EFFECTS ON GROUND-WATER QUALITY OF SEEPAGE FROM A PHOSPHATIC CLAYEY WASTE SETTLING POND, NORTH-CENTRAL FLORIDA

By James D. Hunn and Paul R. Seaber

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ABSTRACT

Water samples were taken from test wells drilled near an inactive phosphatic clayey waste storage settling pond, from the settling pond and its perimeter ditch, and from an active settling pond near White Springs, Hamilton County, in north-central Florida. The purpose was to document the seepage of chemical constituents from the inactive settling pond and ditch into the adjacent surficial ground-water system, and to assess the potential for movement of these constituents into the deeper Floridan aquifer system which is the major source of public supply in the area.

The study area is underlain by at least a 2,500-foot-thick sequence of Coastal Plain sediments of Early Cretaceous to Holocene age. The rocks of Tertiary and Quaternary age that underlie the test site area can be grouped into three major hydrogeologic units. In descending order, these units are: surficial aquifer, Hawthorn confining unit, and Floridan aquifer system. Phosphate deposits occur in the upper part of the surficial aquifer.

Water in the active settling pond is a calcium magnesium sulfate type with a dissolved-solids concentration of 250 milligrams per liter and contains greater amounts of phosphorus, iron, aluminum, barium, zinc, and chromium than the other surface waters. Water in the perimeter ditch is a calcium sulfate type with a dissolved-solids concentration of 360 to 390 milligrams per liter and contains greater amounts of calcium, sulfate, nitrogen, and fluoride than other surface waters. Water from the inactive settling pond is a calcium magnesium bicarbonate type with a dissolved-solids concentration of 140 milligrams per liter and contains more bicarbonate than the other surface waters. Large amounts of the chemical constituents in the phosphate wastedisposal slurry are apparently trapped in the sediments of the settling ponds.

The quality of water in the upper part of the surficial aquifer from wells within 200 to 400 feet of the inactive settling pond shows no signs of chemical contamination from phosphate industry operations. The horizontal groundwater velocity calculated for this aquifer between the ditch surrounding the settling pond and the test wells is between 100 to 2,000 feet per year, which is enough time for water to have reached the test wells in the 6 years the pond has been operating. The ground-water velocity beyond the test wells to a distance of 1 mile is much less. The water in the lower part of the surficial aquifer is almost identical in quality to the water in a distant background uncontaminated well. The chemical and physical reactions occurring within the surficial aquifer, the slow movement of water, and dilution from precipitation recharging the aquifer, minimize the extent and magnitude of contamination effects of seepage from the ditches, settling ponds, or both. The Floridan aquifer system is vertically separated from the inactive settling pond by the Hawthorn confining unit, and the very slow downward leakage to the Floridan, calculated to be 1 foot in about 145 years, is minimal from the overlying surficial aquifer. The water quality in the Floridan aquifer system and Hawthorn confining unit is similar to background water quality. Thus, no aquifer with potential for public water supply usage in the area appears to be adversely affected by leakage from the waste-storage settling pond area under present conditions.

There is evidence of anamolously low water levels in the surficial aquifer in some areas, which indicates a possibility for incipient sinkhole formation. If the Hawthorn confining unit were to be breached by a large sinkhole, an entire settling pond and all of its contents could enter the Floridan aquifer system. Sinkholes are present in adjacent areas. Sinkhole formation would cause presently unforeseen and unpredictable damage to the quality of the Floridan aquifer system waters and cause a threat to part of the main source of water supply throughout the northern Florida-south Georgia area.

INTRODUCTION

This investigation is part of a statewide study of the potential for contamination of ground water by chemical constituents associated with phosphate industry operations. Another part of the statewide investigation, was concentrated in central Florida where most of the Florida phosphate is mined and processed (Miller and Sutcliffe, 1982; 1984). These investigations were conducted in cooperation with the Florida Department of Environmental Regulation on behalf of the U.S. Environmental Protection Agency. The program of collection of hydrologic data during these investigations is designed to be useful to regulatory agencies, the phosphate industry, and others to formulate best management practices for the storage of phosphate industry liquid and solid waste byproducts and to assess the effect of such wastes on Florida's water resources.

Purpose and Scope

The purpose of this report is to document the magnitude and extent of the movement of chemical constituents from an inactive phosphatic clayey waste storage settling pond and its perimeter ditch in north-central Florida into the adjacent surficial aquifer. It also addresses the potential for leakage into the deeper Floridan aquifer system which is the major source of public supply in the area.

The scope of the work included analyzing water samples taken from test wells drilled near the ponds to determine the effects of leakage of wastewater on ground-water quality. Test drilling, geophysical logging, examination of well cuttings, and radiochemical determinations were used to define the geology and hydrology of the area.

Acknowledgments

The authors thank the Occidental Chemical Company, and its Suwannee River plant personnel in particular, for allowing the investigation on its property, for help in selecting test sites, and for providing safety instruction pertinent to the plant area. The test drilling and the geophysical logging were conducted by the U.S. Geological Survey. Lithology of the well cuttings was described by Richard Wolcott of Osprey, Fla. Radiochemical determinations were made by the U.S. Environmental Protection Agency's Eastern Environmental Radiation Facility in Montgomery, Ala. The investigation was conducted in cooperation with the Florida Department of Environmental Regulation on behalf of the U.S. Environmental Protection Agency (Grant Number S-802684017).

DESCRIPTION OF TEST SITE AREA

The study was conducted in the vicinity of settling pond number 4 at a phosphate mining and processing plant in Hamilton County (fig. 1). The company's White Springs complex, which includes the Suwannee River and Swift Creek plants, is the only phosphate mining, beneficiation, and processing operation in north Florida at the present time (1984). Other than phosphate mining, the nearby land is used principally for commercial forestry and agriculture. Hunter Creek, which drains the northern part of the plant, flows east to the Suwannee River. Swift Creek, which drains the western part of the area, flows south to the Suwannee River.

Settling ponds, referred to as "slime ponds" by the phosphate industry, are basically waste disposal-storage-settling areas used to contain the phosphatic clayey wastes of the ore beneficiation and flotation process used to separate phosphate from its associated sand, silt, and clay matrix. Earthen dikes and associated perimeter ditches surround each settling pond as well as the entire waste disposal area. The general hydraulic system of the Suwannee River plant mining and beneficiation area recirculates water through a system of ditches (Ardaman and Associates, Inc., 1978, p. 1-109 to 1-110) and also captures seepage and overflow from the settling ponds. Water in the ponds and ditches contains some of the chemicals used for pH adjustments and for the flotation process: fatty acids, amines, ammonia, kerosene, sulfuric acid, and caustic soda or sodium hydroxide. The phosphate industry operations at the Suwannee River plant are described in detail in Miller and others (1978, p. 99-123) and in Ardaman and Associates, Inc., (1978, p. 1-55 to 1-110).

Settling pond number 4, which covers an area of approximately 725 acres, is at the northwestern edge of the Suwannee River plant area (fig. 2). It has been inactive as a settling pond since early 1979. Pond number 4 was constructed in 1974 in a mined-out area. The 25- to 30-foot high dike around the pond is made of local surficial material derived from mining operations. It is bounded on the north and west by wooded areas, mostly commercial forest, on the east by newly constructed active settling pond number 8, and on the south by other older settling ponds and an active gypsum stack. Settling ponds store wastes from the beneficiation plant and gypsum stacks store wastes from the chemical plant.



Figure 1.--Location of study area, drainage basins, and areas of phosphate mining in eastern Hamilton County, Florida.



Figure 2.--Location of settling pond number 4, test well sites, and surface-water sampling sites.

The settling ponds, mining areas, and ponds under construction abut one another throughout the plant area, making access for test drilling difficult. The western and northern sides of settling pond number 4 are presumably unaffected by other phosphate industry operations. This open area provided the access necessary for direct observation of ground-water conditions around at least part of the perimeter of the pond.

The location of three test well sites (7, 9, and 10) near the pond to the west and north and a test well site (8) located about 1 mile north of the pond and used for background water analyses, are shown in figure 2.

A perimeter ditch surrounds the dike on the north and west sides of the pond. The purpose of the ditch is to capture any seepage through the dike and to carry away excess water from pond number 4 and from other parts of the mining area connected to the general hydraulic system of the mining and beneficiation complex. Flow in the ditch is from east to west along the north side of the pond and from north to south along the west side of the pond. Excess water in the ditch drains eventually to Swift Creek (fig. 1).

The perimeter ditch contains water in the general hydraulic circulation system that flows through the beneficiation plant, active settling pond, and the active mining operations, but not water from the chemical plant or gypsum stacks. The ditch may contain water from the Floridan aquifer system used as makeup water in the beneficiation plant operations.

A low drainage divide extends northward from the settling pond. Ditches, streams, and shallow ground water to the east of the divide drain eastward toward Hunter Creek and other smaller tributaries of the Suwannee River (figs. 1 and 2). West of the divide, surface and shallow ground-water drainage is toward Swift Creek which flows south to the Suwannee River. Site 8 is located on the natural drainage divide. Natural drainage, although frequently altered both by phosphate mining and commercial forestry, has not been changed greatly immediately north or west of pond number 4.

PREVIOUS STUDIES

Vernon and Puri (1965) describe the general geology of the area. Ardaman and Associates, Inc., (1978), Miller and others (1978), and Ceryak and others (1983) provide detailed descriptions of the regional hydrology, geology, and water resources. A generalized description of the hydrogeologic units in Hamilton County, Fla., taken from previous studies, is presented in table 1.

Ardaman and Associates, Inc., investigated seepage from gypsum stacks at the Suwannee River plant area in 1978 to aid in predicting similar seepage at the proposed Swift Creek mine, about 4 miles west of the Suwannee River mine. Ardaman and Associates, Inc., (1978, sec. 3.2) installed test wells at six sites in 1977. Test wells were drilled in 1980 at four sites for the present investigation; they are numbered 7 through 10 in figure 2. The report by Ardaman and Associates, Inc., (1978) contains a complete description of the White Springs complex and is a detailed environmental impact statement for a proposed chemical plant at the nearby Swift Creek plant site. A generalized profile of subsurface conditions at the White Springs complex, taken from the Ardaman and Associates 1978 report, is presented in table 2. Table 1.--Generalized description of hydrogeologic units in Hamilton County, Florida

p. 2-123, table 2.4.1;	
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table	1983,
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1978, p.	
[Modified from Miller and others, '	

Lithology	Very fine to medium-grained brown sand and blue-gray sandy clay. Local peat layers. Brown phosphatic sand, yellow- brown to blue-gray clay, gray phosphatic shell limestone. Contains phosphate ore matrix.	<pre>Green to greenish-gray massive clay. Often fractured. Black clay prominent. Green to greenish-gray fine- to medium-grained sand. Contains blue-green clay, and dolomite limestone. Complexly interbedded shell lime- stone, clay, clayey sand and fine-grained tan to gray sand- stone.</pre>	Limestone, white to cream to tan. Dolomitic or cherty in places. Usually fossiliferous. White to cream coquína in upper part. Gray, fossiliferous fine cyrstalline to granular lime- stone below. Minor brown dolo- mite and green clay. Not encountered in test drilling.
ness et)	0-55		0:150 150- 200
Thick (fe	1-150	0-185	1,250+
Series	Holocene and Pleistocene Pliocene	Miocene	0l igocene Eocene
System	Диа реглагу	Τοτέλατγ	L
Erathem		siozoneC	
ologic unit	ifferentiated and unnamed icial deposits A	Tawfhorn Formation	nnee Limestone Limestone
99	surf		Suwar
Water-bearing properties	Water mainly unconfined. Readily absorbs and stores precipitation until water table rises to land surface. Principal source of baseflow to streams draining area. Uppermost member of Hawthorn Formation is hydraulically continuous locally with surficial deposits and forms lower part of surficial aquifer. Tapped by shallow wells for domestic supply elsewhere.	Because of comparatively low permeabil- ity, most of unit acts to retard the downward movement of water from the surficial to the Floridan aquifer system. Locally yields water under confined conditions from middle part. Basal limestone beds are not considered part of the Floridan aquifer system in study area, but lower part, where permeable, may form part of Floridan aquifer system.	Yields large quantities of water under confined conditions everywhere under mining area. Principal aquifer in Florida and southeast Georgia. Upper part of Suwannee Limestone may function as part of Hawthorn confining unit.
Hydro- geologic unit	Surficial aquifer	Hawthorn confining unit unit	Floridan aquifer system

Table 2.--Generalized profile of subsurface conditions at the White Springs complex

[From Ardaman and Associates, Inc., 1978, p. 2-125, table 2.4-3]

Description	Hydro- geologic	Depth (feet)		
	unit		То	
Sand, gray, brown, or yellowish-brown; slightly silty to silty; occasionally cemented (Pleistocene).	Surficial aquifer	0	5	
Sand, brown, grayish-brown, gray or mottled orange- brown; fine, silty to clayey (Pliocene).		5	19	
Sand, grayish-brown to greenish-gray; fine; phosphatic; clayey in parts; upper layers occasionally leached (phosphate matrix, Hawthorn Formation, upper member A).		19	32	
Limestone, yellowish-gray to gray; weathered; fossiliferous; phosphatic; interbedded with seams of phosphatic sand and 0.5- to 4.0-foot thick layers of blue gray to greenish-gray clay (Hawthorn Formation, lower member A).		32	66	
Clay, light green to dark greenish-gray; plastic; interbedded with soft limestone, clayey silts, and clayey fine sands (Hawthorn Formation, member B).	Hawthorn confining unit	66	85	
Sand, light greenish-gray; clayey, fine; interbedded with cream to white soft limestone and greenish gray clay (Hawthorn Formation, member C).		85	120	
Sandstone; light gray; well-indurated, calcareous, with seams of gray-green clay (Hawthorn Formation, member D).		120	129	
Limestone, white to grayish; sandy; soft to hard; fossiliferous with occasional seams of clay (Suwannee Limestone).	Floridan aquifer system	129	145	
Limestone, gray to white; soft to hard; fossiliferous; interbedded with soft to hard calcarenite (Ocala Limestone).		145	445	
Dolostone, gray to dark brown; interbedded with light yellow orange calcilutite (Avon Park Formation).		445	560	
Calcilutite, light yellow-orange with light yellow dolomite (Avon Park Formation).		560	1,160	

METHODS OF INVESTIGATION

A cluster of test wells was drilled to different depths at three sites (7, 9, and 10) near settling pond number 4 and at background site 8. approximately 1 mile north of the pond (fig. 2). The test wells were installed to determine lithology, measure water levels, and obtain water samples.

Ground-water levels were measured in all the test wells from mid-February to mid-August 1980. Water samples were taken from each well, inactive settling pond number 4 and its perimeter ditch, and, for comparison, from active settling pond number 9 (fig. 2). The water samples were analyzed for both major and minor constituents and properties, nutrients, trace elements, and radiochemical properties. The field work was done from January through August 1980.

A deep test well was drilled first at each site. The four deep test wells were cased and completed as open-hole wells. The deep test wells were completed in the Floridan aquifer system and the Hawthorn confining unit. Shallower test wells were then completed at each site.

Three test wells each were drilled at sites 7, 8, and 9, and four test wells were drilled at site 10 (table 3 and fig. 2). One well at each site was gravel packed in the shallow sand, silt, and clay in the upper surficial aquifer to obtain a water sample from this unit of relatively low permeability. One well at each site was completed in a weathered dolomitic limestone in the lower part of the surficial aquifer, a consistent unit found at depths of about 40 feet below land surface. At site 10, an 85-foot test well was finished in a 4-foot thick sand layer in the Hawthorn confining unit below the dolomitic limestone. This sand layer is not present at the other sites.

The test wells were drilled by conventional rotary methods, and the well cuttings were examined for lithology. Electric, gamma ray, and caliper logs were run for each well. Correlations were made with units reported by Ardaman and Associates, Inc., (1978, p. 2-111 to 2-133) and Miller and others (1978, p. 64).

Shallow well points were installed near site 7 in 1983 to determine why water levels in the surficial aquifer were low in this area.

GEOLOGY

The study area is underlain by a sequence of Atlantic Coastal Plain sediments whose minimum thickness is 2,500 feet (Miller and others, 1978, p. 10). The geology of the area has been well described by Vernon and Puri (1965), Ardaman and Associates, Inc., (1978), Miller and others (1978), and Ceryak and others (1983). Details on physiography, geologic structure, and stratigraphy may be found in these reports. The geology of the area near pond number 4 as revealed by drilling is emphasized below and is related to the regional geology where appropriate. A generalized hydrogeologic cross section (fig. 3) shows the subsurface relation among sites 8, 9, and 10.

9

Table 3.--Records of test wells

[Well number: Well numbers include latitude and longitude and are used to identify wells in U.S. Geological Survey data files. Water level: Depth to water below land-surface datum. Casing diameter in all wells: 4 inches. Hydrogeologic unit: US, upper surficial aquifer; LS, lower surficial aquifer; H, Hawthorn confining unit; and F, Floridan aquifer system]

	Hydro- geo- logic unit		H LS US		F, H LS US		F, H LS US		F H US
	Finish		Open hole Open hole Screen, 5 feet, gravel packed 2-30 feet.		Open hole Open hole Screen, 5 feet, gravel packed 2-15 feet.		Open hole Open hole Screen, 5 feet, gravel packed 2-20 feet.		Open hole Open hole Screen, 5 feet Screen, 5 feet, gravel packed 2-20 feet.
Date	of water level, 1980		02/22 02/22 02/22		02/22 02/22 02/22		02/21 02/21 02/21		$\begin{array}{c} 02/21\\ 02/21\\ 02/21\\ 02/21\\ 02/21\end{array}$
	Water level (feet)		33 16 17		80 3		76 1 1		79 3 1
	Altitude of land surface (feet)	Site 7	130 130 130	Site 8	132 132 132	Site 9	131 131 131	Site 10	131 131 131 131
	Date com- pleted, 1980		02/09 02/09 02/09		02/08 02/08 02/08		02/06 02/07 02/06		02/05 02/05 02/06 02/06
Princinal	water- yielding zone (feet)		147–165 44–58 2–30		165-172 43-51 2-15		144-160 45-55 2-20		120-145 80-85 38-43 2-20
	Depth cased (feet)		86 43 25		98 42 15		90 45 20		119 70 38 20
	Depth of well (feet)		165 58 30		172 51 20		160 55 25		145 85 43 25
	Well number		302752082465001 302752082465002 302752082465003		302842082480101 302842082480102 302842082480103		302738082474601 302738082474602 302738082474603		302731082474801 302731082474804 302731082474802 302731082474803 302731082474803



Figure 3.--Generalized hydrogeologic cross section between test well sites 8, 9, and 10.

Stratigraphic nomenclature and geologic units in the area are given by Miller and others (1978, p. 11, table 3) and Ceryak and others (1983, p. 15, table 1). The boring log profiles given in Ardaman and Associates, Inc., (1978, vol. 1) indicate that the stratigraphy is fairly uniform at the White Springs complex. Table 2 (Ardaman and Associates, Inc., 1978, p. 2-125) shows a generalized profile of subsurface conditions at the White Springs complex to a depth of 1,160 feet.

The lithologic logs in table 4 are composite logs derived from data obtained during drilling of all the test wells at a particular site, examination of the well cuttings, and geophysical logs.

Gamma-ray logs of the deepest test well at each site (figs. 4 and 5) indicate the high natural radioactivity of the phosphate ore matrix, beginning at depths of about 12 feet below land surface, and of a weathered carbonate unit below about 40 feet.

Electric logs (figs. 6-9) indicate water-yielding zones where the spontaneous potential trace is diverted to the left and the resistivity is diverted to the right. The electric logs show water-yielding zones in the shallow carbonate units of the lower part of the surficial aquifer, some of the thin sands in the Hawthorn confining unit, and in the Floridan aquifer system.

	m1 d - 1-	D + 1	A] & 2 &] -	
Material	ness (feet)	beptn to base (feet)	of base (feet)	Hydro- geologic unit
Site 7: Altitude	of land su	urface, 130	feet	
Quaternary and(or) Tertiary: Post-Miocene deposits, undifferentiated.				Surficial aquifer
Sand, very fine to medium, silty, clayey, brown.	3	3	127	
Tertiary: Middle Miocene. Hawthorn Formation, member A:				
Clay, silty, sandy, blue Clay, silty, sandy, brown, with some phosphate	4 37	7 44	123 86	
pebbles. Ore matrix. Limestone, white to brown,	7	51	79	<u>Upper part</u> Lower part
Dolomite, calcareous, hard, brown, with some sand and phosphate pebbles.	10	61	69	
Hawthorn Formation, undifferenti	ated membe	ers B and C	:	
Clay, blue-green Sand, very fine to medium,	17 2	78 80	52 50	Hawthorn confining
Clay, blue-green, with layers of hard gray dolomite.	30	110	20	unit
Clay, blue-green	25	135	-5	
Hawthorn Formation, member D:				
Sandstone, very fine to fine-grained, hard, grav.	5	140	-10	
Clay, blue-green	7	147	-17	
Tertiary: Oligocene. Suwannee Limestone?:				
Clay, soft, white	18	165	-35	Floridan aquifer

Table 4.--Lithologic logs of test wells

aquifer system (?)

Material	Thick- ness (feet)	Depth to base (feet)	Altitude. of base (feet)	Hydro- geologic unit
Site 8: Altitude o	f land su	urface, 132	feet	
Quaternary and(or) Tertiary: Post-Miocene deposits, undifferenti	ated.			Surficial aquifer
Sand, very fine to medium, silty, brown, with black,	6	6	126	
Clay, silty, gray, with some sand	2	8	124	
Tertiary: Middle Miocene. Hawthorn Formation, member A:				
Sand, very fine to medium, silty, brown, with some clay, phosphatic. Ore	35	43	89	
matrix. Limestone, dolomitic, hard, tan to brown, with some	8	51	81	Upper part
sand and phosphate pebbles.				Lower part
Hawthorn Formation, undifferentia	ted membe	ers B and C	•	
Clay, blue-green, with layers of hard gray dolomite.	34	85	47	Hawthorn confining unit
Sand, very fine to medium,	1	86	46	
Clay, blue-green, with layers of hard gray dolomite.	49	135	-3	
Hawthorn Formation, member D:				
Dolomite, light gray, hard Sandstone, light buff to gray	11 19	146 165	-14 -33	
Tertiary: Oligocene. Suwannee Limestone:				
Limestone, light gray to white, sandy.	7	172	-40	Floridan aquifer system

Table	4Lithologic	logs	of test	: wells	Continued

Material	Thick- ness (feet)	Depth to base (feet)	Altitude of base (feet)	Hydro- geologic unit
Site 9: Altitude c	of land su	urface, 131	feet	
Quaternary and(or) Tertiary: Post-Miocene deposits, undifferenti	ated.			
Sand, very fine to medium, with some silt and clay, including	1	1	130	Surficial aquifer
Sand, very fine to medium, silty, clayey, brown.	8	9	122	
Tertiary: Middle Miocene. Hawthorn Formation, member A:				
Clay, brown to gray, silty,	31	40	91	Upper part
Limestone and clay, brown to	4	44	87	nower part
Limestone, sandy, waterbearing	18	62	69	
Dolomite and limestone, clayey	15	77	54	
Hawthorn Formation, undifferentia	ited membe	ers B and C	:	
Clay, blue, with thin layers of brown dolomite.	14	91	40	Hawthorn confining
Clay, blue-green	24	115	16	unit
Hawthorn Formation, member D:				
Limestone, gray, hard, and	20	135	-4	
Clay, blue-green, with very little limestone.	9	144	-13	
Tertiary: Oligocene Suwannee Limestone:				
Limestone, white, and soft calcareous clay.	16	160	-29	Floridan aquifer system

Table 4.--Lithologic logs of test wells--Continued

Material	Thick- ness (feet)	Depth to base (feet)	Altitude of base (feet)	Hydro- geologic unit
Site 10: Altitude o	f land su	urface, 131	feet	
Quaternary and(or) Tertiary: Post-Miocene deposits, undifferenti	ated.			
Sand, brown, and clay, sandy, organic, black.	5	5	126	aquifer
Clay, silty, sandy, gray Clay, red, sandy	3 2	8 10	123 121	
Tertiary: Middle Miocene. Hawthorn Formation, member A:				
Clay, gray, silty, sandy.	28	38	93	Upper part
Limestone, dolomitic, brown to gray, with thin layers of gray clay.	18	56	75	Lower part
Hawthorn Formation, undifferentia	ted membe	ers B and C	:	
Clay, silty, sandy, blue	5	61	70	Hawthorn
Clay, blue, with limestone lavers.	15	76	55	unit
Sand, very fine to fine, silty, brown.	4	80	51	
Clay, blue-green, with lime- stone layers.	12	92	39	
Sand, very fine to fine, silty, brown.	1	93	38	
Clay, blue-green, with lime- stone layers.	27	120	11	
Tertiary: Oligocene Suwannee Limestone:				
Limestone, white, soft	25	145	-14	Floridan aquifer system

Table 4.--Lithologic logs of test wells--Continued



Figure 4.--Gamma-ray logs for sites 7 and 8.



Figure 5.--Gamma-ray logs for sites 9 and 10.



Figure 6.--Electric logs for site 7.

The surficial deposits of post-Miocene age near pond number 4 are composed of a heterogenous mixture of sand, silt, and clay. The uppermost deposit, varying in thickness from 3 to 15 feet and averaging about 5 feet, is generally a fine-grained quartz sand to silty fine sand. Located between this layer of fine sand and the phosphate ore matrix are deposits of low permeability ranging in thickness from 5 to 15 feet, and composed primarily of silty to clayey sands and sandy clays overlying silty sands.

The Hawthorn Formation of Miocene age, which contains the phosphate ore body, underlies the unnamed and undifferentiated surficial deposits. The Hawthorn Formation is composed mainly of layers of gray to green, sandy, phosphatic clay, sand, and dolomitic limestone. The phosphate content and gamma-ray activity of the upper unconsolidated rocks increase rapidly at depths of 10 to 12 feet below land surface, indicating the top of the Hawthorn Formation. The upper part of the formation contains the commercial phosphate deposits, termed matrix by the phosphate industry. Immediately below the matrix in the test site area is a persistent weathered carbonate layer underlain in turn by a blue-green clay unit with thin sand beds. The lower part of the Hawthorn at the test site is either a light-gray dolomite or limestone and a hard, gray sandstone. This unit is not present at site 10 and is interbedded in places with the blue-green clay material.



Figure 7.--Electric logs for site 8.

Cores from the Hawthorn Formation in the Osceola National Forest, about 20 miles southeast of the Occidental plant, were examined by Miller and others (1978) and the Hawthorn Formation was divided into five informal lithologic members. Ardaman and Associates, Inc., (1978, fig. 2.4-8 and pages 2-113 to 2-115) show the following four of these five members to be present at the Swift Creek plant, based on core drilling of a test well:

"Member A: This uppermost Hawthorn unit is highly variable consisting of sands and clayey sands with clay and limestone, phosphatic throughout. At a depth ranging from 25 to 55 feet below the surface, the first limestone layer is encountered * * *. This layer forms the lowermost boundary to which phosphate is currently being mined in Hamilton County because digging indurated material is not economically feasible. Member A, with an overall thickness of about 47 feet, extends below the minable matrix and consists at these lower depths of fossiliferous limestone and some phosphate interbedded with layers of soft clay.

"Member B: This unit consists of massive plastic clay layers alternating with layers of soft limestone with shells and traces of phosphate interbedded with massive clayey silts and clayey fine sand. It is approximately 19 feet thick.





"Member C: This unit is 30 to 35 feet thick and consists of layers of fine sand to clayey sand, rubbly limestone interbedded with layers of clay and incorporating solution pipes tightly filled with clay and clayey sands, as well as clayey sands and sandy clays with seams of sand and calcareous rock.

"Member D: This variable unit consists of fine-grained wellindurated and calcareous sandstone as well as of mottled clay and sands, calcareous, with soft to indurated sandy limestone. It is only 9 feet in thickness."

Member E, the basal Hawthorn unit encountered in the Osceola National Forest investigation, consists of sandstone, limestone, dolomite, and argillaceous limestone, and is absent at the Occidental White Springs complex.

The informal units of the Hawthorn Formation could not be easily distinguished during this investigation because of the nature of the test drilling. Cores are usually necessary to distinguish these units and only cuttings were available at sites 7 through 10. However, member A can be distinguished from the overlying deposits as it contains phosphate grains in its upper sand. The base of a weathered limestone underlying this sand was arbitrarily assigned as the base of member A. Members B and C are virtually indistinguishable without cores. Member D is a hard sandstone or limestone and is shown in table 4 as this member on the basis of correlation with cores from the Ardaman and Associates, Inc., test hole SC-3 (Ardaman and Associates, Inc., 1978, p. 2-133, fig. 2.4-8). The Suwannee Limestone of Oligocene age underlying member D is distinctive and distinguishable from the Hawthorn in rotary test drilling.

The Suwannee Limestone is composed of a relatively soft, white-tograyish, sandy limestone layer with prominent seams and pockets tightly filled with stiff green clay, overlying a hard fossiliferous limestone with thin seams of clay. The Suwannee Limestone in the study area is generally about 15 to 25 feet thick with its base located at approximately the altitude of sea level. It is possible that some or all of the rocks identified in this report as Suwannee Limestone may include the Miocene St. Marks Formation which is known to occur overlying the Suwannee Limestone in parts of Hamilton County (Ceryak and others, 1983, p. 21). The Suwannee and St. Marks would be indistinguishable on the basis of rotary well cuttings.

Underlying the Suwannee Limestone is the Ocala Limestone of Eocene age. The Ocala is a white-to-cream colored limestone which is highly permeable, and, like the Suwannee Limestone, nonphosphatic. The Ocala Limestone was probably not encountered in drilling during this investigation.

HYDROGEOLOGY

The rocks of Tertiary and Quaternary age that underlie the study area can be grouped into three major hydrogeologic units (table 1). In descending order, these units are: surficial aquifer, Hawthorn confining unit, and Floridan aquifer system. The lower Tertiary rocks, which form a confining unit at the base of the Floridan aquifer system, occur at considerable depth in this area (greater than 1,400 feet) and contain highly mineralized water. The relation between the geologic units and the hydrologic units is shown in table 1 and figure 3.

Sediments younger than the Hawthorn Formation are very thin at the test site. A surficial sand, silt, and clay unit underlies a few inches of sandy, organic soil. This unnamed geologic unit, in combination with the underlying unconsolidated sands, including the ore matrix, in the uppermost part of member A of the Hawthorn Formation, constitutes the upper part of the surficial aquifer and ranges from about 35 to 45 feet in thickness.

The lower part of the surficial aquifer is a dolomitic limestone about 10 to 40 feet thick. The limestone contains phosphatic sand, probably as filling in solution openings.

In the mainly unconsolidated upper part of the surficial aquifer, groundwater storage and movement takes place in intergranular openings. In the mainly consolidated calcareous lower part of the surficial aquifer, groundwater movement and storage takes place in both intergranular openings and in secondary openings produced by partial dissolution of the limestone. If extensive, these solution openings could serve as conduits, carrying any contaminants present considerable distances from their source. Both the unconsolidated and consolidated rocks are included in the surficial aquifer because water levels in wells tapping both are virtually identical and respond to stresses in the same way (figs. 10-13).



Figure 10.--Hydrographs of water levels for site 7.



Figure 11.--Hydrographs of water levels for site 8.



Figure 12.--Hydrographs of water levels for site 9.



Figure 13.--Hydrographs of water levels for site 10.

Water in the surficial aquifer is unconfined and is in hydrologic continuity with lakes and streams that intersect the water table. Over much of the study area, the water table is at or within a few feet of land surface throughout the year and is a subdued replica of the topography. Small amounts of water are obtained from the surficial aquifer by shallow domestic wells in areas adjacent to the mining operations.

Rainfall readily infiltrates the surficial aquifer and moves downward to the water table, at which point its movement becomes predominantly lateral. This lateral movement is interrupted locally by small streams, lakes, and swamps into which the ground water discharges. Other major discharge from the surficial aquifer is by evaporation and transpiration where the water table is near the land surface. Pumpage from scattered domestic wells accounts for a minor amount of aquifer discharge. The water levels in the surficial aquifer everywhere in the study area are at higher altitudes than the potentiometric surface of either the Floridan aquifer system or the permeable beds of the Hawthorn confining unit (figs. 10-13). Thus, some discharge from the surficial aquifer also occurs by downward leakage. However, the amount of leakage has been shown to be small by Miller and others (1978, p. 98-99).

The Hawthorn confining unit underlies the surficial aquifer in the entire test site area, and separates it hydraulically from the underlying Floridan aquifer system. Areally, the confining unit is highly variable in thickness and lithologic content but is everywhere an effective confining bed. It is composed of clay, sandy clay, limestone, dolomite, and poorly to wellconsolidated sand and sandstone representing the Hawthorn informal geologic units B, C, and D. The Hawthorn confining unit retards movement of water between the surficial aquifer and Floridan aquifer system to varying degrees depending on its thickness and lithologic character at a given place. Locally, thin sandy beds of the confining unit yield small quantities of water to wells under artesian conditions, but this "secondary artesian aquifer zone" in the Hawthorn confining unit is not as well developed here as it is to the east.

To the south and west of the test site, sinkholes breach the Hawthorn confining unit and facilitate the interchange of water between aquifers. Low water levels in the surficial aquifer near site 7 (fig. 10) may indicate an incipient sinkhole in this area, although there is no surface topographic expression of such. The low water levels form a roughly circular depression in the water table with a radius of about 200 feet and are expressed at land surface as a dry area in the midst of generally wet swamp terrain.

The Floridan aquifer system is the principal source of ground water throughout most of north Florida and southeast Georgia (Stringfield, 1966, p. 95). It consists of thick and areally extensive sequences of interbedded limestones and dolomites of Paleocene to early Miocene age. Although these carbonate rocks differ vertically and horizontally in texture, porosity, and permeability, they are treated as a single hydrogeologic unit or aquifer system. Ground-water storage and movement in the Floridan aquifer system takes place through intergranular openings, cavities, and solution channels. Water in the Floridan occurs under confined or artesian conditions in the study area and over wide areas where it is overlain by the Hawthorn confining unit of much lower permeability. Semiartesian conditions prevail where the Hawthorn confining unit is breached. Unconfined conditions prevail in the area of the Suwannee River downstream from White Springs (fig. 1).

The Floridan aquifer system yields large supplies of ground water to wells; properly constructed wells commonly yield over a thousand gallons per minute. Only a few feet of the upper limestone of the Floridan, probably the Suwannee Limestone, were penetrated by the deepest wells at sites 8, 9, and The deepest well at site 7 penetrated a white, soft clay that resembles 10. the weathered Suwannee Limestone, but the clay was only slightly calcareous and the water level in the well (table 2 and fig. 10) is too high to represent the Floridan. The anamolously high water level could result from downward leakage from the surficial aquifer or from poor well construction, but the anamoly would not be likely to persist because the high transmissivity of the Floridan would rapidly allow the water level to equilibrate at a "Floridan" Therefore, the well most likely bottoms in the Hawthorn confining unit level. and the water level represents that of a water-yielding bed within the Haw-The Hawthorn confining unit is herein defined as the hydrogeologic thorn. unit that overlies the Floridan and exhibits water levels not consistent with Floridan water levels on a regional basis.

The lowermost beds of the Hawthorn Formation are sometimes included in the Hawthorn confining unit and sometimes in the Floridan aquifer system depending on the degree of hydraulic interconnection of these beds with the Floridan. The upper few feet of the Suwannee Limestone, in turn, may be included in the Hawthorn confining unit. The distinction is only applicable in very small areas and is of little significance on a regional basis. However, in the Osceola National Forest study, head differences of tens of feet occurred over a few inches of stratigraphic section near the Hawthorn confining unit and Floridan aquifer system boundary (Miller and others, 1978, p: 91). No distinct confining beds occur below the top of the Suwannee in the uppermost part of the Floridan aquifer system in the study area.

Figures 10 through 13 show fluctuations of water levels in test wells at sites 7, 8, 9, and 10, respectively. Fluctuations in the perimeter ditch and the settling pond are shown in figure 14. A land-surface profile from settling pond number 4 to site 10, a generalized hydrogeologic cross section, and the relation between the water levels in the settling pond, the perimeter ditch, and the ground-water levels in the wells at site 10 are shown in figure 15. Movement of water is outward everwhere from the pond and drainage ditch to the surficial aquifer and downward from the surficial aquifer to the Floridan aquifer system. Figure 15 indicates that most of the head loss occurs in the lower part of the Hawthorn confining unit.

The water levels in the upper and lower parts of the surficial aquifer are nearly the same and are represented by the same line on the graph in most of figures 10 through 13. Ardaman and Associates, Inc., (1978, section 2.6.3.2, p. 199) found a small head difference (up to 1 foot at some locations) between the water table in the surficial sands and the water level in the ore matrix, apparently because of the clayey sands which generally underlie the surficial sands. These clayey sands could cause an apparent artesian storage coefficient in aquifer tests of short duration.

The water level in the deepest well at site 7 (fig. 10) is significantly higher than water levels in the deep wells at the other sites (figs. 11, 12, and 13). As discussed previously, this well likely bottoms in the Hawthorn confining unit and the water level does not represent the potentiometric surface of the Floridan aquifer system.

Water levels in the shallowest wells at sites 9 and 10 were approximately a foot below the water level in the perimeter ditch when the field work was done in 1980. This indicates a slight gradient, and hence seepage will take place from the ditch to the adjacent surficial aquifer. The water levels in the surficial aquifer wells at site 7, east of the drainage divide, were 17 feet below the water level in the perimeter ditch. This most likely represents drainage of the surficial aquifer to the underlying Hawthorn confining unit and possibly to the Floridan aquifer system through a breach in the confining unit. This may indicate that sinkholes are developing in the area of settling pond number 4.

Gradients from the ditch and wells at site 9 outward to wells at site 8 were about 1 foot per mile in June 1980, a relatively low water-table gradient. Ground-water gradients downward from the surficial aquifer to the Floridan aquifer system are about 70 feet of head loss over a thickness of 100 feet of geologic section, or 0.7 foot per foot. This very high vertical gradient indicates a low rate of movement of water vertically through beds of low permeability in the Hawthorn confining unit.



Figure 14.--Hydrographs of water levels for settling pond number 4 and its perimeter ditch.

Ardaman and Associates, Inc., (1978, section 2.6.3.2, p. 2-199) conducted an aquifer test on a 19-foot thick permeable zone which included the ore matrix at the Swift Creek mine, about 4 miles west of the present study This zone underlies the post-Miocene silty and clayey sands. area. The dolomitic limestone unit that represents the lower part of the surficial aquifer as described herein was not present at their test site and probably is replaced by sand in that area. The transmissivity of the ore matrix was determined to be 500 ft^2/d and the storage coefficient to be 7.5×10^{-3} . The horizontal hydraulic conductivity of the phosphate ore matrix is equal to about 10^{-2} cm/sec (Ardaman and Associates, Inc., 1978, p. 2-199), or 28 ft/d. These transmissivity and hydraulic conductivity values are probably comparable to the transmissivity and hydraulic conductivity values of the lower part of the surficial aquifer at the Suwannee River plant study area where the dolomitic limestone unit is included with the ore matrix to form the lower part of the surficial aquifer. The low storage coefficient probably is the result of the short duration of the aquifer test.



Figure 15.--Land-surface profile from settling pond number 4 to site 10 and generalized hydrogeologic cross section.

A method for computing the average velocity of water based on a variant of Darcy's law (Lohman, 1972, p. 10-11) may be expressed as follows:

where

$$\bar{\mathbf{V}} = \underline{\mathbf{KI}}_{\Theta} \tag{1}$$

$$\overline{V}$$
 = average velocity, in feet per day (ft/day⁻¹),
K = hydraulic conductivity, in feet per day (ft/day⁻¹),

I = hydraulic gradient (dh/dl), in feet per foot (ft/ft), where dh/dl
is the unit change in head per unit length of flow, and

 Θ = effective porosity, as a decimal fraction.

Utilizing the hydraulic conductivity determined from the Ardaman and Associates, Inc., aquifer test, hydraulic gradients determined from waterlevel measurements, and porosity estimated from aquifer lithology, the average velocity of ground water from the settling ponds to the test well sites is estimated as follows. The distance from the perimeter ditch to sites 7 and 10 is about 400 feet and to site 9 about 200 feet. A difference of 1 foot of head produces a gradient of 0.005 from the ditch to site 9 and 0.002 from the ditch to site 10. The difference of 17 feet of head produces a gradient of 0.04 from the ditch to site 7. A porosity of 0.2 and a hydraulic conductivity of 28 feet per day (10^{-2} cm/sec) was used in all cases. The calculation for site 10 is given below:

velocity =
$$\frac{(28 \text{ ft/d}) \quad (0.002 \text{ ft/ft})}{(0.2)}$$
 = 0.28 ft/d = 102 ft/yr

The velocity calculations for site 7 are 2,000 feet per year and for site 9 are 250 feet per year. Thus, water could have moved from the pond and ditches to sites 7, 9, and 10 (shallow wells) between the time of the pond's existence (1974) and the time of sampling (1980) if the movement was horizontal in the phosphate ore matrix. The time of movement would have been similar in the uppermost part of the surficial aquifer and probably faster in the lower carbonate unit of the surficial aquifer due to its higher permeability.

The velocity calculations outward from sites 7, 9, and 10 to site 8 show a much slower rate of water movement. Using the same hydraulic conductivity and porosity values as above, but a gradient of 1 foot per mile, that is, 1/5,280 or 1.9×10^{-4} , produces a velocity of 2.6×10^{-2} feet per day or about 10 feet per year. Thus, any horizontal contaminant movement would take more than 500 years to reach site 8.

At the White Springs complex in Hamilton County, the Hawthorn confining unit is approximately 100 feet thick. No permeable zones in the Hawthorn confining unit that are of sufficient thickness to be considered aquifers were found by Ardaman and Associates, Inc., (1978, p. 2-201) or in this investigation.

As shown in figures 10 through 13 and figure 15, there is appreciable head difference across the Hawthorn confining unit at the study area. The head difference between the surficial aquifer and perimeter ditch and the Floridan aquifer system ranges from about 70 to 75 feet. The head difference between the Floridan water levels and the settling pond water levels (fig. 14) is about 90 feet. Most of the head difference is dissipated across one or more layers of tight clay present within the lower part of the Hawthorn confining bed between altitudes of 10 feet and 50 feet (fig. 15). At other areas, the head was dissipated over a thicker section of the confining unit (Ardaman and Associates, Inc., 1978, p. 2-202). The significant head loss experienced as water moves downward through the confining unit is indicative of the poor hydraulic connection that exists between the surficial aquifer and the Floridan aquifer system. Utilizing an estimated transmissivity of 4×10^{-4} ft²/d, a thickness of 70 feet, a vertical hydraulic gradient of 0.7 foot per foot, and a porosity of 0.2 yields an average velocity of water through the Hawthorn confining unit to the Floridan of 2.0×10^{-5} ft/d or 1 foot in about 145 years. Contaminant movement would thus take more than 10,000 years to reach the Floridan aquifer system from the settling pond, if the Hawthorn confining unit were tight and competent.

Miller and others (1978, p. 83) indicated a maximum value of 0.30 inch per year for the annual leakage rate through the Hawthorn confining unit to the Floridan aquifer system. The small volume and low velocity of water moving through the confining unit indicates that the Floridan aquifer system is highly unlikely to receive any measurable amount of contaminants from the existing settling ponds at the Suwannee River plant.

If the Hawthorn is breached by sinkholes, movement of contaminants could be swift and in large amounts. The chemical changes to the water in the Floridan aquifer system would depend upon what contaminant material moved into the Floridan aquifer system. If the sediments trapped in the settling ponds moved into the Floridan, the results would be quite different than if just the decanted water entered the Floridan. No effect would be easily observable if just the decanted water mixed with the Floridan waters. Likewise, no effect would be easily observable if water trapped in the settling ponds or water in the drainage ditches moved vertically downward through the Hawthorn confining unit, because of the small amount of water percolating through the confining bed and dilution by water in the Floridan aquifer system.

WATER QUALITY

Water samples were collected from all test wells, two sampling sites in the perimeter ditch, and settling ponds number 4 and number 9. Pond number 9 is an active settling pond located approximately 1 mile to the southeast of pond number 4 (fig. 2). Samples of water from pond number 9 should indicate what the water quality in pond number 4 was when it was an active pond and may indicate the water quality trapped in the sediments in pond number 4. The test wells were pumped prior to sampling for periods ranging from 1 to 5 hours until the pH and conductivity of the ground water stabilized. The water samples were analyzed by the U.S. Geological Survey for major and minor constituents, physical properties, organics, nutrients, and radiochemicals. The radiochemical analyses were done by the U.S. Environmental Protection Agency's Eastern Environmental Radiation Facility in Montgomery, Ala. The results of the analyses are shown in tables 5 through 12. Surface-water quality is given in tables 5 through 8, and ground-water quality in tables 9 through 12. Table 13 and figure 16 show a summary comparison of water-quality characteristics of the waters of the area.

Constituent or property	Settling	Perimeter	Perimeter	Settling
	pond	ditch,	ditch,	pond
	No. 4	north	west	No. 9
Date of sample	04/02/80	04/02/80	04/02/80	07/10/80
Specific conductance (µS/cm) pH (units) Temperature (°C) Hardness (as CaCO ₃) Hardness, noncarbonate (as CaCO ₃)	242 7.2 19.8 110 7	550 7.2 19.6 220 200	520 7.0 19.2 210 180	346 6.7 31.0 150 94
Calcium, dissolved (as Ca)	22	62	61	36
Magnesium, dissolved (as Mg)	13	16	15	15
Sodium, dissolved (as Na)	6.8	16	16	22
Acidity (as CaCO ₃)	5	45	40	15
Acidity, total heated (as H)	.1	.9	.8	.3
Potassium, dissolved (as K)	6.8	1.7	2.3	1.1
Bicarbonate (as HCO ₃)	124	27	39	70
Alkalinity (as CaCO ₃)	102	22	32	.57
Sulfate, dissolved (as SO ₄)	9.7	190	200	120
Chloride, dissolved (as Cl)	9.5	9.5	9.7	13
<pre>Fluoride, dissolved (as F) Silica, dissolved (as SiO₂) Dissolved solids, residue at 180 °C Dissolved solids, sum of constituents</pre>	1.4	3.1	3.0	2.7
	0.2	14	12	11
	140	390	363	253
	70	314	339	256

Table 5.--Analyses of surface water for major chemical constituents and physical properties

[Concentrations in milligrams per liter unless otherwise noted]

Pond and Perimeter Ditch Water

Water that transports the clay slurry to an active settling pond was not sampled, but was sampled during a study in central Florida (Miller and Sutcliffe, 1984, p. 145-149). The water quality of the slurry in central Florida is shown in table 14 as an idealized analysis of major ions in a settling pond water and in table 15 as concentrations of selected trace elements in the inflow and outflow of a settling pond (Miller and Sutcliffe, 1984, table 17, p. 147, and table 18, p. 149).

Constituent	Settling pond No. 4	Perimeter ditch, north	Perimeter ditch, west	Settling pond No. 9
Date of sample	04/02/80	04/02/80	04/02/80	07/10/80
Aluminum, total recoverable (as A1)	160	120	120	270,000
Antimony, dissolved (as Sb)	0	0	0	1
Arsenic, total (as As)	1	1	1	4
Barium, total recoverable (as Ba)	50	50	50	4,000
Beryllium, total recoverable (as Be)	0	0	0	30
Boron, dissolved (as B)	40	50	50	80
Bromide, dissolved (mg/L as Br)	• 1	• 2	• 1	.2
(as Cd)	0	0	0	28
Chromium, total recoverable (as Cr)	13	3	10	670
Cobalt, total recoverable (as Co)) 0	0	0	18
Copper, total recoverable (asCu) Iodide, dissolved (mg/L as I)	0	0	0	220
Iron, total recoverable (as Fe)	210	80	100	84.000
Lead, total recoverable (as Pb)	2	1	2	40
Lithium, dissolved (as Li)	10	10	10	0
Manganese, total recoverable (as Mn)	40	70	60	520
Mercury, total recoverable (as Hg)	.1	.1	.1	.1
Molybdenum, total recoverable (as Mo)	1	3	3	19
Nickel, total recoverable (as Ni) Selenium, total (as Se)	0 0	0 0	2 0	75 7
Silver, total recoverable (as Ag) Strontium, dissolved (as Sr) Vanadium, dissolved (as V) Zinc, total recoverable (as Zn)	0 70 1 10	0 150 4 10	0 130 4 10	5 40 8 350

Table 6.--Analyses of surface water for minor chemical constituents

[Concentrations in micrograms per liter unless otherwise noted]

Constituent or property	Settling	Perimeter	Perimeter	Settling
	pond	ditch,	ditch,	pond
	No. 4	north	west	No. 9
Date of sample	04/02/80	04/02/80	04/02/80	07/10/80
Total nitrogen (as N)	2.16	11.28	8.6	4.67
Total nitrate (as N)	.0	.2	.23	.15
Total nitrite (as N)	.01	.08	.07	.04
Total ammonia nitrogen (as N)	.05	7.1	6.2	.68
Total organic nitrogen (as N)	2.1	3.9	2.1	3.8
Kjeldahl nitrogen (as N)	2.15	11.0	8.3	4.48
Total phosphorus (as P)	2.5	11.0	9.5	420
Total orthophosphate (as P)	2.1	8.8	8.6	.45
Organic carbon, dissolved (as C)	12.0	14.0	17.0	13.0
Tannin and lignin	1.2	1.2	1.2	.7
<pre>Chemical oxygen demand (COD) Methylene blue active substances (MBAS) (surfactants) Phenols (µg/L) Oil and grease, total recoverable gravimetric</pre>	30 . 0 0 0	58 .1 0 3	48.1 1 0	 7 0

Table 7.--Analyses of surface water for nutrients and organic constituents

[Concentrations in milligrams per liter unless otherwise noted; μ g, micrograms per liter]

Table 8.--Radiochemical analyses of surface water

				226 _{Ra}
Sampling site	Gross alpha	Gross beta	Dissolved	Undissolved
Perimeter ditch, west	2	4.1 ± 118%	0.19 ± 10%	0.11 ± 13%
Perimeter ditch, north	2.0 ± 115%	1	.25 ± 8%	.13 ± 13%
Settling pond number 4	2	4.9 ± 96%	.16 ± 11%	.22 ± 8%
Settling pond number 9	301.6 ± 8%	641.7 ± 3%	1.9 ± 6%	149.0 ± 1%

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	ficia] m]	Acidi tota heat (as		110					l 'v		000	00
perties	Ipper sur Eer syster	Acidity (as CaCO ₃)		 15			10		<mark></mark> 15 25		000	00
sical pro	t: US, t dan aquif	Sodium, dis- solved (as Na)		4.1 4.7 1.0		5.8 6.8	15 		12 12 66		8.1 6.6	4.8
and phy	ogic uni F, Flori	Magne- sium, dis- solved (as Mg)		21 23 .6		28 33 -	3.3 		38 37 4 . 9		29 32 0 7	۲.2 1.0
nstituents	Hydrogeol unit; and	Calcium, dis- solved (as Ca)		41 45 3.5		56 64 	12 		72 66 19		58 64 26	40 6.1
emical co	e noted. Onfining	Hard- ness, noncar- bonate (as CaCO ₃)		100	~l	3 28 	28 		008	2	002	ν <mark>1</mark>
najor che	otherwise wthorn co	Hard- ness (as CaCO ₃)	Site 7	190 210 11	Site 8	260 300 	 77	Site	340 320 68	Site 1	260 290 150	19 19
er for 1	nless (H, Hav	Tem- pera- ture (°C)		21.3 20.1 23.2		20.6 19.7 	19.4 20.7		21.2 20.2 21.3		21.0 21.5	20.8
ound wate	ir liter u aquifer;	pH (units)		7.3 7.4 5.8		7.2 7.2 7.3	ი ი ი.ი		7.1 7.0 5.6		7.3 7.1 6.3	5.3
rses of gr	igrams pe surficial	Specific conduc- tance (µS/cm)		375 416 12		499 505 520	196 186		650 602 182		525 570 300	00C
9 <u>Anal</u> y	ts in mill .S, lower	Date of sample (1980)		04/10 04/08 04/10		04/10 04/02 06/24	04/02 06/24		04/11 03/26 03/26		03/19 03/19	03/20
Table	entration uifer;	Hydro- geo- logic unit		H LS US		F LS LS	US US		F LS US		н Н Н	US
	[Conce aç	Well depth (feet)		165 58 30		172 51 51	20 20		160 55 25		145 85 43	4.) 25

	s- ved ids, of tit- ts		5 1 1		യനിയി		Q 47 19		5 2 0 0
	Di sol sum sum cons uen		5 5 5 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7		120 151 81		42 37 11		1 1 7 2 7 7 7
	Dis- solved solids, residue at 180°C		218 237 		294 307 162		394 377 137		321 335 193 48
	Silica, díssolved (as SiO ₂)		31 28 7 . 8		34 40 15		45 45 34		45 43 14
	Fluo- ride, dis- solved (as F)		0.4 .4				ч. ч. ч.		9.4.6.4
	Chlor- ride, dis- solved (as Cl)		5.7 9.9 1.8		7.3 7.3 27 17		10 9.6 11		5.8 6.3 5.9
	Sulfate, dis- solved (as SO ₄)	Site 7	3.2 3.2	Site 8	13 14 29	Site 9	4.2 0 2.1	Site 10	3.2 1.8 .6
	Alka- linity (as CaCO ₃)		189 208 10		253 268 30		398 337 60		274 318 139 14
	Bicar- bonate (as HCO ₃)		230 254 12		308 327 <u></u> 36		485 410 73		334 388 170 17
0	Potas- sium, dis- solved (as K)		0.7 .8 .6		۰. « ۱		1.0 .7 .4		N. 9. L. N.
	Date of sample (1980)		04/10 04/08 04/10		04/10 04/02 06/24 04/02 06/24		04/11 03/26 03/26		03/19 03/19 03/20 03/20
	Hydro- geo- logic unit		H LS US		F LS US US		F LS US		F H LS US
5	Well depth (feet)		165 58 30		172 51 51 20 20		160 55 25		145 85 43 25

-

[Concen aqu	trations ifer; LS,	in microgra lower suri	ams per li ficial aqu	ter unles: ifer; H, F	s otherwise lawthorn con	noted. Hy nfining uni	drogeologic U t; and F, Flo	Jnit: US Pridan aq	, upper su uífer syst	rficial em]
11.01	Hydro-	Date	Alumi- num,	Anti-		Barium,	Beryllium,	Boron,	Cadmium,	Chromium,
weil depth (feet)	geo- logic unit	or sample (1980)	rocal recov- erable (as Al)	mony, dís- solved (as Sb)	Arsenic, total (as As)	rotar recov- erable (as Ba)	rocar recov- erable (as Be)	als- solved (as B)	rocal recov- erable (as Cd)	cocal recov- erable (as Cr)
					Site	7				
165 58	H LS	04/10 04/08	07 70	00	8	50 50	00	20 10	00	11 11
30	NS	04/10	160	0	0	50	0	10	0	10
					Site {	ωI				
172 51	F LS	04/10 04/02	40 50	00		<50 <50	00	30 20	0 2	12 10
51	LS	06/24	ł	ł	1			!	;	
20 20	SU US	04/02 06/24	1,300 1,600	°	- 2	50	°	80	°	12
					Site	6				
160 55	с н н	04/11	940	00	0 0	100	0	30		17
25 25	US US	03/26 03/26	200 500	00	7 7	<50 <50	00	30 20	00	13 14
					Site	10				
145 85	Έц	03/19	200	00	10	<50	0 0	40 40	00	30
43 25 25	LS US	03/20	100 120	000	- 50	<50 <50		000		19 15

Table 10.--Analyses of ground water for minor chemical constituents

									_		_	_	_
Manga nese, total recov erabl (as M		30 60 10		80 80	10	1		90 1001	20		30	90	30 20
Lith- ium, dis- solved (as Li)		1 1 0		2 10	10	ł		οr) 1		Ŋ	4	7 4
Lead, total recov- erable (as Pb)		0		οv	- 2	ł		4 0	0		0	0	0 0
Iron, total recov- erable (as Fe)		610 70 40		870 40	 7,500	6,900		810 60	1,400		40	90	120 390
Iodide, dis- solved (mg/L as I)	ite 7	0.05 .05 .04	ite 8	.04 .04	.10	1	ite 9	•05	60.	ite 10	0	0	.13
Copper, total recov- erable (as Cu)	δ	000	ία.	00	10	1	50 I	10 0	0	ŝ	0	0	00
Cobalt, total recov- erable (as Co)		0 0 1		00	¦ °	1		10	6		0	0	1
Date of sample (1980)		04/10 04/08 04/10		04/10 04/02	06/24 04/02	06/24		04/11 03/26	03/26		03/19	03/19	03/20 03/20
Hydro- geo- logic unit		H LS US		F LS	LS US	NS		F LS	NS		щ	Н	LS US
Well depth (feet)		165 58 30		172 51	51 20	20		160 55	25		145	85	43 25

Table 10.--Analyses of ground water for minor chemical constituents--Continued

Zinc.	total recov- erable (as Zn)		10	10 10		20	10	8	20	8		10	20 20		10	20	10 10
Vana-	dium, dis- solved (as V)		1	4		6	0	l I	'n	ł		0	00		С	0	00
Stron-	tium, dis- solved (as Sr)		60	160 8		160	360	1	100	ł		260	540 170		100	150	560 20
Silver.	total recov- erable (as Ag)		0	00		0	0	l	0	ł		0	00		C	0	00
	Selenium, total (as Se)		0	00		0	0	ł	0	0		0	00		0	00	00
Nickel.	total recov- erable (as Ni)	Site 7	0	1 2	Site 8	1	ę	ł	4	0	Site 9	ę	4 0	Site 10	С	00	1
Molyb- denum.	total recov- erable (as Mo)		17	5 4		30	0	ł	0	l		16	3		88	50	4 0
Mercury.	total recov- erable (as Hg)		0.1			•1		1	•1	L 1		•1	 • •		1.		
Date	of sample (1980)		04/10	04/08 04/10		04/10	04/02	06/24	04/02	06/24		04/11	03/26 03/26		03/19	03/19	03/20 03/20
Hvdro-	geo- logic unit		Н	LS US		Гл	LS	LS	US	SU		Ŀч	LS US	1	يتر	н	LS US
	Well depth (feet)		165	58 30		172	51	51	20	20		160	55 25		145	85	43 25

Table 10.--Analyses of ground water for minor chemical constituents--Continued

tions in milligrams per liter unless otherwise noted; µg, micrograms per liter. logic unit: US, upper surficial aquifer; LS, lower surficial aquifer; H, Hawthorn confining d F, Floridan aquifer system]	 Date Total T	Site 7	04/10 0.09 0.0 0.0 0.02 0.09 0.11 0.02 04/08 .12 .0 .0 .01 .12 .13 .02 04/10 .08 .06 .0 .01 .08 .09 .26	Site 8	04/10 .17 .0 .09 .17 .26 .02 04/02 .0 .1 .0 .04 .0 06/24	04/02 .57 .0 .01 .33 .57 .90 .08 06/24 .56 .01 .0 .28 .56 .84 .08	Site 9	04/11 .19 .0 .0 .12 .19 .31 2.3 03/26 .08 .0 .0 .04 .08 .12 .09 03/26 .07 .0 .0 .03 .07 .10 4.5	Site 10	03/19 .26 .0 .0 .07 .26 .33 .01 03/19 .36 .0 .0 .07 .26 .43 .01
r unless otherwise cial aquifer; LS,	Total Tota nitrate nitrit (as N) (as N	Site 7	0.0 .0 .0 .0 .0 .0 .0	Site 8		.0.	Site 9	0.000	Site 10	0.0
igrams per lite US, upper surfi aquifer system	Total nitrogen (as N)		0.09 .12 .08		.17 .0 	.57		.19 .08 .07		.26
ons in mill: gic unit: [7, Floridan	Date of sample (1980)		04/10 04/08 04/10		04/10 04/02 06/24	04/02 06/24		04/11 03/26 03/26		03/19 03/19
oncentratic Hydrogeolog unit; and F	Hydro- geo- logic unit		H LS US		H LS LS	SN		F LS US		F H
Ū Ū	Well depth (feet)		165 58 30		172 51 51	20 20		160 55 25		145 85

Table 11.--Analyses of ground water for nutrients and organic constituents

			m. + . 1	- Freedow			Math1		
Well depth	Hydro- geo-	Date of	iotai ortho phos-	Urganıc carbon, dis-	Tannin and	Chemical oxygen	Metnyiene blue active	Phenols (µg/L)	Oil and grease, total
(feet)	logic unit	sample (1980)	phorus (as P)	solved (as C)	lignin	demand (COD)	substance (surfactants)		recoverable gravimetric
					Site	7			
165 58 30	H LS US	04/10 04/08	0.01 .01	3.7 3.3	0.2	11 26	00	0 0 0	-10-
2	2		•	1	Site	° • ■		>	ı
172 51	H LS	04/10 04/02	.02	3. 6 2.5	4.4	26 11	0.1.	0 44	0 7
51 20	S I I	06/24 04/02	80.	34.0	3.6	- 4 - 4 - 4		10-	· ·
07	2 2	00/24	80.	0.62	2.0 Site	6 C0	1	7	-
160 55 25	F LS US	04/11 03/26 03/26	2.3 .09 4.5	 2.6 4.0	. 7 . 4	17 17 27	00	0 12 0	700
					Site	10			
145 85	ыщ	03/19 03/19	.01 .01	4.4 •0	7 .	36 36	00	7 0	v. 0
43 25	LS US	03/20 03/20	1.5 1.2	 2.5	.1	10 11	00	00	2

Table 11.--Analyses of ground water for nutrients and organic constituents--Continued

Well	Hydro-			2:	²⁶ Ra
depth (feet)	geologic unit	Gross alpha	Gross beta	Dissolved	Undissolved
			<u>Site 7</u>		
165	Н	<2	<1	0.41 ± 6%	0.10 ± 20%
58	LS	27.5 ± 21%	$15.0 \pm 22\%$	$1.26 \pm 3\%$	$.15 \pm 11\%$
30	US	1.9 ± 104%	1.4 ± 130%	$.96 \pm 3\%$	$.09 \pm 15\%$ $.33 \pm 6\%$
			Site 8		
172	F	2.4 ± 106%	<1	.69 ± 4%	.12 ± 11%
51	LS	4.0 ± 73%	1.3 ± 130%	1.71 ± 3%	.20 ± 9%
20	US	$25.0 \pm 21\%$	7.8 ± 27%	1.28 ± 3%	.26 ± 8%
			<u>Site 9</u>		
160	F	34.9 ± 19%	27.4 ± 16%	1.2 ± 3%	.55 ± 5%
55	LS	<2	1.1 ± 219%	2.8 ± 2%	.25 ± 7%
25	US	<2	<1	.12 ± 13%	.66 ± 4%
			Site 10		
145	F	6,3 ± 51%	<1	1.1 ± 5%	.1 ± 13%
85	Н	<2	2.2 ± 130%	.28 ± 8%	.08 ± 18%
43	LS	31.3 ± 19%	$2.4 \pm 31\%$	$.30 \pm 7\%$	$.05 \pm 24\%$
25	US	6.2 ± 44%	3.0 ± 79%	.18 ± 9%	$.12 \pm 12\%$ $.12 \pm 12\%$

Table 12.--Radiochemical analyses of ground water

[Analyses by the U.S. Environmental Protection Agency; concentrations in picocuries per liter (pCi/L). Hydrogeologic unit: US, upper surficial aquifer; LS, lower surficial aquifer; H, Hawthorn confining unit; and F, Floridan aquifer system]

The chemical constituents in the inflow to the pond are mostly retained in the pond with the solids, and the water is somewhat purified or decanted by flowing through the pond according to Miller and Sutcliffe (1984, p. 145). Miller and Sutcliffe also indicate that the concentrations of dissolved constituents in the active settling pond are relatively constant throughout the year. The chemical character of the slurry water in north Florida is probably similar to that in central Florida, and the settling pond water analysis shown in table 14 is similar to that of active settling pond number 9 water.

The chemical character of the pond waters and the perimeter ditch waters in the present study area are given in tables 5 through 8.

40

							Source of W	ater								
	Pre-		Surface wat	er					Gr	ound wate	şr					
Constituent	cip-			Peri-					Hydro	geologic	unit					
	ita-	Settli	puod bui	meter			surficial a	quifer				Hawthor	c	-	loridan	
	tion			ditch		Upper	oar t		Lower	part	ຮັ	onfining .	uni t	aqui	fer syste	Ē
	Ð	(2)	(3)	(†)	(5)	(6)	(2)	(8)	(6)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Specific	ŝ	242	346	520-550	12-182	186-196	53-200	217-415	300-602	505-520	375	570	232-440	368-538	525-650	6 8
conductance	•	1									•					
(Jus/cm)							1					1				
pH (units)	5.4	7.2	6.7	7.0-7.2	5.3-5.8	5.3-5.5	4.8-7.2	6.5-7.6	6.3-7.4	7.2-7.3	7.3	7.1	7.2-9.0	7.1-7.9	7.1-7.3	7.2
Calcium (as Ca)		22	36	61-62	3.5-19	5	3.0-12.0	18.6-53.0	45-66	2	41	2	9.1-75	51-72	58-72	56
Magnesium		13	15	15-16	.6-4-9	3.3	1.3-4.8	9.4-27.2	9.2-37	33	21	32	8.7-24	18-31	29-38	28
(as Mg)																
Sodium (as		6.8	22	16	1.0-66	15	2.1-21.5	3.3-9.7	4.7-12	6.8	4.1	6.6	15-31	7.3-25	8.1-12	5.8
Na)																
Potassium		6.8	1.1	1.7-2.3	6	8.	.24-8.9	.06-2.39	.78	<u>°</u>	.7	8.	1.8-22	.96-66	.5-1.0	٥.
(as K)															1	
Bicarbonate		124	2	27-39	12-73	19-36	:	:	170-410	327	230	388	:	:	334-485	308
(as HCO_3)																
Alkalinity		102	22	22-32	10-60	16-30	0-40	110-260	139-337	268	189	318	121-324	192-404	274-398	253
(as caco)		r	007	100, 200	(r r			r		i		6 ~ 6	;
Sulfate (as		7.6	120	002-041	0-6-0-	14-29	0*-0*0	1.0-1.1	0-5.2	þ	2.2	1.8	+s-0"l>	171-7.0	2.4-2.6	<u>1</u>
su) Chloride	2	9.5	13	9.5-9.7	1.8-11	17-27	3.0-27	4.0-7.6	7.9-9.9	7.3	5.7	6.3	4.5-9.0	3-18	5.8-10	7.3
(as Cl)																
Fluoride		1.4	2.7	3.0-3.1	7	.2	.12-1.5	.28-1.1	67-	8.	4.	4.	.81-1.8	.32-1.6	.56	.7
(as F)																
Dissolved		140	253	363-390	48-137	162	53-292	142-291	193-377	307	218	335	166-424	246-421	321-394	294
solids,																
residue										i	:					
Aluminum (as		160	270,000	120	120-500	1,300-1,600	:	:	40-200	50	40	100	:	:	200-940	40
Al, in Jug/L	~	ŝ	000	ŝ	ç	ŝ			ŝ		ł	1				ŝ
Barium (as		20	4,000	20	06>	05	:	:	<50	50	^ 50	<50	:	:	<50-100	0ç>
Ba, in																
Jug/L) Chacamium (ac		17	670	7.10	10-15	12	:	:	10-10	ç	÷	¢	:	;	17-20	10
		ũ	0/0	01-0	CI -01	21	;	:	61-01	2	=	2	:	;	nc-11	2
LL, ID J9/L																

Table 13...<u>Comparison of rainfall, surface.water, and ground-water quality</u> [Concentrations are in milligrams per liter unless otherwise noted]

See footnotes at end of table.

		ļ	10	fare wat	La			Source of w	later		ound wate						
Constitu	ent cì	ו ה_ט	Inc		Peri-					Hydro	geologic	unit					
	ŭ. L	L .	Settling	puod i	meter			Surficial a	quifer				Hawthor	c		·loridan	
	Ţ	5			ditch		Uppei	- part		Lower	part	COL	fining	unit	aqui	ifer system	
	5		(2)	(3)	(†)	(2)	(9)	(2)	(8)	(6)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Iron, to	tal		.21	84	.0810	. 04 - 1	6.9-7.5	.79-7.5	.31-5.2	.0612	•0•	.61	.00	9.4-74.	.06-1.1	.0481	.87
recover (as Fe) Manganes total (able e, as		.04	.52	2090-	.0102	.01	.012044	< .0188	.031	.08	.03	.06	<.0108	.0106	.0309	.08
Mn) Strontiu	E		.07	-04	.1315	.00817	5	<.0515	<.0542	.1656	.36	90.	.15	.0930	.0620	.1026	.16
(as Sr) Zinc, to	tal		-01	.35	-01	.0102	.02	.006032	<.0168	.0102	.0	-0	.02	.0413	<.0111	-01	.02
(as Zn) Nitrogen		16	2.16	4.67	8.6-11.2	8 .0710	.5657	<.02-1.05	<.0218	.0812	0	60.	.36	.1432	.0837	.1926	.17
total (as N) Phosphor total	us,	10	2.5	420	9.5-11.0	.26-4.5	.08	.404-5.40	.27-18.6	.02-1.5	.02	.02	.01	.36-5.6	.13-1.6	.01-2.3	-02
(as P) Organic carbon,	5	м	12.0	13.0	14-17	2.2-4.0	29-34	6.0-62.5	4.5-22.5	2.6-3.3	2.5	3.7	0	7.0-34	3.0-28	4.4	3.6
dissolv (as C) Radium 2 dissolv	ed 26,		.16	1.9	. 19 25	.1296	1.28	.3-1.5	.1-7.9	.3-2.8	1.71	-41	.28	1.4-2.0	.5-3.7	1.1-1.2	69.
(1) (1) (2) (3)	Precipi Settlin Settlin	tatio 19 pon	n station d number d d number (l at Live 4. 9.	. Oak, Fla.	Irwin and	Kirkland (1	980).		(10) Lime (11) Hawt fe	sstone. (horn Fm.,	Site 8, s , members	ampling C and D	depths 42). Site 7	-51 feet. , sampling	depths 86	-165
£ 6 8	Perimet Post-Mi	er di ocene	and phosi	h and we phate mat	st sampling trix. Site	g sites). es 7, 9, and	d 10, sampli	ng depths 1-3	30 feet.	(12) Hawt (13) Hawt	horn Fm., horn Fm.,	, member	C. Site C. Swif	t Creek W	ling depth ell site, .	s 80-85 fe Ardaman and	μ.
66	Post-Mi	ocene	Swift (Creek we	uis. suu Il site, Ar	daman and A	is depuis to), sampling		сл (14) Suwa	innee and	ocala Liu Vacata Liu	mestones	ullis yu iz Swift (Creek well	site, Arda	man
(8)	phosphat	te mat	J Teet, ti trix. Swi	nree wet ift Creel	ls. k well site	e, Ardaman a	ind Assoc. (1978),		ап (15) Намt	ka Assoc. horn Fm.,	(19/8), member 1	sampuing and Su	l deptns id Wannee Lir	og-800 tee mestone. 3	t, tour wel Sites 9 and	10, 10,
(6)	sampl Limestor	ing d	epths 20- [,] Sites 7, \$	43 feet, 9, and 10	four wells O, sampling	: J depths 38-	58 feet.			sa (16) Hawt	mpling de horn Fm.,	epths 90- member (160 feet 0 and Su	Wannee Lir	mestone.	Site 8,	
										sa	mpling de	epths 98-7	172 feet				



Table 14.--Idealized analysis of water from a phosphate settling pondnear Bartow, Fla.

	Cations	······		Anions	
Species	Concen- tration (mg/L)	Concen- tration (me/L)	Species	Concen- tration (mg/L)	Concen- tration (me/L)
Ca ⁺²	44	2.196	s04 ⁻²	140	2.915
Na ⁺¹	29	1.261	Alkalinity	70	1.399
Mg ⁺²	15	1.234	c1 ⁻¹	17	.480
к+1	1.6	.041	F ⁻	1.7	.089
sr ⁺²	.14	.002	NO3 ⁻¹	.92	.066
NH4 ⁺¹	2.8	.200			
Total		4.934	Total		4.949

[From Miller and Sutcliffe, 1984, table 17, p. 147] [mg/L, milligrams per liter; me/L, milliequivalents per liter]

Table 15.--Concentrations of selected trace elements in the inflow and outflow of a phosphate settling pond near Bartow, Fla.

[From Miller and Sutcliffe, 1984, table 18, p. 149] [T = total, TR = total recoverable; µg/L, micrograms per liter]

		Mean of	
Element	Inflow concentration $(\mu g/L)$	two outflow concentrations (µg/L)	Percentage reaching outflows
Aluminum TD	/20.000	60	0.01
	420,000	00	0.01
Arsenic, 1	20	4	15
Barium, TR	3,600	100	3
Cadmium, TR	430	0	0
Chromium, TR	1,500	3	.2
Cobalt, TR	66	0	0
Copper, TR	350	2	.6
Iron, TR	100,000	60	.06
Lead, TR	72	0	0
Manganese, TR	·5 , 600	70	1
Nickel, TR	750	5	• 7
Selenium, T	8	0	0
Zinc, TR	3,000	10	.3

Settling pond waters from ponds 4 and 9 are not similar in chemical character. As shown in table 5, settling pond number 4 contains water with the lower amount of dissolved solids (140 mg/L) and lower specific conductance (242 μ S/cm) than overflow from pond number 9. Pond 4 contains a calcium magnesium bicarbonate water. The water in active settling pond number 9 has a dissolved-solids concentration of 253 mg/L and a conductance of 346 μ S/cm and is a calcium magnesium sulfate water. The amount of bicarbonate present in pond 9 is about one-half that of the inactive pond water and the amount of sulfate is about 12 times greater.

Water in settling pond number 9 contains relatively large amounts of almost all the trace metals analyzed with significantly higher amounts of aluminum, barium, chromium, iron, and zinc (table 6) than water in settling pond number 4. Strontium and lithium are the only trace metals present in greater amounts in the older, inactive settling pond number 4 than in the active settling pond number 9.

In terms of nutrients, the active settling pond water is much higher in total phosphorus and nitrogen content (table 7) than the inactive settling pond water. The water in older settling pond 4 has been diluted in concentration by rainfall on the pond as well as by settling out of the solid materials as the water is decanted. A comparison of major chemical constituents of the two settling pond waters is given on the Piper diagram in figure 16.

The water in the perimeter ditch has a dissolved-solids concentration of 363 to 390 mg/L and a specific conductance of 520 to 550 μ S/cm and is a calcium sulfate water. It is similar in chemical character to water in active pond number 9 in terms of major constituents (table 5) and nutrients (table 7), but similar to inactive pond number 4 in terms of trace elements (table 6) and radioactivity (table 8). The ditch is connected to the general hydraulic circulation system of the Suwannee River beneficiation plant, and thus contains some Floridan aquifer system makeup water. The perimeter ditches also receive drainage from the active mining operations as well as overflow from the settling ponds. The calcium and sulfate may be added from the beneficiation processes. Some precipitation and settling, and hence decantation, has occurred in water in the active pond number 9 and a great deal of settling has occurred in the water in pond number 4.

Trace metals are lower in concentration in the perimeter ditch water than in the active settling pond water, except for strontium and lithium, and are similar to concentrations in the inactive settling pond water except for a higher strontium and lower chromium concentration. Nutrients in the perimeter ditch water, except for higher concentrations of phosphorus, are similar to those in pond number 4. Nitrogen concentration is greater in the ditch water than in either storage pond. Total phosphorus concentration is higher in the water in the perimeter ditch than in the older, inactive settling pond water, but much lower than in the active settling pond.

If water were seeping to the surficial aquifer from the perimeter ditches rather than from settling pond number 4, the concentrations of calcium, nitrogen, phosphorus, strontium, and sulfate in the aquifer, should be detectably higher than if they were seeping directly from the inactive settling pond number 4. On the other hand, the bicarbonate, and possibly iron and manganese, concentrations should be detectably lower as an index of groundwater contamination. This assumes no chemical reactions in the ground water. Indicators of leakage from an active settling pond and an indication of leakage from the water from the bottom of pond number 4 would be a higher phosphorous and trace metal concentration, notably alumium, barium, chromium, zinc, and iron concentrations.

Radioactivity is higher in water in active settling pond number 9 than in both the perimeter ditch water and in the water in settling pond number 4 (table 8). A high radioactivity concentration in the adjacent ground water would indicate water came from an active settling pond. According to findings in the central Florida investigation, this radioactivity is typical in the water and sediments of an active settling pond (Miller and Sutcliffe, 1984, p. 147).

The clays in the ponds have a low hydraulic conductivity and release water slowly. Thus, slow release would aid in modifying the chemical character of the ground water by chemical and physical reactions with the aquifer material and aquifer water.

Background Ground-Water Quality

Wells were installed at site 8 in order to define background ground-water quality. This site is located 1 mile from the edge of pond number 4 and is distant from any active phosphate mining. The previously calculated groundwater velocities from the settling pond to site 8 indicate that ground water could not have moved from the pond to site 8 since the time of the construction of pond number 8.

A well at site 8 in the upper part of the surficial aquifer at a depth of 20 feet produced water with a dissolved-solids concentration residue of 162 mg/L and a specific conductance of 196 μ S/cm (table 9). The water lacks a clearly defined chemical character but has a large percentage (48 percent) of sodium chloride relative to its low total dissolved solids (sum of 88 mg/L). It has very high iron (7.5 mg/L) and aluminum (1.3 mg/L) concentrations (table 10), as well as a rather high nutrient concentration (table 11) and radioactivity (table 12). It is not similar to water from the same hydrogeologic strata in Osceola National Forest (Miller and others, 1978, p. 70-71). Thus, this water was most likely contaminated somehow from anthropogenic activities and cannot be reliably used as background water quality except in a general manner. The water from the same part of the surficial aquifer in the Osceola National Forest is a water having dissolved solids of 32 to 46 mg/L, and a specific conductance ranging from 50 to 80 μ S/cm.

A well in the lower part of the surficial aquifer at site 8 at a depth of 51 feet in the dolomitic limestone produced water with a specific conductance of 505 to 520 μ S/cm. This water is a calcium magnesium bicarbonate water with a dissolved-solids concentration (residue) of about 300 mg/L. It is similar in chemical character to waters from member A of the Hawthorn Formation of the surficial aquifer in Osceola National Forest (Miller and others, 1978, p. 70-72).

A well at site 8 into the Floridan aquifer system at a depth of 172 feet produced typical Floridan water. This is a calcium magnesium bicarbonate water with a specific conductance of about 500 μ S/cm and a dissolved-solids concentration (residue) of about 300 mg/L. The water shows no signs of contamination.

The fact that the upper part of the surficial aquifer appears contaminated makes sophisticated comparison with similar wells at sites 7, 9, and 10 very difficult, if not impossible. However, using part of the analysis, and analyses of similar water from adjacent areas, a comparison can be made with respect to contamination from phosphate industry operations.

Water From the Surficial Aquifer

The following describes water quality from sites 7, 9, and 10, unless reference is specifically made to site 8, the background site. The water in the upper part of the surficial aquifer at depths down to 30 to 40 feet appears similar to but less concentrated than that in inactive pond number 4 or in the perimeter ditch (table 13, columns 2, 4, and 5). Specific conductance ranges from 12 to 182 μ S/cm, which is less than the 242 μ S/cm of the inactive settling pond number 4. The dissolved-solids concentration is 48 to 137 The pH ranges from 5.3 to 5.8 units compared to 7.2 of the older mg/L. settling pond. The ground water is a calcium bicarbonate type (fig. 16) like that of pond number 4 compared to a calcium magnesium sulfate water in pond number 9 and a calcium sulfate water in the perimeter ditch. Most trace metals are similar in concentration to that of pond number 4 or perimeter ditch water (table 13). The iron concentration is highly variable, ranging from 40 to 1,400 μ g/L. Sulfate and aluminum are similar in concentration to the water in pond number 4. Nitrates, phosphates, and other nutrients are uniformly low in concentration in the upper part of the surficial aquifer (table 11) and similar to that of the pond number 4 water (table 7). Ground water from site 8 (table 13, column 6), the control well, is similar in the upper 20 feet to that at sites 7, 9, and 10, as well as to that in settling pond number 4, except for the relatively high concentrations of sodium, chloride, sulfate, and aluminum.

Water in the surficial aquifer may contain some water that has seeped out of the perimeter ditch or from pond number 4, but this contaminant water has probably been diluted by recharge from rainfall. In addition, chemical and physical processes most likely would have changed the chemical character of the water that has seeped out into the aquifer. Radioactivity is higher in this aquifer than in either the perimeter ditch or pond number 4 water (tables 8 and 12) so that radiochemicals are not useful as tracers.

The distinguishing chemical characteristics mentioned earlier for the pond waters or the perimeter ditch water are not readily distinguishable in the upper part of the surficial aquifer water adjacent to pond number 4. The waters from shallow test wells at sites 7, 9, and 10 are lower in total dissolved solids than the pond and ditch waters and, in that sense, resemble the background water-quality data from site 8. In terms of cations and trace metals, they appear to be a mixture between site 8 water and the perimeter

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ditch water, but in terms of anions, appear to be a mixture between settling pond 4 and site 8 water (see figure 16 and table 13). Thus, no distinctive chemical characteristics are readily discernible so that they appear unaffected by the pond or ditch waters, although overall, they most resemble the decanted overflow from pond number 4. Hence, no contamination can be shown in a chemical sense.

Water from the lower part of the surficial aquifer at depths from 40 to 80 feet has a specific conductance which is greater than that in the upper part of the aquifer. The background water from the lower part of the aquifer at site 8 is similar to that in wells at sites 7, 9, and 10. The specific conductance ranges from 300 to $602 \text{ }\mu\text{S/cm}$. Dissolved-solids concentrations range from 193 to 377 mg/L and increase with depth. The water is a calcium bicarbonate water and is not similar in general chemical character to waters in the perimeter ditch or in the active settling pond, but is similar to that in inactive settling pond number 4 (fig. 16). Sulfates are low, ranging from 0 to 3.2 mg/L. Trace metals are low in concentration, except for strontium, which ranges from 160 to 560 μ g/L. The water composition is similar to that reported elsewhere in the Hawthorn unit A part of the surficial aquifer. Radioactivity of the water varies (table 12) and is higher than that in the pond and ditch waters (table 8) but is similar to that found in the Osceola National Forest Hawthorn ground water (Miller and others, 1978, p. 71). It is, however, lower than that found in pond number 9 water (table 8). No direct contamination can be shown in a chemical sense.

The similarity in chemical character of the well waters and pond number 4 is not necessarily an indication of contamination by seepage from pond number 4; ambient native ground water has moved through the phosphate ore and would be expected to be similar in chemical character to water that has been exposed to the ore during the mining process.

Ground-water contamination from the ore-beneficiation plant sites is difficult to detect in the surficial aquifer. The use of more sophisticated methods to detect small concentrations of contaminants was not warranted in this study because contaminants have not significantly changed the ambient ground-water chemistry of the aquifer as indicated by comparison with background water quality. Direct contamination by seepage to the surficial aquifer from the settling ponds is likely minimal because almost all the concentrated contaminants in the slurry are trapped with the clayey waste disposal material in the low hydraulic conductivity sediments of the storage pond.

Water From the Hawthorn Confining Unit

Water from the Hawthorn confining unit from depths below 70 feet ranges from 375 to 570 μ S/cm in specific conductance, from 218 to 335 mg/L in dissolved solids, and is similar to that found in the Osceola National Forest in the Hawthorn confining unit (Miller and others, 1978, p. 75). No water from the Hawthorn confining unit was obtained at site 8. The water at sites 7, 9, and 10 is a calcium bicarbonate water and is similar to that obtained from the lower part of the surficial aquifer but slightly higher in overall concentrations (table 9). Trace metals, except for iron, aluminum, and strontium, are low in concentration (table 10). Nitrates, phosphorus, and other nutrients are also low in concentration (table 11). Radioactivity is relatively low (table 12) and similar to water reported by Miller and others (1978, p. 78). This water appears to be influenced in chemical composition by movement of water downward from the surficial aquifer and not from the settling ponds and ditches.

Water From the Floridan Aquifer System

Water from the Floridan aquifer system is a calcium bicarbonate water that ranges in specific conductance from 499 to 650 μ S/cm and in dissolvedsolids concentrations from 294 to 394 mg/L (table 9). Sulfates are relatively low in concentration, ranging from 3.2 to 13 mg/L. Chlorides range from 5.8 to 10 mg/L. Trace metals, except for iron, aluminum, and strontium, are low in concentration (table 10). Nitrates, phosphates, and other nutrients are low in concentration (table 11). The Floridan aquifer system water has low radioactivity (table 12). It is similar to Floridan aquifer system water reported elsewhere in the area by Ardaman and Associates, Inc., (1978) and Miller and others (1978). The water obtained from the Floridan aquifer system at site 8 is very similar to that obtained from the Floridan aquifer system at sites 9 and 10. This water appears not to be influenced in chemical composition by movement of contaminated water downward from the surface or overlying aquifer.

CONCLUSIONS

The quality of water from wells tapping the surficial aquifer within 200 to 400 feet of the perimeter ditches and inactive settling pond shows no chemical signs of contamination from the phosphate industry operations. The necessary conditions, to prove aquifer contamination in a physical sense, are the existence of an aquifer, source of contamination, hydraulic connection between the source and aquifer, and hydraulic gradient. These conditions were met at the test site, but no definitive increase in concentration with time or change from background water quality could be shown.

The horizontal ground-water velocities calculated for the surficial aquifer between the inactive settling pond ditch and the test wells is between 100 (site 10) and 2,000 (site 7) feet per year. This is sufficient time, in the 6 years of the pond's operation, for contamination to have reached either the lower or upper part of the surficial aquifer at the test well sites nearest to the pond. Waters from the wells in the upper part of the surficial aquifer have total dissolved-solids concentrations which are relatively similar, but less concentrated than the pond and perimeter ditch waters. The cations and trace metals in the upper surficial aquifer waters may indicate a perimeter ditch source and the anion content a settling pond source, but no distinctive chemical characteristics are evident in the upper surficial aquifer waters near the settling pond. Thus, water may have moved into the surficial aquifer from the phosphate industry operations, but no chemical evidence of this movement exists.

Horizontal movement of ground water outward from the pond and the nearby test wells is at a rate of about 10 feet per year; accordingly, no areally extensive contamination of the surficial aquifer is likely for a long time, if at all. The water in the lower part of the surficial aquifer is almost identical in quality to the water in a distant (1 mile) background uncontaminated well. Thus, no contaminants from the phosphate industry operations appear to have reached either the upper or lower part of the surficial aquifer at a distance of 200 to 400 feet from the inactive settling pond. Of course, water has moved into the aquifer closer to the pond, but its chemical character is unknown.

The chemical and physical reactions occurring within the surficial aquifer, the slow movement of water, and dilution from precipitation recharging the aquifer, minimize the extent and magnitude of contamination effects of any seepage from the ditches, inactive settling pond, or both. In addition, the relatively elevated concentrations of phosphorus, sulfate, iron, aluminum, barium, chronium, zinc, nitrogen, and radioisotopes that are associated with the solid phase of the phosphatic clayey wastes appear to be effectively trapped with the clays of the waste-settling areas, as evidenced by the water quality of the decanted outflow as opposed to that of the incoming wastes. Some of this material may solubilize after settling and may then percolate through the bottom of the pond into the underlying sediments.

Similarly, the waters in the Hawthorn confining unit and in the underlying Floridan aquifer system have not been affected by the phosphate industry operations. The Floridan aquifer system is separated from the settling ponds and ditches by the Hawthorn confining unit. The time calculated for water to move vertically through the Hawthorn to the Floridan is in thousands of years at a rate estimated to be less than 3 inches per year. The water quality in the Floridan aquifer system and in the Hawthorn confining unit is similar to background water quality. Thus, no aquifer with potential for public water supply usage in the area appears to be adversely affected by leakage from the waste-storage settling pond area under present conditions, or is likely in the future if conditions now operating are maintained.

However, there is evidence of anamolously low water levels in the surficial aquifer in the vicinity of site 7. This indicates the possibility of incipient sinkhole formation. If the Hawthorn confining unit were to be breached by a large sinkhole, an entire settling pond and all of its contents could enter the Floridan aquifer system. Sinkhole formation in the vicinity of a settling pond would cause unforeseen and unpredictable damage to the waters of the Floridan aquifer system. This would then pose a threat to part of the main source of water supply throughout the northern Florida-south Georgia area.

REFERENCES

- Ardaman and Associates, Inc., 1978, Environmental impact statement, Occidental Chemical Company, Swift Creek Chemical Complex, Hamilton County, Florida, 5 volumes: Ardaman and Associates, Inc., Orlando, Fla.
- Ceryak, Ron, Knapp, M. S., and Burnson, Terry, 1983, The geology and water resources of the upper Suwannee River basin, Florida: Florida Bureau of Geology Report of Investigations 87, 165 p.
- Irwin, G. A., and Kirkland, R. T., 1980, Chemical and physical characteristics of precipitation at selected sites in Florida: U.S. Geological Survey Water-Resources Investigations 80-81, 70 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

- Miller, J. A., Hughes, G. H., Hull, R. W., Vecchioli, John, and Seaber, P. R., 1978, Impact of potential phosphate mining on the hydrology of Osceola National Forest, Florida: U.S. Geological Survey Water-Resources Investigations 78-6, 159 p.
- Miller, R. L., and Sutcliffe, Horace, Jr., 1982, Water-quality and hydrogeologic data for three phosphate industry waste-disposal sites in central Florida, 1979-1980: U.S. Geological Survey Water-Resources Investigations 81-84, 77 p.
- Miller, R. L., and Sutcliffe, Horace, Jr., 1984, Effects of three phosphate industrial sites on ground-water quality in central Florida, 1979 to 1980: U.S. Geological Survey Water-Resources Investigations Report 83-4256, 184 p.
- Stringfield, V. T., 1966, Artesian water in Tertiary limestone in the southeastern states: U.S. Geological Survey Professional Paper 517, 225 p.
- Vernon, R. O., and Puri, H. S., 1965, Geologic map of Florida: Florida Division of Geology Map Series 18, 1 sheet.

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