Prepared in cooperation with the
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Interpretation of Major Ion Analyses

Dominant Water Types

In addition to dissolved chloride, other dissolved ions in ground water are primarily calcium, magnesium, sodium, potassium, bicarbonate, and sulfate. The Stiff diagrams in figure 6 are graphic representations of the major ionic (chemical) composition of ground water based on milliequivalents per liter at selected sites in Broward County. The size of each diagram and the dissolved solids concentration (shown on the top of each diagram) indicate the degree of mineralization, and the shape of a diagram indicates water type (which dissolved inorganic ions are dominant). For the reader's convenience, the concentration of each ion in milligrams per liter is shown beside each milliequivalent spike. Calcium bicarbonate, sodium chloride, and mixed-ion ground water are the types that most commonly occur in the surficial aquifer system in Broward County.

In Broward County, calcium bicarbonate type ground water results from the dissolution of limestone, calcite-cemented sandstone, and carbonate sands. Calcium bicarbonate water is dominant at shallow depths beneath most of the county and at all depths in parts of northeast Broward County (wells G-2325 and G-2342 to G-2344). On a Stiff diagram for calcium bicarbonate water, calcium has the longest spike on the cation side of the diagram, and bicarbonate has the longest spike on the anion side.

Sodium chloride water in Broward County results from incomplete flushing of ancient seawater or from seawater intrusion. Sodium chloride water from ancient seawater inundations was initially found beneath the conservation areas at depths of 90 to 180 feet, except in the far west (wells G-2329, G-2330, G-2338 to G-2340, and G-2346) and in the vicinity of wells G-2319 and G-2341. Sodium chloride water was evident in samples beginning at a depth of 179 feet in the vicinity of well G-2327 (southeast Broward) and at 209 feet in the vicinity of the Dixie well field (well G-2345). Seawater intrusion produces the sodium chloride ground water near New River (well G-2347). On a Stiff diagram for sodium chloride water, the sodium plus potassium spike is longest on the cation side of the diagram, and the chloride spike is longest on the anion side.

Mixed-ion ground water occurs when no ion constitutes as much as 50 percent of the cations or of the anions. Mixed-ion ground water is produced by mixing at the interface between two or more parent water types; it may also be produced by the natural softening of calcium bicarbonate water. On a Stiff diagram for mixed-ion water, the length of no ion spike is as long as the sum of the lengths of the other two spikes on the same side.

In Broward County, mixed-ion water that results from ground-water mixing is usually found at depth, below the calcium bicarbonate water and above the sodium chloride water. It also occurs in coastal areas along the boundary of the intruding wedge of seawater. When mixed-ion water is produced between shallow calcium bicarbonate water and deep sodium chloride water, it commonly represents the deepest extent of potable water.

Mixed-ion ground water occurs at depths of less than 100 feet near the eastern levees (wells G-2321, G-2341, and PB-1428). The fact that this mixed-ion water occurs at shallow depths, may have dissolved solids higher than ground water in deeper zones, and is not always immediately underlain by sodium chloride water, suggests that it is not the result of mixing with residual seawater from a deeper zone. The mixed-ion water is probably produced by the mixing of calcium bicarbonate ground water with more mineralized water from beneath the conservation areas. It is also possible that ground water from the conservation areas migrates upward into transecting canals and then flows eastward where it infiltrates the calcium bicarbonate waters of the shallow aquifer. This process may explain the composition of ground water in the vicinity of well G-2322 (next to the North New River Canal) where dissolved solids decrease with depth, and well G-2324 (next to the Hillsboro Canal) where dissolved solids decrease with depth, and calcium bicarbonate water was found beneath mixed-ion water.

Potability of Ground Water

The potability of ground water is mainly determined by the concentrations of major ions. In south Florida, dissolved chloride usually is the limiting ion. Figure 7 shows a cross-sectional representation of ground-water type in Broward County and the approximate depth of 250-mg/L dissolved chloride concentration. The zone of freshwater in the surficial aquifer system beneath Broward County varies in depth. A large area of ground water west of the coastal ridge has elevated dissolved solids concentrations because of its carbonate hardness (calcium and magnesium carbonates) but meets drinking water standards for all other dissolved constituents. This water could be used for agricultural and industrial purposes and, with treatment, could be potable.

Geochemical Processes

Ground water in Broward County is commonly affected by natural softening. For instance, naturally softened ground water occurs when calcium ions in solution are exchanged for sodium ions from a base-exchange medium such as clay. Evidence of softening of ground water is found in the western three-quarters of the county (figs. 6 and 7), but it is most evident and widespread along the western edge. On a Stiff diagram that depicts softened water, the sodium plus potassium spike is longer than the chloride spike so that the water seems to be a mixed-ion or sodium bicarbonate type. For example, figure 6 shows that ground water in well G-2318 at a depth of 149 feet has undergone softening, whereas ground water at a depth of 78 feet has not.

Furthermore, some ground water also is enriched with magnesium and sulfate ions; that is, these ions occur at higher concentrations than can be expected by the simple dilution of seawater. For this discussion, magnesium-enriched water refers to those waters that have a higher milliequivalent ratio of magnesium to chloride than the 1:5 ratio of seawater. Magnesium-enriched ground water can result from cationic exchange between magnesium and calcium, from the leaching of magnesium calcite (calcite with magnesium impurities), from dolomite rock, or in western Broward County possibly from dolomite mud. In Broward County, most ground water that is not a sodium chloride type is enriched with magnesium. Magnesium to chloride ratios usually are slightly higher beneath the conservation areas, but beyond this there is no apparent trend. Magnesium to chloride ratios more than 1:1 occur in shallow ground water beneath the conservation areas (wells G-2313 and G-2320) and in the southeast (well G-2327).

Sulfate-enriched waters have a sulfate to chloride milliequivalent ratio higher than the 1:10 ratio of seawater. Sulfate-enriched water may result from the dissolution of sulfate minerals such as gypsum, from the oxidation of metallic sulfides such as pyrite, or from the oxidation of hydrogen sulfide (or hydrosulfide) derived from organic deposits. All high sulfate concentrations (more than 100 mg/L) in Broward County ground water are found in areas with diluted seawater. However, shallow ground water in much of the eastern third of the county (wells G-2318, G-2323, G-2324, G-2327, G-2328, G-2342, G-2344, G-2345, and G-2347) is sulfate enriched with the highest ratios in the vicinity of the Pompano and Dixie well fields (wells G-2344 and G-2345). Shallow ground water in the middle of the county along the Broward-Palm Beach County line (well G-2315) also is enriched with sulfate, as is ground water in deeper zones in the middle of Conservation Area 3A (well G-2320).

Other Chemical Constituents

Fluoride is another constituent of ground water which is mentioned here because it is of interest in public water supplies. In Broward County, dissolved fluoride concentrations ranged from 0.1 to 1.0 mg/L, well below the Florida standard of 1.4 mg/L in effect for this temperature regime (Florida Department of Environmental Regulation, 1982); the average and median concentrations were both 0.4 mg/L. Fluoride concentrations of more than 0.6 mg/L were found in ground water beneath the levees (wells G-2311 to G-2313, G-2315, G-2316, G-2321, G-2341) and in the vicinity of well G-2323 (northeast Broward County).

The color of each Stiff diagram in figure 6 indicates the dissolved iron concentration in ground water. Although most ground water in Broward County has iron concentrations of more than 300 µg/L (micrograms per liter)--the Florida secondary drinking water standard (Florida Department of Environmental Regulation, 1982)--the actual concentrations vary widely both areally and with depth. Beneath the western third of the county, dissolved iron concentrations generally range from 300 to 1,000 µg/L. In the eastern two-thirds of the county, iron concentrations tend to be higher and more variable than in the west, ranging from 10 to 9,800 µg/L. Dissolved iron, manganese, and aluminum concentrations are shown in table 1.

Concentrations of nitrite, nitrate, and orthophosphorus are low (generally less than 0.1 mg/L); ammonia concentrations are higher and show more variability than the other nutrients (table 1). Although there are pockets of ammonia-rich ground water (see wells G-2312, G-2318, G-2322, G-2328, G-2347, and PB-1428), there is no areal or vertical trend, and ammonia concentrations are otherwise 1 mg/L or less.

The results of analyses for selected dissolved trace elements found in Broward County ground water and the Florida standard for each are shown in table 2. Concentrations of dissolved arsenic, barium, lead, zinc, selenium, and mercury were less than the maximum contaminant levels established by the primary and secondary drinking water regulations (Florida Department of Environmental Regulation, 1982). One sample from well G-2328 equaled the recommended limit for cadmium (10 µg/L), one sample from well G-2320 equaled the recommended limit for chromium (50 µg/L), and one sample from well G-2321 exceeded the recommended limit for chromium. These concentrations may be due to contamination by the drilling process as they are notably higher than cadmium and chromium concentrations found in Broward County ground water in 1983 and 1984 (Waller and Cannon, 1986) or in adjacent Dade County ground water in 1984 (W.H. Sonntag, U.S. Geological Survey, written commun., 1985).

CONVERSION FACTORS AND ABBREVIATIONS

Factors for converting inch-pound units to metric (International System) units and abbreviation of units

Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot per per day (ft^2/d)	0.0929	square meter per day (m^2/d)
square mile (mi^2)	2.590	square kilometer (km^2)
million gallons per day per foot (Mgal/d)/ft	0.1438	square meter per second (m^2/s)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

SUMMARY

This report presents water-quality data collected in 1981 and 1982 during the drilling of test holes at 27 sites throughout Broward County. Determinations were made for the following physical properties and chemical constituents: pH, alkalinity, specific conductance, major ions, selected nutrients and dissolved iron, aluminum, and manganese. Determinations for the trace elements--arsenic, barium, cadmium, chromium, lead, zinc, selenium, and mercury--were made at 14 wells.

In Broward County, water in the surficial aquifer system beneath the Atlantic Coastal Ridge is a calcium bicarbonate type and is potable, under existing State standards, to a depth of 200 feet or more. Exceptions are in areas of seawater intrusion along the coast and in the vicinity of New River near Fort Lauderdale. Dissolved iron concentrations beneath the Atlantic Coastal Ridge are variable but generally exceed 1,000 µg/L.

Water in the surficial aquifer system between the coastal ridge and the conservation areas is potable and usually is a calcium bicarbonate type for the first 140 feet or more below land surface. Between depths of 140 and 230 feet, ground water generally grades into a mixed-ion water type. Mineralization of water in this interval is high, but ground water in some instances is still potable. In the vicinity of wells G-2327 and G-2345, diluted seawater occurs beneath the mixed water zone; in the vicinity of well G-2342, ground water is a potable calcium bicarbonate type to a depth of 300 feet. Dissolved iron concentrations between the coastal ridge and the conservation areas are variable but generally exceed 1,000 µg/L.

Beneath the conservation areas and the western edge of Broward County, ground water in the first 100 feet below land surface generally is either a calcium bicarbonate type or a mixed-ion type. At depths between 100 and 200 feet, diluted residual seawater occurs, except along the far western edge of the county. Residual seawater is least diluted in the north. Dissolved iron concentrations generally are between 300 and 1,000 µg/L but increase to the east of the conservation areas.

Other findings of the investigation include: (1) Ground water in some areas west of the coastal ridge probably would be suitable for most domestic, agricultural, and industrial uses if it were treated for carbonate hardness; (2) ground water in much of Broward County is chemically altered by natural softening and magnesium enrichment (natural softening increases to the west and is very pronounced beneath the far western edge of the county); and (3) there is evidence of mineralized water from the conservation areas mixing with ground water east of the levees.

REFERENCES CITED

Beetem, W.A., Friedman, L.C., Perryman, G.R., and Watterson, C.A., 1981, Water quality laboratory services catalog: U.S. Geological Survey Open-File Report 80-1279.
Causaras, C.R., 1985, Geology of the surficial aquifer system, Broward County, Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4068, 167 p., 2 sheets.
Davis, J.H., Jr., 1943, The natural features of southern Florida: Florida Geological Survey Bulletin 25, 311 p.
Fishman, M.J., and Brown, Eugene, 1976, Selected methods of the U.S. Geological Survey for the analysis of wastewaters: U.S. Geological Survey Open-File Report 76-177, 87 p.
Florida Department of Environmental Regulation, 1982, Public drinking water systems: Chapter 17-22 *in* Florida Administrative Code.
Franks, B.J., ed., 1982, Principal aquifers in Florida: U.S. Geological Survey Water-Resources Investigations Open-File Report 82-255, 4 sheets.
Goerlitz, D.F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A3, 80 p.
Klein, Howard, Armbruster, J.T., McPherson, B.F., and Freiberger, H.J., 1975, Water and the south Florida environment: U.S. Geological Survey Water-Resources Investigations 24-75, 165 p.
Parker, G.G., Ferguson, G.E., Love, S.K., and others, 1955, Water resources of southeastern Florida, with special reference to geology and ground water of the Miami area: U.S. Geological Survey Water-Supply Paper 1255, 965 p.
Sherwood, C.B., McCoy, H.J., and Galliher, C.F., 1973, Water resources of Broward County, Florida: Florida Bureau of Geology Report of Investigations 65, 141 p.
Skougstad, M.W., Fishman, M.J., Friedman, L.C., Erdmann, D.E., and Duncan, S.S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.
Waller, B.G., and Cannon, F.L., 1986, Water-quality data for the ground-water network in eastern Broward County, Florida, 1983-84: U.S. Geological Survey Open-File Report 86-313, 68 p.

Table 2.--*Concentrations of selected trace elements in water from the surficial aquifer system, Broward County, 1981-1982*[1]

[Concentrations shown in micrograms per liter]

Local well no.	Sampling depth (feet)	Dissolved arsenic	Dissolved barium	Dissolved cadmium	Dissolved chromium	Dissolved lead	Dissolved mercury	Dissolved selenium	Dissolved zinc
Limits[2]		50	1,000	10	50	50	5,000	10	2
G-2319	39	2	60	1	10	1	60	<1	<0.1
	119	1	100	<1	10	1	10	<1	.3
	208	-	100	1	10	1	30	<1	.2
G-2320	119	1	20	<1	50	2	10	<1	.2
G-2321	49	1	30	<1	<10	2	5	<1	<.1
	149	1	10	1	60	1	4	<1	.2
G-2322	49	1	30	<1	10	1	10	<1	<.1
	119	1	30	<1	<10	2	110	<1	.1
G-2327	39	1	8	<1	10	3	20	<1	<.1
	139	1	30	4	<10	11	<4	<1	<.1
G-2328	29	1	3	6	<10	1	3	<1	<.1
	119	1	10	10	10	4	30	<1	<.1
G-2329	79	1	40		10	2	6	<1	.4
G-2330	39	2	40	<1	20	8	30	<1	<.1
	89	1	10	8	30	6	30	<1	.1
	149	2	100	1	30	4	30	<1	<.1
G-2341	29	2	30	4	10	1	30	<1	.1
	109	1	20	<1	10	10	9	<1	.1
G-2342	139	1	30	<1	<10	1	20	<1	.2
	229	1	50	<1	10	3	10	<1	<.1
G-2344	59	1	20	4	<10	2	30	<1	<.1
	99	2	10	4	<10	6	30	<1	.1
	159	1	10	3	10	8	30	<1	<.1
	199	<1	10	3	<10	8	8	<1	<.1
	259	1	10	3	10	2	20	<1	<.1
	309	1	20	<1	10	1	30	<1	<.1
	359	1	50	<1	10	10	20	<1	<.1
	409	3	50	<1	<10	9	20	<1	.8
G-2345	69	2	20	2	10	3	110	<1	<.1
	159	1	20	6	10	<1	20	<1	<.1
G-2346	40	1	30	<1	10	<1	10	<1	<.1
	140	1	9	5	10	7	7	<1	<.1
G-2347	40	1	30	3	10	1	210	<1	.2
	120	1	<50	2	10	5	140	<1	<.1
	209	<1	200	2	30	5	170	<1	.2

[1]If a constituent was not detected in a sample, the constituent is reported as less than the detection limit (for example, <100). There may be more than one detection limit reported for a particular constituent because other constituents in a sample may interfere with an analysis, necessitating the use of alternative methods of analysis with higher or lower detection limits. Dashes (--) indicate that the sample was not analyzed for a constituent.

[2]Florida Department of Environmental Regulation, 1982.

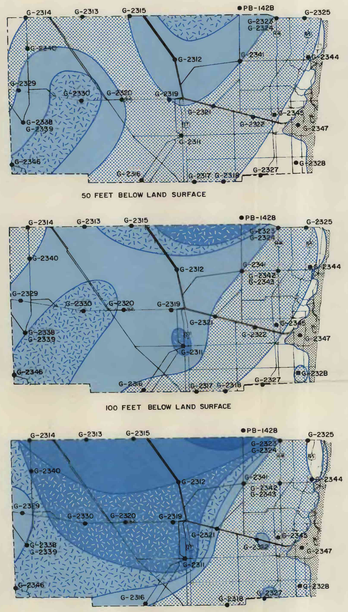

Figure 5.--Areal variation of specific conductance at 50-, 100-, and 150-foot depths within the surficial aquifer system.

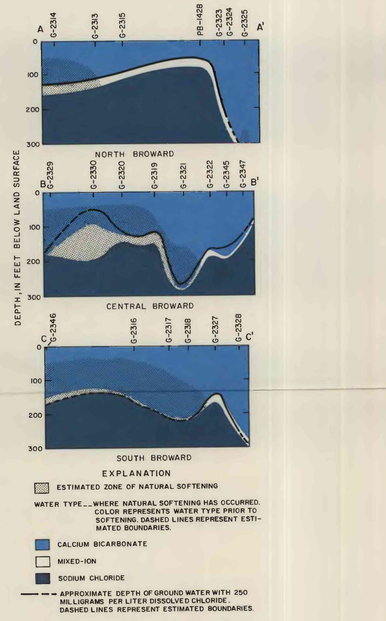

Figure 7.--Water types in the surficial aquifer system and approximate depth of ground water with 250 milligrams per liter dissolved chloride. (Locations of transects shown in fig. 2).

Table 1.--*Concentrations of selected metals and nutrients in water from the surficial aquifer system, Broward County, 1981-1982*[1]

Local well no.	Sampling depth (feet)	Metals (micrograms per liter): Dissolved iron	Dissolved manganese	Dissolved aluminum	Nutrients (milligrams per liter): Total ammonia nitrogen	Total nitrite nitrogen	Total nitrate nitrogen	Total orthophosphorus
G-2311	19	1,100	70	20	0.89	<0.01	<0.01	0.08
	49	490	20	30	.56	<.01	<.01	.07
	84	2,700	40	20	.45	<.01	<.01	.10
	119	2,600	40	<10	.44	<.01	<.01	.04
	169	1,700	50	10	.55	<.01	<.01	.01
	192	480	120	20	.55	<.01	<.01	.06
G-2312	109	2,500	30	20	2.6	.01	<.01	.03
	139	1,100	40	30	1.0	<.01	<.01	.01
	169	2,300	40	20	.36	.01	<.01	.05
G-2313	69	820	10	20	.33	<.01	<.01	.01
	119	290	10	20	.37	<.01	<.01	.01
	159	760	20	30	.53	<.01	<.01	.06
G-2314	49	390	10	10	.71	<.01	<.01	.02
	129	710	20	20	.52	<.01	<.01	.02
G-2315	49	760	20	30	.12	<.01	<.01	.01
	119	1,600	10	20	.41	<.01	<.01	.02
	149	1,200	20	30	.55	<.01	<.01	.01
G-2316	39	920	30	40	.36	<.01	<.01	.01
	99	500	10	20	.33	<.01	<.01	.01
	149	440	10	30	.27	.01	.02	.01
	179	400	30	10	.42	.01	<.01	.01
G-2317	49	1,500	20	20	.27	.01	<.01	.01
G-2318	29	1,600	40	20	.90	.01	<.01	.01
	78	1,800	30	20	1.5	.01	<.01	.02
	149	850	10	20	.41	.01	<.01	.01
	185	20	--	10	.44	.01	<.01	.02
G-2319	39	2,500	80	10	.84	.01	<.01	.01
	119	530	20	30	.37	.01	<.01	<.01
	159	1,100	20	30	.40	.01	<.01	.01
	208	100	60	20	.67	.01	<.01	.01
G-2320	29	5,400	110	10	.92	.01	<.01	<.01
	79	830	10	20	.25	.01	<.01	<.01
	119	680	20	20	.21	.01	<.01	<.01
	159	650	10	<100	.30	<.01	<.01	<.01
G-2321	49	1,100	20	<100	.98	.01	<.01	.08
	75	700	20	<100	.93	<.01	<.01	.02
	149	1,700	10	<100	.41	<.01	<.01	<.01
	179	1,400	20	<100	.43	<.01	<.01	<.01
G-2322	49	1,800	20	<100	.67	.03	<.01	.80
	79	1,400	30	100	1.3	.01	<.01	.21
	119	2,200	30	<100	1.4	<.01	<.01	.02
	159	4,100	50	<100	1.1	<.01	<.01	.01
G-2323	99	1,500	20	<100	.31	<.01	<.01	.11
	169	1,700	20	200	.31	<.01	<.01	.08
	179	1,600	40	200	.33	<.01	<.01	.01
G-2324	45	320	20	20	.43	.02	<.01	.09
G-2325	300	30	20	20	.19	.01	<.01	.04
G-2327	59	230	7	<10	.41	<.01	<.01	.01
	108	1,500	20	100	.72	<.01	<.01	.03
	139	8,100	50	<100	.23	<.01	<.01	.02
	179	560	10	10	.42	<.01	<.01	.02
	239	720	10	<100	.45	<.01	<.01	<.01
G-2328	29	40	6	20	.02	.01	.86	<.01
	69	1,000	20	<10	1.3	<.01	<.01	<.01
	119	1,300	10	100	.65	.01	<.01	<.01
	179	5,500	40	<100	.79	.01	<.01	.09
	269	1,200	70	<100	.28	.01	<.01	.05
	220	<10	20	30	.30	.04	.54	.01
G-2329	79	480	6	<10	0.38	0.08	0.01	<0.01
	119	360	10	<10	.38	.01	<.01	.01
G-2330	39	2,200	40	<10	.50	.01	<.01	.02
	89	780	6	<10	.27	<.01	.01	.01
	149	590	10	<10	.30	<.01	<.01	<.01
G-2338	109	660	10	20	.38	<.01	.01	<.01
	149	820	20	<10	.41	.01	<.01	.02
G-2339	25	140	10	100	.55	.01	<.01	.06
G-2340	69	850	10	<100	.37	<.01	.01	<.01
	109	640	10	100	.41	.01	<.01	.02
	139	700	10	<10	.51	.01	.01	.02
G-2341	29	1,700	20	<100	.42	.01	<.01	.03
	99	440	10	100	.55	<.01	.01	.07
	109	610	7	<100	.85	<.01	.01	.02
G-2342	99	1,100	10	<100	.42	<.01	.01	.01
	139	1,600	40	<100	.29	<.01	.01	.06
	179	1,800	20	<10	.25	<.01	<.01	<.01
	229	1,900	10	<100	.33	<.01	.01	.01
	279	2,800	30	100	.31	<.01	<.01	.02
G-2343	25	730	20	30	.59	.04	<.01	.64
G-2344	59	1,500	7	<100	.50	<.01	<.01	.01
	99	1,800	20	<100	1.0	.01	<.01	.02
	159	1,800	20	<100	.27	.01	<.01	.02
	199	900	30	<100	.33	<.01	<.01	<.01
	270	6,900	100	<100	.93	.01	<.01	.05
	309	7,400	20	<100	.70	.01	<.01	.01
	359	4,800	60	<100	.35	<.01	.01	<.01
	409	2,600	90	<100	.30	<.01	.02	<.01
G-2345	69	1,300	20	<100	.56	<.01	.06	.05
	109	3,900	10	<10	.73	<.01	<.01	.02
	159	1,500	10	200	.42	<.01	<.01	<.01
	209	2,000	10	<10	.45	.01	.03	<.01
G-2346	60	1,000	10	<100	.29	.01	.01	<.01
	100	910	10	200	.29	<.01	<.01	<.01
	140	8,100	--	<100	.29	<.01	<.01	<.01
G-2347	40	1,500	20	100	.90	<.01	<.01	<.01
	80	2,000	30	200	.82	<.01	<.01	.01
	120	6,600	50	<100	1.2	<.01	<.01	<.01
	160	8,300	110	300	3.5	.01	.01	.02
	209	3,200	80	100	2.9	<.01	<.01	<.01
	269	9,800	120	<10	2.1	.01	<.01	<.01
PB-1428	49	1,500	30	<10	6.4	<.01	<.01	<.01
	89	1,000	30	70	1.9	<.01	<.01	<.01
	129	380	40	100	.62	<.01	<.01	<.01
	189	1,500	20	<10	.72	<.01	<.01	.04

[1]If a constituent was not detected in a sample, the constituent is reported as less than the detection limit (for example, <100). There may be more than one detection limit reported for a particular constituent because other constituents in a sample may interfere with an analysis, necessitating the use of alternative methods of analysis with higher or lower detection limits. Dashes (--) indicate that the sample was not analyzed for a constituent.

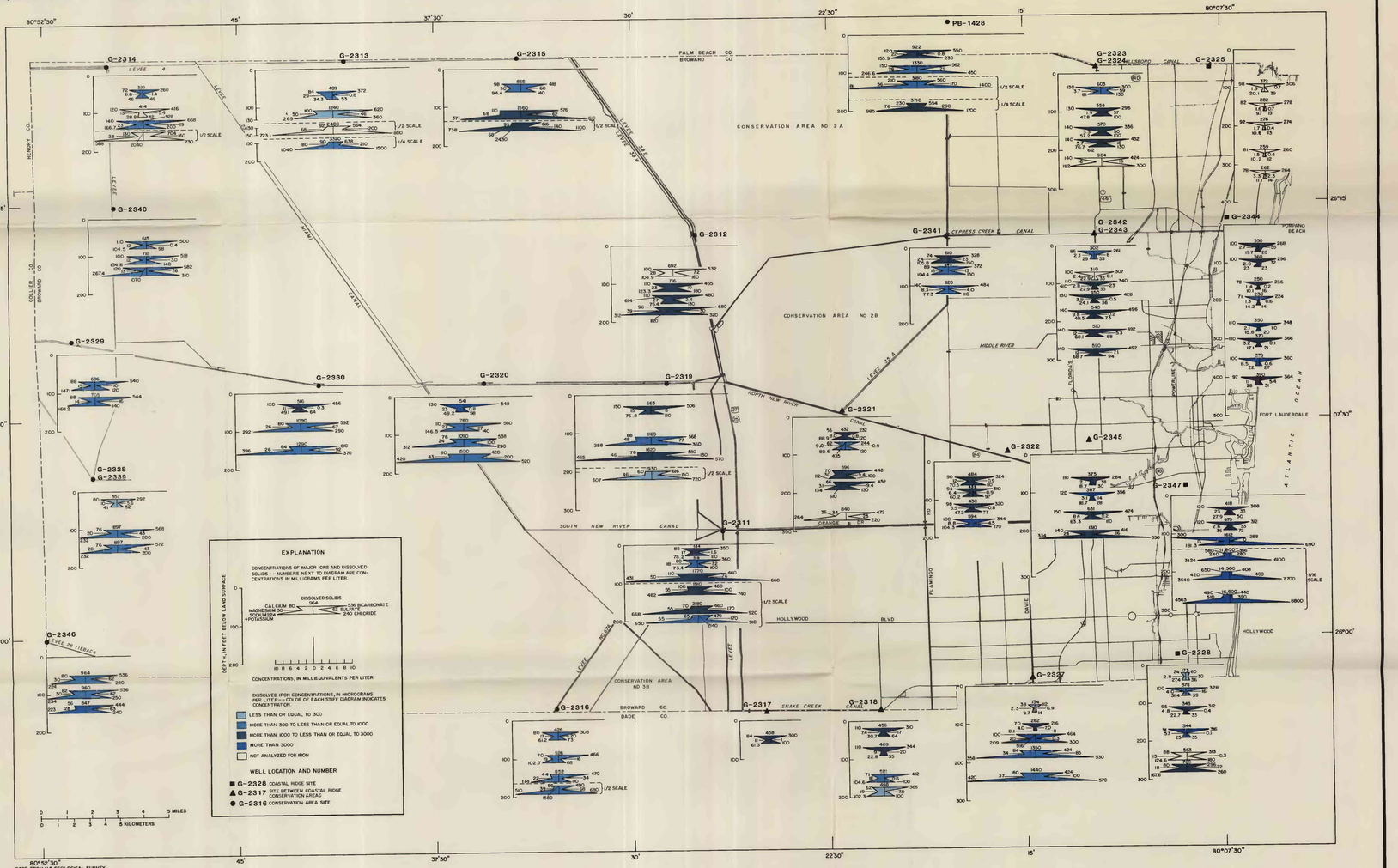

Figure 6.--Concentrations of major ions, dissolved solids, and dissolved iron in water from the surficial aquifer system.

CHEMICAL CHARACTERISTICS OF WATER IN THE SURFICIAL AQUIFER SYSTEM, BROWARD COUNTY, FLORIDA

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1987