Groundwater Trend Monitoring Network Results
(2009 to 2022)

Division of Environmental Assessment and Restoration
Watershed Monitoring Section
Florida Department of Environmental Protection
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Goal of the Groundwater Trend Monitoring Network

The purpose of the Groundwater Trend Monitoring Network is to examine water quality changes in groundwater systems over time. The Trend Monitoring Network consists of fixed monitoring stations across the state. The Trend Network provides long-term spatial and temporal information about water resources and potential changes from anthropogenic or natural influences, including extreme events (e.g., droughts and hurricanes).

Monitoring Design

The Groundwater Trend Monitoring Network consists of 51 fixed stations (Figure 1) used to quantify water quality trends in groundwater resources by obtaining chemistry and field data from confined and unconfined aquifers. DEP chose station locations, based on the USGS 8-digit drainage basins, to obtain a representative statewide distribution. Each quarter, staff collect water samples and field measurements at all stations in the Groundwater Trend Network. In addition, staff measure field analytes in the unconfined aquifer stations monthly. Please see the *Design Document* (Florida Department of Environmental Protection 2022) for more information on the Trend Network design.

Water Quality Trend Detection

DEP uses the Seasonal Kendall (SK) test for individual station water quality indicator trend detection. The Trend analysis protocols are provided in the document Status and Trend Monitoring Networks Trend Data Analysis Protocols (Florida Department of Environmental Protection 2024). For all trend analyses run, statistical significance is defined as when the probability of rejecting the null hypothesis of no change (probability value [p-value]) is < 5%.

When testing for trends using time series data, variations added by regularly spaced cycles make it more difficult to detect trends if they exist (Gilbert 1987). Regarding environmental data, Gilbert states that major cycles often are referred to as seasonality. To address this issue, Hirsch and Slack (1984) developed the SK test, which significantly reduces or removes the effect of seasonal cycles. DEP used the SK test to look for trends for each indicator at each groundwater trend site, performing the analyses with R software (R Core Team 2022) version 4.1.3 and the kendallSeasonalTrendTest function in the EnvStats R package (Millard 2013).

The SK test uses the median difference among all observations over the time series to calculate a Sen Slope (SS) and corresponding p-value (along with other statistics). The SS estimates the magnitude of change for a water quality indicator over the period of record. Reporting a trend as increasing or decreasing indicates the direction of the slope and does not necessarily indicate impairment or improvement in the analyte being measured. The *Design Document* (Florida Department of Environmental Protection 2022) contains a detailed explanation of the information goals for the Trend Monitoring Network, including data sufficiency and analytical methods.

Results

Of the 51 fixed Groundwater Trend Network stations, 46 have sufficient data for SK analyses. DEP conducts groundwater trend analyses using the SK test every 4 years for each station.

The latest analyses included data collected from January 2009 through December 2022. DEP's laboratory conducted the groundwater analyses on total rather than dissolved constituents. Water quality indicators examined included water temperature (Temp), specific conductance (SC), dissolved oxygen (DO), potential of hydrogen (pH), water level (WL), total dissolved solids (TDS), total organic carbon (TOC), total coliform (TC), total ammonia nitrogen (TAN), total nitrate+nitrite (NOx), total Kjeldahl nitrogen (TKN), total nitrogen (TN), orthophosphate (OPO4), total phosphorous (TP), total potassium (K), total sulfate (SO4), total sodium (Na), total chloride (CL), total calcium (CAL), total magnesium (Mg), turbidity (Turb), and total alkalinity (ALK). Appendix A provides additional information about water quality indicators.

Confined and unconfined groundwater trend station analysis outcomes are provided for each of the stations for each indicator tested in Table 1 and Table 2. Statewide summaries of these outcomes follow in Table 3 and Table 4.

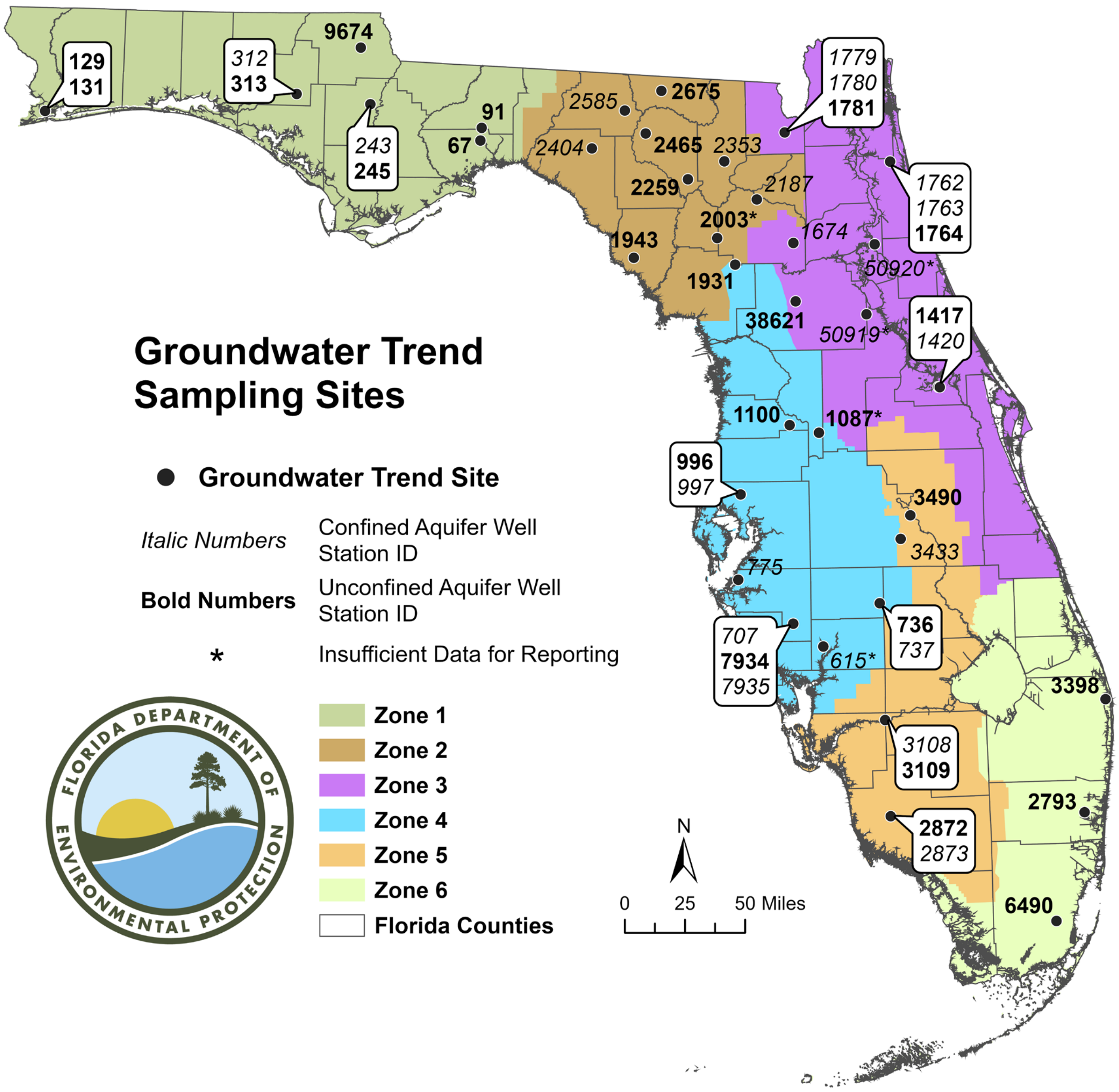

Figure 1. Groundwater Trend Network sampling sites

Table 1. Trends for specified analytes for 23 confined aquifer stations in the Groundwater Trend Monitoring Network

Note: A positive trend is indicated with a plus sign (+), a negative trend is indicated with a minus sign (-), insufficient evidence to determine a trend is indicated by a lower-case letter "o", and insufficient data to determine a trend is indicated by (ISD). Analyses are based on data collected between January 2009 and December 2022, with the following exceptions:
[1]For all stations, the period of record for ALK, CAL, CL, K, Mg, Na, NOx, SO4, TAN, TKN, TN, and TP reporting begins in October 2009.
[2]For stations 50919 and 50920, the period of record begins in June 2017.

Station	ALK[1]	CAL[1]	CL[1]	DO	K[1]	Mg[1]	Na[1]	NOx[1]	OPO4	pH	SC	SO4[1]	TAN[1]	Temp	TC	TDS	TKN[1]	TN[1]	TOC	TP[1]	Turb	WL
243	o	o	o	+	o	o	o	o	o	-	+	o	-	o	o	o	o	o	-	o	o	+
312	-	-	o	o	o	+	o	o	o	-	-	-	-	o	o	-	o	o	-	o	-	+
615	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD
707	-	+	o	-	o	+	o	o	-	o	+	+	o	+	o	+	o	o	o	-	o	+
737	o	-	+	-	o	+	+	o	-	o	o	o	o	o	o	o	o	o	o	-	-	o
775	o	+	o	-	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	+
997	-	+	+	-	o	+	+	o	o	o	o	+	o	o	o	o	o	o	-	o	+	o
1420	o	o	o	o	o	o	o	o	o	o	o	o	o	+	o	o	o	o	-	o	o	+
1674	o	o	-	+	o	o	o	-	+	-	-	o	o	+	o	-	o	-	o	o	o	o
1762	o	+	o	+	o	o	o	o	o	o	o	o	o	+	o	o	o	o	o	-	o	o
1763	o	o	o	+	o	o	o	o	+	o	o	o	o	o	o	o	+	+	o	o	o	o
1779	o	o	-	+	o	o	-	o	o	o	o	-	o	+	o	-	o	o	-	o	o	+
1780	o	o	o	o	o	o	o	o	o	o	o	o	-	+	o	o	o	o	-	+	o	+
2187	-	+	o	-	o	o	o	o	-	o	+	+	-	o	o	o	o	o	o	-	-	+
2353	+	+	+	+	+	+	+	o	+	o	+	o	o	+	o	+	o	o	o	+	o	+
2404	o	+	o	o	-	o	o	o	o	o	o	-	o	+	o	o	-	-	-	-	o	o
2585	+	+	o	o	o	o	o	o	+	o	o	-	o	+	o	o	o	o	o	o	o	o
2873	o	o	o	-	o	o	-	o	o	o	-	o	o	o	o	o	o	-	-	o	o	+
3108	+	-	o	-	-	-	-	o	o	+	o	-	-	-	o	-	-	-	-	o	-	o
3433	o	+	+	-	o	o	+	o	o	-	+	+	o	+	o	o	o	o	-	+	o	ISD
7935	o	+	-	o	o	+	-	o	o	o	-	-	-	+	o	o	-	-	-	o	o	+
50919[2]	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD
50920[2]	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD

Table 2. Trends for specified analytes for 28 unconfined aquifer stations in the Groundwater Trend Monitoring Network

Note: A positive trend is indicated with a plus sign (+), a negative trend is indicated with a minus sign (-), insufficient evidence to determine a trend is indicated by a lower-case letter "o", and insufficient data to determine a trend is indicated by (ISD). Analyses are based on data collected between January 2009 and December 2022, with the following exceptions:
[1]For all stations, the period of record for ALK, CAL, CL, K, Mg, Na, NOx, SO4, TAN, TKN, TN, and TP reporting begins in October 2009.
[2]For station 38621, the period of record begins in July 2010.
[3]For station 9674, the period of record begins in January 2012.

Station	ALK[1]	CAL[1]	CL[1]	DO	K[1]	Mg[1]	Na[1]	NOx[1]	OPO4	pH	SC	SO4[1]	TAN[1]	Temp	TC	TDS	TKN[1]	TN[1]	TOC	TP[1]	Turb	WL
67	o	+	o	-	o	o	o	o	-	-	+	o	o	o	o	o	o	o	o	-	o	ISD
91	o	+	o	-	o	o	o	+	-	-	o	o	-	+	o	o	o	o	-	o	o	o
129	o	+	o	o	-	+	o	o	o	-	o	o	-	o	o	o	o	-	o	o	o	+
131	o	+	+	o	o	o	+	o	o	-	+	-	o	+	o	+	-	-	o	-	o	+
245	o	o	+	-	o	+	+	+	o	-	+	-	o	+	o	o	o	+	-	o	-	+
313	+	o	+	-	o	+	+	-	o	-	+	+	-	+	o	+	o	-	o	o	-	+
736	-	-	+	-	-	o	+	o	-	-	-	-	+	o	o	-	-	-	-	-	o	o
996	+	+	o	-	o	-	-	o	o	+	+	-	-	o	o	+	+	o	+	+	+	o
1087	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD
1100	+	+	-	o	o	o	o	o	+	o	o	-	o	o	o	o	o	o	-	+	+	+
1417	o	o	o	o	o	o	-	o	o	+	o	-	o	+	o	o	o	o	o	o	o	+
1764	-	-	o	o	+	o	o	o	o	-	+	o	+	+	o	+	+	+	+	o	o	o
1781	-	-	o	o	o	-	o	o	-	o	-	-	-	+	o	-	o	-	o	-	o	+
1931	+	+	+	-	o	+	+	+	+	-	+	+	-	o	o	+	o	+	o	+	o	+
1943	+	+	+	-	o	+	+	o	o	o	+	-	o	+	o	+	o	o	-	o	o	o
2003	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD	ISD
2259	-	o	+	o	+	o	+	+	+	o	o	+	o	+	o	o	+	+	-	+	-	+
2465	-	-	-	o	o	-	-	-	o	+	-	-	o	+	o	-	o	-	-	o	o	+
2675	-	-	o	o	o	o	-	o	o	+	-	-	o	+	o	-	o	o	o	o	o	+
2793	o	-	-	+	o	-	o	o	o	o	o	-	-	+	o	-	-	-	-	o	-	-
2872	o	o	o	-	-	-	o	-	o	+	-	-	o	o	o	o	o	-	-	-	o	+
3109	-	-	-	-	-	-	-	o	-	+	-	-	-	+	o	-	o	o	o	o	o	o
3398	-	o	o	+	o	o	o	o	-	o	-	o	o	+	o	-	o	o	-	-	-	o
3490	+	o	-	-	o	o	-	o	o	o	-	o	-	+	o	o	o	o	-	-	o	o
6490	-	o	+	+	o	-	+	o	o	o	o	-	-	+	o	o	+	o	-	o	o	o

Station	ALK[1]	CAL[1]	CL[1]	DO	K[1]	Mg[1]	Na[1]	NOx[1]	OPO4	pH	SC	SO4[1]	TAN[1]	Temp	TC	TDS	TKN[1]	TN[1]	TOC	TP[1]	Turb	WL
7934	+	-	+	-	-	-	+	o	o	o	-	-	+	+	o	o	+	+	+	o	-	+
9674[3]	o	o	+	-	+	+	o	+	+	-	+	o	o	+	+	o	o	+	o	o	o	ISD
38621[2]	+	+	+	o	o	+	+	-	o	-	+	o	o	+	o	+	o	o	o	o	-	+

Table 3. Groundwater trend summary by analyte for confined aquifer stations (2009-2022)

Note: Percentages were based on sample sizes of 20 confined stations for all of the analytes with the exception of WL. Percentages for WL were based on 19 confined stations, as 1 station had insufficient WL data for analyses.

Analyte	Decreasing Trend (%)	Increasing Trend (%)	Insufficient Evidence of Trend (%)
Alkalinity	20.0	15.0	65.0
Calcium	15.0	50.0	35.0
Chloride	15.0	20.0	65.0
Dissolved Oxygen	40.0	30.0	30.0
Kjeldahl Nitrogen	15.0	5.0	80.0
Magnesium	5.0	30.0	65.0
Nitrate+Nitrite	5.0	0.0	95.0
Orthophosphate	15.0	20.0	65.0
pH	20.0	5.0	75.0
Potassium	10.0	5.0	85.0
Sodium	20.0	20.0	60.0
Specific Conductance	20.0	25.0	55.0
Sulfate	30.0	20.0	50.0
Total Ammonia Nitrogen	30.0	0.0	70.0
Total Coliform	0.0	0.0	100.0
Total Dissolved Solids	20.0	10.0	70.0
Total Nitrogen	25.0	5.0	70.0
Total Organic Carbon	55.0	0.0	45.0
Total Phosphorus	25.0	15.0	60.0
Turbidity	20.0	5.0	75.0
Water Level	0.0	57.9	42.1
Water Temperature	5.0	55.0	40.0

Table 4. Groundwater trend summary by analyte for unconfined aquifer stations (2009-2022)

Note: Percentages were based on sample sizes of 26 unconfined stations for all of the analytes with the exception of WL. Percentages for WL were based on 24 confined stations, as 2 stations had insufficient WL data for analyses.

Analyte	Decreasing Trend (%)	Increasing Trend (%)	Insufficient Evidence of Trend (%)
Alkalinity	34.6	30.8	34.6
Calcium	30.8	34.6	34.6
Chloride	19.2	42.3	38.5
Dissolved Oxygen	50.0	11.5	38.5
Kjeldahl Nitrogen	11.5	19.2	69.2
Magnesium	30.8	26.9	42.3
Nitrate+Nitrite	15.4	19.2	65.4
Orthophosphate	23.1	15.4	61.5
pH	42.3	23.1	34.6
Potassium	19.2	11.5	69.2
Sodium	23.1	38.5	38.5
Specific Conductance	34.6	38.5	26.9
Sulfate	57.7	11.5	30.8
Total Ammonia Nitrogen	38.5	11.5	50.0
Total Coliform	0.0	3.8	96.2
Total Dissolved Solids	26.9	26.9	46.2
Total Nitrogen	30.8	23.1	46.2
Total Organic Carbon	46.2	11.5	42.3
Total Phosphorus	26.9	15.4	57.7
Turbidity	26.9	7.7	65.4
Water Level	4.2	58.3	37.5
Water Temperature	0.0	73.1	26.9

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Appendix A. Water Quality Indicators

Alkalinity is a measure of the buffering capacity of water to the addition of an acid. Anions form in groundwater consisting of bicarbonates, carbonates, phosphates, sulfides, silicates and some organics. The primary anion is bicarbonate. The analysis of alkalinity is reported as milligrams per liter of $CaCO_3$ (calcium carbonate).

Calcium is a metal that occurs naturally in Florida's groundwater through the solution of calcite and dolomite. Calcium concentrations in groundwater are a direct result of contact time of the water with underground formations. The analysis of total calcium is reported as milligrams per liter.

Chloride, when found in groundwater, is typically conservative chemically and does not participate in mineral precipitation, biological, or microbial processes. Two major sources of chloride are rainfall deposition of marine aerosols and saltwater encroachment. The analysis of chloride is reported as milligrams per liter (mg/L). The Environmental Protection Agency (EPA) has set a Secondary Drinking Water Standard for chloride of 250 mg/L.

Dissolved oxygen (DO) is a measure of the saturation of oxygen in water. Its concentration in water is dependent on both temperature and pressure. DO in groundwater is different in comparison to DO in surface water which is exposed to the atmosphere. Freshly recharged groundwater has higher concentrations of DO than groundwater that has resided in aquifers for a long time. The analysis of DO is reported as percent saturation.

Magnesium is a metal. Major sources of magnesium in Florida's groundwater are derived naturally from sea water and through the solution of dolomite and from the ionic exchange with magnesium rich clay minerals. Magnesium concentrations in groundwater are a direct result of contact time of the water with underground formations. The analysis of magnesium is reported as milligrams per liter.

The **potential of hydrogen** (pH) is measured in standard units (SU) and ranges between zero (very acidic) to 14 (very basic). For example, the pH of lemon juice is approximately two SU. Water with a pH of seven SU is considered neutral. The pH measurement in groundwater is highly influenced by the concentration of dissolved carbon dioxide (CO_2) gas that can lower pH. Interactions of groundwater with bicarbonates, phosphates, and nitrates can increase pH. Concentrations of pH are also influenced by sources of water pollution such as runoff and wastewater discharge. The groundwater criterion for pH has been established by the Environmental Protection Agency's Secondary Drinking Water Standard for pH between 6.5 and 8.5 SU. Values falling outside this range do not meet the secondary standard.

Total Kjeldahl Nitrogen (TKN) measures the sum of ammonia and organic nitrogen in water. The nitrogen compounds encourage growth of algae and eutrophication leading to anoxic conditions. TKN is one component of total nitrogen. Criteria for total nitrogen and other nutrients in surface water have been adopted into numeric nutrient standards for the State of Florida. Due to the complexity of nutrients and how they are evaluated, please visit the Numeric Nutrient Criteria website for more information.

Nitrate is composed of one nitrogen and three oxygen atoms (NO_3) and **nitrite** is composed of one nitrogen and two oxygen atoms (NO_2). The important sources of nitrogen for groundwater come from organic nitrogen, **ammonia** (NH_4), nitrate, and nitrite. These compounds are related by oxidation and reduction processes through inorganic and microbial processes. Additionally, other sources of nitrogen are derived from infiltration of surface water containing storm water runoff from land areas containing fertilizers or from animal and human wastes. The pH of the water influences which forms are more likely present. Nitrate and Nitrite are reported as N (nitrogen) in milligrams per liter (mg/L). The EPA has set a drinking water standard for nitrate at 10 mg/L and a standard for nitrite at 1 mg/L. Since the toxicity for nitrate and nitrite together is additive, the EPA set a standard for both at 10 mg/L (Please see the Inorganic Contaminants Standards webpage).

Total Nitrogen (TN) measures the sum of nitrate, nitrite, and Total Kjeldahl Nitrogen in water. The nitrogen compounds encourage growth of algae and eutrophication leading to anoxic conditions. While there are no drinking water quality standards for TN in groundwater, the Environmental Protection Agency (EPA) does have drinking water standards for nitrate (10 mg/L), nitrite (1 mg/L), and the combination of the two (10 mg/L). Please visit the Inorganic Contaminants Standards web page for more information. Additionally, surface water criteria for TN apply to spring vents. Due to the complexity of nutrients and how they are evaluated, please visit the Numeric Nutrient Criteria website for more information.

Orthophosphate is represented as PO_4^{-3} and is the dissolved form of phosphorus in groundwater. Orthophosphate is evaluated in a filtered sample. The most important sources of phosphate in Florida are the phosphate-bearing sediments found throughout in the Hawthorn Group. These are carbonate-fluorapatite [$Ca_5(PO_4,CO_3)_3F$] and carbonate-hydroxylapatite [$Ca_5(PO_4,CO_3)_3(OH)$]. In acidic environments, orthophosphate is released into solution and is freely available for uptake by plants and animals. In alkaline environments, phosphoric and carbonic acids are neutralized, and orthophosphate forms complex precipitates, therefore removing it from solution and incorporating it back into limestone sediments. Orthophosphate is reported as P (phosphorus) in milligrams per liter.

Phosphorus is necessary for many life processes and is present in dissolved and mineral forms. The major sources of phosphorus are the phosphate rich clays overlying the Floridan Aquifer; the most significant aquifer in the state of Florida. Total phosphorus (TP) is reported in milligrams per liter. There are no TP criteria for groundwater. The criteria for TP concentrations in surface water have been adopted into numeric nutrient standards for the State of Florida. Due to the complexity of nutrients and how they are evaluated, please visit the Numeric Nutrient Criteria website for more information.

Potassium is a metal. It is primarily derived from sea water and potassium rich clays.

Sodium is a metal. The main source of sodium is from the mixing of sea water and groundwater near the coast in the salt water interface zone. A secondary source is from deep connate saline water that originated from ancient oceans. Sodium is reported as total sodium in water in milligrams per liter (mg/L). The State of Florida has set a secondary drinking water standard for sodium at 160 mg/L. The standard was set to protect individuals that are susceptible to sodium sensitive hypertension or diseases that cause difficulty in regulating body fluid volume (Please see the Inorganic Contaminants Standards webpage).

Specific conductance is a measurement of the electrical conductivity of water at 25 degrees centigrade. The specific conductance of water is measured in microsiemens (µS).

Sulfate is composed of one sulfur atom and four oxygen atoms (SO_4^{-2}). The dissolution of gypsum and anhydrite is the most important natural source of sulfur in Florida's aquifers. Sulfate is reported as SO_4^{-2} in milligrams per liter (mg/L). The Environmental Protection Agency (EPA) has set a Secondary Drinking Water Standard for sulfate of 250 mg/L.

Total dissolved solids (TDS) is a measurement of the total mass of ionic compounds in water. Two major sources of TDS are saline waters and ionic rich carbonate aquifers. TDS is reported in milligrams per liter (mg/L). The State of Florida (Florida Administrative Code 62-550) set a Secondary Drinking Water Standard for TDS of 500 mg/L.

Total organic carbon (TOC) is present in aquifer systems as humic substances derived from the microbial decay of leaf litter, soil organics, and soil biota waste products. In aerobic conditions, microbial activity can reduce TOC concentrations, however in anaerobic conditions, microbial activity can be limited and TOC concentrations remain unchanged. TOC is reported in milligrams per liter (mg/L).

Temperature is a measure of the molecular activity within a solution measured against a reference scale. Temperature varies greatly with seasonal conditions and within climatic and microclimate zones. Temperature is typically measured in degrees Celsius.

Total coliforms consist of all sources of bacteria including soil bacteria and those bacteria found in the gut and intestinal tracts of both animals and man. They enter waterways through direct discharge or via wastewater treatment systems. Sources include septic tank system discharges, wastewater treatment plant discharges, sewage collection system overflows, and agricultural and urban runoff. Rain events may re-suspend bacteria or wash them into nearby streams or canals. The State of Florida has set a single sample maximum for total coliform of four colony counts per 100 milliliters of fluid.

Turbidity is a measurement of the clarity of a solution. High turbidity causes water to appear cloudy or opaque. Sources contributing to high turbidity include the presence of small particulates of clay, silt, or other materials. These particulates may serve as points of attachment for metals, bacteria, or other compounds.

Water Level is a measurement of the level of the water within a monitoring well as compared to the land surface elevation or the distance between the level of the water within the well and the measuring point elevation. The measuring point is most commonly located at the top of the well casing.