aquitard, or layer of low hydraulic conductivity separating them. Water is discharged from these aquifers by seepage to confined aquifers, by evapotranspiration, and by discharge to lakes, creeks, or wells. In rural areas, this shallow aquifer is often tapped for domestic water supplies.

The quality of water in water table aquifers is generally quite good for drinking purposes. Higher iron and tannic acid concentrations may preclude use of this water by industry. However, the shallow depth, relatively low volumes, and lack of protective barrier to prevent migration of pollutants downward from the surface make them particularly vulnerable to contamination. Septic tank drain fields are a common source of contamination, particularly if a well is downgradient from the field. Non-point sources, such as pastures and feedlots, can add nutrients and bacteria, which help account for higher average nitrate levels in shallow aquifers. Other parameters, such as pH, specific conductance, alkalinity, and major cations are found in lower concentrations in water table aquifers than in confined aquifers. This is due to recharge by rainwater containing low concentrations of these parameters, by the nature of the aquifer material, and by shorter residence times (Ceryak et al., 1983).

The water table generally conforms well to the topography of the land surface. Water levels of the water table aquifer occurring on the plateau generally range from 100 to 150 feet MSL. Flow directions vary locally, but tend toward creeks or lakes, which drain the area, or toward the escarpment (Clark et al., 1964).

Secondary aquifers occur in areas where the Hawthorne Formation exhibits sufficient lateral extent and contains lenses of material of sufficient hydraulic conductivity. These aquifers vary in number and extent, but are always situated between the water table aquifer and the underlying Floridan. Composition of the medium is variable, but is usually a sand, limestone-dolomite lens, or shell bed sandwiched between clay layers. Recharge occurs from the water table aquifer above, or upward from the Floridan below, depending on the vertical hydraulic gradient of the respective aquifers. Quality of water in these aquifers is generally between that of the water table and Floridan Aquifers, with the exception of fluoride and orthophosphate, whose concentrations are higher due to sources within the Hawthorne (Ceryak et al., 1983). Yield to wells tapping these aquifers is small, with specific capacities ranging from .2 to 10 gal/min per foot of drawdown, but is sufficient for domestic supplies (Clark et al., 1964).

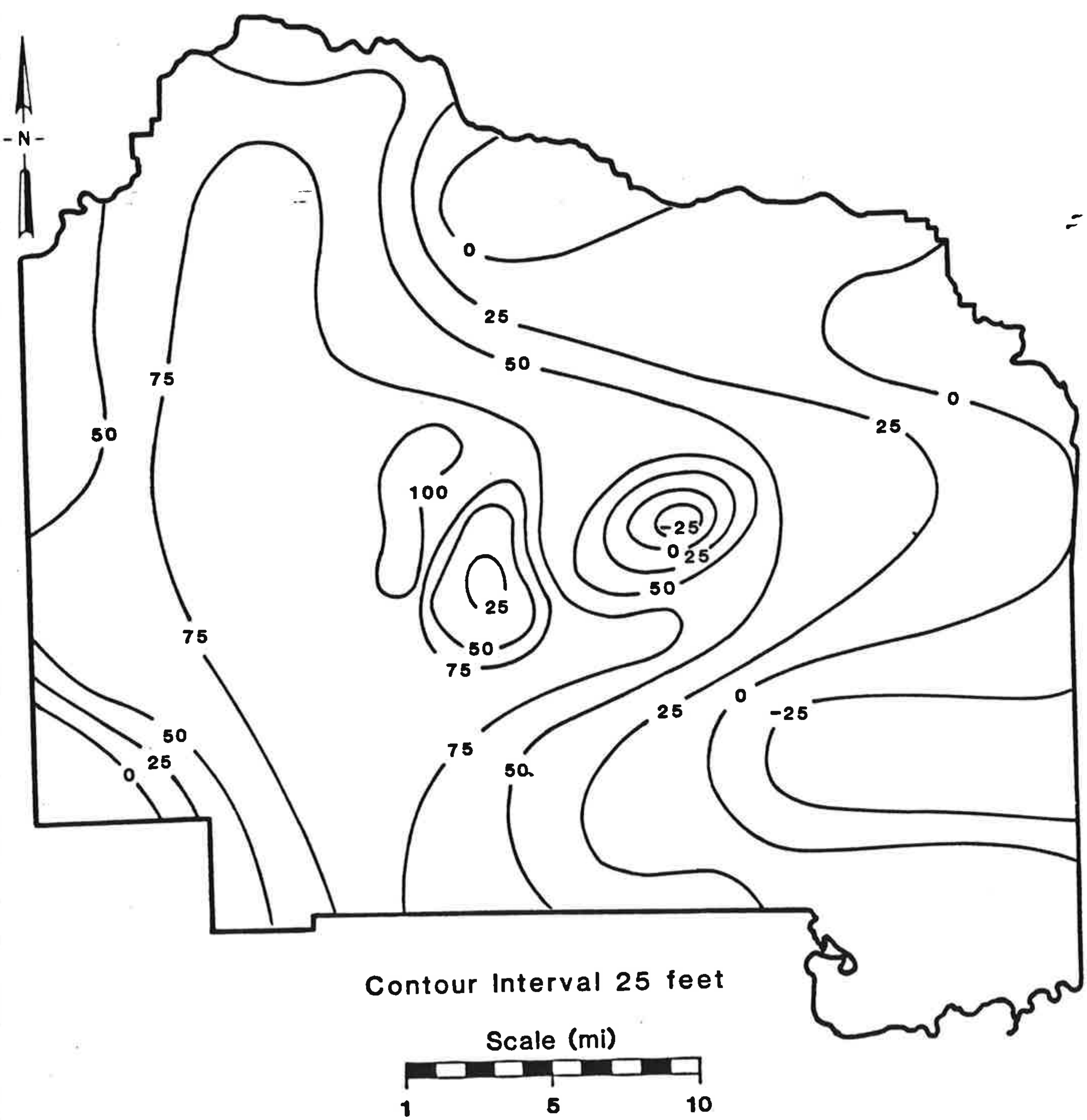
The Floridan Aquifer is the largest fresh water aquifer in the southeast United States, and underlies almost all of Florida (Cooper et al., 1953). It occurs throughout Alachua County, and provides most of the water used for public supplies. The Floridan is a confined aquifer where overlain by sediments of low hydraulic conductivity such as the Hawthorne Formation, and is unconfined where thinly veneered by sands or exposed at the surface, such as in the limestone plain or prairie areas.

The Floridan Aquifer occurs in the interconnected limestone formations of Eocene age, which together function as a hydrologic unit. In Alachua County, water supplies are usually drawn from the upper Floridan, or Ocala Group of limestones. The thickness of the zone of potable water can range from around 700 feet in southwest Alachua County to near 1250 feet in the northeast due to the regional dip in strata (Causey and Leve, 1976). The elevation of the top of the Ocala Group is highly variable due to its having been eroded. Major troughs on its surface are explained by fluvial erosion processes occuring in the early Miocene. This variability is highly accentuated by localized secondary solutioning. In Alachua County, "top of rock" can occur from -25 feet up to 100 feet MSL (Knapp, 1979; fig. 6). Comparison of well logs shows that elevations of the limestone surface in the Gainesville Regional Utilities Murphree well-field differ by 65 feet over a quarter mile distance between two wells. As previously mentioned, local variations can be even more extreme (Pirkle, 1956a).

The potentiometric surface of the Floridan Aquifer in September 1980 as mapped by the USGS is given by Navoy (1981).
The arrows indicate generalized direction of flow, as determined from the hydraulic gradients. A groundwater divide exists in eastern Alachua County to divert groundwater either toward the Santa Fe River or Orange Creek discharge areas. Although water levels were taken during the "wet" season, total fluctuation of potentiometric head in the Floridan Aquifer ranges between 5-10 feet over most of the county,

Figure 6.

Top of Lithologic Units of the Floridan Aquifer with Respect to NGVD (Knapp, 1979).



except near the Santa Fe River and under the Brooksville Ridge (Ceryak, 1985; fig. 7).

Recharge to the Floridan Aquifer occurs through recharge wells or sinking streams, by direct infiltration where the aquifer is unconfined, or by downward leakage from overlying aquifers. Recharge can also occur where sinkhole collapse causes slumpage and breaching of overlying confining sediments (fig. 8). Many lakes in the Keystone Heights area of Clay County to the northeast occur in basins formed by sinkhole collapse. The high potentiometic surface in this region is thought to result from this type of recharge (Clark et al, 1964).

Another area considered to be a high recharge area is where the Floridan Aquifer is unconfined, thinly veneered with sandy, clastic sediments, such as in the karstic Limestone Plain or Cross Valley region (Phelps, 1984). Assuming an actual evapotranspiration figure of 40 in/yr and zero runoff, a conservative recharge rate for this area would be 12 in/yr or around 6×10^5 gal/mi^{2}d.

In areas where the Floridan Aquifer is confined, recharge can occur only if the hydraulic head of the overlying water table or secondary aquifer is above that of the confined aquifer. This occurs over most of the plateau region. The rate of recharge is dependent on this head differential, and the hydraulic conductivity of the clay constituting the aquiclude. Except for local areas where breaching sinkholes occur, recharge in this area is generally low, on the order of 2 in/yr (U.S. Dept. of Interior, Geological Survey, 1981).

Quantification of recharge is complicated by the many variables involved in the process. Although groundwater mounds are widely used

Figure 7.

Total Fluctuation, in Feet, of Groundwater Level in the Floridan Aquifer in Alachua County, Florida (Ceryak, 1985).

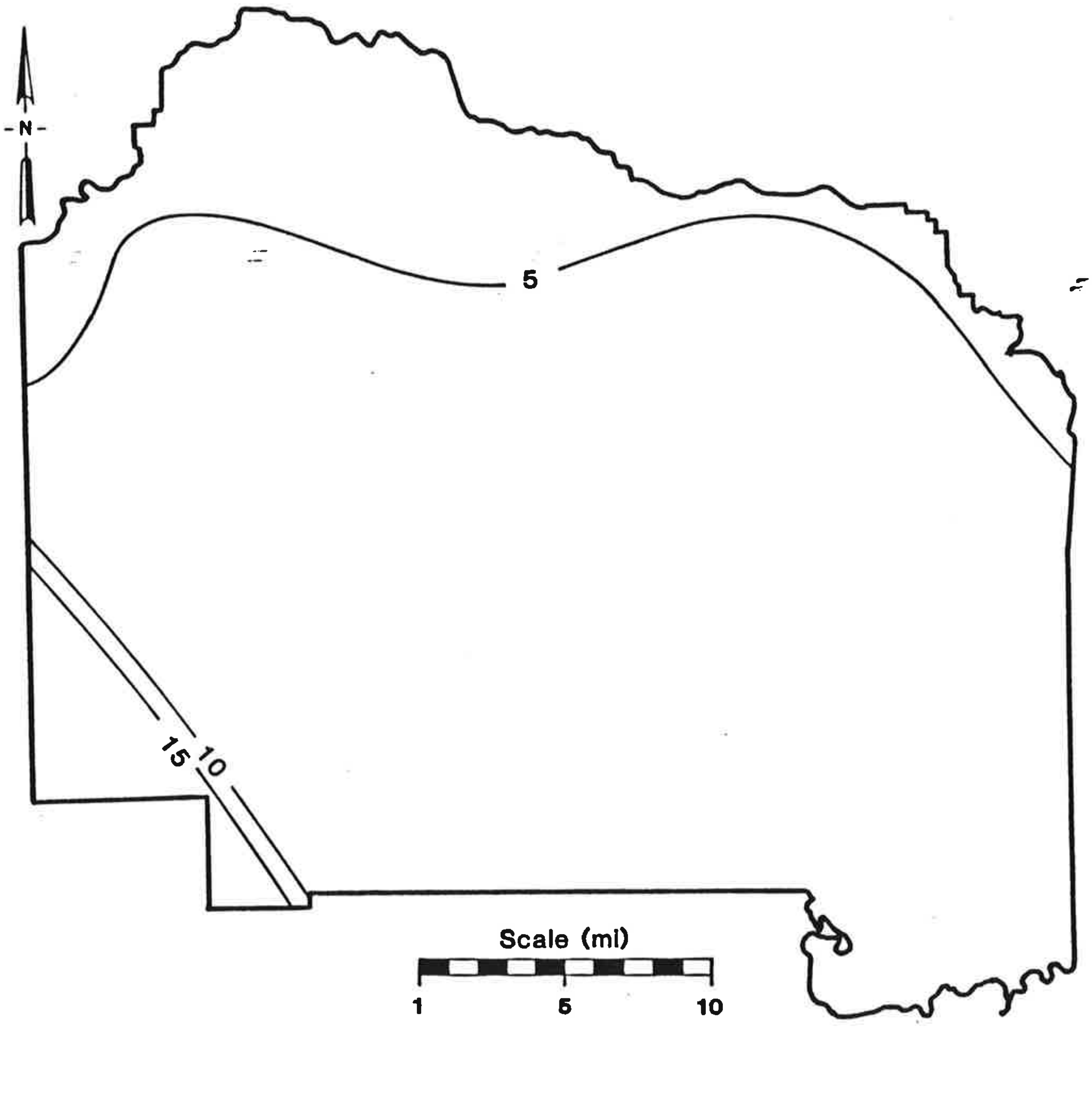
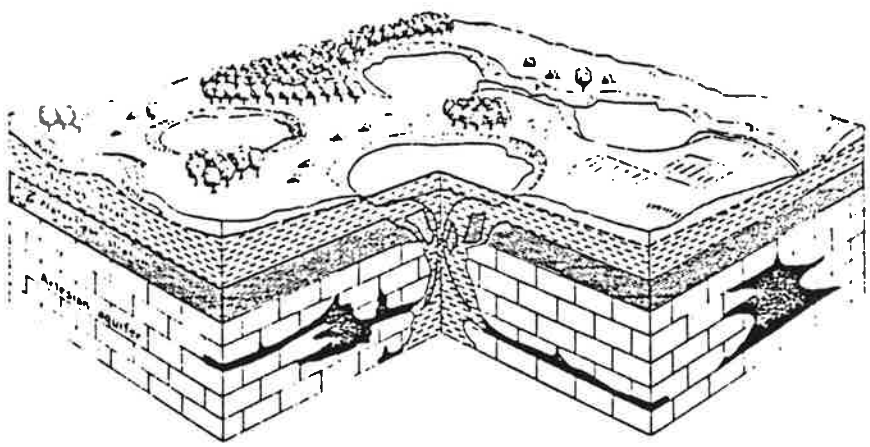


Figure 8. **Recharge through Sinkhole**
(Cooper et al., 1953)



to indicate areas of recharge, they can also result from downward seepage or upward leakage from confined aquifers (US Dept. of Interior, 1977). Recharge or discharge may take place anywhere from the potentiometric high to the potentiometic low where geologic and hydrologic conditions are favorable. Recharge is directly or indirectly related to infiltrating soil moisture, evapotranspiration, horizontal and vertical hydraulic conductivities of shallow aquifer sediments, hydraulic conductivities of confining units overlying the aquifer, hydraulic conductivities of the confined aquifer formation(s), topography, porosity, thickness or storage of the shallow aquifer (where present), thickness of the confining unit(s), thickness of the confined aquifer, hydraulic head diffential between aquifers, and hydraulic gradients of the respective aquifers. From Darcy's Law, specific discharge is proportional to the steepness of the hydraulic gradient, and also to hydraulic conductivity and porosity of the medium. This may not be a linear relationship in fractured limestone where the flow regime can become turbulent (Freeze and Cherry, 1979).

Assuming continuity of flow rate, the spacing of potentiometric contours (hydraulic gradient) is dependent on aquifer thickness and hydraulic conductivity of the medium. For example, for a constant flow and constant horizontal hydraulic conductivity, a doubling of the distance between contours with intervals of equal head difference implies a doubling of aquifer thickness. Since well logs show that aquifer thickness generally decreases to the west, in the downgradient direction, and assuming cross sectional flow is not decreasing down-gradient (valid in rural areas receiving recharge and lacking major pumping wellfields), an increase in contour spacing such as occurs in the limestone plain would imply an increase in transmissivity or horizontal hydraulic conductivity. This is supported by the presence of caves and fracture traces due to proximity to the Ocala Uplift, whose crest flexure has generated concentrated vertical fractures allowing larger flow volumes (fig. 9 , 10). In their study of regional groundwater flow, Freeze and Witherspoon (1967) demonstrated the relationship between gradients, hydraulic conductivity, and flow directions. Gentle gradients represent areas where flow is nearly horizontal. When a zone of high hydraulic conductivity, such as fractured limestone, underlies a zone of lesser hydraulic conductivity, such as surficial clays, the result is an increase in recharge area, an increase in the vertically downward flow component, a decrease in horizontal gradients, and an increase in overall quantity of flow. Buried zones of high hydraulic conductivity tend to diminish the importance of topographic definitions of recharge and discharge, and can also intensify recharge. Anisotropy, or non-uniform horizontal and vertical hydraulic conductivities, can also affect regional flow patterns. In addition to recharge, discharge, changes in hydraulic conductivity, and aquifer thickness, boundary conditions within the aquifer also affect the hydraulic gradient (Pride et al., 1966).

There are several methods for estimating recharge. Most commonly used are water budgets, closed contours, and leakage rates through confining units. All methods assume that the amount of water percolating down into the aquifer equals the net outflow from that aquifer. Flow in confined aquifers may be three dimensional, whereas flow in unconfinined aquifers supported by an aquiclude may be modeled

Figure 9.

Occurrence of High-permeability Zones in Solution-enlarged Fractures Along the Exposed Crest of an Anticline in Carbonate rock.

(Freeze and Cherry, 1979)

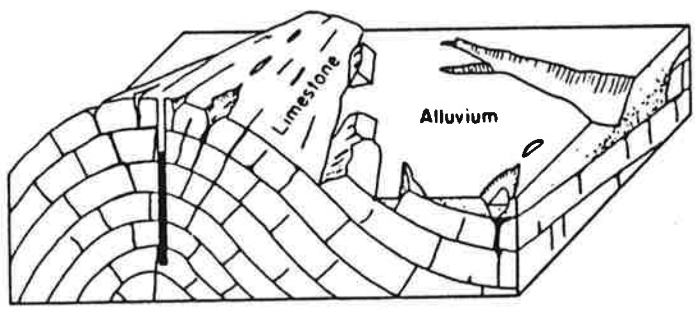
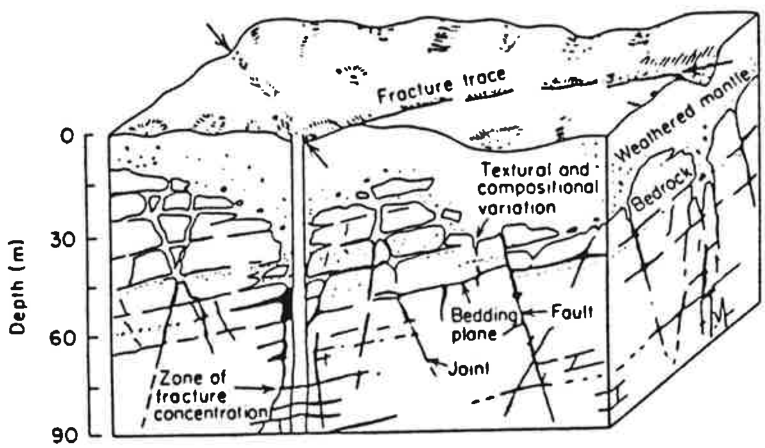


Figure 10.

Occurrence of Permeability Zones in Fractured rock.

(Freeze and Cherry, 1979)



in two-dimensions. Unless areal variations in hydraulic conductivity, thickness of aquifers and confining units, and head differences are described, only rough estimates of recharge can be made. Computer simulation using flow models that consider the spatial variability of these parameters gives the best estimates of recharge (Phelps, 1978).

Aquifer properties in Alachua County have not been well described in the literature. Estimates of transmissivity for the Floridan aquifer in northeast Alachua County range from 160,000 gal/d ft (Clark et al., 1964) to 250,300 gal/d ft (Phelps, 1978). An estimate of the coefficient of storage is .0001. Yield to wells is good, with specific capacities ranging from 3 to 20,000 gal/min per foot of drawdown (Clark et al., 1964).

Hydraulic conductivity is a function not only of the medium, but also of the properties of the fluid flowing through it. A typical range for groundwater flowing in sand-clay (such as constitute the water table aquifers) is 10^{-7} to 10^{-1} cm/s. For aquifers composed of non-homogeneous lithologies such as the secondary aquifers found within the Hawthorne Formation, where composition can range from sandy clay to fractured sandy dolomitic limestone, a rough range of 10^{-7} to 10^{-3} cm/s would apply. In the karst limestones of the Floridan aquifer, hydraulic conductivity may be greater than 1 cm/s due to high secondary permeability (Freeze and Cherry, 1979; Kubal, 1973).

Porosities of aquifer materials can range from .25 to .7 for unconsolidated deposits. The porosity of a well indurated unfractured limestone is low (.05) but can reach .5 for the karstic or fractured limestones or poorly indurated chalks which contitute the Floridan Aquifer (Freeze and Cherry, 1979).

One estimate of flow velocity in the Floridan Aquifer based on carbon 14 dating is .07 ft/d (Freeze and Cherry, 1979). However, this may not be representative of true flow velocities in the karstic fractured limestones of Alachua County, where velocities are almost certain to be higher (Kubal, 1973).

Discharge from the Floridan Aquifer occurs over a much smaller area in Alachua County than does recharge. Discharge occurs in the area north of, and surrounding Lochloosa Lake, as manifested by the presence of several springs in that area (Phelps, 1984). Other areas discharging the Floridan are the Orange Creek basin just east of Orange Lake, and springs and base flow feeding the Santa Fe River in the northwest part of the county. In times of high potentiometric head, discharge may occur upward into lakes in southern Alachua County (Clark et al., 1964).

Alachua County contains ten named springs. Glen Springs in Gainesville discharges the water table or secondary aquifer to a tributary of Hogtown Creek. Boulware Spring in southeast Gainesville discharges the shallow aquifer where the Hawthorne escarpment meets the Cross Valley region. Iron Spring and Sulphur Spring in Hawthorne discharge the water table aquifer in that area. Magnesia Spring near Grove Park is a discharge point for the Floridan Aquifer, and helps feed Lochloosa Lake. Hornsby Spring north of High Springs is a first magnitude spring, discharging an average of 163 $ft^3/_s$ of Floridan aquifer to the Santa Fe River. Darby Spring, and Poe Springs west of High Springs, are similar discharge points for the Floridan Aquifer. Several small springs near the town of High Springs were once used as a water supply for that town (Rosenau et al., 1977).

The quality of natural, unaffected groundwater in a carbonate terrain such as Alachua County is dependent on the concentration of dissolved species at equilibrium. As rainfall or surface water percolates through the soil zone, dissolved oxygen from the water is consumed by organisms and replaced by organic acids and carbon dioxide from respiratory processes. As a result, groundwater has a much higher partial pressure of carbon dioxide than the atmosphere. This charging water has reduced pH due to formation of carbonic acid from solubilization of the carbon dioxide. This acidified water then reacts with carbonates present in limestone or dolomite to reach an equilibrium:

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{++} + 2HCO_3^-$$

This dissolution process takes place along joints, cracks in the bedding plane, and fractures, producing sinkholes and caves and increasing the secondary permeability of the rock. This reaction proceeds until equilibrium is reached; carbonic acid is consumed and the bicarbonate ion becomes the dominant species. If the system is closed to the atmosphere, such as may occur where clay beds overlie the limestone, the availability of carbon dioxide is the limiting factor in the process, instead of the solubility of the carbonates. This may explain why sinkhole activity appears to be more prevalent in the limestone valley region, which is an open system, than in the highland plateau. In addition to the partial pressure, water temperature also affects the solubility of carbon dioxide and hence that of the limestone, and affects the pH at equilibrium (Freeze and Cherry, 1979; fig. 11).

Carbonate rock aquifers under water table conditions allow carbon dioxide free entry into the groundwater. As carbonic acid is

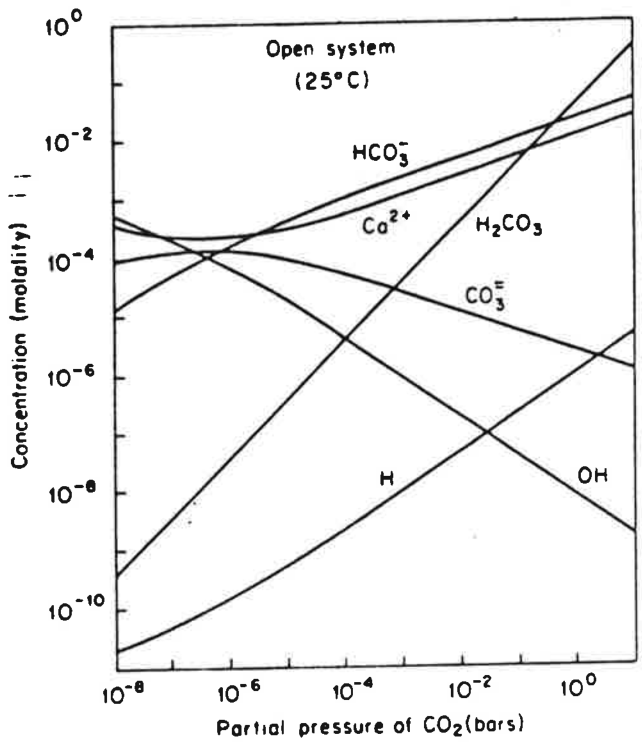


Figure 11. Equilibrium Diagram of Water in a Carbonate Aquifer. (Freeze and Cherry, 1979).

essentially unlimited, the dissolution of the carbonates proceeds freely as long as mixing occurs. Therefore the rate of dissolution is higher in these regions, the pH of the groundwater is lower (less than 8.0 at equilibrium versus over 9.0 for closed systems), and higher concentrations of dissolved species are attained (hardness increases). Generally, shallow groundwater, especially in recharge areas, has less dissolved solids and a higher concentration of bicarbonate ion. Concentrations of dissolved ionic species increases along the flow path in open systems. Lab studies show equilibrium being reached within days, whereas studies in the more complex field environment indicate weeks or even months of residence time for groundwater to reach saturation equilibrium. Likewise, over-saturation is not uncommon, especially in closed systems, as evidenced by deposition of calcite on well screens in these regions (Freeze and Cherry, 1979).

Water Usage

In 1975, it was estimated that 19.9 MGD of groundwater were withdrawn for domestic water supplies in Alachua County. Of these, 14.9 MGD were for public water supplies. Industrial usage that same year was 6.5 MGD. Irrigation requirements for 7354 acres in Alachua County were met by withdrawals from both groundwater (4.5 MGD) and surface water supplies (1.5 MGD). Thermoelectric usage of groundwater required 1.4 MGD. Total groundwater withdrawal in Alachua County in 1975 was 32.3 MGD (US Dept. of Interior, Geological Survey, 1981). This represents almost a 300% increase over the 11 MGD withdrawn in 1960 (Clark et al., 1964).

Summary

The concentrations of naturally occurring substances found in groundwater are dependent on hydrologic, geologic, and geochemical processes, as well as factors such as topography and areas of discharge. When attempting to interpret natural groundwater quality data, it is necessary to examine the role of these factors and processes. Topography and discharge areas influence regional groundwater flow directions, with geology and aquifer properties affecting flow velocities, flow volumes, and residence times. Aquifer properties such as porosity and vertical and horizontal hydraulic conductivities, along with head differentials determine rates of recharge that can affect concentrations of dissolved substances. Vertical and horzontal hydraulic conductivities also determine depths to which recharge waters will migrate and mingle with deeper, more mineralized water (Freeze and Witherspoon, 1967). Local geological features such as fracture traces, sinkholes, and discontinuous beds can have a significant impact on local water quality.

A thorough understanding of the local geology and geohydrology is important also in delineating areas that may be sensitive to groundwater contamination, and extremely useful in the process of siting hazardous waste facilities, landfills, waste lagoons, injection and drainage wells, and public supply wells.

III AMBIENT GROUNDWATER QUALITY MONITORING NETWORK

Introduction

.One of the primary purposes of the ambient groundwater quality monitoring network being designed for Alachua County is to detect concentrations of indicator parameters that deviate significantly from the established background, in order to protect as many water supply systems as possible. The data from this network will be used by regulatory and planning agencies to reduce the potential for contamination of both public and private water supply systems.

There are documented instances of public supply well contamination in Florida due to non-natural sources. Of public wells supplying potable water, 48 have been contaminated by pesticides and 42 have been known to be contaminated with volatile organic compounds or metals. Of private supply wells, 19 are contaminated with fertilizer ingredients, 790 with pesticides, 95 with petroleum products, and 459 with volatile organics or metals. In addition, 51 wells are suspected of being contaminated (FDER, 1985b). At the present time, 61 wells in Alachua County are known to be contaminated (ACDES, 1985).

There are currently in Alachua County 29 community water supply systems, 44 non-community supply systems, and 11 systems that fall into other categories as defined by chapter 17-22 of the Florida Administrative Code (Hurst, 1985).[1] None of these public water

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[1] FAC 71-22.103 "Community water system" is defined as a public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

"Non-community water system" is a public water supply system that serves at least 25 individuals daily at least 60 days of the year but is not a community water system.

supply systems, including that of the city of Gainesville, serving a population of 165,000, have any monitoring wells up-gradient of the well field to detect contaminated groundwater before it is pumped into the distributon system. Moreover, none of the municipalities with a public water supply system have any type of management program to prevent contamination from entering their groundwater supply.

All groundwater used for public supply in Alachua County is classified G-II by the FDER. This is a general category for potable groundwater with a total suspended solids content of 10,000 mg/l or less. All classes of groundwater are required by state statute at all times to be free from components of discharges in concentrations that are harmful to plants or organisms native to the soil; carcinogenic, toxic, mutagenic, or teratogenic to humans; acutely toxic to aquatic indigenous species influenced by groundwater; pose serious danger to the public health, safety, and welfare; create a nuisance; or impair the reasonable and beneficial use of adjacent waters (FDER, 1983). However, this legislative "wish" is not a management program, nor does it specify just how to protect the groundwater.

The Florida Safe Drinking Water Act mandates periodic sampling of community public water supplies to see whether they exceed primary and secondary maximum contaminant levels. These standards for groundwater are found in chapter 17-3 or 17-22 of the Florida Administrative Code. The primary and secondary standards, applicable class of public supply system, and frequency of required sampling are listed in Table 1. Non-community and private systems supplying groundwater are required to meet only primary microbiological and nitrate standards. As can be seen, many of the parameters require testing on an infrequent basis.

Table 1 Water Quality Standards (Maximum Contaminant Levels or MCLs) for Florida groundwater used as a drinking water supply. (Compiled from FAC Chapter 17-22.104,5; HRS Chapter 10D-4)

Standard Classification	Distribution System	Parameter	MCL(μg/1 unless otherwise noted)	Frequency of Testing
Primary-Inorganics	community	As,Cr,Pb,Ag	50	3 year intervals
Primary-Inorganics	community	Cd, Se	10	3 year intervals
Primary-Inorganics	community	Hg	2	3 year intervals
Primary-Inorganics	community	Ba	1000	3 year intervals
Primary-Inorganics	community and private	NO_3 (as N)	10000	5 year interval for private
Primary-Inorganics	non-community	NO_3 (as N)	10000-20000	5 year interval for non-community
Primary-Inorganics	community	Na	160000	3 year intervals
Primary-Inorganics	community	F	1400-2400 (dependent on air temperature)	3 year intervals
Primary-Organics	community	Endrin	0.2	As deemed necessary by FDER
Primary-Organics	community	Lindane	4	As deemed necessary by FDER
Primary-Organics	community	Methoxychlor	100	As deemed necessary by FDER
Primary-Organics	community	Toxaphene	5	As deemed necessary by FDER
Primary-Organics	community	2,4-D	100	As deemed necessary by FDER
Primary-Organics	community	2,4,5-T (Silvex)	10	As deemed necessary by FDER
Primary-turbidity	community	———	1 T.U.	3 year intervals
Primary-microbiological	community	———	1 organism/100 ml sample	frequency is dependent on population served
Primary-microbiological	non-community and private	———	1 organism/100 ml sample	quarterly
Primary-radionucleides	community	Radium 226 + Radium 228	5pCi/l	4 year intervals
Primary-radionucleides	community	Gross Alpha	15 pCi/l	4 year intervals
Primary-radionucleides	community	Beta particle	Dose of 4 mrem/yr	4 year intervals
Primary-trihalomethanes	community	Sum of all THMS	100	4 year intervals
Primary-volatile organic compounds (VOC's)	community	Trichloroethylene	3	3 year intervals
Primary-volatile organic compounds (VOC's)	community	Tetrachloroethylene	3	3 year intervals
Primary-volatile organic compounds (VOC's)	community	Carbon Tetrachlornde	3	3 year intervals
Primary-volatile organic compounds (VOC's)	community	1,2-Dichloroethane	3	3 year intervals
Primary-volatile organic compounds (VOC's)	community	Vinyl chloride	1	3 year intervals
Primary-volatile organic compounds (VOC's)	community	1,1,1-Trichloroethane	200	3 year intervals
Primary-volatile organic compounds (VOC's)	community	Benzene	1	3 year intervals
Primary-volatile organic compounds (VOC's)	community	Ethylene dibromide	0.02	3 year intervals
Secondary	community	Color	15 color units	3 year intervals
Secondary	community	Cu	1000	3 year intervals
Secondary	community	Fe	300	3 year intervals
Secondary	community	Mn	50	3 year intervals
Secondary	community	Zn	5000	3 year intervals
Secondary	community	Chloride	250000	3 year intervals
Secondary	community	Sulfate	250000	3 year intervals
Secondary	community	TDS	500000 (greater if no other MCL exceeded)	3 year intervals
Secondary	community	Corrosivity	neither corrosive nor scale forming	3 year intervals
Secondary	community	Foaming agents	500	3 year intervals
Secondary	community	Odor	3 (Threshold Odor No.)	3 year intervals
Secondary	community	ph	6.5 (minimum allowable; pH units)	3 year intervals
Synthetic organic contaminants (SOC's)	community	List of 118 compounds including purgeables, pesticides, base and acid extractables	No set standards	3 year intervals

The VOC and SOC organic compounds listed are only this year beginning to be tested for in many water supply systems, so there is a scarcity of data on these compounds. Often, complaints by persons consuming the water are the first indication that the water is contaminated, especially for private or non-community systems.

Design Approach

The overall approach taken in the design of the ambient groundwater quality monitoring network is to consider the physical network not only as a system to be sampled to determine "background" water quality, but also as a continuing means to provide reliable and meaningful water quality data as input to the management decision making process. This research is the first, or base phase of that on-going network.

The FDER definition of background water quality encompasses two concepts: pristine and non-pristine (FDER, 1985a). Pristine background quality is somewhat idealized, and hard to delineate. What this monitoring effort will attempt to do is describe non-pristine background water quality, that is, groundwater influenced by man but whose quality is representative of the general groundwater quality of the area.

It is orginally intended to comply with as many of the FDER statewide network goals as practicable, and also to address the unique needs of Alachua County. This network will be considered a separate, individual component of the statewide network, and will not duplicate or detract from monitoring efforts already undertaken by the water management districts having jurisdiction in the county, who will essentially relinquish altogether, or retain abbreviated roles in the statewide network insofar as Alachua County is concerned.

There were three steps taken in the establishment of the preliminary network:

- Data aquisition
- Site screening and evaluation
- Preliminary network/design objectives

The final design step listed is still in the active stage, and will remain flexible to the changing objectives of the program's sponsors.

Data Aquisition

In the search for existing surface and groundwater quality data for Alachua County, the following entities were contacted:

- U.S. Geological Survey, Orlando and Tallahasse offices (USGS)
- Alachua County Department of Environmental Services (ACDES)
- Florida Department of Environmental Regulation (FDER)
- Suwannee River Water Management District (SRWMD)
- St. Johns River Water Management District (SJWMD)
- Environmental Protection Agency (EPA)
- Florida Bureau of Geology (FBOG)
- University of Florida (UF)
- Private consulting companies
- Gainesville Regional Utilities (GRU)

The results of that file search are as follows:

USGS:

- The USGS has the most comprehensive ambient surface and groundwater quality database on Alachua County.
- The same data that go into the USGS database WATSTORE go into EPA's STORET database.
- USGS does not try to monitor "affected" groundwater unless that effort is associated with a special project.
- Alachua County is in both the Orlando and Tallahassee Districts.

- USGS currently monitors 2 surface water sites bimonthly in Alachua County for water quality:
  Santa Fe River at Worthington Springs (02321500)
  Orange Lake at Orange Lake (02242450)

- Data received include 67 surface water sites in the county that USGS had previously sampled for various water quality parameters. All are "ambient" lakes, rivers, or streams, except for 3 sample points at Lake Alice, which is a polishing pond for STP effluent for U.F.

- USGS has previously sampled 4 springs in the county: Glen, Poe, Magnesia, and Hornsby Springs.

- USGS data included water levels, stage, elevation, or discharge for many wells and surface water sites not used for this report.

- Data received included 213 wells with groundwater quality data, 13 of which had been sampled more than once.

- Currently, USGS is monitoring only 3 wells in Alachua County, near Alachua Sink, as well as the sink itself, for groundwater quality as part of a special project.

- USGS station names for wells are composed of latitude, longitude, and sequence number. Occasionally abbreviated versions of latitude and longitude are used. e.g. 293723082120101 may also appear as 93721201.

- Printout of water quality file on Alachua County contains both surface water and groundwater quality data.

- Printout of well inventory file on Alachua County contains technical well data compiled from field site schedules. 62 wells (out of 213 listed in the water quality printout) were listed.

- Wells are sorted by latitude/longitude in the database.

- Surface water sites are given a station number composed of a 2-digit part number (basin code) plus a 6-digit downstream order number.

- Most of the groundwater quality data are from sampling undertaken in either 1960, for a regional water resources publication, or 1976, as part of a special study.

- USGS database contains some data from other sources such as water management districts. There is no designation as to source of data.

- Technical well information of USGS database is often incomplete.

- USGS currently monitors 16 surface water stations, and 71 wells in Alachua County for water levels only.

SJWMD:

- SJWMD is not doing any current ground or surface water quality monitoring in Alachua County.

- SJWMD database has separate files for groundwater and surface water. There are a variety of formats by which the data can be presented.

- Surface water quality data received from SJWMD consist of 71 stations in Alachua County (15 lakes, 51 streams, and 5 springs), with data sources listed as either USGS or FDER. 56 of these stations were sampled more than once.

- Groundwater data received from SJWMD contained 238 wells, 44 of which were used for water level measuremtns only. Of the remaining 194 wells, only 3 have been sampled more than once.

- With the exception of 2 wells used for water level measurements by SJWMD, the source of all groundwater data is the USGS.

- No technical well information is available on wells from the database.

- SJWMD uses a 6 digit station identification number from abbreviated latitude and longitude in their water quality database, e.g.

  927203

  9= second digit of latitude degrees
  27= minutes of latitude
  2= second digit of longitude degrees
  03= minutes of longitude

- USGS data entered into SJWMD database are considered "provisional" and may be subject to 1-2% error.

- Wells greater than or equal to 6 in. diameter require a permit in SJWMD. Also, <u>any</u> size well that is capable of producing 100,000 GPD of flow, and <u>any</u> public supply well (community and non-community) requires a permit.

- A large number of driller's logs for private wells in Alachua County are available through a SJWMD database, but are either located by township, range, and section or do not have a location associated with them.

- SJWMD intends to drill wells at 4 sites in that part of Alachua County in which they have jurisdiction in the next FY as part of their FDER authorized ambient groundwater monitoring network.

SRWMD:

- SRWMD has separate files for groundwater and surface water data, except for the water quality data file (WATQ), which is combined.

- Groundwater data files are in 5 databases:
  - WP- Well permitting
  - PSW- Public supply wells
  - TWI- Technical well information
  - GWL- Groundwater levels
  - WATQ- Water quality (shared with surface sites)

- Surface water stations are contained in 2 databases:
  - STATION- Location and description of stations
  - WATQ - water quality sampled at station

- SRWMD uses site identification numbers (common to all SR databases) based on township, range, and section. For example:
  - \- 02 17 31 002

-	=	south of baseline
02	=	township
17	=	range
31	=	section number
002	=	sequence number

- Surface water data retrieved for Alachua County listed 8 stations, 4 of which had been sampled more than once. One of the remaining stations was not found in the water quality (WATQ) file.

- Groundwater quality data retrieval listed 82 sites in WATQ, of which 9 had been sampled more than once. 28 of the wells (single sample history sites) corresponded to USGS wells.

- Other SRWMD data source is USGS, but is designated such in only one database, TWI, for groundwater data.

- <u>All</u> public supply wells, whether community or non-community, are permitted by SRWMD (since 1983).

- SRWMD was able to furnish 9 driller's logs on wells in Alachua County.

- SRWMD generated groundwater quality data in SRWMD files result from a special study begun in 1976.

- SRWMD is not currently doing any water quality monitoring in Alachua County.

FDER:

- FDER has an extensive database system called the "Groundwater Pollution Source Management System" (GMS) containing three subsystems:
  GPSI - Groundwater Pollution Source Inventory
  GTRS - Groundwater Testing and Reporting Subsystem
  HWMS - Hazardous Waste Management Subsystem

- The GMS database system is designed for facilities requiring permits, rather than for storage of ambient water quality data. These databases and their component files are in various stages of completion or revision, and data received may be incomplete or incorrect.

- The database for ambient ground and surface water quality has not yet been completed.

- Other than water quality data from monitoring wells or associated with permitted facilities, no ambient groundwater quality data are available from FDER for Alachua County.

- The EPA STORET database was accessed through FDER. The retrieval for Alachua County contained 243 stations, of which 21 were groundwater stations (wells associated with permitted facilities). Of the remaining 222 surface water stations, 118 were judged to be "ambient" sites, whose sources were mostly USGS, SJWMD, or ACDES, or undetermined (17 sites). Of the 118 stations, 77 had been sampled more than once for water quality; 34 had been sampled only once, and 7 stations had no water quality data associated with them. Some surface water quality sampling was done as early as 1947 in Alachua County by the USGS.

- Out of 21 wells listed in STORET, 4 are no longer in existance, 4 are monitoring wells at Alachua Sink, 12 are municipal water supply wells, and 1 is a SRWMD monitoring well.

- A data retrieval from the GMS system listed 14 permitted facilities requiring monitoring. Seven of these were sewage treatment plants (no wells), 4 county landfills with monitoring wells, 1 sewage treatment plant with injection and monitoring wells (Kanapaha), 1 power plant (no wells), and 1 industrial site with monitoring wells (General Electric).

FBOG:

- From FBOG files on Alachua County, 52 lithologic well logs (containing latitude and longitude) were procured which represent approximately one third of all county logs available from FBOG. Of these, 3 corresponded to sites with water quality data.

- Geophysical logs are available on 64 wells in the county. Of these logs, 28 have latitude and longitude associated with them. None of these logs correlated with well sites having water quality data.

ACDES:

- At the present time, ACDES is sampling groundwater quality only at "affected" sites. These include 24 wells and 5 surface water sites at the 4 county landfills, sampled every 6 months for conductivity, nitrate, iron, chemical oxygen demand, and other parameters as deemed necessary by FDER, and monitoring wells at a site where suspected leaking underground gasoline storage tanks are contaminating groundwater. ACDES formerly monitored 3 wells at Alachua Sink, now taken over by USGS.

- ACDES has had an ambient surface water quality sampling program since 1976. At present, 40 sites are sampled on a sporadic basis. No database exists to handle these data at ACDES.

- Surface waters in Alachua County presently being sampled by ACDES include:
  - Blues Creek (5 stations)
  - Hogtown Creek (6 stations)
  - Lake Elizabeth (1 station)
  - Little Hatchett Creek (5 stations)
  - Newnans Lake (3 stations)
  - Possum Creek (4 stations)
  - Sweetwater Branch (5 stations)
  - Tumblin Creek (4 stations)
  - Turkey Creek (7 stations)

- Of these surface waters, Blues Creek, Turkey Creek, Hogtown Creek, Possum Creek, and Sweetwater Branch enter the groundwater system by way of sinkholes.

EPA, GRU, UF, and Private Consultants:

- No significant water quality data received from these sources other than EPA STORET data retrieved through FDER.

- Some accessory well data received on wells owned by GRU and UF; well logs from consultants on clients' public supply wells.

Many problems were encountered during this phase of the project, or became apparent as the data were compiled and mapped. A list of typical problems and their sources are as follows:

USGS:

- Technical well information encoded and unclear; listed for only 30% of wells having water quality data.

- Personnel unable to decode hydrologic basin or sub basin codes, or identify several USGS sites found in STORET.

- Latitude/longitude not used with many surface water sites.

- Routinely uses code description for Floridan Aquifer for most wells in well inventory, even when well does not tap that aquifer. Estimate 34% of those checked were questionable.

- Water levels between the original site schedule and the well inventory file occasionally were different.

- Both surface and groundwater sites were mixed in the water quality retrieval, and were difficult to separate.

- Errors in data:

  - Well plots in middle of Lake Lochloosa (keypunch error?)
  - Latitude/longitude for well does not agree with original driller's log.
  - Keypunch errors; decimals off (no land surface datum of 8.0 feet in county); site ID numbers not agree with latitude/longitude; latitude off several minutes.
  - Reporting errors: Iron reported as ug/l, measured in mg/l makes all iron data from 1960 suspect.

- Data value in USGS file may not agree with value as reported in another agency database. May be difficult to determine source of data to check.

- USGS has not updated drainage basins. Boundaries and areas may be off considerably.

- Lists Blues Creek as draining to Oklawaha River Basin.

SRWMD:

- Most common problem was difficulty locating sites accurately using township/range/section (TRS) system.

- When latitude/longitude was given for a site, several sites plotted miles away from their TRS location. Deleted sites that were not cross referenced by latitude/longitude (approximately 5-10% of those listed).

- Cross referencing sites between files is hampered by non-unique TRS ID numbers.

- Discrepancies between files: WP file lists at least 10 sites being constructed in 1983 or 1984; WATQ file lists the same sites as sampled between 1976 to 1982.

SJWMD:

- Map plotting error of SJWMD groundwater sites on DOT base map is approximately 0.7 miles in any given direction.

- Although a large number of driller's logs are available, they either have a TRS location or none at all. There is no way to cross reference permit numbers for these wells with latitude and longitude. SJWMD permitting section uses TRS, water quality database uses latitude and longitude.

- Of 30 geophysical logs for wells in Alachua County, none of the wells appear in their water quality database.

- Suspected keypunch errors, and discrepancy between actual and reported locations.

FDER:

- Difficult to get FDER sites to agree with other agencies' by latitude/longitude. Estimate up to 40% disagreement.

- Difficult to separate "ambient" from "affected" sites, and surface from groundwater sites in STORET. FDER is not receiving much support or data contribution from other agencies to update and maintain their data in STORET due to the complexity of reporting forms required.

- FDER database is not compatible with other agencies, whereas SJWMD and SRWMD are compatible with each other.

- Due to system revision status, GMS reports can be misleading, or in error. For example, violations flags in facility monitoring reports can indicate that no data were reported. Clarity is a problem, and omissions are common.

FBOG:

- Base map locating wells having lithologic logs is accurate only to section, as BOG used TRS location methods exclusively until recently adding latitude and longitude to logs they receive. Roughly two thirds of logs in BOG files are in the TRS system, often located only to section (if an old well) or second quarter of a section. The remaining logs have latitude/longitude.

- Less than half of the geophysical logs available on county wells had latitude/longitude associated with them.

ACDES:

- No database.

- No easy access to data, which may be filed under local site name not otherwise identified as a monitoring station.

- No ambient water quality data shared with other agencies since 1981.

- Parameters analyzed for or analytical methods used seem to have changed sporadically. For example, values for NO_3 as NO_3 are mixed in with values for NO_3 as N , with no notation to signify which is which or documentation to record the change.

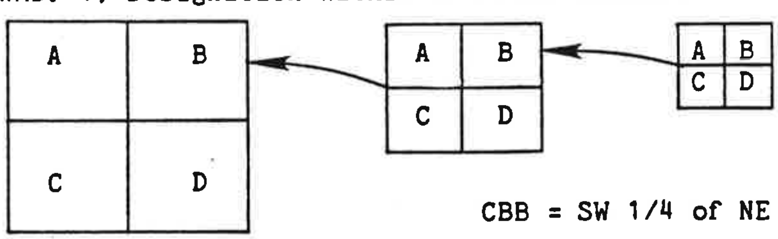
- Current ambient monitoring is carried out on an infrequent schedule.

All Agencies:

- Obvious differences between agencies in methods used to locate or identify sites. Often poor site agreement on locations.

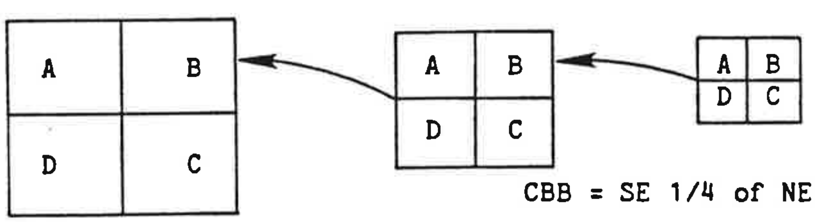
- Disagreement between SRWMD and USGS and within the agencies themselves regarding use of quarter-quarter-quarter (QQQ) breakdown within a section.

SRWMD: 1) Designation within database manual:



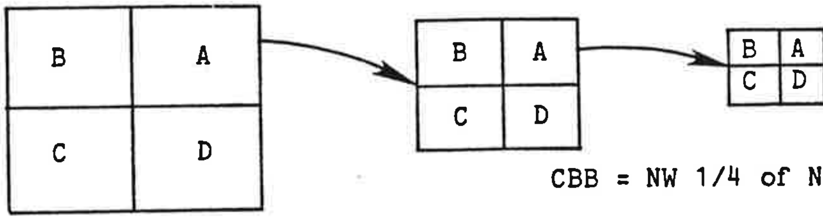
CBB = SW 1/4 of NE 1/4 of NE 1/4

2) Designation reported used by other SRWMD personnel:



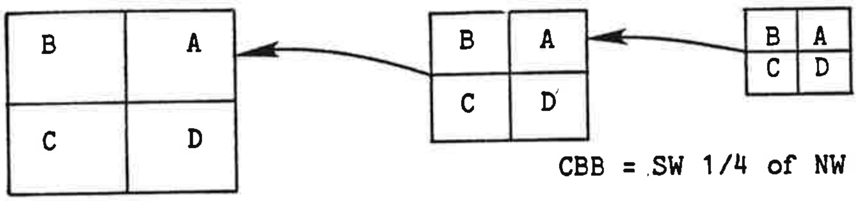
CBB = SE 1/4 of NE 1/4 of NE 1/4

USGS: 1) Designation reported as that used by USGS (US Dept. of Interior, 1977):



CBB = NW 1/4 of NW 1/4 of SW 1/4

2) Designation reported used by USGS Orlando office:



CBB = SW 1/4 of NW 1/4 of NW 1/4

- The Florida Bureau of Geology (FBOG) uses the same QQQ system designation as method (2) of the USGS.

- Sites contained in data from all agencies were difficult to classify as to whether they represented ambient (unaffected) or affected waters (such as STP discharge zones).

- As agencies share data back and forth between databases, it is difficult to identify the original source of the data unless agency ID is encoded with the data.

- Inconsistent choice of water quality parameters between agencies and within agencies reduces amount of data useful for analysis.

- Map accuracy on DOT base maps is limited by non-uniform map tic spacing, and by variation in scale between "identical" maps.

Screening Process

It was initially decided to establish a physical ambient ground-water quality monitoring network (AGWQMN) using existing wells cased into the upper Floridan Aquifer that had previously been sampled by an agency. Three factors supported this decision: 1) most previously sampled wells were in the Floridan Aquifer, 2) a larger network could be sampled on a limited budget than would exist if new wells had to be constructed, and 3) limiting candidates to sampled wells would reduce the universe of existing potential candidate wells by virtue of sampling precedence and history of accessibility to a starting field of around 300 wells. At the beginning of the design phase, it was not known how much budget would be allocated to the network, or whether sponsorship would come from the FDER. Therefore economic efficiency dictated some decisions that were made. Also, initially selecting sites with a previous sampling history assumed some screening had been previously done by the selecting agency. Moreover, the early water quality data, when compared to recent samplings, would be useful for describing temporal changes in quality. This design attempts to select the best of the existing wells to get maximum utilization from existing data.

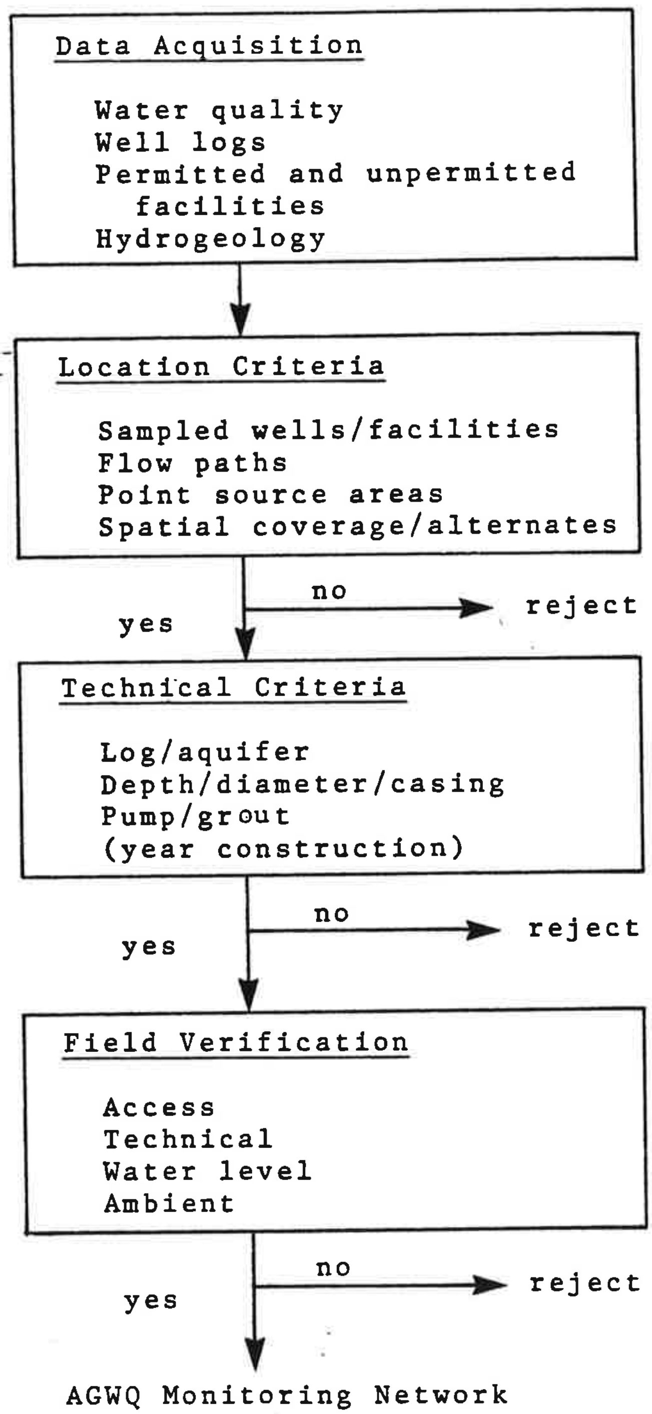
Sources of potential existing monitor wells included wells in the agency databases, public supply wells, and wells in the active phase of the permitting process at the water management districts. Private wells outside of agency water quality files were not actively searched, due to paucity of technical information for older wells, or uncertain access.

The screening procedure to develop the preliminary network of existing wells was a four step process. A flowchart describing the procedure is found in Table 2.

The first step, that of data aquisition, has already been described, along with the many problems inherent in the data received.

The next step, that of well and facility location, was essentially a mapping procedure. A base map of convenient dimensions was provided by the State of Florida Department of Transportation (DOT) for Alachua County on a scale of 1/2 inch = 1 mile. This was of sufficient detail to show surface water features, corporate limits,

Table 2 Flowchart for Site Selection of Preliminary Network



highways, and section boundaries. Most importantly, it provided both tics for township-range-section (TRS) and latitude/longitude location methods. All unique wells with water quality data from agency files (282 wells) were located on this base map by measuring off of a latitude/longitude grid. Consensus among agencies was that latitude/longitude was the preferred method of location, especially for Alachua County which contains many irregular sections and non-section land grant parcels. Wells cross-referenced only by TRS were rejected because of the problem of location. Next, facilities with permits, obtained from FDER's GMS database were located, along with unpermitted sites or facilities of which FDER has locational knowledge. Facility as used here refers to a site where hazardous waste is generated, stored, treated, or disposed, or where other types of waste, eg. landfills or STP percolation ponds, may infiltrate to groundwater. Other point sources, such as spills of hazardous wastes, or sites of chemical or pesticide fires have been located as knowledge of sites was received.

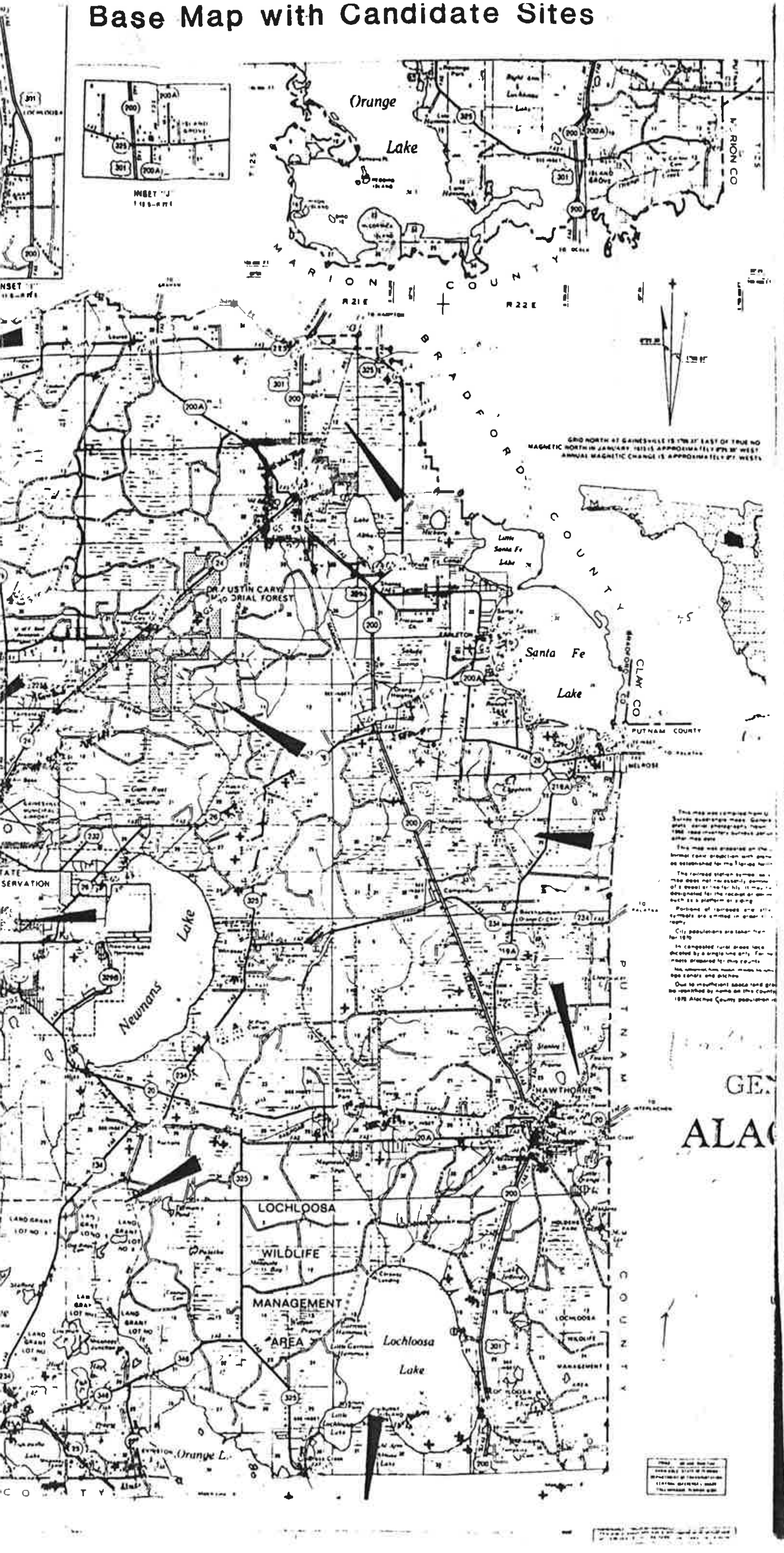
The FDER definition of ambient does not include zones of influence for waste facilities. Rather than describe a zone of discharge using permit information based on mixing zones or property boundaries, for the preliminary network a conservative safety zone based on a chosen one mile radius was assigned to each facility within which no monitoring well could be placed. General flow directions in the Floridan Aquifer were then superimposed to help determine migration directions for potential contaminants. If sampling for characteristic indicator parameters outside this zone detects a site influence, the ambient network will be adjusted, or that well declared a non-ambient monitoring well.

Well selection would try to cover as much of the county as possible, in all the physiographic regions, keeping alternate sites in mind if the well was later deleted. The best choice of well is that owned by the network agency for guaranteed access and quality assurance purposes; however, in this case private wells were included in the preliminary network. A map showing locations of candidate wells and facilities is shown in figure 12.

The third step considered technical criteria. The well under consideration must have total depth, casing depth, diameter, and year and method of construction known, or else have a geophysical log available. Cable tool drilled wells are acceptable in areas where the Floridan is unconfined, as long as casing is seated into the top of the rock. This information can be obtained from the driller's log. If the well is located in an area where there are water table or secondary aquifers, information to ensure grout integrity (to prevent cross flow between aquifers) and ensure that the well screen is open only to the Floridan (or designated aquifer) must be available. A geophysical log is the most direct evidence, but depth knowledge, along with lithologic logs and a knowledge of respective potentiometric heads for aquifers will usually suffice. When sufficient data are available, a statistical correlation of certain water quality parameters also helps to differentiate between waters of the three types of aquifers.

A well diameter of 4 in. is preferred, as this can accomodate a 4 in. submersible pump, does not require large purge volumes, and is amenable to most logging equipment. Larger diameters are acceptable

Base Map with Candidate Sites



if pumping public supply wells are used. For later phases of the network, if budgets allow construction of agency owned wells and purchase of new equipment, 2-3 in. wells may be constructed at reduced cost, allowing faster purging in the field and greater network coverage and sampling efficiency. Casings of existing wells are almost never constructed of ideal monitoring well materials, teflon or stainless steel. PVC and steel are commonly used and are acceptable for most parameters. There is a possibility of PVC contributing certain organics, and the steel attenuating a percentage of the metals in the sample stream, which can be factored into error analysis (Scalf et al., 1980). Finally, in order of preference for volatiles sampling, the well should 1) have no pump, whereby a stainless steel or teflon bailer would be used, 2) use a submersible pump, or 3) use suction lift type pumps or pumps already mounted on the well, allowing for possible error in sampling volatiles.

The final step in well selection involves field checking the well to ensure integrity and type of casing; verify access, condition of cover, and pump type; take a water level reading to establish which aquifer(s) the well is screened into; and verify the ambient nature of the site as much as possible. A grab sample may also be taken at this time to correlate certain parameters with aquifer type.

Based on these steps, existing wells will be screened and either rejected or selected for the preliminary network.

Network Design

A field of 282 candidates was screened through the first three steps. This reduced the number of candidates to 25 provisional wells for the preliminary network. Eight of the wells are to be geophysically logged as a substitute for driller's log availability. Field checking water levels should erase uncertainties regarding whether some of the wells are in the Floridan Aquifer. Field checking local topography and well placement will assess the suitability of wells with respect to grouting and construction method. Grouting is optional where the Floridan is unconfined, as long as no surface runoff or septic tank drainage has access to the well bore. Wells with diameters greater than 4 in. are included, assuming these production wells will be steadily pumped, thus alleviating the problem of pumping large volumes of casing. All wells have been sampled only once, with the exception of one of the GRU wells. Most other municipal wells supplying water to towns in Alachua County were eliminated due to proximity to an unpermitted landfill, permitted STP percolation pond, or effluent spray irrigation field. To ensure good spatial coverage, each of several sites close to other candidate wells were eliminated from the preliminary network and kept as alternate wells. Casing material was predominantly steel, especially for early cable tool drilled wells, which were generally not grouted. Schedule 40 PVC is emerging as the material of choice for modern 4 in. domestic wells. Except for three GRU supply wells which are deeper, well depths ranged between 55 ft. for unconfined Floridan to 275 ft. for confined Floridan wells on the plateau escarpment. Pumps, when present, are generally turbine or submersible.

Of the wells selected, 19 are from the USGS database, 3 from SRWMD, and 3 are public supply wells recently offered to the network but not included in a database. Assuming that the field verification step, which is incomplete at this point, does not point out disqualifying problems in these wells such as inability to take a raw unfiltered water sample, these 25 sites will form the preliminary backbone upon which the network will be built (figure 13).

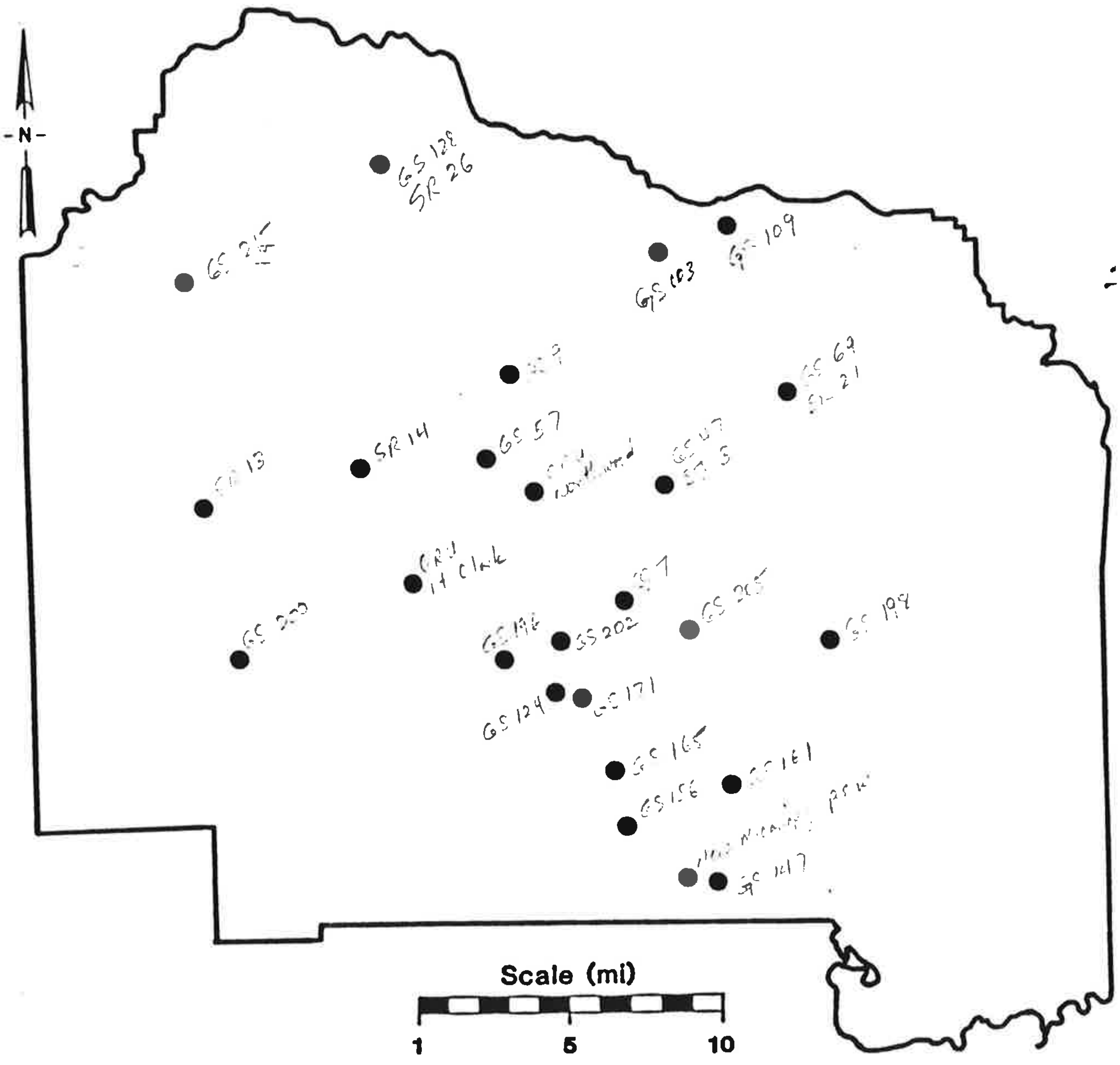
This network, superimposed on the whole of Alachua County, leaves large areas unmonitored. In the future, these gaps must be filled to provide more meaningful data. Several approches may be used: 1) go back into agency databases and repeat the screening and selection process for unsampled wells, i.e. those monitored for water levels only, 2) tap the files of the water management districts for wells permitted for new construction in those areas, then contact the permittee for approval and easement, or 3) as budget allows, contract out construction of new monitoring wells, preferentially siting them on state owned lands or right-of-ways. Most likely a combination of these three choices will be utilized; choice 1 and 2 for economic reasons, and choice 3 for quality control and assured well construction standards. Additional advantages of constructing new wells are flexibility in their placement, and valuable hydrogeologic information gained from well logging and aquifer tests to acquire knowledge of local aquifer properties and flow velocities.

As new monitoring wells are selected for addition to the network, a well will be constructed into each aquifer existing at that site. This will enable water quality determinations to begin on water table and secondary aquifers within the county. Although the preliminary network design was based only on wells screened into the Floridan Aquifer, later phases of the AGWQMN will involve all aquifers used for water supplies in the county.

At this point, additional research will need to be done before site selection to cover network gaps begins. Existing water quality

Figure 13.

Ambient Ground Water Quality Monitoring Network Wells



data must be analyzed to determine parameter concentrations, and satisfactory explanations to account for variability in the water quality data must be reached. Correlation of water quality patterns with land use, non-point sources, recharge areas, population density, and hydrogeologic factors such as thickness of confining units must be attempted. Mapping of areal extent and depths of aquifer units from log information, and calculation of flow directions in the water table and secondary aquifers will also help ensure that the best choices for additional site locations will be made.

Sampling of the preliminary network can begin as soon as the field verification step is completed and selection of a FDER-approved lab for analyses is made. The FDER has compiled a list of parameters they would like to see included in the initial sampling round of AGWQMN wells to establish a baseline on as many parameters as possible (Table 3). In addition to the "routine" major ions and bacteriological analyses, many synthetic organics and metals, along with radionucleides are included, which represent a departure from traditional water quality analyses. To reduce the large cost of analysis for long lists of individual organic compounds, a total organic carbon and purgeable organic halides scan (EPA method 601, 602) will first be run to determine the presence of these classes of compounds. A complete priority pollutant scan (EPA method 622) may also be run when indicated. Choice of parameters to include in subsequent sampling will be based on findings from this round of sampling.

Several parameters and parameter classes are indicators of different sources of groundwater contamination (Dever, 1983; Table 4). These indicators would remain a part of the analytical procedure for a

Table 3 Initial Parameters for Ambient Groundwater Network (FDER, 1985)

Major Ions

HCO_3^-	F^-
CO_3^{2-}	Cl^-
SO_4^{2-}	
PO_4^{3-}	

Metals

As	Pb	Cu	Ba
Se	Zn	Ca	Ag
Mn	Cd	Cr	Mg
Hg	Fe	Na	K

Microbiological

Total Coliform
Fecal Coliform

Field Measurements

pH
Specific Conductance
Temperature
Eh
S^{2-}

Radiometric

(If in suspect area:)
Gross Alpha
Gross Beta

Organics

Total organic carbon (TOC)
Purgeable organic halides (POX)
(if either TOC or POX is significant, include the following:)

Lindane	Methoxychlor	Toxaphene
Endrin	2,4, D	2,4,5 TP (Silvex)
Benzene	Carbon Tetrachloride	1,2-Dichloroethane
1,1,1-Trichloroethane	1,1-Dichloroethane	Tetrachloroethylene
Trichloroethylene	Vinyl chloride	EDB
Chloroform		

(Also any pesticides likely to be in area as determined by FDER's Pesticide Group)

Other

Total dissolved solids (TDS)
CN^-
NO_3^-

Table 4 Indicator Parameters for Detection of Contamination for Various Sources (Dever, 1983)

Source Class	Contaminant Source	Indicator Parameter
Municipal	Land Application of sewage sludge or wastewater	NO_3, coliform bacteria, As, Cd, Cr, Pb, Ag
	Landfills	NO_3, Cl^-, specific conductance, As, Cd, Cr, Pb, Hg, TOC[1], TOX[2]
Industrial	Petroleum storage and transport	Benzene, Toluene, total petroleum hydrocarbons
	Industrial chemical storage and disposal	TOX
Agricultural	Fertilizers	NO_3
	Pesticides	TOX

[1] TOC = total organic carbon

[2] TOX = total organic halides

site if areal reconnaissance indicates potential contaminant sources upgradient of that monitoring well. For non-point sources of potential contamination such as agricultural areas or rural areas with domestic septic tanks, characteristic indicators such as nitrate or pesticides would be employed to try to differentiate this diffuse source from natural background. Nutrients and chloride are good indicators of sewage contamination, and would be monitored closely downgradient of any STP discharges to detect any influence from those sources on background water quality. Chloride is a conservative tracer found in many waste streams, and is not readily adsorbed, or altered by biological processes. Thus it is a good choice for indicator of many contaminant sources that may possibly affect the network. In general, once the initial round of sampling was completed, future sampling would delete tests for many of the metals, radionucleides, cyanide, and sulfide unless these parameters were significant in the first analyses. Detection of organics would rely on TOC and TOX, which would be retained. Field measurements of pH and specific conductance, along with the more usual analyses for major ions and bacteria, would also become routine. With the exception of the volatiles scan, monitoring of surface waters that flow into sinkholes will retain the same parameters as for the network wells, along with biological oxygen demand (BOD_5), total suspended solids (TSS), Kjeldahl nitrogen (NO_3-Kjel), and possibly dissolved oxygen (D.O.).

Once the initial sampling for the wide range of parameters is completed, frequency of sampling for the chosen indicator and background parameters will be on a routine basis. More frequent sampling may be attempted at first to establish initial trends, especially if there is significant variation in key constituents with each sampling event. Once the effect of seasonal variations on the data is known, the frequency of routine sampling will largely be dependent on aquifer transmissivity and flow velocities. Unless it is determined that certain wells are placed in areas where large volumes of flow or relatively high flow velocities occur, or preliminary data indicate high variability, groundwater sampling and analyses on a semi-annual basis will become routine. Surface water stations will be monitored more frequently, most likely on a quarterly basis.

Data received from monitoring efforts are only as good as the quality assurance (QA) program that must accompany them. The subjective quality rating assigned to agency data reviewed ranges from "good" to "very poor," mainly because of data handling from the point of analysis to data basing. There are many points in this process that can attach a poor quality rating to otherwise good data, assuming sampling and analyses were correctly carried out in the first place. Improper (or lack of) use of STORET codes when recording data, inconsistent designation of samples or sampling sites, changing of sampling station names or locations, not recording time of sampling for surface water samples, recording dissolved or suspended species as totals for that parameter, confusing of parameters such as organic nitrogen with Kjeldahl or total nitrogen, unfamiliarity with analytical codes or methods, and keypunch errors in the recording or transfer of data are some of the commonly overlooked errors outside of the more typical sampling and analytical errors that can make this type of data and its subsequent analysis meaningless.

Proper procedures to be followed in sampling for water quality data are outlined by several agencies (FDER, 1981; U.S. Environmental Protection Agency, 1980). A guide to modern hardware available for proper sampling of wells is offered in Nielsen and Yeates (1985). Proper analytical procedures to be followed in handling water quality analyses are given by the American Public Health Association (1980) and by periodically updated versions of the methods published by the U.S. Environmental Protection Agency (1979).

Some quality control steps to be taken in the design and operation of the AGWQM network are as follows:

- As budget permits, gradually phase out existing wells which do not meet current monitoring well standards in favor of a denser network of wells constructed to rigid specifications. Phase out an existing well immediately if well is suspected cause for erroneous data.

- Sample network wells and conduct basic laboratory analyses using in-house personnel and facilities as much as possible to ensure standard operating procedures are followed, and to minimize sample transport, storage, and chain of custody problems.

- Periodically review the quality assurance program of the selected lab.

- Enclose samples made with EPA standards with field samples sent to labs to check precision. Also send split and duplicate samples.

- Require data management personnel to become familiar with sampling and analytical procedures, and natural water quality ranges to detect and interpret anomalous data.

- Ensure proper data handling; labeling data entry and cross referencing; and that complete records are maintained in database files.

- Ensure that analytical procedures used are encoded with the data, along with STORET numbers for the actual parameters measured.

A database will be constructed to contain water quality data as they are received from the network. This database will be compatible with other agencies as much as possible. There will be at least three files: one for surface water quality data, one for groundwater quality data, and one for technical information of the AGWQM network wells. It will have the capacity to expand as the number of network wells increases, or as new parameters are added to the list. It will have file sorting, and statistical analysis capability. Site identification will include components of latitude and longitude for positive location identification. Data will be cross referenced as to source of data and date of sampling, and provision made for some type of quality confidence level assignment to differentiate data from existing wells from data collected from wells constructed with monitoring specifications. A key to the abbreviated fields in each record will be maintained at the beginning of each file.

In addition to the three listed files, header files may also be employed to maintain records of station activity. Typical fields in the header may contain site ID, location, aquifer, sample history, and statistics such as means and ranges for water levels and water quality parameters.

The hardware for the initial database will consist of an IBM-PC XT with 512K memory, compatible with PRIME systems already in use at the water management districts. A double disc drive will be employed, along with a DOS operating system, and an internal Hayes SMART modem.

The data management software to be employed will be furnished by Henco, Inc., and is called PC-Info. This software occupies 1 megabyte of disc space, and includes an upload/download capability to a mini or main frame. This manager allows flexible data manipulation: indexing, sorting, finding, editing, appending, deleting, formating of output, and report generation. Mapping or plotting software may also be employed for contouring of parameters obtained from the AGWQM network. Several packages containing contour plotting programs are available from In-Situ, Inc. Large scale Calcomp plotters may also interface with the IBM-PC hardware.

IV RESULTS AND DISCUSSION

Analysis of Groundwater Quality Data

No attempt has been made to analyze existing water quality data from surface water stations in Alachua County. Basic water quality parameters such as hardness, specific conductance, chloride, and dissolved solids in various surface water bodies in the county are discussed in some detail in Clark et al. (1964).

Some generalizations about surface water drawn from the data presented by Clark et al. (1964) are as follows: 1) There is not much difference in concentrations between surface and groundwater for chloride, nitrate, and fluoride, 2) pH, sodium, and potassium are slightly higher in groundwater than in surface water, and 3) calcium, magnesium, bicarbonate, silica, dissolved solids, hardness, and specific conductance are much higher in groundwater than in surface water. Also, water quality in the Santa Fe River takes on more of the characteristics of groundwater as it flows out onto the limestone plain and is recharged from springs.

Of the 282 wells with existing groundwater quality data, 13 were identified as tapping an unconfined aquifer, and 25 identified as wells drawing water from a secondary aquifer. Since no technical well information or lithologic logs were available for these wells in an unconfined or secondary aquifer, no distinction could be made between unconfined Floridan and water table aquifers. Therefore, no attempt has been made at this time to characterize the water quality of the water table and secondary aquifers in Alachua County. Means and ranges for major constituent parameters in the water table and secondary aquifers from a region of similar geology located north of Alachua County is given in Table 5 (Ceryak et al., 1983). These

Table 5
Means and Ranges of Major Constituent Parameters in the Water Table and Secondary Aquifers (Ceryak et al., 1983). The Range of the Data is Two Standard Deviations Around the Mean. Concentrations are mg/l.

Parameter	Water Table Aquifer (61 samples) Min.	Max.	Mean	Secondary Aquifer (7 samples) Min.	Max.	Mean
pH	4.5	6.25	5.4	7.2	9.5	8.0
Specific conductance	10	140	62.5	120	350	180
Alkalinity	0	20	2.5	85	175	130
Ca	0	16	2.5	12	42	23
Mg	0	5	2.5	8	22	15.3
Na	0	14	5.5	1.8	13.9	6.5
K	0	5.2	1.7	0.5	6.0	1.8
Cl	0	21.6	10.4	4.5	8.9	6.2
NO_3	0	8.3	2.2	0.0	1.0	0.1
F	0	0.34	0.075	0.25	1.0	0.52
O-PO_4	0	0.66	0.17	0.0	1.18	0.34
HCO_3	—	—	—	—	—	—
SO_4	0	19	4.4	0.0	21.5	6.5

values fell within the ranges for these types of aquifers in the Alachua County area reported by Clark et al. (1964). The final AGWQM network for Alachua County will include monitoring wells in the surficial and intermediate aquifers (where present) to provide data necessary for water quality analyses on these aquifers.

Means, ranges, and standard deviation of water quality parameters for the Floridan Aquifer were calculated using existing data from wells selected for the AGWQM network in Alachua County. These data, which represent major water quality constituents, are compared with values reported for the Floridan Aquifer in or adjacent to Alachua County by other authors (Clark et al., 1964; Freeze and Cherry, 1979; Ceryak et al., 1983; Silverman, 1983; Table 6). Although the sample population of network wells is small, the mean parameter values for AGWQMN wells lay within the ranges reported for the Floridan Aquifer by the other authors. However, the small sample population, along with limited spatial variability in the preliminary network wells, may account for some higher averages than reported by the other authors. Values for sodium, potassium, chloride, nitrate, and bicarbonate are above average, which is explained by most of the wells being situated either in the confined Floridan Aquifer, in the Northern Highlands Marginal Zone, or near the cross county fracture trace. Higher levels of soluble salts in wells of the confined Floridan may be due to weathering of clays, while high levels in unconfined wells may indicate surficial sources. The fracture trace may also allow mixing of deeper, mineralized water with that of the upper Floridan, increasing concentrations of dissolved substances. High bicarbonate levels are also associated with recharge areas such as found along

Table 6

Comparison of Quality of Groundwater in the Floridan Aquifer from AGWQ Network Wells with Reported Values. Major Constituents, Concentrations as mg/l.

	AGWQMN Wells					Clark et al., 1964		Freeze & Cherry, 1979		Ceryak et al., 1983			Silverman, 1983 (41-47 replicates)		
Parameter	Sample Pop.	Min.	Max.	Mean	Std. Dev.	Min.	Max	Mean	Std. Dev.	(-2σ) Min.	$(+2\sigma)$ Max.	Mean	Min.	Max.	Mean
pH	17	6.5	8.4	7.7	.6	--	--	7.69	0.25	6.8	8.0	7.8	--	--	--
Specific Conductance	22	200	783	416	146	--	--	--	--	195	480	338	113	525	327
Ca	19	34	138	70.8	27.4	--	--	56	25	26	87	54	19.8	88.4	58.6
Mg	19	2.4	22	9.7	6.8	--	--	12	13	0.0	29	12.5	0.0	31.9	6.5
Na	16	1.5	31	10.9	8.0	3.5	92	7.9	5.3	1.0	17.8	5.3	1.0	10.0	3.8
K	15	0.3	9.4	1.8	2.4	0.1	8.9	1.0	0.8	0.2	1.7	.75	0.0	1.7	.42
Cl^-	22	4.0	67	15.7	15.0	2.5	145	12	9	3.0	22	8.3	2.6	30.0	6.9
NO_3	10	0.09	9.7	2.1	3.0	0.0	60	--	--	0.0	2.15	0.4	0	3.09	.58
F	19	0.1	0.7	0.36	0.17	0.0	2.2	--	--	0.0	.64	0.25	0.0	0.48	0.12
PO_4	5	0.03	.46	0.14	0.18	--	--	--	--	0.0	.36	0.09	0	.15	.05
HCO_3^-	13	142	422	235	79.3	21	430	160	40	--	--	--	--	--	--
SO_4	17	0.8	148	23.9	36.8	.4	344	53	94	0.0	64	16	0	76	10.09

fractures or margins of plateaus (Freeze and Cherry, 1979; Freeze and Witherspoon, 1967). In addition, four network wells extend deeper into the more mineralized zones of the aquifer, and exhibit higher concentrations of these parameters.

An attempt was also made to map the water quality of the Floridan aquifer in Alachua County using the Surface II computer graphics software developed by the Kansas Geological Survey (Sampson, 1978). No differentiation was made between confined versus unconfined for the 22 wells from which major constituent water quality parameters were available. Maps showing the spatial variability of concentrations of specific conductance, chloride, calcium, fluoride, nitrate, bicarbonate, and sulfate were produced, and are reproduced in figures 14 through 20. Mapping of orthophosphate was not attempted due to insufficient data.

The Surface II graphics software determines contour intervals from the range of values in the data set. Consequently, if there is a high (or low) outlying value, many contours will be structured around this point. This can result in a misleading interpretation, especially for a contour map constructed from relatively few data points. Therefore, the contour maps should be used only to spatially visualize the water quality data values, rather than obtain information concerning actual localized values of water quality parameters.

These maps indicate generalized patterns of water quality, made up of single measurements taken at different points in time. These maps represent the best quality ambient water data available at this time. However, to more accurately represent actual ambient water quality in Alachua County, it is recommended that : 1) more data points or network wells be located or constructed for finer grid

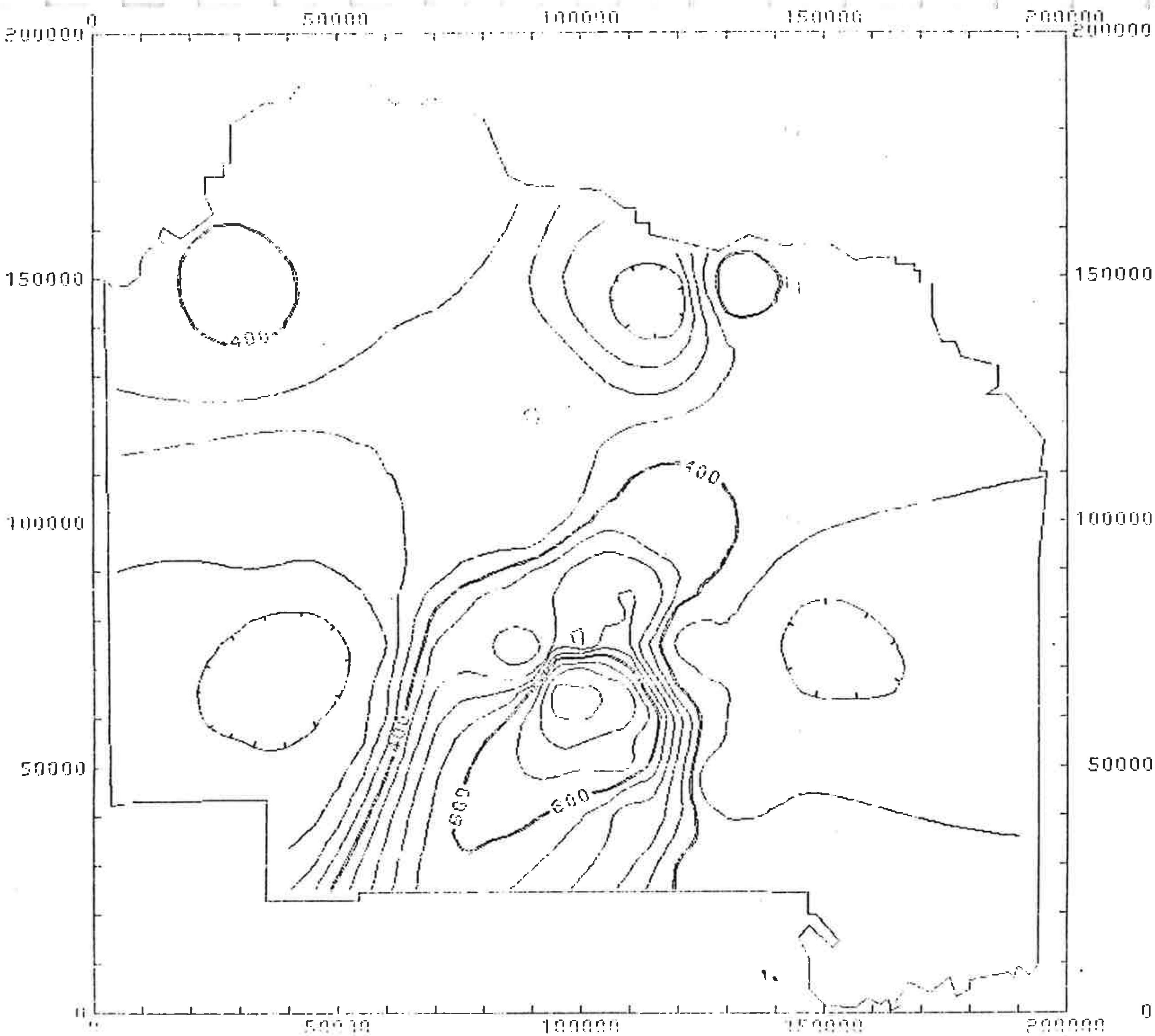


Figure 14. Water Quality in Floridan Aquifer in Alachua County, Florida. Specific Conductance, in mg/l. Contour interval is 40 μmhos/cm.

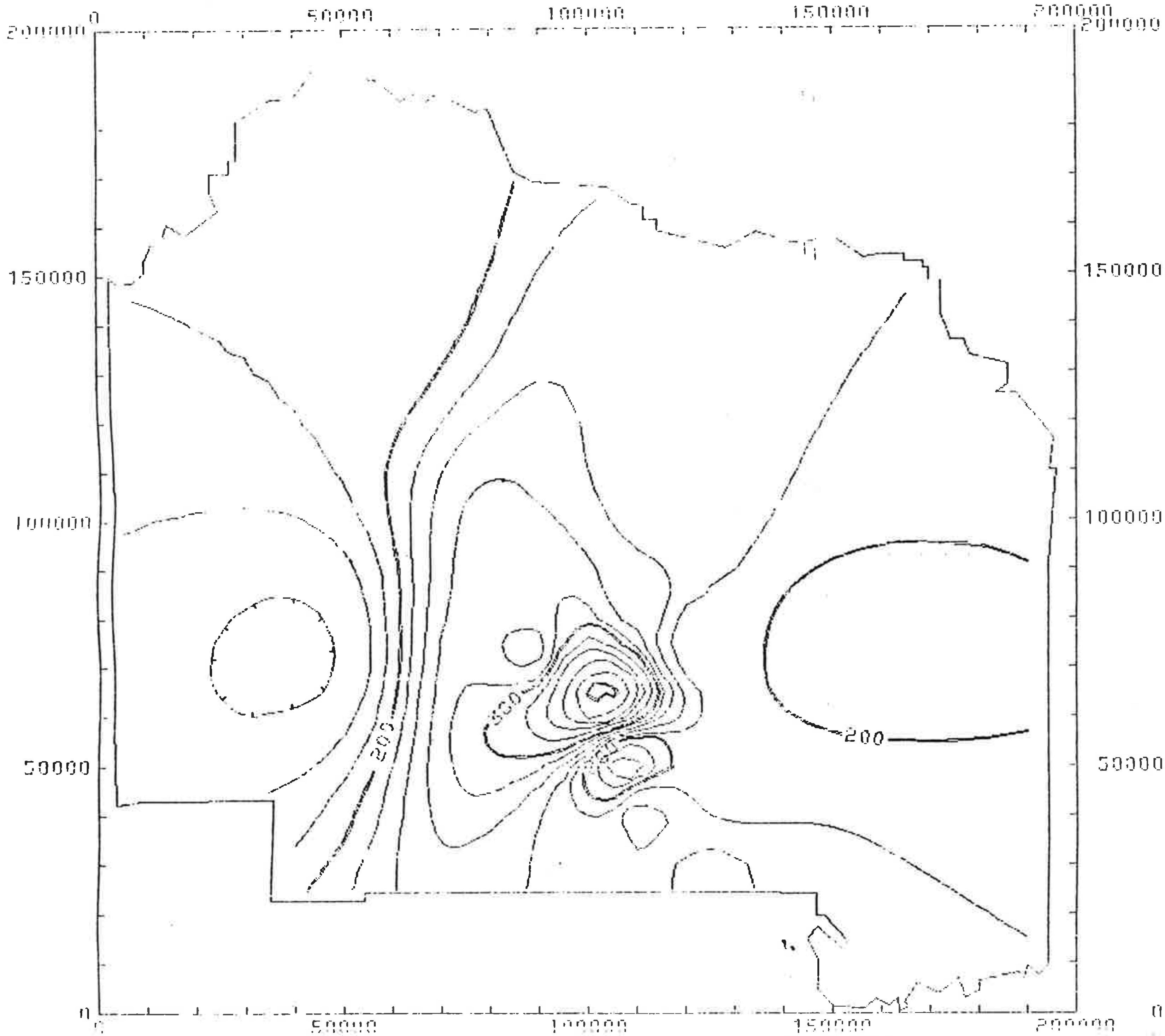
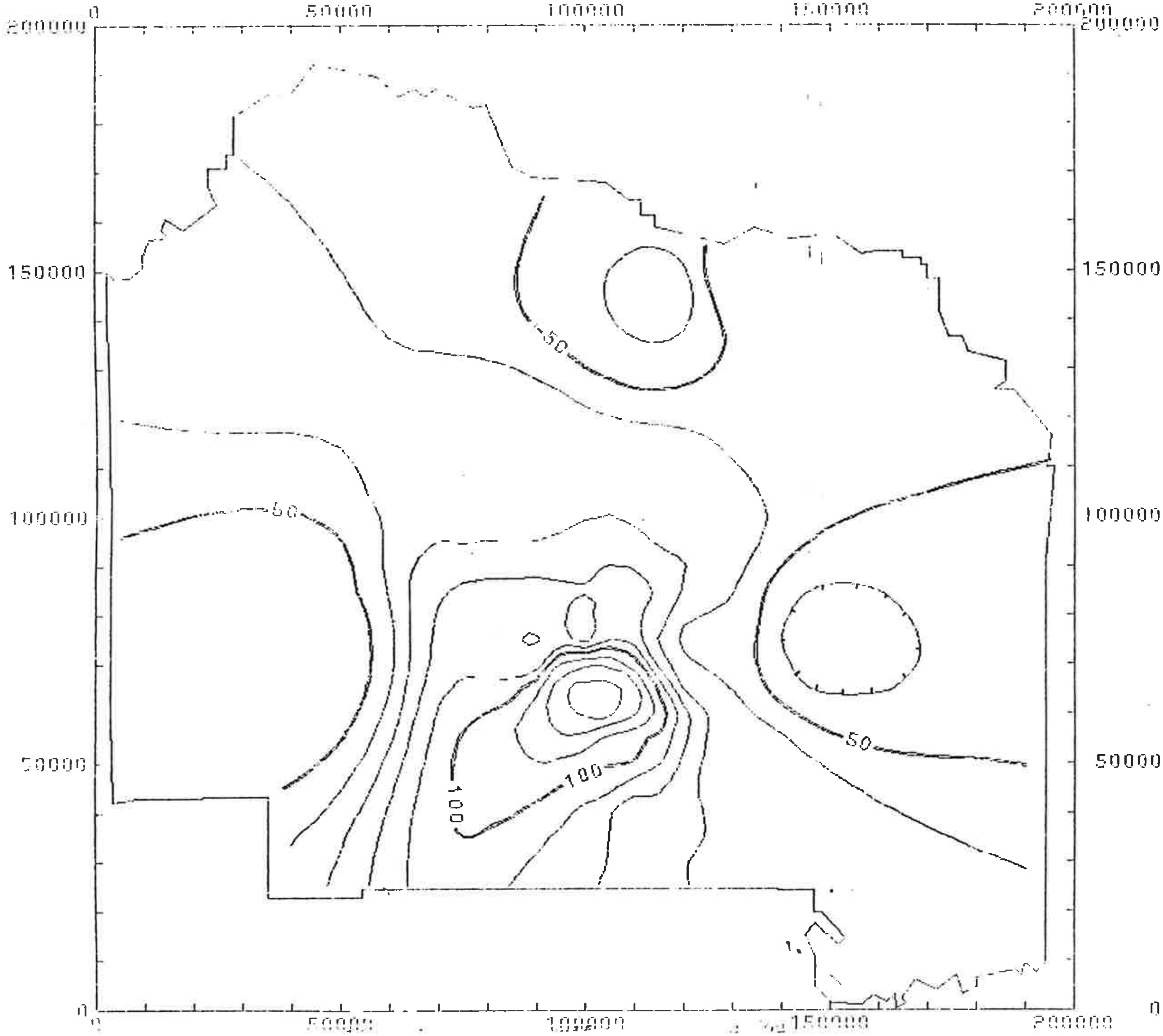
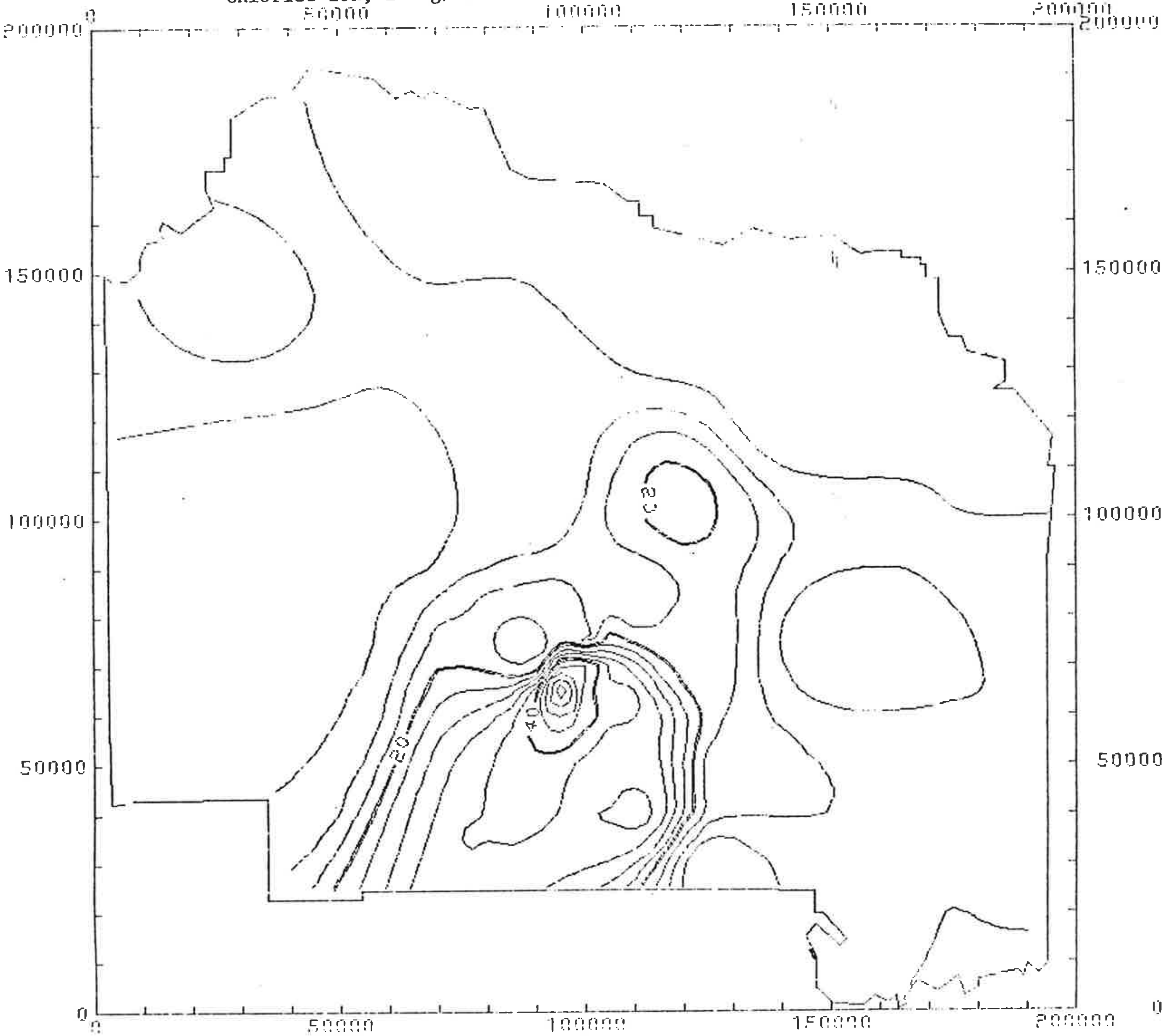


Figure 15. Water Quality of Florida Aquifer in Alachua County, Florida.



F[illegible]e 1 [illegible] Wa[illegible] Qua[illegible] of [illegible]orid[illegible] Aqu[illegible] in [illegible]chu[illegible]unt[illegible], Flo[illegible].
Calcium ion, in mg/l. Contour interval [illegible] 10 mg/l.

...gure . ...r Q...ty ...lo... n A...er ...lac... Co..., ...da.
Chloride ion, in mg/l. Contour interval is 5 mg/l.



igu 8. er lit Fl la fer Ala Co 7, ida
Nitrate ion, in mg/l. Contour interval is 1.0 mg/l.

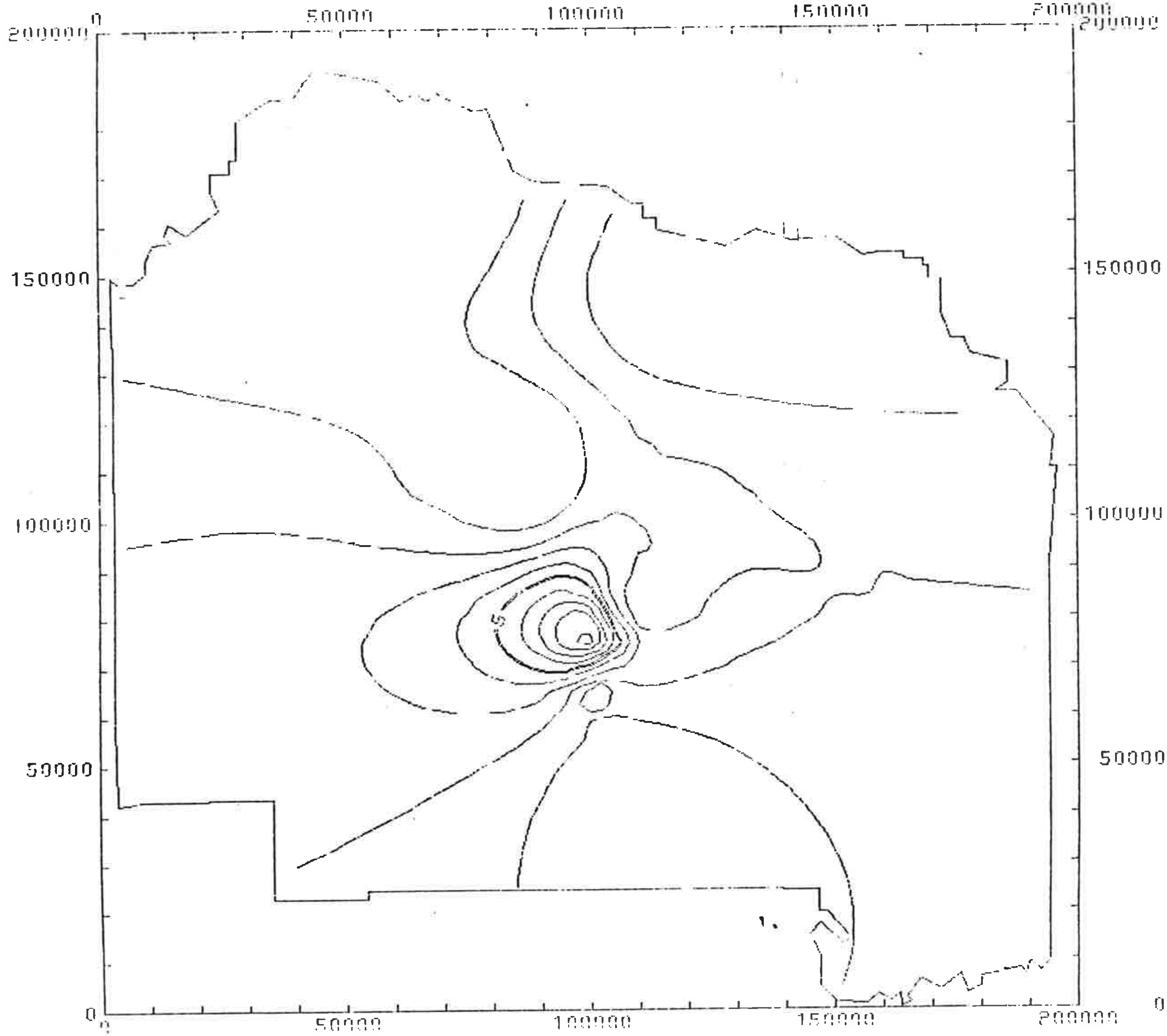


Figure 19. [illegible]
Sulfate ion, in mg/l. Contour interval is 10 mg/l.

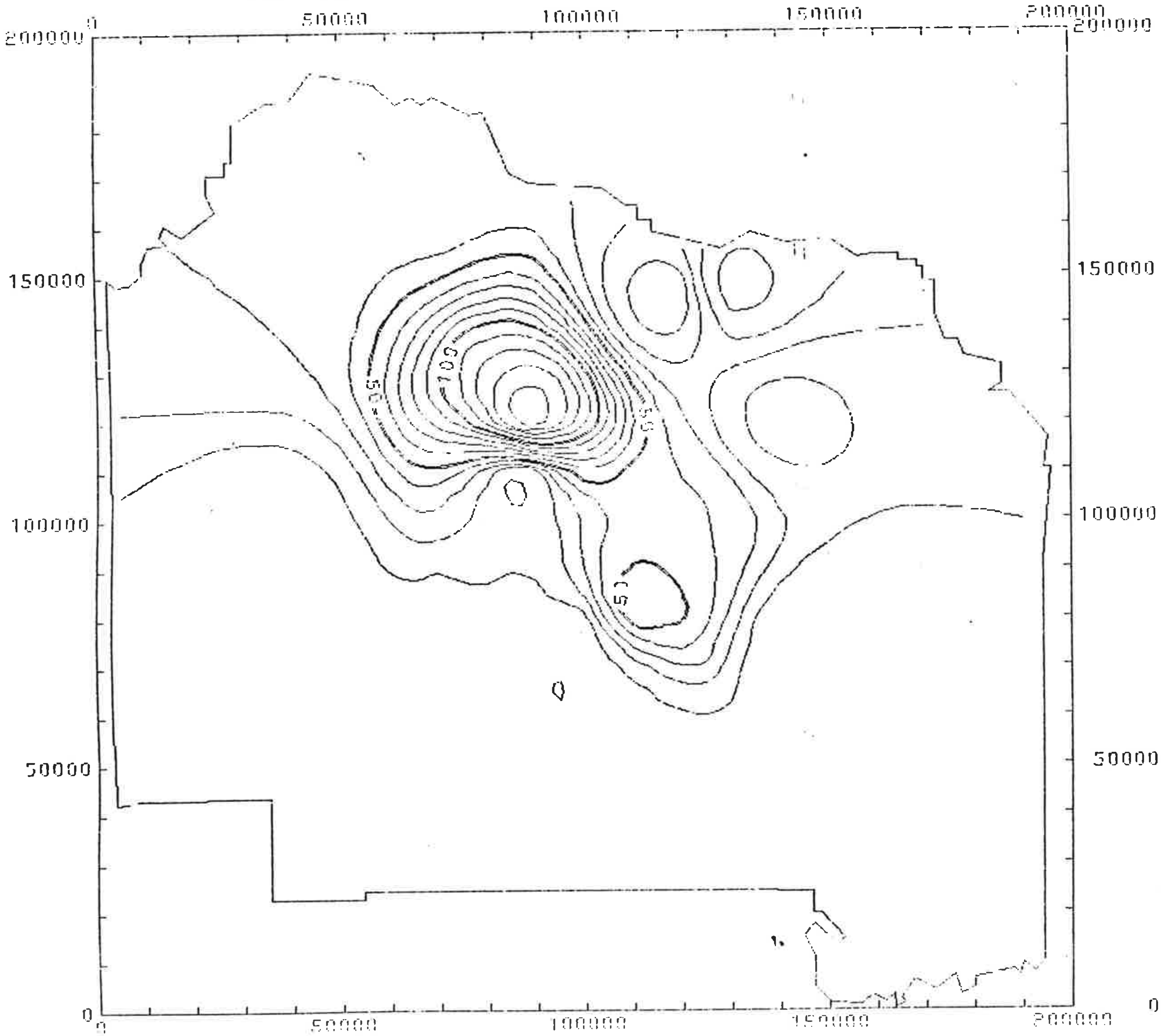
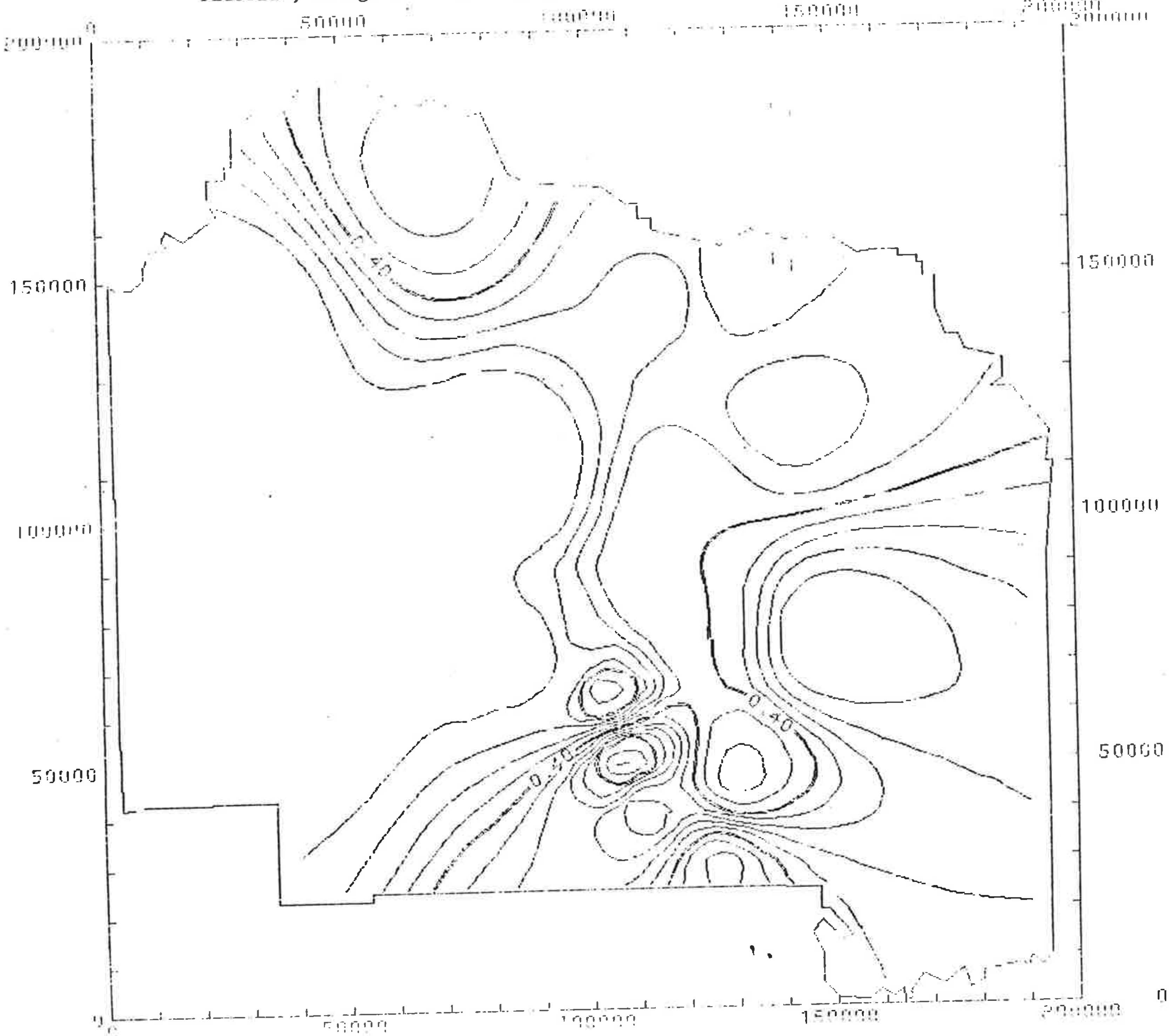


Figure [illegible]. Water Quality of [illegible]rid[illegible] Aqui[illegible] in [illegible]chu[illegible] [illegible]unt[illegible], Flor[illegible]. Fluoride, in mg/l. Contour interval is [illegible] mg/l.



resolution, 2) that these additional sites or wells meet quality control requirements to ensure meaningful data, and 3) an attempt be made to sample network wells as close to one point in time as possible to diminish the effects of time and water level changes on parameter values.

A Piper trilinear diagram was constructed to visually indicate the percentages of major ions making up the groundwater of the Floridan Aquifer sampled by the AGWQM network wells (fig. 21). The class of water indicated by this plot is the calcium + bicarbonate type typical of the Floridan Aquifer reported by Silverman (1983) and Ceryak et al. (1983).

Surficial aquifers tend to have relatively high sodium, chloride, potassium, and nitrate levels due to the high solubility of these ions and their presence on the land surface. Lower values of pH, specific conductance, alkalinity, calcium, and magnesium are found in shallow aquifers due to absence of reactions with carbonate lithologies and the presence of relatively high amounts of carbon dioxide (Ceryak et al., 1983).

Secondary aquifers tend to average between the surficial and Floridan Aquifer in concentrations of major constituent ions, with the exception of fluoride and orthophosphate. These two parameters are present in relatively high concentrations due to the presence of fluorapatite and phosphatic clays in the Hawthorne Formation where these aquifers occur.

Waters of the Floridan Aquifer are characterized by higher relative values of specific conductance, alkalinity, calcium, magnesium,

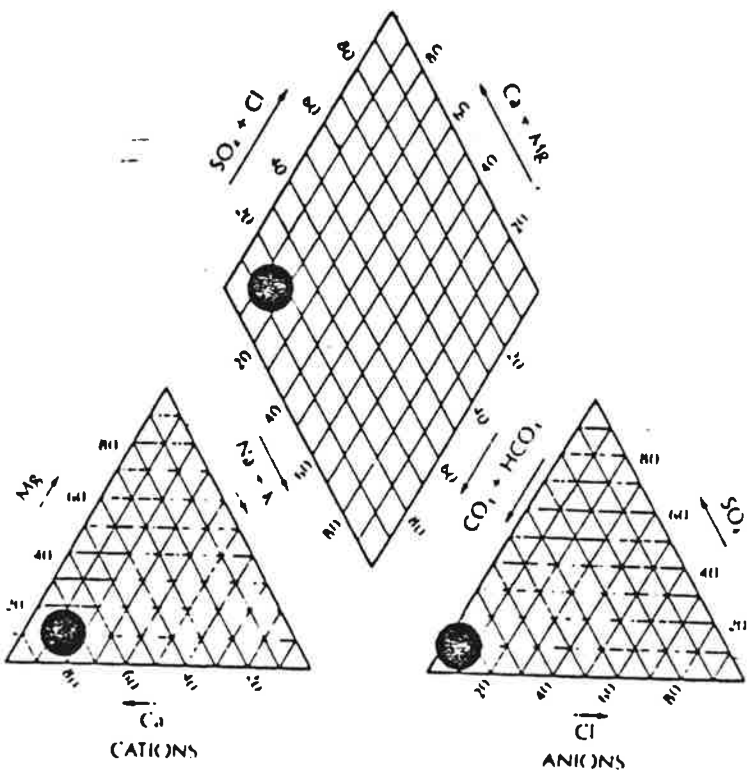


Figure 21. Trilinear Diagram of Water in Floridan Aquifer from AGWQMN Wells.

pH, and sulfate, due to dissolution of the parent carbonates of the Ocala Formation and deeper limestones.

Statistical cluster analyses conducted on major constituents in the waters of these three types of aquifers demonstrated a strong positive correlation between certain groupings of constituents and an aquifer system from which they were derived. The ions sodium, potassium, chloride, and nitrate were strongly correlated, and associated with shallow aquifers. Fluoride and orthophosphate were correlated and associated with secondary aquifers within the Hawthorne units. The group that was associated with dissolution of carbonates included pH, specific conductance, alkalinity, sulfate, calcium, and magnesium, and was associated with waters of the Floridan Aquifer. Cluster analysis is therefore a useful tool for checking groundwater withdrawn from a monitoring well as to aquifer source (Ceryak et al., 1983).

Factor analysis has also been used to study chemical processes affecting the composition of groundwater, relating residence times and rates of dissolution to the processes. Mapping of areal recharge patterns and zones of high hydraulic conductivity such as fracture traces or cavern systems, can also be facilitated using factor analysis (Lawrence and Upchurch, 1982).

In general, the concentration of dissolved substances increases with depth to the bottom of the Hawthorne units, but can decrease somewhat as the top of the Floridan is reached. This variability in water quality from the upper Floridan is related to recharge rates of the respective aquifers, solubility of aquifer materials, and transmissivity within the aquifers. The fractured, solution-riddled upper Floridan Aquifer has higher transmissivity than the less soluble dolomites more frequently encountered in secondary aquifers, and corresponding shorter residence times for infiltrating groundwater to reach saturation equilibrium. Reduced potassium levels in the confined Floridan may be due to the preferential adsorption of potassium by overlying clays. Sodium levels increase slightly with depth partly because of its release due to weathering of clays containing the ion. Iron concentrations tend to be highest in shallow aquifers and generally decrease with depth. Sulfate concentrations tend to vary sporadically, and are associated with the presence of localized gypsum deposits, reduction of sulfur compounds by bacteria, or water being drawn from deeper, more mineralized zones (Clark et al., 1964).

Factors affecting the measurement of geochemical parameters encompass the following: geological siting, environmental influence, well depth, hydrologic flow regime, water level fluctuations, temporal and spatial variability, and sampling and laboratory bias. Of these, assuming temporal and spatial variability are averaged out and sampling error and analytical bias are factored in, geology is considered the most significant factor affecting natural water quality, with environmental influences highly significant where the aquifer is unconfined and receiving recharge from above (Silverman, 1983).

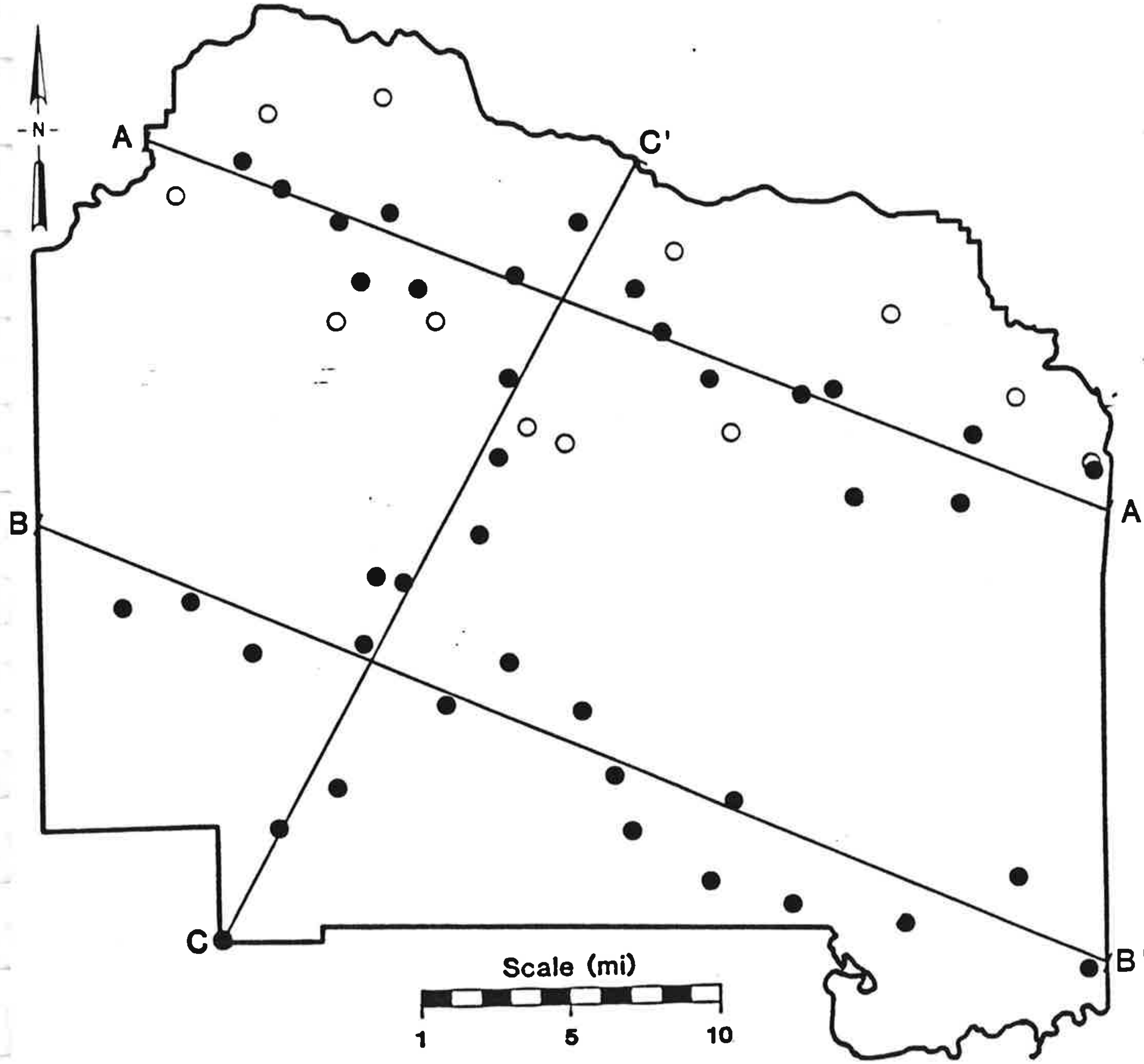
In the Alachua County area, a study involving sampling wells in the Floridan Aquifer demonstrated the correlation of certain water quality parameters with water levels. It was found that specific conductance, fluoride, magnesium, and orthophosphate were negatively correlated with potentiometric levels in the aquifer, while calcium was positively correlated, and sodium, chloride, and sulfate showed no correlation at all. Lower concentrations occuring during higher water levels is thought to be due to dilution effects of recharge waters, while higher values are related to downgradient sites allowing a longer residence time for concentrations to increase (Silverman, 1983).

The study also showed the high lateral heterogeneity in the parameters studied, especially for sodium and sulfate. Sodium, and to a lesser degree of correlation, fluoride, potassium, and magnesium, were found in higher concentrations where the Floridan is confined by the clays of the Hawthorne, predominantly in wells of the Northern Highlands plateau. The Hawthorne is thought to contribute these ions to the Floridan by downward leakage. Potassium is released by the weathering of montmorillonitic clays found in the Hawthorne. Higher silicates found in wells in this region also indicate clay weathering as a source. Likewise, where sources are distant or absent, lower concentrations of certain parameters are found. Reduced levels of sodium, potassium, orthophosphate, magnesium, and fluoride in areas where the Floridan is unconfined indicate less overlying parent material of the Hawthorne or Alachua Formation. Higher nitrate levels, and to a lesser degree, levels of orthophosphate in these areas are explained by the use of agricultural fertilizers and septic systems in these regions (Silverman, 1983).

Geochemical traverses across Alachua County were constructed to relate geohydrology to ambient water quality in the Florida aquifer. The sites of the traverses, along with locations of Floridan wells with water quality data used in the analyses, are shown in figure 22. In addition to AGWQM network wells adjacent to the traverse, several wells not chosen for the preliminary monitoring network were included to provide sufficient data for the analyses. The selection of non-

Figure 22.

Geochemical Traverses A-A', B-B', and C-C', Showing Location of Wells.



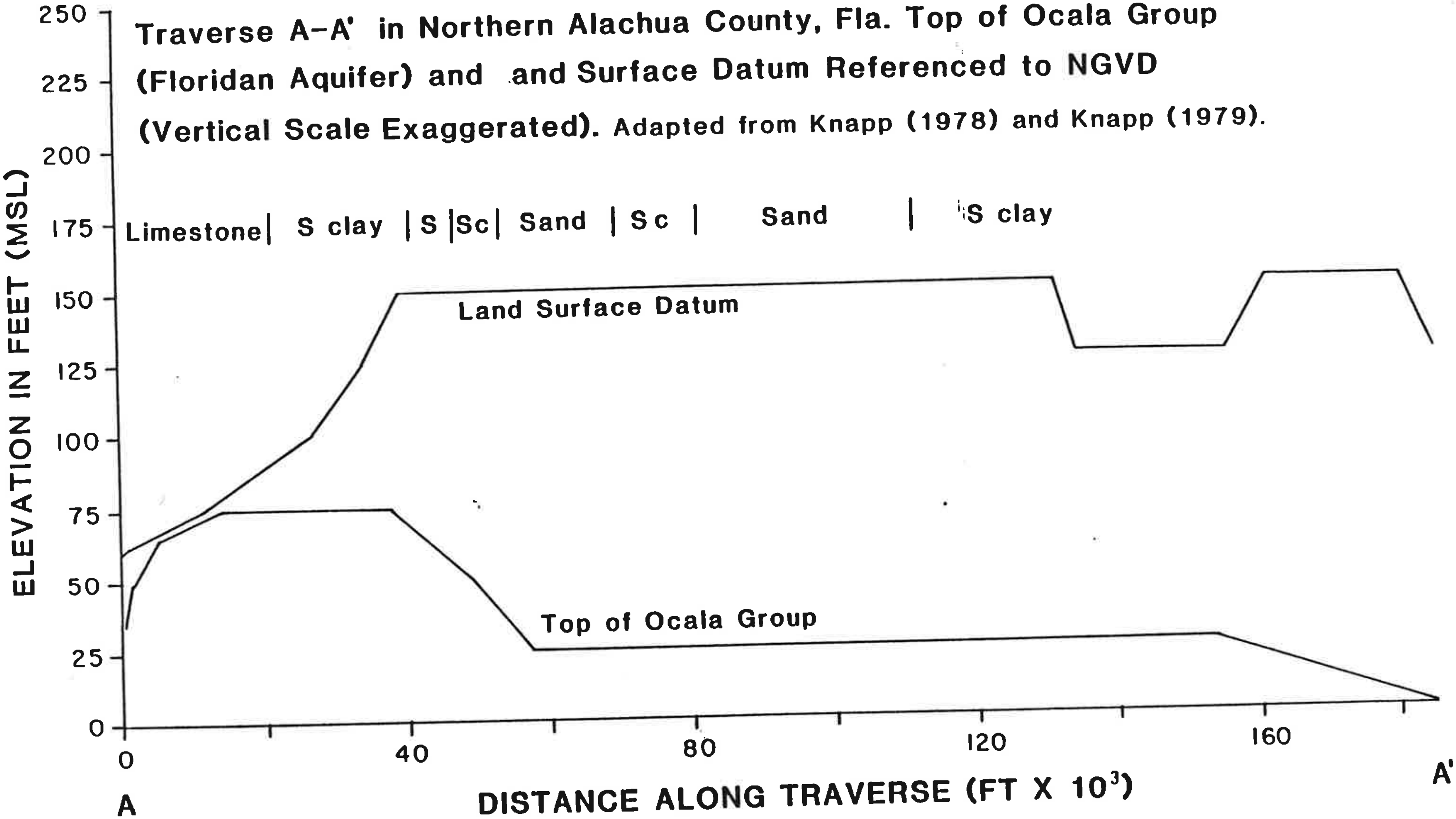
● WELLS SELECTED FOR GEOCHEMICAL TRAVERSE WATER QUALITY ANALYSIS

○ WELLS WITH SUPPORTING WATER QUALITY DATA AVAILABLE network wells was based on proximity to the traverse, and technical well information, rather than completeness of data. The traverses were located to minimize lateral distances to wells along it, and to avoid facilities or municipalities where possible non-ambient ground-water conditions may exist. Values of the major ions, pH, and specific conductance from data for the selected wells were then plotted against distance along the traverse to determine the relationship between location, flow path, and water quality.

Traverse A-A' in northern Alachua County was constructed parallel to generalized flow directions in the Floridan Aquifers. Sediments overlying the Ocala Group limestones decreased in thickness from near 100 feet along the first two thirds of the traverse (going from east to west along the flow path), to near zero in the latter third, and ranged in composition from sandy clay and sands to limestone (fig. 23). The Florida Bureau of Geology Map Series 92 (Knapp, 1979) and Map Series 79 (Knapp, 1978) were used to delineate surficial lithologies and depths to top of the Ocala Group limestones.

Two separate graphs for each parameter were constructed from data taken from two separate points in time to detect time differences in the data set. Since the data from most wells used in these analyses were from only one sampling event, different wells had to be used to construct the two graphs. This introduced the additional variables of well location, depth of sample, surficial lithologies, and flow regime, which make strict comparisons between the two graphs for each parameter somewhat tenuous. Generally, there is good agreement in the shape of the curves and magnitude of values reported for the two sampling events despite the fact that completely different wells miles

Figure 23.


Traverse A–A' in Northern Alachua County, Fla. Top of Ocala Group (Floridan Aquifer) and and Surface Datum Referenced to NGVD (Vertical Scale Exaggerated). Adapted from Knapp (1978) and Knapp (1979).
Limestone | S clay | S | Sc | Sand | S c | Sand | S clay
Land Surface Datum
Top of Ocala Group
ELEVATION IN FEET (MSL)
250
225
200
175
150
125
100
75
50
25
0
0
40
80
120
160
A
A'
DISTANCE ALONG TRAVERSE (FT X 10³)

apart were used in constructing the graphs. In some cases, a parameter was measured in one sampling period and not in the other. Such was the case for sodium and potassium. In those cases, only one graph is presented.

Plots of major ions show a general increase in dissolved calcium, magnesium, bicarbonate, and specific conductance along the first part of the flow path (figs. 24 , 25). Data for sodium and potassium for early traverse wells were scarce, but values from substitute wells indicate they too increase along the flow path (fig. 26). This increase may indicate a general increase in dissolved solids with residence time in low TDS recharge waters, especially when confined by sandy clay overburden, permitting little recharge to occur. As the flow path moves out under predominantly sandy soils, an increase in recharge occurs, accompanied by a decrease in dissolved solids due to dilution. Further along the traverse, dissolved solids tend to increase again as sandy clay again becomes the dominant surficial lithology, and with increased time of residence. As the Ocala Group limestones begin to crop out near the end of the traverse, and overburden becomes essentially non-existent, recharge again increases and concentrations of dissolved solids again decline. Chloride does not follow this pattern. Chloride is related more to environmental factors than are the other natural water quality parameters, and variability in chloride data may indicate variation in environmental sources such as marine aerosols, septic tanks, selective sorption of compounded cations such as potassium by clays and release of chloride, or weathering of clays in the Hawthorne (fig. 27).

Sulfate was extremely variable along the traverse (fig. 28), with values ranging from 0.5 to 168.0 mg/l reported. Natural sources of

Figure 24.

Geochemical Traverse A–A' in Northern Alachua County, Fla. Calcium and Magnesium from 1960 and 1976 Samplings. Flow Direction is from Right to Left.

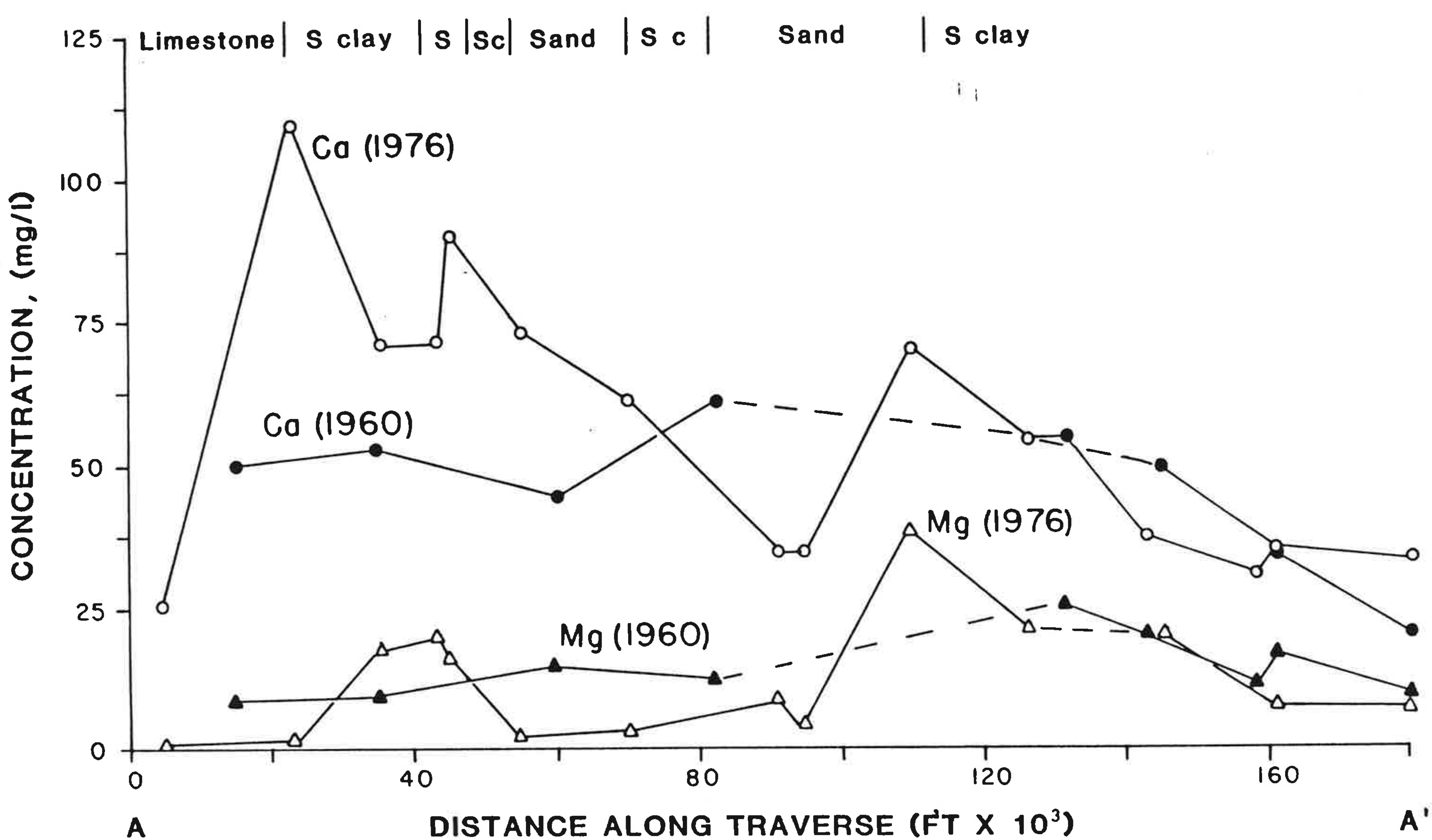


Figure 25.

Geochemical Traverse A-A' in Northern Alachua County. Fla. Bicarbonate and Specific Conductance. Flow Direction Is From Right to Left.

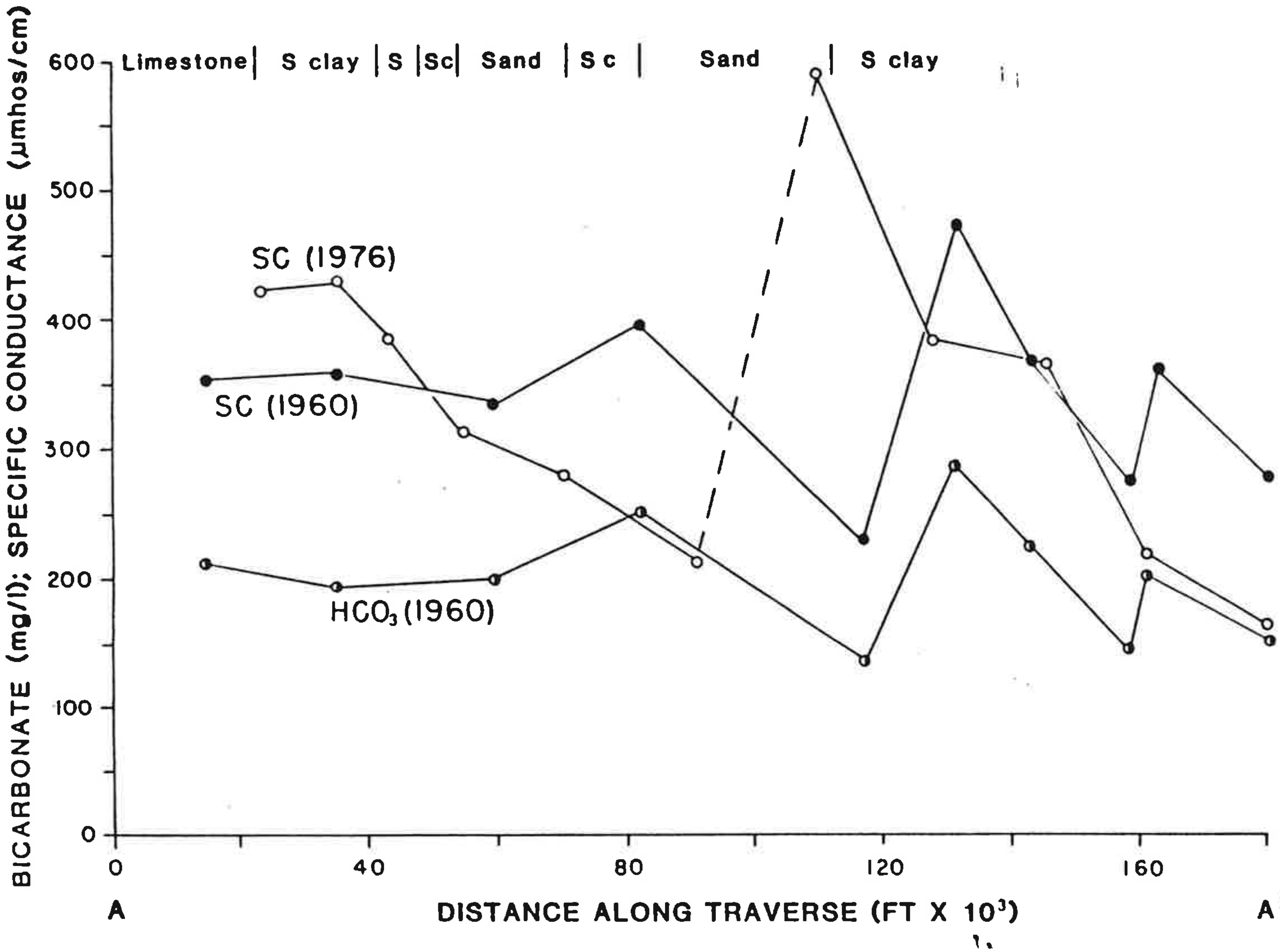


Figure 26.

Geochemical Traverse A–A' in Northern Alachua County, Fla. Sodium, Potassium and pH. Flow Direction is from Right to Left.

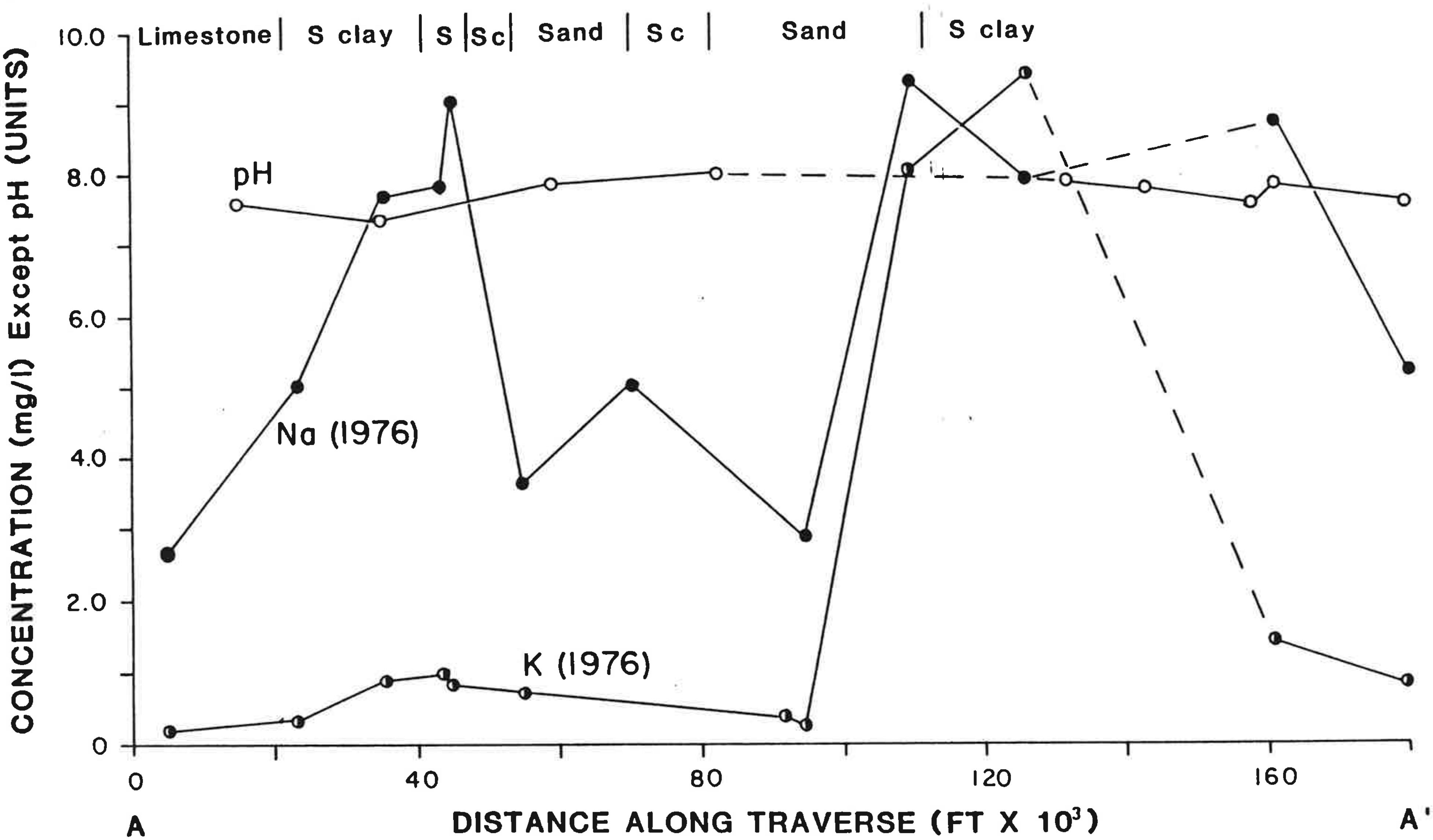


Figure 27.

Geochemical Traverse A–A' in Northern Alachua County, Fla.
Chloride and Fluoride from 1960 and 1976 Sampling.
Flow Direction is from Right to Left.

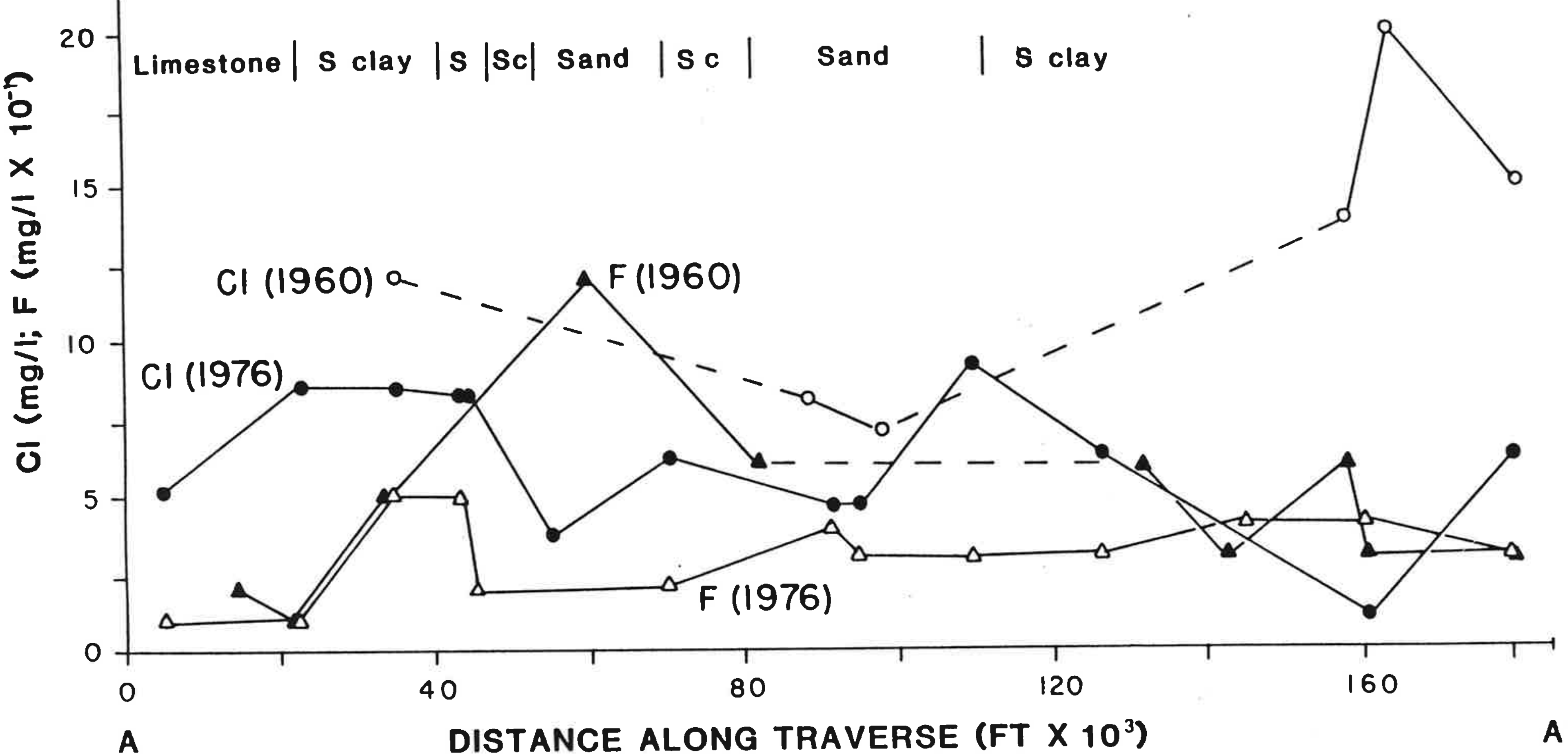
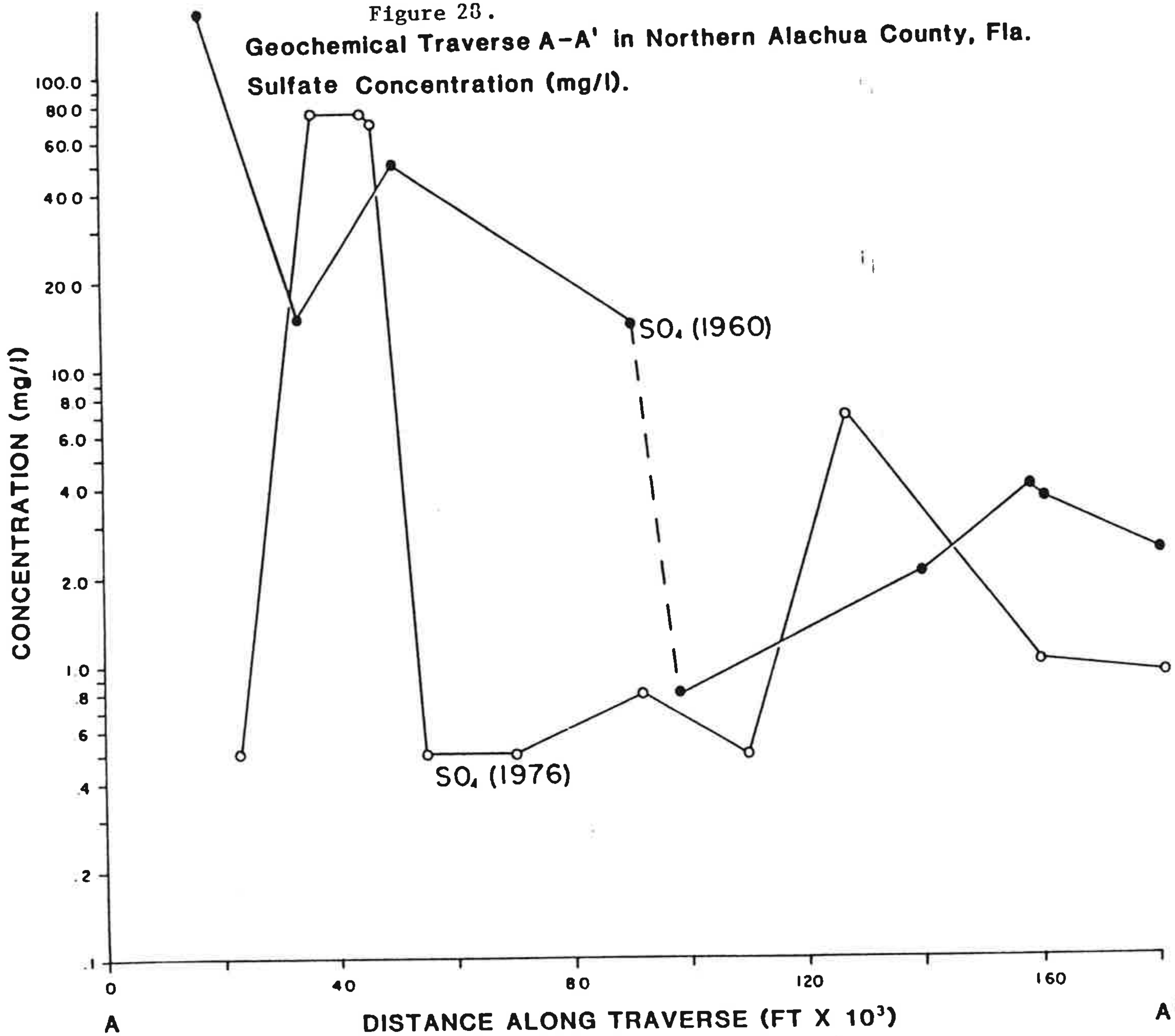


Figure 28.

Geochemical Traverse A-A' in Northern Alachua County, Fla.

Sulfate Concentration (mg/l).



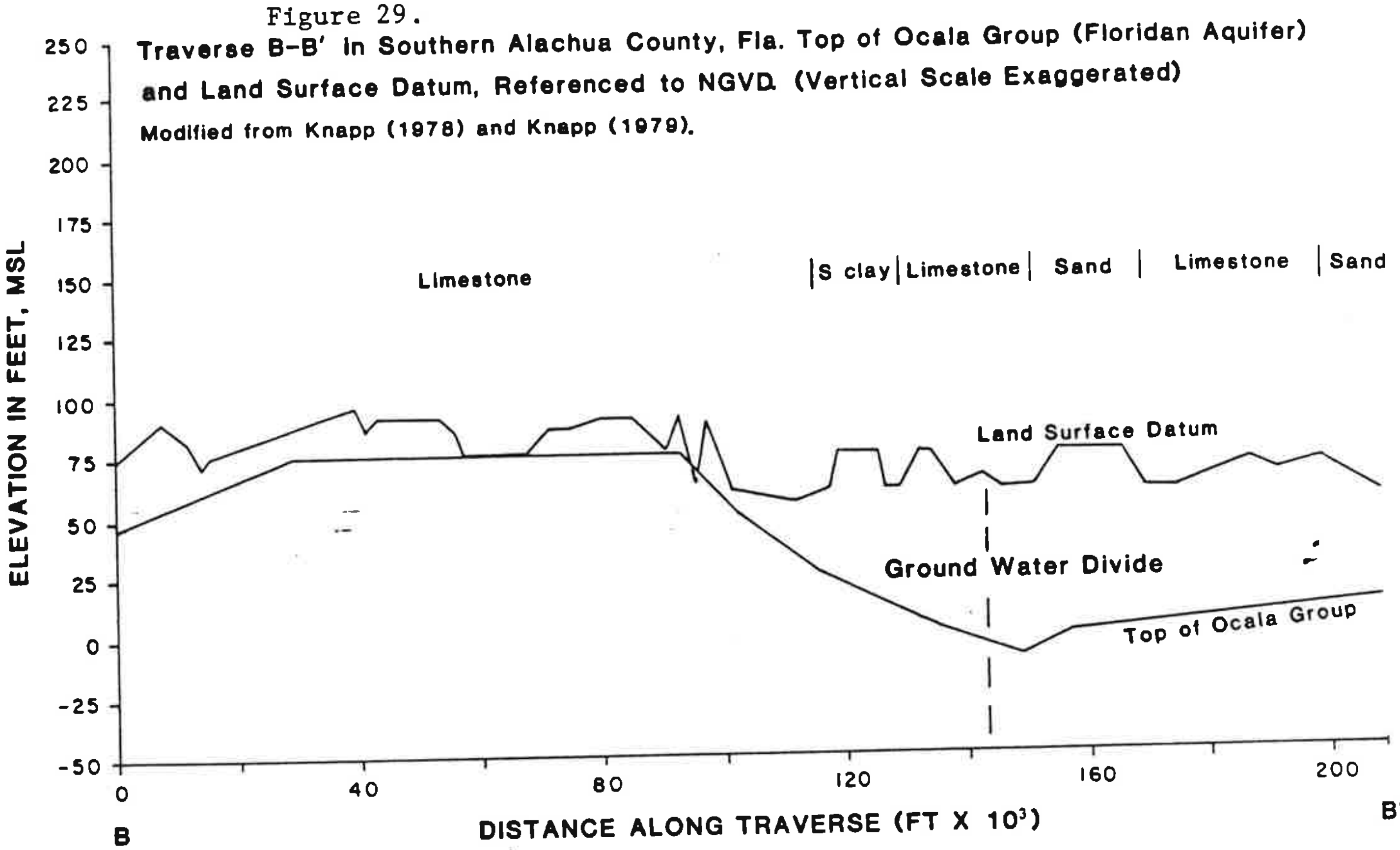
sulfate occur at depths much deeper than any of the private wells sampled. Data from wells other than those included in the traverse were checked to detect a spatial pattern to the high sulfate values, but a random pattern seemed to occur. Since the high sulfate concentrations exceed the maximum reported natural range for that parameter, it is assumed that the source is either industrial discharges or upconing of deeper waters from a more mineralized zone. The area of random, high sulfate concentrations extends from near the Deerhaven power generating station northwest of Gainesville west and north past Alachua to the Santa Fe River. The cross county fracture zone cuts across this area, and deep fractures and high flow velocities possible in this zone, along with proximity to a regional discharge area, may account for poorly mixed, mineralized waters approaching the surface in this region.

The increase in pH along most of the traverse is characteristic of a closed system. The lower pH toward the end of the traverse represents an increase in carbonic acid characterizing an open system.

A second traverse B-B' across the southern part of Alachua County is shown in cross section in figure 29. In this traverse, the Ocala Group limestones are much closer to the surface, overlain by less than 75 feet of sands and sandy clays. A groundwater divide is encountered approximately one third of the way along the traverse (from east to west). All wells along this traverse were sampled in 1960, therefore, values for sodium and potassium were incomplete.

Along the first part of the traverse, flow direction is nearly at right angles to the traverse. The cross county fracture zone cuts across this traverse in the area between Haile Sink and Lochloosa

Figure 29.



Traverse B-B' in Southern Alachua County, Fla. Top of Ocala Group (Floridan Aquifer) and Land Surface Datum, Referenced to NGVD. (Vertical Scale Exaggerated)
Modified from Knapp (1978) and Knapp (1979).
ELEVATION IN FEET, MSL
250
225
200
175
150
125
100
75
50
25
0
-25
-50
Limestone
S clay
Limestone
Sand
Limestone
Sand
Land Surface Datum
Ground Water Divide
Top of Ocala Group
0
40
80
120
160
200
B
B'
DISTANCE ALONG TRAVERSE (FT X 10³)

Lake. This may account for some of the variability in the natural water chemistry measured in that area (fig. 30 & 31). The higher pH, fluoride, calcium, and specific conductance indicate a groundwater approaching equilbrium, or deeper more mineralized waters reaching the environment of the wells by way of the fracture zone. Research done in this area indicates that higher values of certain parameters such as chlorides, fluorides, and specific conductance in this area may be due to recharge of urban runoff and treated effluent at Alachua Sink on Paynes Prairie (Phelps, 1985).

As the traverse passes the fracture zone, wells sampled along the flow path show a more predictable water chemistry. A slow decline in most ions indicates an area of recharge on the limestone plain, with the effects of dilution offsetting the increase in dissolved solids one would expect to find in the direction of flow.

A third traverse C-C' was constructed at right angles to the other traverses and at right angles to flow in the Floridan Aquifer as shown in figure 22. The cross section (figure 32) shows a relatively thin depth to aquifer limestone in the southern part, with the aquifer overlain by thicker sediments in the north. Although the wells used in constructing the water quality graphs were sampled at different times between 1960 and 1982, it is assumed that the curves will be similar in shape and magnitudes to those of a discrete sampling. This assumption was valid for traverses A-A' and B-B'.

From figures 33 and 34, it can be seen that values for all parameters from C to C' tend to increase from south to north until north of the Gainesville area, where values again decline. This may be due to increased recharge and subsequent dilution in the areas toward the ends of the traverses, with less recharge in the central

Figure 30.

Geochemical Traverse B-B'. In Southern Alachua County, Fla. Calcium, Magnesium, and pH. (Data from 1960 Sampling)

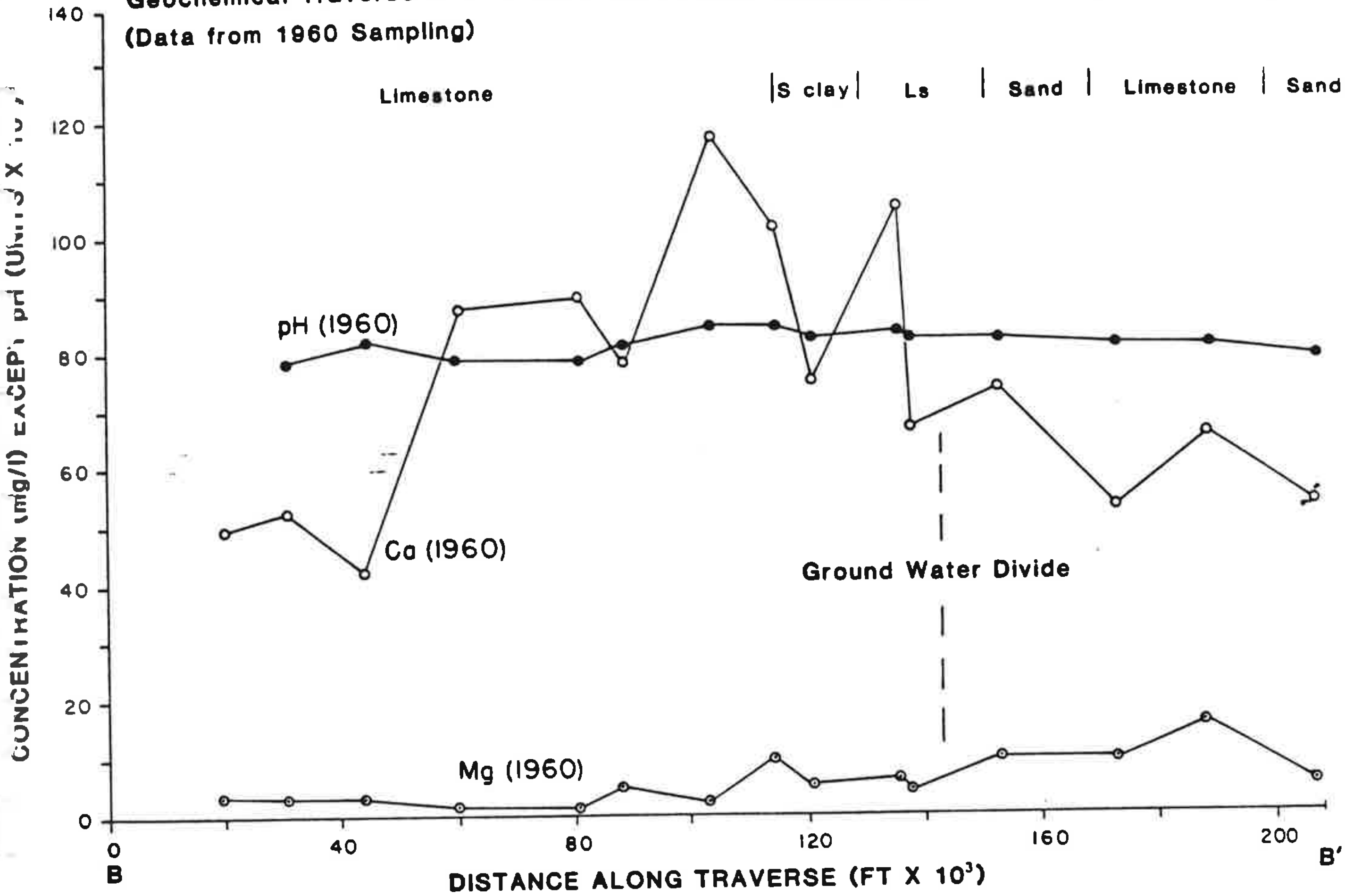


Figure 31.
Geochemical Traverse B-B' in Southern Alachua County, Fla. Chloride, Fluoride, Bicarbonate, and Specific Conductance from 1960 Sampling.

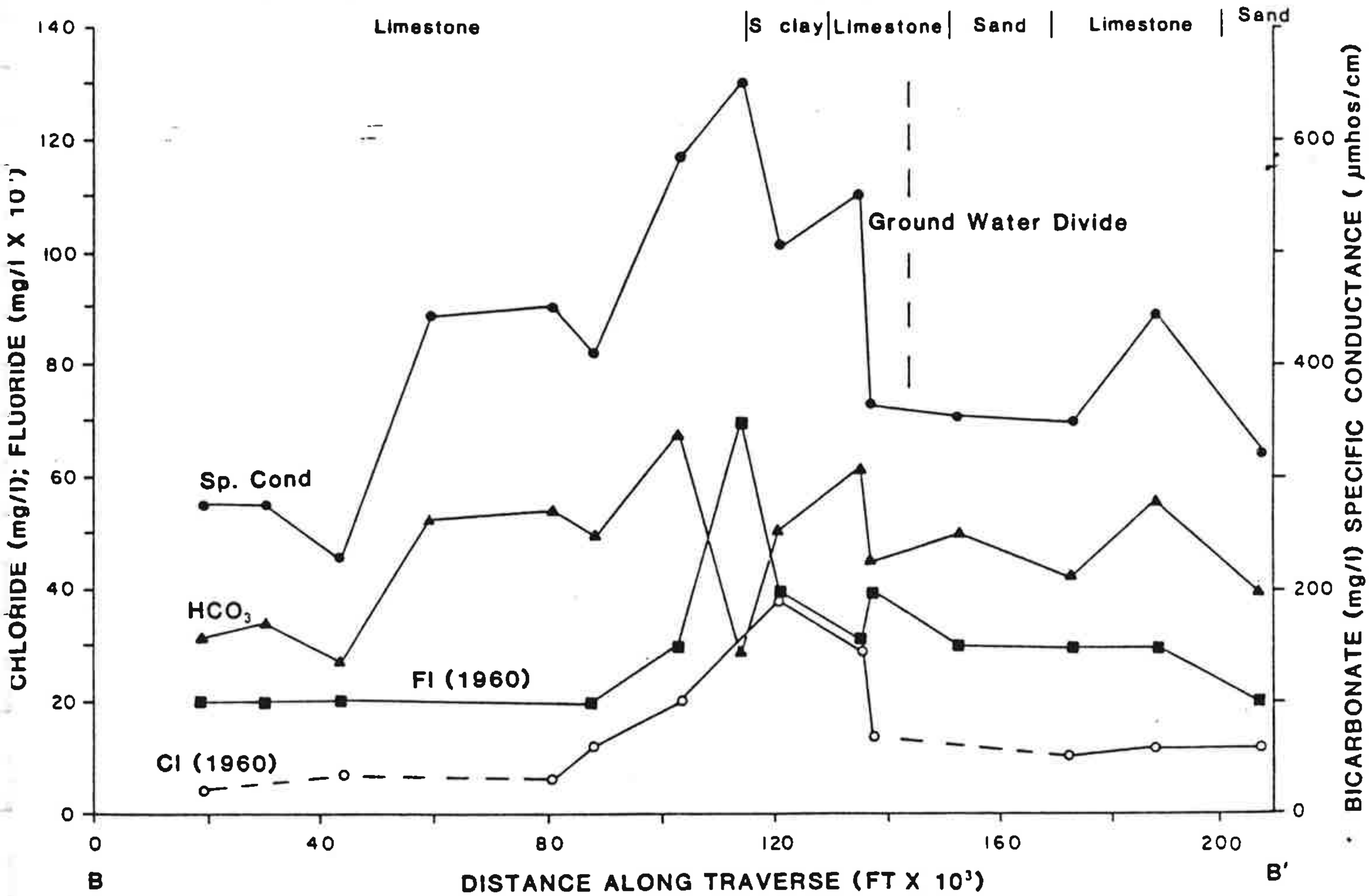
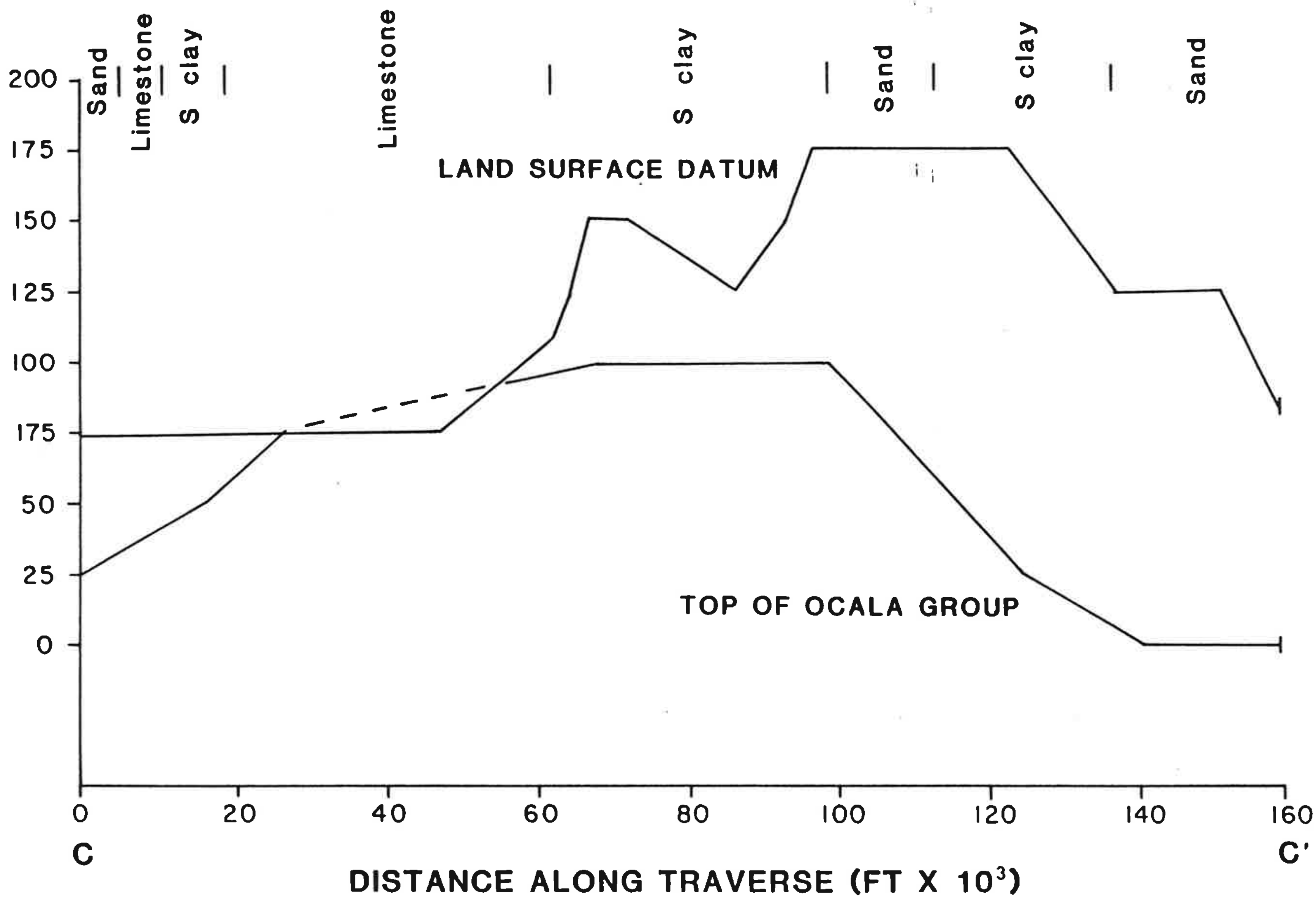


Figure 32.

Traverse C–C′. Top of Ocala Group (Floridan Aquifer) and Land Surface Datum Referenced to NGVD. Adapted from Knapp (1978) and Knapp (1979). Vertical scale exaggerated.



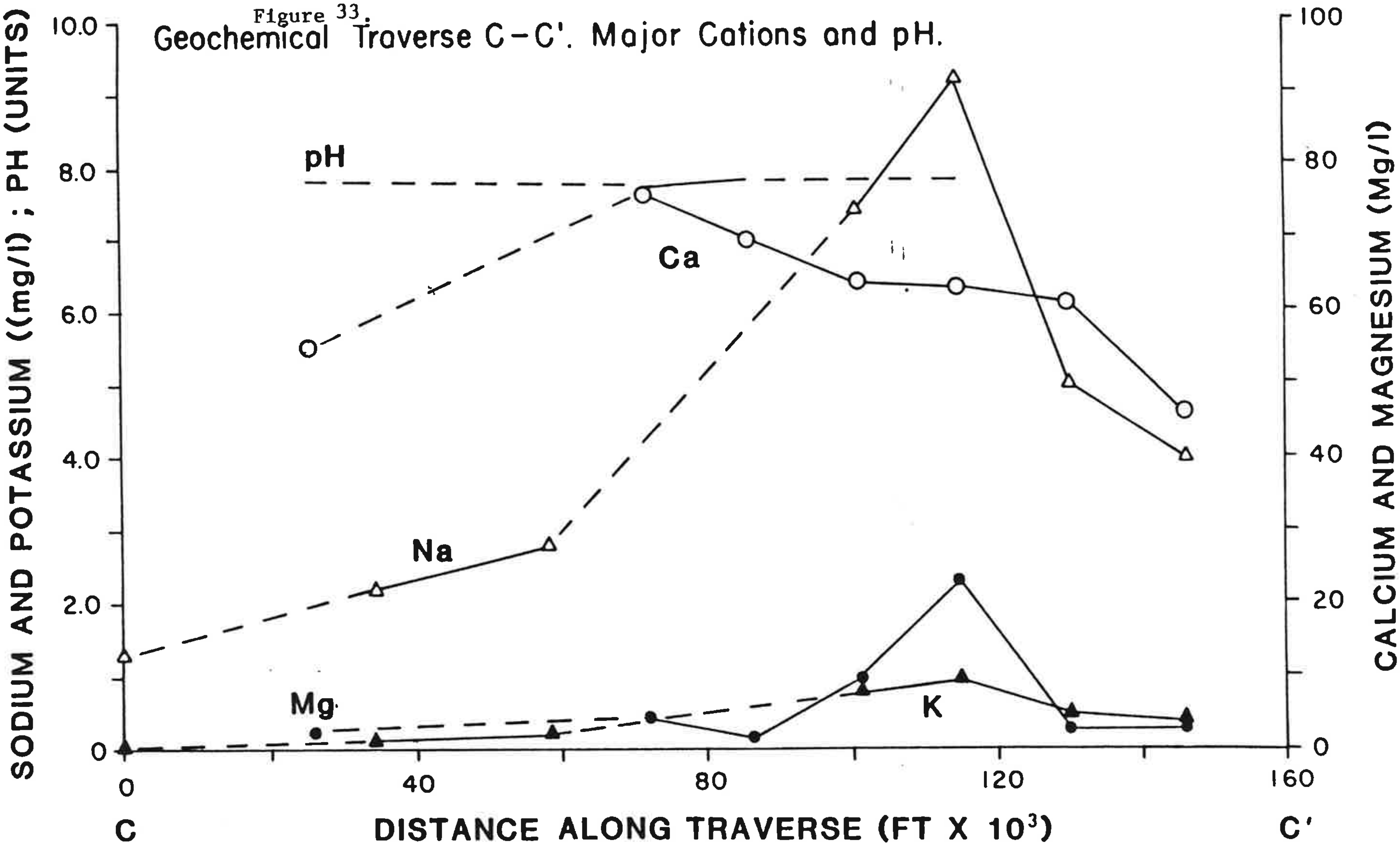
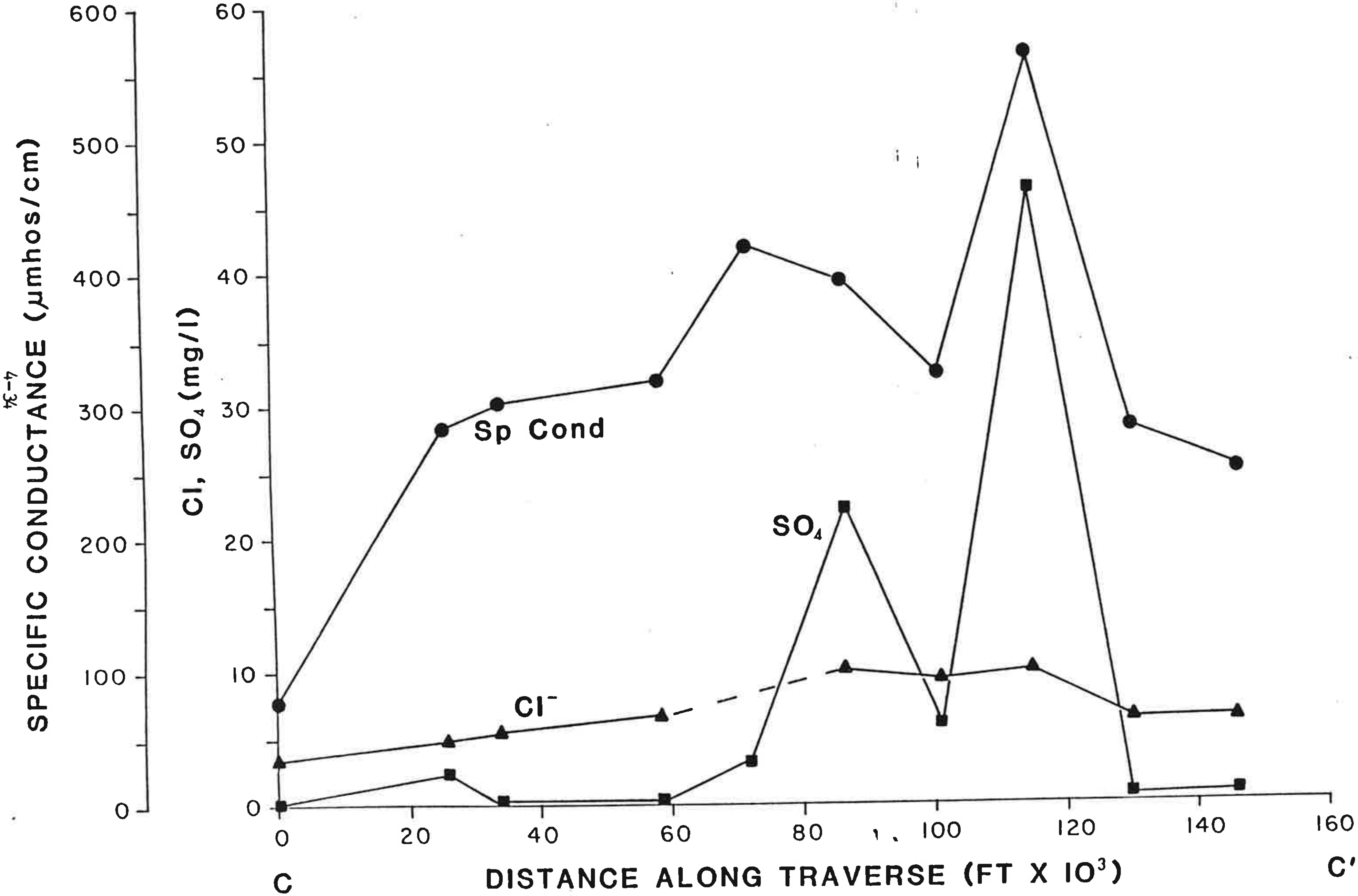


Figure 33. Geochemical Traverse C–C'. Major Cations and pH.

Figure 34. Geochemical Traverse C–C′. Major Anions and Specific Conductance.



section where the aquifer is overlain by thicker units of the Hawthorne clays. Concentrations of dissolved solids are low in most wells underlying the Brooksville Ridge sands at the southwestern end of the traverse due to high recharge in that area. Higher concentrations west and northwest of Gainesville may be partly due to injection wells and sinks in the Gainesville area contributing dissolved solids. The cross county fracture trace cutting through that area may also be partly responsible for higher concentrations, as evidenced by the relatively high sulfate concentrations exhibited by two wells in the trace vicinity.

As with the computer generated water quality maps, the water quality traverses are meant to describe general patterns of water quality through an area. These graphs are constructed from few data points scattered over large physical distances and often at different points in time. The maps used to delineate surface lithologies and depths to Floridan Aquifer are general, and are used only because of the scarcity of data from good lithologic logs. Many variables interact to fix water quality values in a well at any point in time. For these reasons, caution should be exercised in drawing definitive conclusions about the water quality of an area using only the graphs presented. A broader network of wells, constructed to current monitoring well standards and logged, then sampled several times around a fixed point in time with a program of quality assurance, is necessary to give definitive statistical validity to data portraying areal groundwater quality.

Groundwater Management

Ideally, all areas of Alachua County serving as recharge areas for aquifers from which potable water supplies are drawn should receive management protection. Since this encompasses practially all of the county, there should be a countywide program of groundwater management. This should include the following components:

- AGWQM network
- Solid and hazardous waste management program
- Definition of areas sensitive to groundwater comtamination

The AGWQM network is essential to establish background water quality in the county and detect changes or patterns that may indicate an influence by contamination. The network will help define sensitive areas such as public supply wellfield cones of depression and areas where unconfined aquifers exist. It also may indicate impacts on unconfined aquifers due to non-point sources such as septic tank usuage and fertilizer application. Monitoring in areas where there is little variation in water quality and land use or population density may be reduced and increased in areas of greater variability.

A solid and hazardous waste management program in Alachua County should accomplish the following objectives: 1) identify sources of active and potential contamination, 2) select alternatives to landfilling of wastes, and 3) establish a program for dealing with hazardous waste in the county. Source identification for inactive or as yet unknown sites may be accomplished using the AGWQM network or areal reconnaisance. Landfills, as previously constructed, have demonstrated an inability to adequately protect neighboring groundwater from their contaminants, even when lined with layers of relatively impermeable clays (Table 7). Solvents commonly discarded

Table 7

Representative Ranges for Various Inorganic Constituents in Leachate From Sanitary Landfills

Parameter	Representative range (mg/ℓ)
K^+	200–1000
Na^+	200–1200
Ca^{2+}	100–3000
Mg^+	100–1500
Cl^-	300–3000
SO_4^{2-}	10–1000
Alkalinity	500–10,000
Fe (total)	1–1000
Mn	0.01–100
Cu	<10
Ni	0.01–1
Zn	0.1–100
Pb	<5
Hg	<0.2
NO_3^-	0.1–10
NH_4^+	10–1000
P as PO_4	1–100
Organic nitrogen	10–1000
Total dissolved organic carbon	200–30,000
COD (chemical oxidation demand)	1000–90,000
Total dissolved solids	5000–40,000
pH	4–8

Source: Freeze and Cherry (1979)

in landfill refuse, such as acetone, methanol, or ethylene glycol (found in antifreeze) can increase the hydraulic conductivity of montmorillonite clays commonly used to line waste impoundments by three orders of magnitude or more (Brown and Anderson, 1983; fig. 35, Table 8). Separation of waste types at the source, or incineration of wastes may be acceptable alternatives to landfills with high future costs. Hazardous wastes as regulated under the Federal RCRA program presently deal only with large generators, transporters, treatment, storage, or disposal facilities, and do not address the waste stream entering the environment by way of the small generator. Presumably, hazardous wastes from these small quantity handlers are discarded to landfills or legally disposed on their own property, posing a threat to groundwater. Unrecycled hazardous waste from regulated facilities is currently shipped out of state at great expense. Participation by the county in setting up centralized collection and transfer facilities, or waste exchanges for recyling of hazardous wastes would reduce these costs and discourage "midnight dumping" of wastes (FDER, 1982a). Programs such as the recent "Amnesty Days" held in Alachua County are effective in removing considerable quantities of hazardous waste from disposal in the environment (ACDES, 1985).

Some areas of Alachua County are more susceptible to contamination of the Floridan Aquifer than others. An area where the Floridan is unconfined, overlain only by a thin veneer of sediments, or where the terrain is dotted by numerous sinkholes is one such area. This area generally coincides with the Limestone Plain or Cross-Valley region of western and southern Alachua County. Another important area is that area lying along and adjacent to the cross

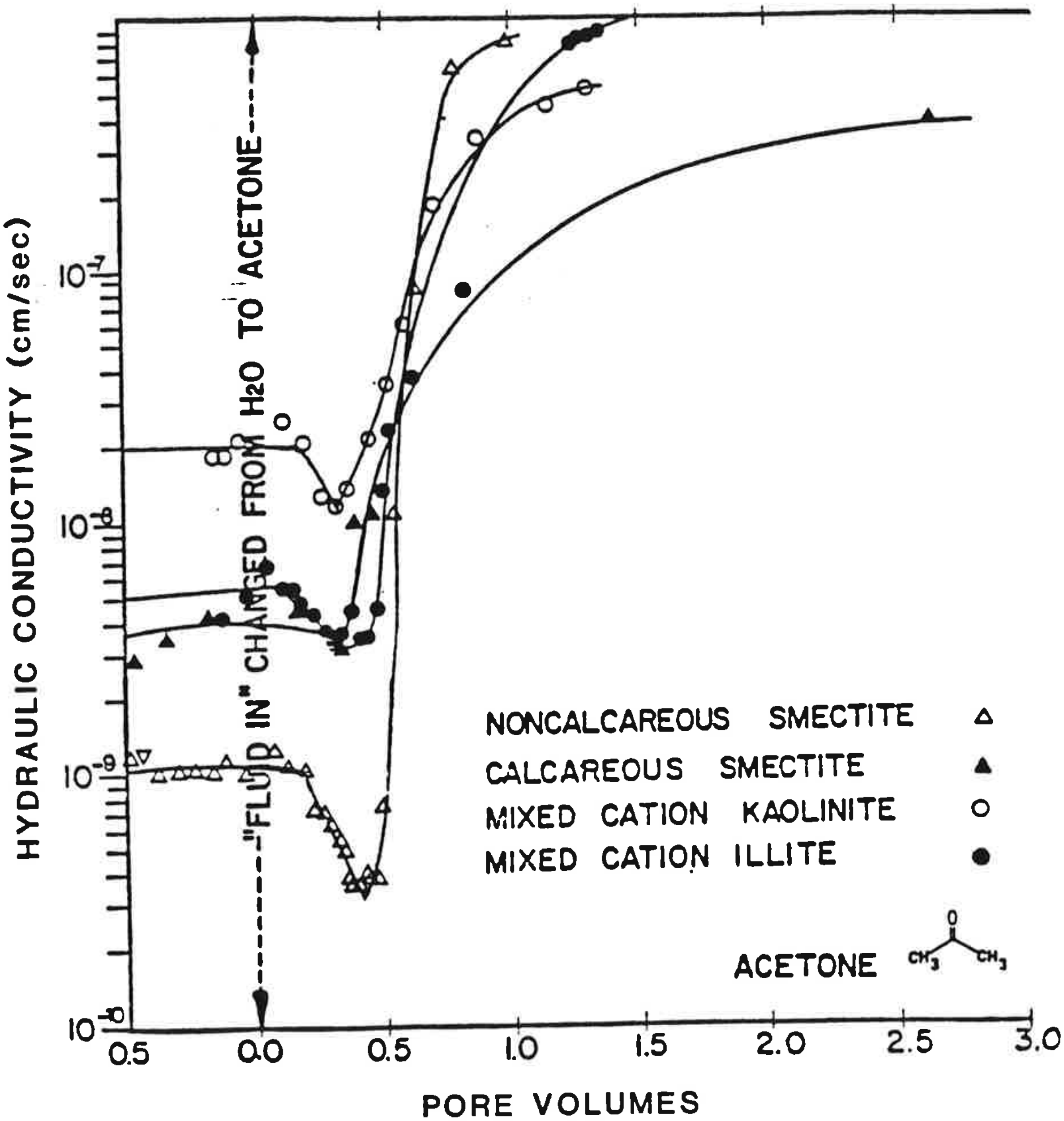


Figure 35. **Hydraulic Conductivity of the Four Clay Soils to Acetone (Brown and Anderson, 1983)**

Table 8

PERMEABILITY* OF NONCALCAREOUS SMECTITIC CLAY SOIL TO THE FOLLOWING FLUID SEQUENCE: WATER (0.01N $CaSO_4$)-TEST FLUID-WATER (0.01N $CaSO_4$)

Test Fluid	Initial Permeability to Water (0.01N $CaSO_4$) (cm sec^{-1})	Permeability to Test Fluid (cm sec^{-1})	Final Permeability to Water (0.01N $CaSO_4$) (cm sec^{-1})
Aniline	$2.91(\pm0.23) \times 10^{-9}$	2.2×10^{-7}	2.3×10^{-8}
Methanol	$1.55(\pm0.17) \times 10^{-9}$	1.1×10^{-6}	6.0×10^{-8}
Ethylene Glycol	$1.39(\pm0.14) \times 10^{-9}$	3.1×10^{-7}	1.1×10^{-7}

* Hydraulic Conductivity is current preferred usage.
SOURCE: Brown and Anderson (1983).

county fracture trace, due to increased infiltration, higher flow velocities, and the potential for rapid transport of undispersed contaminant slugs to wells in the area (fig. 2). Surface water bodies directly recharging the aquifer, such as sinking streams, the Sunshine Lake area, Alachua Sink, Haile Sink, Orange Lake, and Kanapaha Prairie indicate sensitive groundwater "watershed" area and should be monitored closely. There should be monitoring upgradient of all 41 public community supply well sites, and supervision of land use within their cones of depression, especialy where the aquifer is unconfined. Other sensitive areas include those areas with high population densities where residents do not subscribe to sewer or trash collection services, and areas encompassing industries that generate small quantities of hazardous waste or have standard industrial classification (SIC) codes that indicate potential hazardous waste streams (U.S. Environmental Protection Agency, 1976).

V SUMMARY AND CONCLUSIONS

This research has examined and evaluated existing data pertaining to groundwater quality in Alachua County for the primary purpose of setting up an ongoing ambient groundwater quality monitoring network and database for management of groundwater resources. An attempt was made to characterize the hydrogeology of the county and its influence on water quality, and identify surface water bodies that influence groundwater quality. Using existing wells and associated data, a screening process for quality control produced a preliminary groundwater monitoring network consisting of 25 wells.

Existing data on wells and values of their associated water quality parameters were evaluated and retained if subjective quality control standards were met. Using these data, water quality analyses of the Floridan Aquifer in Alachua County were undertaken. Using AGWQM network wells, maps showing distribution of values of water quality were produced. Three geochemical traverses across the county were constructed, and water quality data from associated wells analyzed to show the relationship of hydrogeology to water quality.

Finally, areas most sensitive to groundwater contamination and requiring some type of protection or management strategy were delineated, and suggestions made to reduce the potential impact of waste generation on groundwater resources in the county.

The preliminary AGWQM network establishes a baseline for local water quality in the Floridan Aquifer. However, the limited number of monitoring wells in the preliminary network is insufficient to describe areal water quality in detail due to gaps in the network and limited existing data from single sampling events. At this time there is no existing network to monitor surficial and intermediate aquifers.

The final version of the AGWQM network will monitor all three aquifer systems in Alachua County.

Following procedures outlined in Chapter III, it is recommended that spatial gaps in the network be filled with wells that meet monitoring well specifications, and a network of wells be placed in the surficial and intermediate aquifers in those areas of the county where they are extensive enough to be a significant water supply source. In the Northern Highlands plateau, Floridan Aquifer wells at a density of one per township may be sufficient for background data, whereas in the Limestone Plain, a denser network may be warrented depending on land use practices. Land use will also be a significant factor in siting the surficial and secondary aquifer networks. A denser monitoring network for all aquifer types is warrented in the vicinity of the fracture trace, and near the edge of the Northern Highlands Marginal Zone or escarpment, major centers of population, sinks receiving surface drainage, and cones of depression from major pumping wellfields. Data from existing monitoring programs at facilities should be screened and utilized, especially for sites with injection wells, to determine any impact on background water quality. Areas more susceptible to groundwater contamination also should warrent a denser monitoring network.

Data from driller's logs and geophysical logs should be utilized to map aquifer bearing geological units, and clay units of sufficient thickness and lateral extent to warrent their classification as aquicludes. This mapping is necessary to define extent, depth, and thickness of aquifers for siting future monitoring network wells. In addition, some aquifer testing should be attempted whenever new monitoring wells are installed to establish a data base on hydraulic conductivity, transmissivity, and flow velocities for aquifers in an area to enhance understanding of the water quality data.

An ambient groundwater quality monitoring network should be an invaluable tool to planners, decision makers, and persons charged with protection of environmental resources and public health. The network will serve as an aid to detect regional and land usage influences on groundwater quality and may even help detect point sources before a contaminant appears in a drinking water supply system. It will aid in siting waste facilities, landfills, injection wells, and public supply wells, and may eventually dictate areal land use practices. Above all, knowledge of the natural local quality of groundwater and the factors and processes that influence it can be obtained from analyzing the data obtained from this network, and will thus benefit the future generations totally dependent on it as a resource to be protected.

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