

Groundwater Level Conditions for the Upper Floridan Aquifer Based on Percentile Ranks Pilot Study for May, 2010

(Florida Salinity Network Workgroup, September, 2015)

Introduction

The Salinity Network Workgroup (SNW) was authorized by the Florida Water Resources Monitoring Council in 2011. The SNW consists of members from the Florida Department of Environmental Protection (DEP) including the Florida Geological Survey (FGS), Florida's five water management districts (WMDs), federal agencies, counties, universities, volunteer monitoring groups, and the private sector. The SNW coordinates the statewide monitoring efforts of the corresponding Salinity Monitoring Network, which is a collaboration of existing monitoring networks. This network is currently network of wells, but is open to expanding to springs and surface-water sites. Because the network consists of existing networks, its operation requires no additional funds from the citizens of Florida.

From the late 1990s and continuing through 2011, Florida experienced frequent and extended periods of below normal rainfall, with resulting declines in groundwater levels (GWLs) in the Upper Floridan aquifer (UFA). With declining GWLs, saltwater encroachment can become a concern, especially in the coastal regions. Although the lowering of GWLs does not necessarily mean that saltwater encroachment will happen, it does increase the potential for it to occur. Encroachment can occur horizontally from the lateral movement of saltwater along our coasts, and upward vertical movement of saltwater in our aquifers near our coasts. It can also occur from upward vertical migration of saline water found in the interstitial pore spaces of deeper rocks in the interior of Florida.

The UFA underlies the entire state and it supplies greater than 60% of groundwater used by Floridians. For this reason it is important to periodically report on the conditions of the aquifer. In terms of quantity, conditions can be represented by changes to GWLs in the aquifer. GWL elevations are referenced to a vertical datum, which can be generalized as feet above mean sea level (MSL).

The balance between groundwater recharge, storage, and discharge controls groundwater levels in an aquifer. Physical and hydraulic properties of the aquifer and climatic conditions affect this balance. GWLs in Florida show a natural cyclic pattern of seasonal fluctuation, typically rising in the wet season and falling during the dry season. The magnitude of GWL fluctuations can vary from season to season and year to year in response to varying climatic conditions. The magnitude of GWL fluctuations also varies in response to multi-year and decadal climatic cycles. GWLs decline during extended periods of low rainfall, and GWLs rise following periods of high rainfall. In parts of Florida, GWLs can follow the surface topography in a subdued form.

GWLs are often expressed as potentiometric levels. Potentiometric maps, or potmaps for short, are extremely important for geologists, hydrologists, and engineers who use the detailed GWL maps for modelling purposes. Currently, the FGS works with each of the five WMDs to produce statewide potmaps of the UFA.

Across the state, GWLs in the UFA can vary naturally by over 100 feet. This presents a challenge in objectively describing if a GWL is higher or lower than normal. In order to address this challenge, governmental agencies in Florida developed a method for reporting GWLs using percentile ranks. As defined by Agresti and Franklin (2009) a percentile is a value such that x percent of the observations fall below or at that value. As a simplified example, suppose a GWL monitoring well has 114 measurements over a span of 20 years. Suppose that a GWL value of 58 feet was collected in May, 2010. When describing GWL conditions for May 2010, the GWL measurement is assigned a percentile rank (PR) of 86 because of the 114 GWLs, 86% of them are less than (or equal to) 58 feet, while 14 percent of the GWL observations for that well are greater than 58 feet.

Figure 1 displays GWLs in an imaginary well as: (1) feet above MSL and (2) as PRs for the period January, 1980 through May, 2010. Dots represent GWLs obtained every other month in feet above MSL (left vertical axis) and squares depict GWL PRs (right vertical axis). The maximum GWL occurred in March, 2007, while the lowest occurred in March, 2002 (open boxes). In the figure, the variability of GWLs is much less than PRs. The range of GWLs is approximately 40 feet, while the range of the PRs is 100. Note during the driest time period (2000-2005), GWLs and PRs fluctuated less, and give the appearance of being measured at a relatively higher frequency.

Figures 2 and 3 show how the GWL conditions can be displayed regionally both as a potentiometric surface and as PRs. The contours on the potmap (Figure 2) represent the GWL surface of the UFA, relative to MSL for the specific time period (May, 2010) in the St. Johns River Water Management District (SJRWMD). The figure has been cut out of a southeastern United States potmap of the UFA generated by the USGS (Kinnaman and Dixon, 2011). The dots on the map represent individual well locations. Data presented as contours in the pot surface map can potentially be more difficult to understand than data presented as PRs. For example, knowledge of historic conditions is required in order to understand if an elevation representing a GWL of 65 feet is high or low. PRs answer this question by presenting the GWL data relative to other GWL measurements at the same well. The PR map (Figure 3) displays GWLs in terms of PRs for the SJRWMD for May, 2010. It was produced by the SJRWMD (2010). Pink, red, and yellow dots represent GWLs with lower PRs, green dots represent GWL with normal PRs, while blue, and black dots represent GWLs with higher PRs.

Typically, many more wells are used to map the potsurface than are used to determine the PRs. Wells used to generate the potsurface only need one measurement for a specific time period. Those needed to produce PRs require a long period of record (POR) that encompasses the entire range of high and low GWLs.

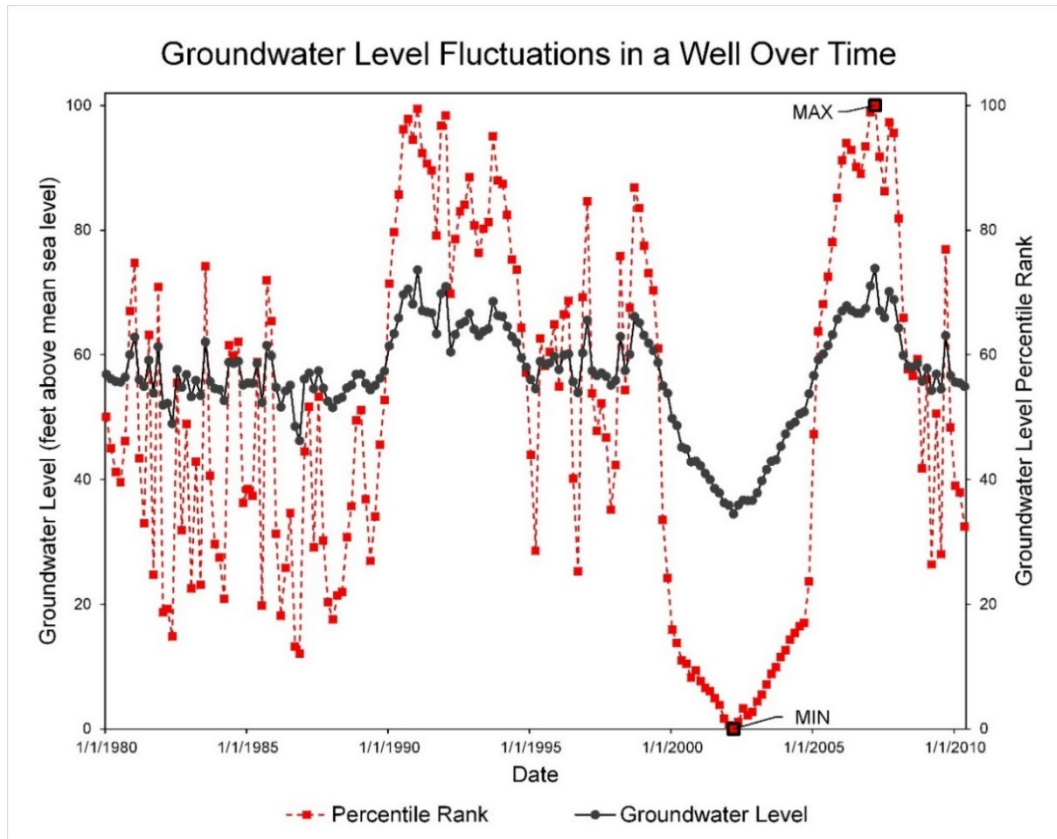


Figure 1. Hypothetical groundwater levels in feet (MSL) and in percentile ranks in an imaginary well tapping the Upper Floridan aquifer (January, 1980 through May, 2010).

GWL Monitoring Networks in Florida

Many of the participating agencies of the SNW operate and maintain GWL monitoring networks. Data from the networks are used for a variety of purposes. They are used to evaluate the response of aquifer systems to changes in weather and groundwater withdrawals (GWWs), to meet growing water supply needs, to evaluate trends, and to determine the effectiveness of water management programs. In addition long-term, systematic measurements of GWLs provide data needed to assess current hydrologic conditions and to identify how they vary over time. The Suwannee River Water Management District (SRWMD), the SJRWMD and the Southwest Florida Water Management District (SWFWMD) each have many UFA monitoring wells with adequate data for producing PR maps. There are relatively fewer UFA wells with sufficient data available in the Northwest Florida Water Management District (NFWFMD) and the South Florida Water Management District (SFWMD). Although the UFA underlies the entire state, in the westernmost Florida panhandle (e.g., two westernmost counties) and in south Florida, it dips deeper beneath land surface. In both regions, groundwater is generally withdrawn from shallower aquifers and only a minor proportion is taken from the UFA. As a result, there exist only a few wells tapping the UFA, with a sufficient data and a long enough period of record (POR), for the generation of PRs for GWLs.

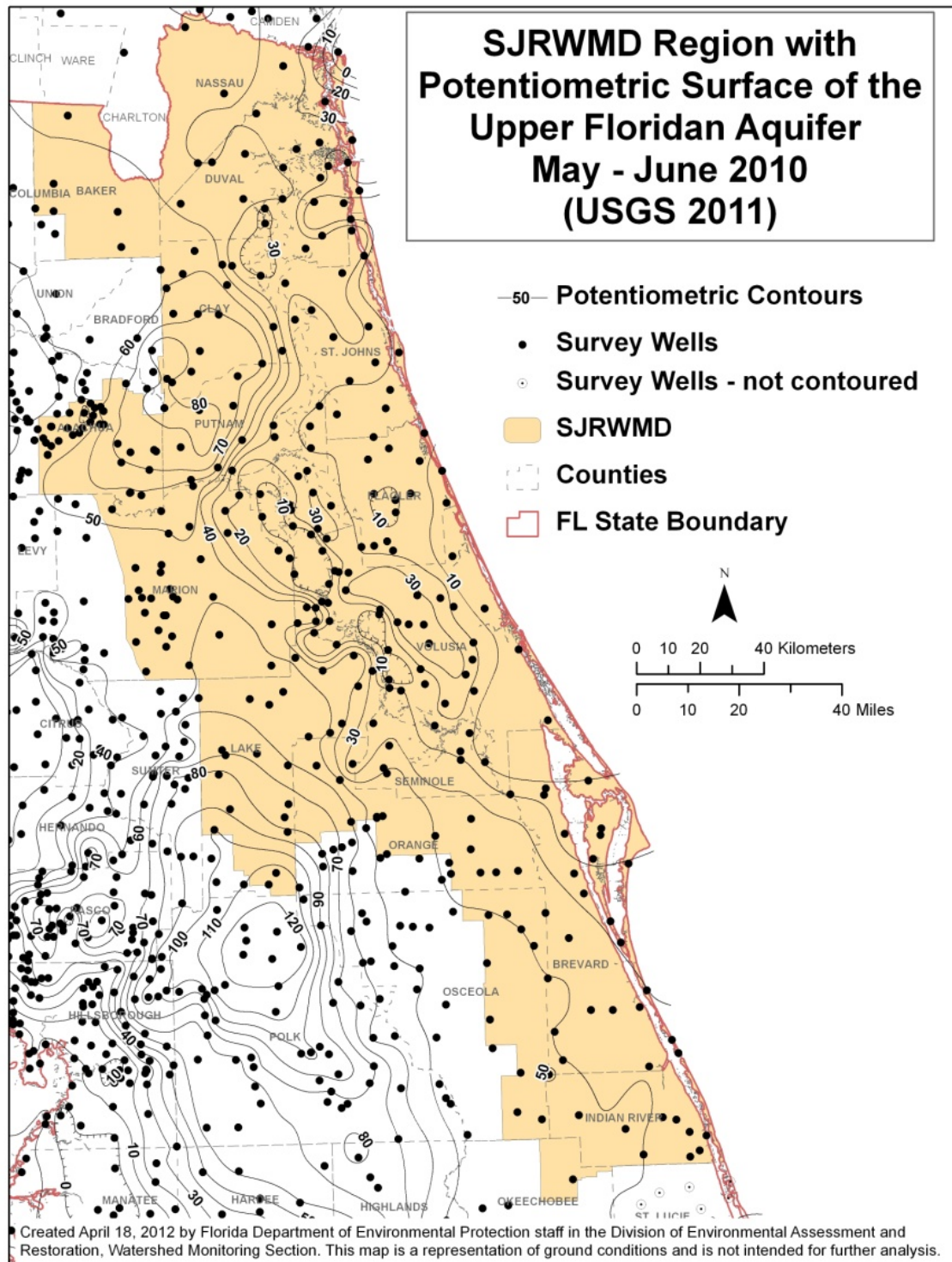


Figure 2. Potentiometric surface map of the Upper Floridan aquifer for in the St. Johns River Water Management District, May-June, 2010 (Modified from Kinnaman and Dixon, 2011).

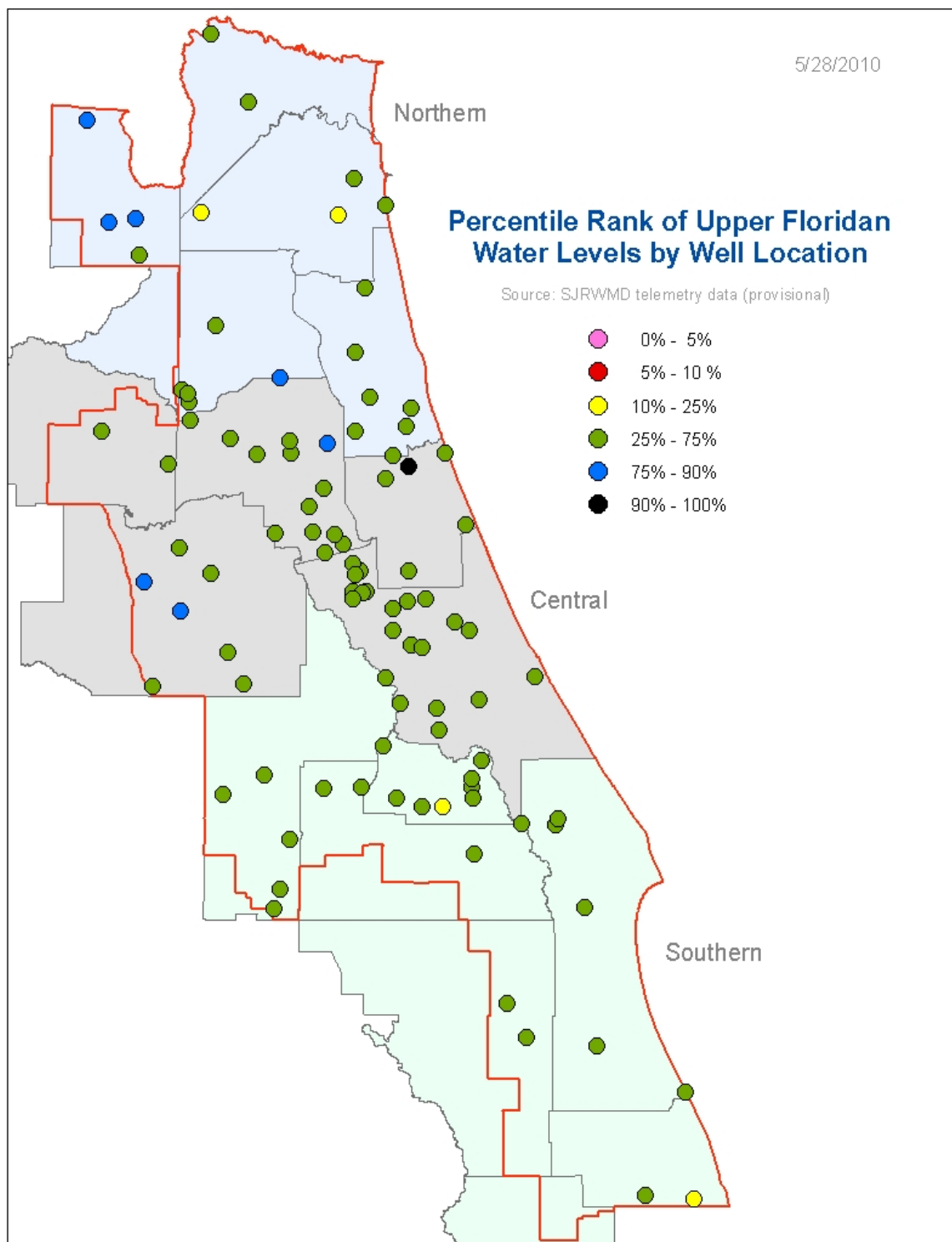


Figure 3. Percentile ranks of GWLs in the Upper Floridan aquifer by well location, May, 2010 in the St. Johns River Water Management District.

Development of the State of Florida Groundwater Level Condition Percentile Ranking Reports

The SNW believes that percentile ranks are an effective way to relay GWL conditions to the citizens of Florida. However, in order to generate meaningful PRs, GWL data collected over many years are required to ensure that the POR encompasses a representative historical range of water level fluctuations and to track temporal trends. The SNW recommends that a monitoring well should have a POR going back to at least 1980. Unfortunately only a minor number of the UFA wells have a POR going back that far. For this reason each SNW participant selects their own POR that provides for the maximum number of wells encompassing the longest POR and historical range of groundwater level fluctuations as possible.

The SNW participants propose that statewide GWL PR maps and corresponding reports should be periodically generated, and has developed guidelines for producing PR maps (Appendix A). However, three of Florida's WMDs, the SRWMD, the SJRWMD, and the SWFWMD, already produce UFA GWL conditions reports for the UFA in their respective regions, based on PRs. The three sets of WMD reports are similar but vary in what they specifically describe in the reports. Rather than have the three WMDs modify their reports that are already accepted by the public, the SNW participants agreed to collectively and periodically generate composite, statewide GWL conditions reports for the UFA based on the individual reports. The remaining entities use guidelines generated by the SNW.

Some agencies obtain continuous GWL measurements (e.g., every 15 minutes). Continuous measurements require their own unique set of procedures in order to determine a GWL PR for the month. For example they may take the mean of the daily averages for the month, or possibly the mean GWL on a specific day of the corresponding month. The choice is theirs. Appendix B discusses supplemental information regarding the development and use of GWL PR maps by each of SNW participant. To produce statewide maps, participants send spreadsheets to DEP that contain the location of their wells (e.g., latitude and longitude) plus the corresponding PRs recorded to the tenth of a PR increment. DEP then transfers the locations and PRs into a statewide map and prepares a corresponding draft report. The draft report is reviewed by participants before the final report (map and text) is produced.

Figure 4 is a composite map of GWL percentile rankings by Florida's WMDs for May, 2010. Methodology used for calculating PRs varied among the different entities. Each symbol is color-coded and represents the location of a UFA monitoring well and the PR for each well during the date indicated on the map. Although PRs are calculated to the 0.1 PR increment, they are always rounded up to the next integer (Triola, 1998). For the map in Figure 4, red diamonds represent PRs $\leq$ the 10th percentile. That is, the (rounded-up) PR at the corresponding well site is 10 or less. Orange boxes represent PRs from 11 to 24, green circles represent PRs from 25 to 75, light-blue triangles represent PRs from 76 to 89, and dark-blue stars represent PRs 90 and greater. For May 2010, the most abundant symbols are green circles. This means that groundwater conditions in the UFA were generally in the normal range during that time period.

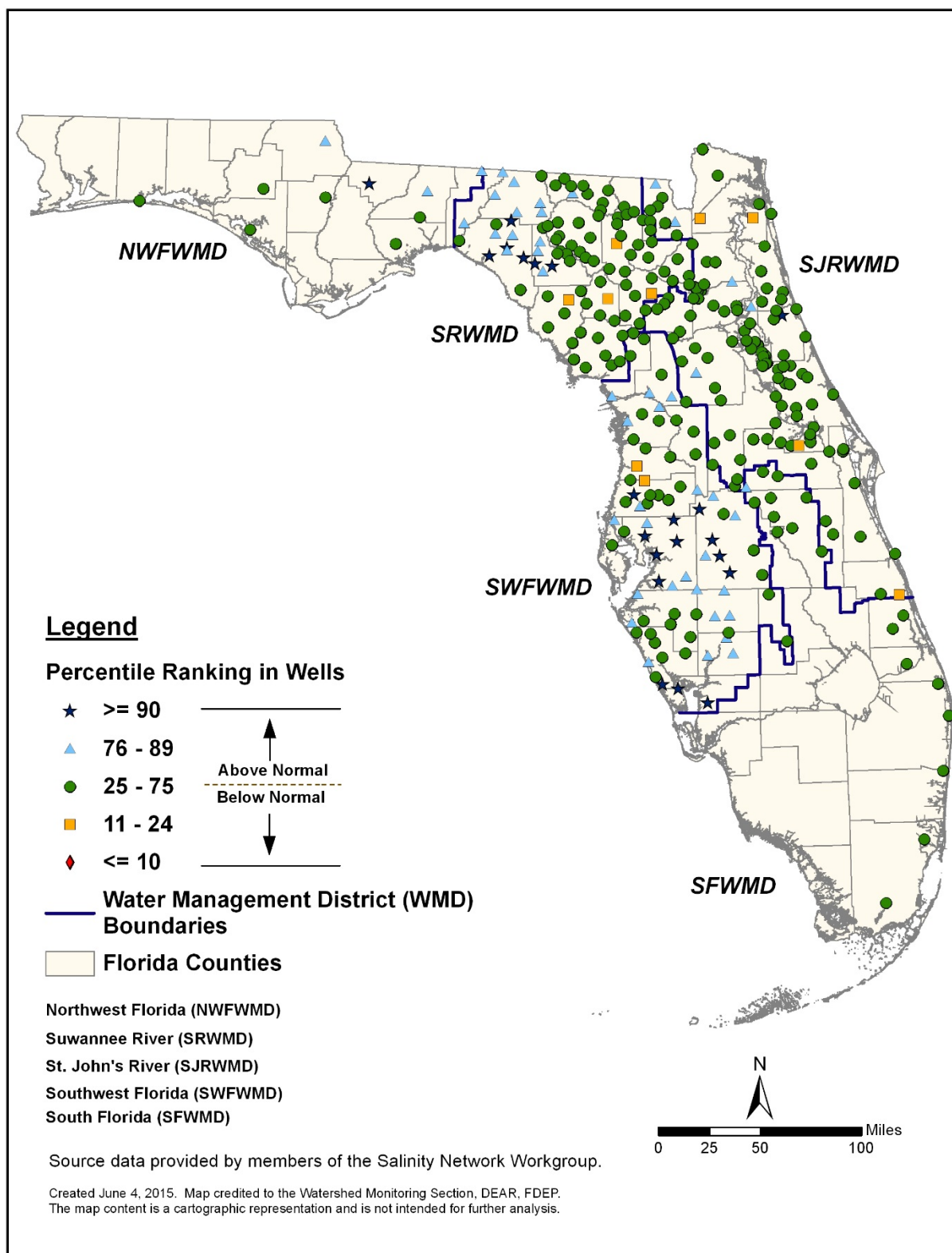


Figure 4. Groundwater level conditions in the Upper Floridan aquifer in Florida in percentile ranks, May 2010.

Both GWL potmaps and PR maps are important for communicating the groundwater conditions. The SNW and the FGS are working cooperatively to potentially display the two sets of maps for May and September of each calendar year.

The production of this report could not have occurred without the efforts of many of the staff at the participating entities of the SNW. A list of the individuals who contributed to the development of the PR index is found in Appendix C.

References Cited

- Arresti, A. and Franklin, C, 2009, Statistics: the art and science of learning from data, 2nd ed.: Upper Saddle River, NJ, Pearson/Prentice Hall, 767 p.
- Kinnaman, S.L. and Dixon, J.F., 2011, Potentiometric Surface map of the Upper Floridan aquifer in Florida and in parts of Georgia, South Carolina, and Alabama, May-June 2010: U.S. Geological Survey Scientific Investigation Map 3182.
- St. Johns River Water Management District Percentile Rank of the Upper Floridan Water levels by well location, May, 2010: St. Johns River Water Management District Provisional Map, May, 2010.
- Triola, M.F., 1998, Elementary Statistics, 7th ed.: Reading, MA, Addison-Wesley, 791 p.

Appendix A. Salinity Network Workgroup Guidelines for Percentile Ranking Index Methods

Percentile Ranking Index Equation. Several PR equations are available in the literature. Equation 1 is available in many software packages including Microsoft Excel and for this reason, it is the recommended equation. PRs are always rounded up to the next integer.

$$PR(x) = [(\# \text{ OBS} < x) / (n-1)] \times 100 \quad (1)$$

In the following set of numbers arranged from smallest to largest, what is the PR of $x = 23$?

21, 22, 22, **23, 23**, 24, 25, 28, 37, 45, 48, and 67

There are 12 observations ($n = 12$) and the number of observations ($\# \text{ OBS}$) less than 23 equals three. Considering round up,

$$PR(23) = [3/11] \times 100 = 0.273 \times 100 = 27.3; \text{ rounded up} = 28.$$

The percentile rank of 23 equals 28.

Observation used to determine PR. If multiple GWLs are obtained within a month, the monthly mean or median is recommended. However, other measurements are acceptable and the observation used needs to be conveyed to the SNW.

Color scheme.

The recommended color scheme for PRs is:

≤ 10	Red Diamonds
11 to 24	Orange Squares
25 to 75	Green Circles
76 to 89	Light-Blue Triangles
≥ 90	Dark-Blue Stars

If a groundwater level is minimum for the POR, a red diamond inside a square box is used.

If a groundwater level is maximum for the POR, a dark-blue star inside a square box is used.

Period of Record. The recommended POR is 1980 to present. However, since relatively few Salinity Network wells have a POR for this length, each participating agency determines its own POR. To the extent practical, their POR covers the historical maximum and minimum GWLs.

Continuous Groundwater Records versus Discrete Measurements. Participating agencies who use continuous water level recorders make their own determination regarding monthly central tendencies for groundwater levels to be converted to percentile ranks.

Minimum Percentage of Missing Observations. The recommended number of missing monthly values is 5% or less. However, participating entities may include wells with a higher percentage, but must clarify for the statewide GWL PR map.

Seasonality and Climate-Related Effects. At the current time, the effects of seasonality on water levels are ignored, other than simply indicating when wet and dry seasons occur. In the future, if the effects of changing climatic conditions are quantified, the effects will be discussed in the texts associated with statewide GWL PR maps.

Appendix B. Supplemental Information

Appendix B1. Northwest Florida Water Management District

The NFWFMD reviewed UFA wells with long-term water level data. Although there are a number of wells with more than 20 years of record, there are significant data gaps corresponding to periods of limited monitoring activities. To achieve the goal of creating a map that shows UFA PRs across the District, it was necessary to include wells with greater than 5% missing values. The criteria used for inclusion in the PR analysis were: (1) UFA well that is not actively pumped, (2) at least 25 years of GWL data, and (3) less than 25% missing quarterly or monthly GWL values during the preceding 25-year period. For May, 2010 the POR used in the analysis is 1986-2010. The NFWFMD enhanced the spatial and temporal resolution of its water level monitoring network beginning in 2004. As additional data are collected, the criteria for inclusion in the PR analysis are anticipated to be revised to reduce the number of allowable

missing values. Although a limited number of UFA wells (nine) have sufficient long-term data for PR analysis, there are many more wells that are used in the NFWFMD to create seasonal and annual potentiometric surface maps.

Many monitoring wells have varying frequencies (daily, monthly, or quarterly) of GWL measurements over the POR. For such wells, water level data was reduced to either a monthly or a quarterly frequency to minimize the potential for temporal bias. When monthly frequencies were used, the value nearest to the 15th day of each month was selected. When quarterly frequencies were used, values nearest to February 15th, May 15th, September 15th, and November 15th of each year were selected. When hourly or continuous water levels were available, the daily maximum water level for the 15th of the month was used in the analysis. All groundwater elevations were converted to feet above MSL.

Percentiles were calculated in Excel using the entire period of record. For the May, 2010 measurement, the POR was extended through 2014. This effort maximized the likelihood that the percentiles capture the full range of historical GWL values. The PR values were then calculated for May 2010 values.

Appendix B2. Suwannee River Water Management District

The SRWMD uses the guidelines found in Appendix A. The SRWMD uses approximately 100 UFA wells. All but three have a POR of over 25 years and all have less than 25% missing values. The frequency of measurement has varied over the years. Virtually all currently have continuous monitoring in place that measure GWLs at least every hour. For the few remaining manually-read wells, a single value, generally from the first two weeks of the month is used for PR calculations. The daily mean GWL from the 27th of a given month are used for PR calculations from continuously monitored wells.

Appendix B3. St. Johns River Water Management District

At the end of each month, SJRWMD produces an UFA groundwater level report that evaluates the status of aquifer storage and changes in water levels over time. GWL data over two to three decades are required to compile a record that encompasses the historical range of water level fluctuations and to track temporal trends.

Wells with monthly water level records starting around 1980 provide a satisfactory well sample that includes periods of historical high and low groundwater levels. An examination of UFA water levels using PRs indicates that the highest water levels across the District occurred in March, 1998. The lowest water levels occurred in June, 2000. The District's "normal" wet season is June through September with UFA water levels often rising (with a lag time) into late fall or early winter. The lowest UFA water levels normally occur in May just before the wet season begins.

Since the highest and lowest UFA levels occurred in 1998 and 2000 respectively, a data set using telemetered water levels with data since 1998 was utilized to report monthly changes in UFA water levels based on PRs. The median monthly value from each well is used for the calculations. The monthly report is intended to graphically rank where current UFA levels are with respect to period of record highs (March, 1998) and lows (June, 2000) and to map the ranks for wells across SJRWMD. UFA wells selected for inclusion into the report have a minimum period of record from 1998 to present with less than 5% of missing monthly data. The wells also have to be in the SJRWMD telemetry recorder network so that wells with near real-time data can be included in the report. As of January, 2015 the monthly report utilizes 107 wells.

PRs are calculated by ranking all the GWLs from lowest to highest and determining the percentage of observations below the observation of interest for the current month. The PR method is an effective way to compare observations by reducing the effects of outliers and provide an easily interpretable relative standing. “Normalizing” the water levels to percentile ranks allows one to compare and track District-wide and regional changes.

Appendix B4. Southwest Florida Water Management District

To aid the monitoring and management of water resources in the SWFWMD, a number of district reports are produced at weekly and monthly intervals that characterize present-day water-level elevations over the SWFWMD in relation to their historical elevations. SWFWMD staff have drawn upon the available data to develop estimates of historical GWLs occurring within the counties encompassed by the district. The SWFWMD has cooperatively collected GWLs with the USGS, Tampa Bay Water, and other government agencies. Much of the earliest record, dating from the 1930s through the 1960s was collected by the USGS. The record exists mostly as instantaneous, manually collected data, and as daily maximum values condensed from hourly recorder data. The SWFWMD became more actively involved in data collection in the 1970s and forward. Similar to USGS data from the earliest periods, the SWFWMD records consists of instantaneous measurements and hourly values reported as daily maximums. The District's Supervisory Control and Data Acquisition (SCADA) system for near-real-time electronic data collection also became an important tool for collecting GWL data beginning in 1989. Most of the District's GWL data are now collected by Hydrologic Data Section staff, using the SCADA system, data recorders and periodic manual readings.

Of greatest interest for GWL reporting purposes in the SWFWMD are wells representative of the UFA and intermediate aquifers. The UFA and intermediate aquifers are the preferred source of good quality groundwater for domestic, commercial and agricultural uses. GWLs rise and fall seasonally due to the annual cycle of rainfall and water demands, with the highest GWLs typically observed in September or October following the wet season (June through September) in central Florida, and seasonal lows occurring in April and May at the end of the dry season (October through May). Seventy-seven wells were selected for weekly reporting of GWLs, and monthly summarization in the SWFWMD's Hydrologic Conditions Report. Wells were selected that had at least 20 years of record, and that together proportionally represented the District's

total area. Nineteen percent of the 77 wells used, have GWL data covering a 50-year (or more) period; 43 percent have GWL data covering a 40-year period; 88 percent have GWL data covering a 30-year period; and 100 percent have GWL data covering a 20-year period. UFA wells are preferred. However, in some very limited areas of the southern SWFWMD, a few UFA wells also partially penetrate the intermediate aquifer system. They were selected because they had long POR and were the only wells with available data record in the area.

For the purpose of consistency in statistical calculation and reporting, daily maximum values are used. Data from well sites with hourly and sub-hourly recorder frequency are reduced to a single maximum daily value. Many wells include periods of record keeping when only a single manual data point was collected biweekly or monthly. These manual points are used when a maximum daily value is not available. A daily record is created by interpolating daily values through the POR, if the gap between individual data points is less than 60 days. If the gap exceeds 60 days then interpolation is not performed and the gap is considered for calculation purposes as 'missing data'. Interpolation captures water level distributions while the water-level is rising and falling seasonally. However, it is unlikely that it captures the true high and low GWLs that may occur between the actual sample events. Many District wells, particularly those with the longest record, display a declining trend in GWL likely due to a combination of decreasing rainfall and increasing water demand. The percentile tables developed from these data incorporate this trend, with the result that some wells may fall in the lower percentile range with greater probability and frequency because they no longer or less frequently achieve the higher GWLs measured early in the record period.

PRs are calculated from the interpolated record in weekly intervals to remove the effects of seasonality. That is, each week, data are compared to data from the same week from previous years. So the data set for week five (early February) is composed only of data collected in week five for the entire POR. Note this could be up to 40 years of data. Percentile tables are only updated once per year. That is, they are not calculated each time we update the report. This effort ensures that if re-calculations are run, the results will be the same because the source percentile tables are the same. New data are only added to the dataset annually. If a comparison value falls between two percentiles, the greater percentile is used (the PR is rounded up).

Weekly SWFWMD summary reports compare the current week's PR for each well with the weekly PR of all daily maximum GWLs occurring in the given week for the POR (e.g. For each well, PRs from week 1 of the current year are compared to PRs from week 1 of all previous years in the POR). The last weekly report of each month is used to characterize GWLs for the month as reported in the Hydrologic Conditions Report.

In its monthly Hydrologic Conditions Report, the SWFWMD also presents comparisons of surficial aquifer GWLs and well-field monitor well GWLs. Percentiles are not calculated or

reported for these wells. GWLs for wells in the surficial and wellfield well reports are compared to the prior month's GWLs, and to GWLs for the same month in the prior year.

Appendix B5. South Florida Water Management District

The SFWMD uses the guidelines found in Appendix A. For the 18 wells selected, the frequency of measurement has varied over the years. Each well has less than 5% missing values. Each of the SFWMD wells currently has a continuous recorder that measures GWLs every 15 minutes; however, the three USGS wells record the daily maximum water levels. For the sake of consistency and availability of data, PRs were calculated using the daily maximum water levels for each well during a 6.5-year period of record (January 1, 2004, to May 31, 2010). For each well, percentile rankings were calculated for each day in May 2010 based on the daily maximum water levels for the period of record. The median value of the PRs for each day in May 2010 was submitted as the final PR.

Appendix B6. Alachua County

Alachua County (Environmental Protection Department) uses the guidelines found in Appendix A. Their 23 wells each have a POR of over 20 years with less than 25% missing values. The frequency of measurement has varied over the years. However, most wells are measured at least semi-annually, typically in May and September. Median values for the months sampled are used for analyses. Alachua County has no continuous recorders.

Appendix B7. Florida Department of Environmental Protection

The Florida Department of Environmental Protection determines PRs for 12 UFA wells with long-term GWL data. The wells are spread across the entire state. Each well has at least 20 years of GWL data. Wells were not eliminated because of missing data. The frequency of missing values is about 25% until the late 1990s. From that time forward, missing values are less than 5%. The 12 wells are sampled either monthly or quarterly and seldom sampled more than one time for each month sampled. For each well, medians values are determined for each month that the well was sampled. As an example for each well, for May, 2010 monthly median values were determined from the beginning of the POR through May, 2010. For each of the 12 wells, Excel was used to determine PRs.

Appendix C. Acknowledgements

The following individuals contributed to the development of the SNW PR index methodology. The SNW sincerely thanks them for their efforts.

Alachua County Environmental Protection Department:

Robin Hallbourg, Jim Hatchitt, Jim Myles

Florida Department of Environmental Protection:

Gail Sloane, Rick Copeland, Kate Muldoon, Stephanie Sunderman-Barnes, Lisa VanHoudt, and Andy Woeber

Florida Geological Survey:

Jon Arthur, Jim Cichon

Northwest Florida Water Management District:

Tony Countryman, Kathleen Coates

St. Johns River Water Management District:

Don Boniol, Nathan Johnson, Tom Mirti

South Florida Water Management District:

Cindy Bevier, Lucia Baldwin, Anne Dodd

Southwest Florida Water Management District:

Dave DeWitt, Roberta Starks, Granville Kinsman, Steve Desmith

Suwannee River Water Management District:

Megan Wetherington, Tom Mirti

U.S. Geological Survey:

Scott Prinos