**Prepared in cooperation with the Puerto Rico Department of Natural and Environmental Resources**

# Hydrologic Conditions in the South Coast Aquifer, Puerto Rico, 2010–15

By Sigfredo Torres-González and José M. Rodríguez

Open-File Report 2015–1215

**U.S. Department of the Interior**
**U.S. Geological Survey**

**U.S. Department of the Interior**
SALLY JEWELL, Secretary

**U.S. Geological Survey**
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016



Suggested citation:

Torres-González, Sigfredo, and Rodríguez, J.M., 2016, Hydrologic conditions in the South Coast aquifer, Puerto Rico, 2010–15: U.S. Geological Survey Open-File Report 2015–1215, 32 p., http://dx.doi.org/10.3133/ofr20151215.

ISSN 2331-1258 (online)

## Contents



## Figures

## Tables



## Conversion Factors

Inch/Pound to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| acre | 0.4047 | hectare (ha) |
| acre | 0.004047 | square kilometer ($km^2$) |
| | Volume | |
| gallon (gal) | 3.785 | liter (L) |
| gallon (gal) | 0.003785 | cubic meter ($m^3$) |
| million gallons (Mgal) | 3,785 | cubic meter ($m^3$) |
| | Flow rate | |
| gallon per day (gal/d) | 0.003785 | cubic meter per day ($m^3/d$) |
| gallon per day per square mile [$(gal/d)/mi^2$] | 0.001461 | cubic meter per day per square kilometer [$(m^3/d)/km^2$] |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second ($m^3/s$) |

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (μg/L).

## Datum

Vertical coordinate information is referenced to local mean sea level.

Horizontal coordinate information is referenced to the Puerto Rico Datum, 1940 adjustment.

## Abbreviations

| | |
|---|---|
| N | nitrogen |
| NOAA | National Oceanic and Atmospheric Administration |
| NWIS | National Water Information System |
| ppm | parts per million |
| PRASA | Puerto Rico Aqueduct and Sewer Authority |
| TDS | total dissolved solids |
| USGS | U.S. Geological Survey |

## Acknowledgments

The Puerto Rico Department of Natural and Environmental Resources provided access to data and encouragement for the publication of this report.

Fernando Gómez-Gómez (USGS, retired) and the late Rafael Dacosta (USGS, retired) contributed to developing the early framework for understanding the hydrogeology of the South Coast aquifer. Thanks to Marilyn Santiago for assistance with figures and tables. Technical reviews by Eve Kuniansky, Dave Sumner, and Scott Prinos, data review by Sandra Kinnaman, and editorial reviews by Kim Haag, all from the U.S. Geological Survey.

# Hydrologic Conditions in the South Coast Aquifer, Puerto Rico, 2010–15

By Sigfredo Torres-González and José M. Rodríguez

## Abstract

In 1958, the U.S. Geological Survey began documenting hydrologic conditions, including groundwater levels, groundwater withdrawals for agricultural irrigation and public water supply, and water quality, in the South Coast aquifer, Puerto Rico. This information has improved the understanding of the water resources of the region. The hydrologic data indicate that (1) groundwater levels declined as much as 40 feet in the Salinas area and 11 feet in the Guayama area during 2012–14; (2) groundwater withdrawals for agricultural irrigation increased from 6.0 to 10.5 million gallons per day, or 75 percent, from 2010 to 2012; and (3) total groundwater withdrawals decreased from 29.3 to 23.8 million gallons per day from 2010 to 2014. The quantity and quality of water in the aquifer is primarily affected by variations in aquifer recharge as a result of changing rainfall or modes of irrigation; however, the spatial patterns and magnitude of water withdrawals for all uses have a secondary impact on the quantity and quality of water in the aquifer.

National Oceanic and Atmospheric Administration data from climatological stations indicate that the 30-year normal precipitation for the period 1991–2010 in the South Coastal and Southern Slopes climatological regions was about 37.74 and 61.61 inches, respectively; the 30-year moving average precipitation for the period 1985–2014 was 37.94 and 61.80 inches, respectively, for these regions. The mean annual precipitation during 2012–14 was 13 percent below the 30-year moving average for the South Coastal climatological region and 7.7 percent below for the Southern Slopes climatological region. When rainfall is below the 30-year moving average, recharge is diminished and groundwater levels decline. Annual precipitation in the South Coast aquifer, which includes a large part of the South Coastal and Southern Slopes climatological regions, was 39.42, 37.25, and 34.89 inches per year for 2012, 2013, and 2014, respectively.

Water level declines reduce the thickness of freshwater in the unconfined parts of the South Coast aquifer. Additionally, the pumping-induced migration of poor-quality water from deep or seaward areas of the aquifer can contribute to reductions in the thickness of freshwater in the aquifer. The reduction in the freshwater saturated thickness of the aquifer in areas near Ponce, Juana Díaz, Salinas, and Guayama is of particular concern because the total saturated thickness of the aquifer is thinner in these areas. Total dissolved solids concentration in groundwater samples indicates a small positive trend in Ponce, Santa Isabel, Salinas, and Guayama. Diminished aquifer recharge during 2012 to 2015 and, to a lesser extent, increased groundwater withdrawals have resulted in a reduction in the freshwater saturated thickness of the aquifer. The reduction in freshwater saturated thickness of the aquifer may affect freshwater resources available for agriculture and public water supply. A prolonged time period with reduced aquifer recharge may have substantial implications for groundwater levels and fresh groundwater availability.

## Introduction

Documenting current and past hydrologic conditions and predicting future conditions are essential for the sustainable management of water resources. The U.S. Geological Survey (USGS) has collected hydrologic and hydrogeologic data in Puerto Rico since 1958, including records of streamflow, reservoir storage, groundwater levels, and water quality. When used in conjunction with rainfall records collected by the National Oceanic and Atmospheric Administration (NOAA), hydrologic data can improve the understanding of the water resources of the region. The data and interpretations provided by the USGS may also enhance the ability of water-resource managers to document past trends and inform predictions of future trends in water availability and water quality related to variations in groundwater withdrawals, agricultural practices, and weather. Hydrologic data collected by the USGS are made available to the public and to the water resources community online by the Caribbean-Florida Water Science Center San Juan office (http://pr.water.usgs.gov/) and at the USGS National Water Information System (NWIS) Web site (http://nwis.waterdata.usgs.gov/pr/nwis/nwis). Local and regional patterns in precipitation, temperature, and other meteorological parameters have been documented by NOAA since the 1900s (http://www.weather.gov/climate/xmacis.php?wfo=sju).

The South Coast aquifer, which is part of the South Coast Province of Puerto Rico (fig. 1), is the principal source of potable water for the towns of Santa Isabel, Coamo, Salinas, parts of Ponce, Juana Díaz, and Guayama, and supplies (2014) about 16.71 million gallons per day (Mgal/d) to Puerto Rico Aqueduct and Sewer Authority (PRASA) public-supply wells. The aquifer is also a primary source of water for agricultural use, and about 45 wells provide (2014) an estimated 7.11 Mgal/d of groundwater to irrigate crops in the area (W.L. Molina, U.S. Geological Survey, written commun., May 5, 2015). The South Coast aquifer receives the infiltrating residual of precipitation, evapotranspiration, and surface runoff, and is affected by groundwater withdrawals. Prior to the elimination of furrow irrigation in the mid-1980s to early 1990s, the aquifer was primarily recharged by return flow from surface-water irrigation. Historically, the quality of the groundwater in the South Coast aquifer was characterized by low nitrate concentrations (less than 6.0 milligrams per liter [mg/L] and total dissolved solids concentrations ranging from 300 to 600 mg/L, making the water suitable for irrigation use and marginally suitable for potable water supply. With the discontinuation of furrow irrigation and the associated irrigation return flow, the South Coast aquifer is recharged almost exclusively by precipitation and intermittently by streamflow infiltration.

The South Coast aquifer extends across the South Coast Province, an area that is warmer and drier than other parts of Puerto Rico. The locations of active National Weather Service (NWS) rainfall stations operated by NOAA are shown in figure 2. The average precipitation for the 30-year period of record (1985–2014) in the South Coastal climatological region (fig. 2) was about 37.94 inches, on the basis of data from the following 15 long-term (active and discontinued) NWS rainfall stations: Aguirre Salinas, Central San Francisco, Ensenada 1W, Guayanilla, Lajas Substation, Ponce 4E, Ponce City, Ponce Mercedita, Potala, Río Canas, Río Jueyes, Sabater, Santa Isabel 2 ENE, Santa Rita, and Yauco. The average precipitation for the 30-year period of record (1984–2013; the period of record differs by 1 year because data for 2014 were missing) in the Southern Slopes climatological region (fig. 2) was 63.57 inches, on the basis of the following 28 long-term (active and discontinued) NWS rainfall stations stations: Benavente-Hormigueros, Cabo Rojo, Caonillas Villalba, Coamo 2SW, Corral Viejo, Guayabal, Guayama, Humacao 2 SSE, Josefa 5, Juana Díaz Camp, Maunabo, Mayaguez city, Mayaguez AP, Melanía dam, Naguabo 3E, Naguabo 6W, Paraiso, Patillas, Patillas dam, Peñuelas 1NE, Puerto Real, Roosevelt Roads, Sabana Grande 2ENE, San Germán 4W, Villalba 1E, Yabucoa 1NNE, Yauco 1NW, and Yaurel 3NNE.

For the South Coastal and Southern Slopes climatological regions, when precipitation is above the 30-year moving average, water levels rise (with increased recharge) and water quality generally improves (with addition of freshwater to the aquifer). When precipitation is below the 30-year moving average, natural aquifer recharge is relatively low, groundwater levels decline, and water quality (including total dissolved solids concentrations) may deteriorate with lateral intrusion of seawater and local (pumping-induced) upconing of deeper poor-quality water. It is apparent from the historical precipitation record that when annual precipitation is less than 10 percent (or 30.11 inches – red horizontal line in figure 3) of the minimum 30-year moving average over the period of record, a relative dry period occurs. This condition is less severe in the Southern Slopes climatological region because the minimum 30-year moving average precipitation (60.10 inches) is higher than that of the South Coastal (33.46 inches) climatological region (fig. 3). When precipitation is below 10 percent of the minimum 30-year moving average, the drought interval is estimated as the number of years between rainfall deficits and is represented by the violet bars in figure 3. Under these conditions, the average drought interval for the South Coastal climatological region is estimated at 3.0 years and for the Southern Slopes climatological region is estimated at 6.1 years (fig. 4). Herein, the term drought interval is used; however, a deficiency in rainfall of more than 35 percent below the minimum 30-year moving average precipitation could better explain the drought of 2012–14 (and the first 9 months of 2015). For the South Coastal climatological region, the drought interval is estimated at 38.3 years and more than 67 years, respectively, for 35 and 40 percent below the minimum 30-year moving average (fig. 4). The drought interval for the Southern Slopes climatological region is estimated at 29.3 years and more than 100 years, respectively, when 35 and 40 percent below the minimum 30-year moving average intervals are evaluated (fig. 4).

The effects of intermittent wet and dry years have substantial implications for variations in aquifer recharge and, therefore, groundwater levels. By convention, NOAA uses the 30-year normal precipitation estimated at the end of each decade and includes the period of 1981–2010. The 30-year moving average precipitation is preferred over the 30-year normal precipitation because it can be applied to any arbitrary interval of years and not just to the standard decadal intervals used in computation of the NOAA 30-year normal precipitation.

Population at the municipalities of Juana Díaz, Santa Isabel, Coamo, Salinas, Guayama, Arroyo, and Patillas, along the South Coast aquifer, increased about 8,000 from 1980 to 2013 (fig. 5). On the other hand, Ponce had a reduction in population of more than 23,000 from 2000 to 2013 (U.S. Census Bureau, 1980–2013).

Historically (1914–2014), water that has been transferred from the north coast of Puerto Rico through a network of irrigation canals, known collectively as the Irrigation District, has mitigated the effects of relatively low precipitation on agriculture in the vicinity of the South Coast aquifer. The Irrigation District in the South Coast aquifer is composed of the Canal de Juana Díaz, serving the Ponce, Juana Díaz, and Santa Isabel areas; the Canal de Patillas, serving the Salinas, Guayama, Arroyo, and Patillas areas; the Canal de Guamaní Oeste (West), serving the Salinas and Guayama areas; and the Canal de Guamaní Este (East), serving parts of Guayama, Arroyo, and Patillas areas (fig. 1). Since 1914, most of the southern part of the island has had access to this irrigation network which has provided water for crops such as sugarcane (from the 1910s to 1985, Torres-González, 1991) and vegetables and fruits (since 1987, Kuniansky and Rodríguez, 2010). A full transition to drip irrigation techniques occurred in 1991; these techniques have not only reduced total agricultural water use, but also have limited net aquifer recharge.

## Hydrologic Conditions in the South Coast Aquifer

Hydrologic conditions described in this report for the South Coast aquifer include precipitation, groundwater levels in selected USGS observation wells, groundwater withdrawals for agricultural irrigation, and water quality. A detailed evaluation of the hydrologic conditions is presented for the period 2010 to 2015.

### Precipitation

Precipitation data for the relatively dry 2012–14 period were available at five NWS rainfall stations: (1) Ponce 4E, (2) Santa Isabel 2ENE, and (3) Aguirre Salinas, located in the South Coastal climatological region; and (4) Juana Díaz Camp, and (5) Guayama 2E, located in the Southern Slopes climatological region. A deficit in precipitation can be established if the accumulated precipitation in a year is compared to the 30-year moving average statistic at a local or regional scale. The local scale will use the 30-year moving average precipitation for the NWS rainfall station, and the regional scale will use the 30-year moving average of annual precipitation of all NWS rainfall stations for the particular climatological region.

In the domain of the South Coast aquifer, rain gages at Ponce 4E, Juana Díaz Camp, Aguirre Salinas, and Guayama 2E recorded annual precipitation below the 30-year moving average for the period 2012–14 (table 1; fig. 6) with the exception of Aguirre Salinas, which in 2013 registered an accumulation of 15.8 percent above the 30-year moving average (23.9 percent at a regional scale), and Ponce 4E, which in 2012 registered an accumulation slightly above the 30-year moving average (0.9 percent at a regional scale). In 2014, annual precipitation was about 59.7 percent below the 30-year moving average at Ponce 4E (58.7 percent below at a regional scale) and about 28.2 percent below the 30-year moving average in Juana Díaz Camp (51.3 percent below at a regional scale). Aguirre Salinas and Guayama 2E showed similar departures from the 30-year moving average precipitation of 24.5 and 24.2 percent, respectively, at a local scale and 19.2 and 26.3 percent, respectively, at a regional scale. No precipitation data are available for the NWS rainfall station Santa Isabel 2 ENE since 2011 (table 1). Annual precipitation was within about 9.4 percent below the 30-year moving average at a regional scale (16.1 percent below when evaluated at a local scale) at Santa Isabel 2ENE in 2010 and 112.2 percent above the 30-year moving average at a local scale (127.1 percent above when evaluated at a regional scale) at Aguirre Salinas in 2011 for the South Coast aquifer. Rainfall departures from the estimated 30-year moving average precipitation for each NWS rainfall station are summarized in table 1 at both local and regional scales. Extended periods of below-average rainfall affect the availability and management of surface-water and groundwater resources. Droughts not only reduce aquifer recharge, but also are accompanied by increased groundwater withdrawals to replace water supply typically derived from rainfall.

## Groundwater Levels in Selected USGS Observation Wells

The USGS measures water levels monthly in 23 observation wells in the area of the South Coast aquifer (fig. 1; table 2). The screened wells are open to the South Coast aquifer, and measured water levels in these wells represent water levels in the aquifer. The tightly cased observation wells are distributed along the coastal areas as follows: nine wells between Ponce and Juana Díaz, six wells in Santa Isabel, and eight wells between Salinas and Guayama. In wells equipped with pressure transducers, depth-to-water data are collected at hourly intervals (table 2). Water levels in the Ponce to Juana Díaz coastal areas are represented in this report by piezometer JAC-6. Water levels in the Santa Isabel coastal areas are represented by the Alomar 1 well, because of the length of record, the location, and the reliable response to groundwater recharge and withdrawals. Piezometer A RASA represents conditions in the Salinas coastal areas, and the Jobos well represents the Guayama coastal areas (fig. 7).

As a consequence of the recent (2012–14 and continuing into 2015) drought, water levels in piezometer JAC-6, in the Ponce to Juana Díaz coastal area, decreased by 6.25 feet (from November 27, 2013, to July 30, 2014) prior to a tropical depression in August 2014 that delivered heavy rainfall and reversed the declining water level trend. The water level increased from about 20 feet to 25 feet above mean sea level by September 11, 2014. By February 2015, water levels had decreased about 2 feet, to 23.27 feet above mean sea level (fig. 7*A*).

Groundwater withdrawals and a reduction in aquifer recharge from the loss of irrigation return flow have lowered the water table below sea level throughout most of the Santa Isabel area (Kuniansky and others, 2004). The decrease in aquifer recharge, which previously was provided by irrigation return flow (discontinued by the early 1990s), is an unintended consequence of the large-scale implementation of groundwater microdrip highly efficient irrigation systems. Groundwater levels in Alomar 1 well, in the Santa Isabel coastal area, have been below mean sea level since January 2014 (fig. 7*B*).

Heavy precipitation raised groundwater levels to 7.73 feet above mean sea level in December 2011, but groundwater levels declined to 3.92 feet below mean sea level by March 2015. Nevertheless, groundwater levels during the recent drought (2012–14 and the first 5 months of 2015) were higher than during previous droughts in 1994–98 and 2001–03.

In the Salinas area, water level data from piezometer A RASA indicated a reduction in aquifer saturated thickness of 33.45 feet from October 2011 to March 2015 (fig. 7*C*). Because this observation well is not located near a pumping center, the measured loss in thickness could be representative of a regional water level decline. The reduction in the saturated thickness in piezometer A RASA is the result of sustained groundwater withdrawals and a deficit in aquifer net recharge from precipitation or any possible return flow from crop irrigation.

In the Guayama to Arroyo coastal areas, groundwater levels in the Jobos well have declined almost 10 feet between March 2013 and May 2015 (fig. 7*D*). This decline is similar to the negative trend in piezometer A RASA in the Salinas area for the same period. If groundwater levels are below mean sea level for an extended period of time, the aquifer could be subject to changes in water quality as the seaward hydraulic gradient in the aquifer is reversed and freshwater is replaced by seawater moving inland toward the pumping centers.

## Surface-Water Deliveries

In 2010, the Guayama Irrigation District withdrew 16.67 Mgal/d of water from the Lago Patillas and the Lago Melanía reservoirs, the Rio Guamaní, and from an intra-basin water transfer from Lago Carite to the Río Guamaní. These streams and reservoirs transferred 5.36 Mgal/d of water to agricultural lands in the municipalities of Arroyo, Guayama, Patillas, and part of Salinas (W.L. Molina, U.S. Geological Survey, written commun., May 5, 2015).

The Juana Díaz Irrigation District withdrew 11.62 Mgal/d exclusively from Lago Guayabal in the municipality of Villalba and conveyed 5.16 Mgal/d of water to agricultural lands in the municipalities of Juana Díaz, Santa Isabel, and part of Salinas to the west of Río Nigua. Surface-water deliveries represent almost 25 percent of the total water use in the Ponce to Patillas area and about 8 percent of the induced aquifer recharge from applied irrigation and artificial recharge projects (W.L. Molina, U.S. Geological Survey, written commun., May 5, 2015).

## Groundwater Withdrawals

Groundwater withdrawals for public water supply within the area of the South Coast aquifer increased from 14.2 Mgal/d in 1990 to a peak of 25.9 Mgal/d in 2005 and then decreased to 23.82 Mgal/d in 2014 (fig. 8; table 3). This reduction in groundwater withdrawals is not sufficient to halt the decreasing trend in groundwater levels in coastal areas, which were mostly at or below mean sea level, near pumping centers, during 2015. Groundwater use for irrigation decreased from 52.6 Mgal/d in 1990 to 7.11 Mgal/d in 2014 (fig. 8), a reduction of 86 percent.

## Groundwater Quality

Groundwater quality can change when the water table is below sea level in coastal areas or when the intensity of pumping induces local upconing of deeper, poor-quality water. When the water table is below sea level, the natural discharge of groundwater along the coast is reversed and can result in the inland movement of seawater or upconing of low-quality water (Kuniansky and others, 2004; Kuniansky and Rodríguez, 2010).

Historic groundwater quality data obtained from selected wells in the South Coast aquifer indicate increasing trends in total dissolved solids (TDS) concentrations in the Ponce, Santa Isabel, and Salinas areas (fig. 9). A decreasing trend in TDS concentrations was observed in the Juana Díaz area (fig. 9).

Some agricultural wells in the southeastern coastal areas of Santa Isabel were reported to be abandoned by farmers during 2008 because TDS concentrations had exceeded 1,600 mg/L (W. Martínez, Puerto Rico Land Authority, oral commun., July 15, 2008). In 2014, samples collected from agricultural and public-supply wells in the Santa Isabel area had TDS concentrations that ranged from 473 to 1,080 mg/L at wells 15 and 12, respectively (fig. 10); TDS concentrations in wells in the Salinas coastal area ranged from 443 to 615 mg/L at well 23 and well 35, respectively (fig. 11). Samples collected from 2007 to 2014, from observation wells 29 and 26 located near the coast, had TDS concentrations ranging from 483 to 19,500 mg/L, respectively (fig. 11; table 4). As of October 2014, the greatest increase in TDS concentrations occurred in the Ponce area, from 942 to 1,520 mg/L at well 4 (fig. 10; table 4).

The ionic composition of water is an indicator of the water source. Distinct zones (hydrochemical facies) in the South Coast aquifer have waters with characteristic ionic composition, and the waters in these zones are referred to as “water types.” The water types can be described using the trilinear diagram method (Piper, 1944; Rodríguez and Goméz-Goméz, 2008). Predominant water types in the South Coast aquifer are sodium bicarbonate [$NaHCO_3$], sodium chloride [NaCl], calcium bicarbonate [$Ca(HCO_3)_2$], and calcium chloride [$CaCl_2$] (Gómez-Gómez, 1990). The $NaHCO_3$ water type results from the weathering of plagioclase minerals present in the volcanic rocks along the northern perimeter of most of the South Coast aquifer and in areas where the volcanic rocks form the base of the aquifer. The NaCl water type results from seawater encroachment along the coast and the $Ca(HCO_3)_2$ water type is derived from freshwater infiltration through soils and surficial deposits. The $CaCl_2$ water type results from groundwater dissolution of limestone rocks that lie along the perimeter of the aquifer or at depth, especially in the western half of the coastal plain.

The ionic composition of groundwater in wells south of Highway 2 near Ponce indicates a $CaCl_2$ water type (Rodriguez and Gómez-Gómez, 2008). In the Juana Díaz area, the composition of groundwater is mostly a $Ca(HCO_3)_2$ water type. In the Santa Isabel area, the principal water type in wells parallel to Río Coamo is also $Ca(HCO_3)_2$, indicating the streamflow-infiltration effects of Rio Coamo. In the Salinas area, the effect of streamflow infiltration also is evident in wells east of Río Nigua, which show a $Ca(HCO_3)_2$ water type (fig. 12). Continued groundwater withdrawals and a reduction in aquifer recharge may cause a change in ionic composition of groundwater. Wells yielding $Ca(HCO_3)_2$ type water may, in time, yield $CaCl_2$ type water and those yielding a $CaCl_2$ type may eventually yield a NaCl type water (Gómez-Gómez, 1990). The change from $Ca(HCO_3)_2$ type water to $CaCl_2$ type water ($CaCl_2$ in figure 12) is observed in wells 14, 16, and 19 near the coast of Santa Isabel and well 32 in Salinas.

Nitrate concentrations in natural groundwaters are typically less than 2 mg/L $NO_3$-N (Mueller and others, 1995). Nitrate in groundwater can occur at elevated concentrations as a result of inorganic fertilizer application, seepage from septic systems, and manure from domestic animal operations. The U.S. Environmental Protection Agency (1995, 2009) has established a drinking-water standard for nitrate-nitrogen ($NO_3$-N) of 10 mg/L.

In 2002, nitrate concentrations ranged from 0.67 to 15 mg/L $NO_3$-N in wells in the coastal plain and from 25 to 76 mg/L $NO_3$-N in wells in the foothills north of the coastal plain along the Salinas area (Rodríguez, 2006). Nitrate concentrations in the coastal plain were associated with inorganic fertilizers and natural vegetative decay. Rodríguez (2006) indicated that nitrate concentrations in wells in the foothills north of the coastal plain were associated with organic waste sources, land application of manure, and seepage from septic systems. In 2014, nitrate concentrations in wells located in the coastal plain in the Salinas area ranged from 3.7 to 11.7 mg/L $NO_3$-N. Samples collected from well 32 in Salinas (fig. 11) indicate a slight decreasing trend $NO_3$-N concentration from 2007 to 2014 (fig. 13). Samples from well 33, which is in the foothills north of the coastal plain (fig. 11) indicate nitrate concentrations of 35 and 16.9 mg/L in 2002 and 2014, respectively.

Nitrate concentrations ranged from 1.3 to 23.6 mg/L $NO_3$-N in wells in the coastal plain of the Santa Isabel area during 2008 (Rodríguez, 2013). The nitrate concentrations in wells in the eastern and west-central parts of the intensively cultivated areas of the coastal plain in Santa Isabel were associated with soil nitrogen. It is likely that soil nitrate produced by ammonia volatilization of nitrogen fertilizer percolates to the groundwater, given the intensive use of synthetic fertilizers and the high $NO_3$-N concentrations detected in the areas located east and west of Río Coamo. In 2014, $NO_3$-N concentrations in wells in the Santa Isabel area ranged from 8.9 to 21.5 mg/L $NO_3$-N. Nitrate concentrations in well 16 in Santa Isabel (fig. 10) indicate an increasing trend from 2007 to 2014 (fig. 14).

## Summary

The U.S. Geological Survey documents hydrologic conditions in Puerto Rico and provides hydrologic data that can help improve understanding of the water resources of the region. Groundwater from the South Coast aquifer is the principal source of potable water for towns along the southern coast of the island and also is a primary source of water for agricultural irrigation. The quantity and quality of water in the aquifer is primarily affected by variations in aquifer recharge as a result of changing rainfall or modes of irrigation; however, the spatial patterns and magnitude of water withdrawals for all uses have a secondary impact on the quantity and quality of water in the aquifer.

Annual precipitation during 2012–14 ranged from 15.8 percent above the 30-year average to 59.7 percent below, and during 2010–11 ranged from 12.3 to 112.2 percent above the 30-year average evaluated at a local scale in the vicinity of most of the South Coast aquifer. Precipitation was 15.8 percent above the 30-year average at one site (Aguirre Salinas) in 2013. Annual precipitation during 2012–14 ranged from 1.9 percent above to 59.7 percent below the 30-year annual average for all 3 years at the four sites with an available record (Ponce 4E; Juana Diaz Camp; Aguirre Salinas; and Guayama 2E). Extended periods of below-average precipitation not only reduce aquifer recharge, but also can lead to increased groundwater withdrawals to replace water supply normally derived from precipitation.

Groundwater levels in monitoring wells in the Santa Isabel coastal areas were below mean sea level during December 2013 to March 2015. In the Alomar 1 well, heavy rainfall raised groundwater levels to 7.73 feet above mean sea level in December 2011, but groundwater levels declined to 3.92 feet below mean sea level by March 2015. In the Salinas area, water levels measured at piezometer A RASA indicated a reduction in aquifer saturated thickness of 33.45 feet from October 2011 to March 2015. In the Guayama to Arroyo coastal area, groundwater levels in the Jobos well declined almost 10 feet from March 2013 to May 2015.

Diminished aquifer recharge during 2012–15 and, to a lesser extent, increased groundwater withdrawals have resulted in a reduction in the freshwater saturated thickness of the aquifer. This diminished aquifer recharge may affect freshwater resources available for agriculture and public water supply. The reduction in recharge, if extended, may have substantial implications for aquifer recharge and, therefore, groundwater levels and fresh groundwater availability.

Groundwater quality can change when the water table in coastal areas is below sea level for an extended period of time because the natural discharge of groundwater along the coast is reversed, resulting in the inland movement of seawater or upconing of low-quality water. Groundwater withdrawals and a reduction in aquifer recharge from the loss of irrigation return flow have lowered the water table below sea level throughout most of the Santa Isabel area. Groundwater quality data from selected wells in the South Coast aquifer indicate small but steadily increasing trends in total dissolved solids concentrations from the 1980s to 2014 in the Ponce, Santa Isabel, Salinas, and Guayama areas. A decreasing trend in total dissolved solids concentrations was observed in the Juana Díaz area.

In 2014, nitrate concentrations in wells in the Santa Isabel area ranged from 8.9 to 21.5 mg/L $NO_3$-N. Nitrate concentrations in well 16 in Santa Isabel indicate an increasing trend from 2007 to 2014. In 2014, nitrate concentrations in wells in the coastal plain in the Salinas area ranged from 3.7 to 11.7 mg/L $NO_3$-N. Samples collected from well 32 in Salinas indicate a slight decreasing trend from 2007 to 2014.

## References

Gómez-Gómez, Fernando, 1990, Hydrochemistry of the South Coastal Plain Aquifer System of Puerto Rico and its relation to surface-water recharge, *in* Gómez-Gómez, Fernando, Quiñones-Aponte, Vicente, and Johnson, A.I., eds., Aquifers of the Caribbean Islands, Proceedings of the International Symposium on Tropical Hydrology, San Juan, PR, July 23-27, 1990, AWRA Monograph Series no. 15, p. 57-75.

Gómez-Gómez, Fernando, Rodríguez-Martínez, Jesús, and Santiago, Marilyn, 2014, Hydrogeology of Puerto Rico and the outlying islands of Vieques, Culebra, and Mona: U.S. Geological Survey Scientific Investigations Map 3296, 40 p. plus 2 pls., accessed November 2015 at http://dx.doi.org/10.3133/sim3296.

Kuniansky, E.L., Gómez-Gómez, Fernando, and Torres-González, Sigfredo, 2004, Effects of aquifer development and changes in irrigation practices on ground-water availability in the Santa Isabel area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 03–4303, 56 p.

Kuniansky, E.L., and Rodriguez, J.M., 2010, Effects of changes in irrigation practices and aquifer development on ground-water discharge to the Jobos Bay National Estuarine Research Reserve, near Salinas Puerto Rico: U.S. Geological Survey Scientific Investigation Report 2010–5022, 106 p.

Miller, J.A., Whitehead, R.L., Oki, D.S., Gingerich, S.B., and Olcott, P.G., 1997 (revised 1999), Ground water atlas of the United States—Segment 13, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands: U.S. Geological Survey Hydrologic Atlas 730-N, 36 p. (Also available at http://pubs.er.usgs.gov/publication/ha730N.)

Molina-Rivera, W.L., 1996a, Ground-water use from the principal aquifers in Puerto Rico during calendar year 1990: U.S. Geological Survey Fact Sheet 188-96, 3 p.

Molina-Rivera, W.L., 1996b, Puerto Rico water-use program: public-supply water use and wastewater disposal during 1990: U.S. Geological Survey Fact Sheet 098-96, 3 p.

Molina-Rivera, W.L., 1998, Estimated water use in Puerto Rico, 1995: U.S. Geological Survey Open-File Report 98-276, 28 p.

Molina-Rivera, W.L., 2005, Estimated water use in Puerto Rico, 2000, U.S. Geological Survey Open-File Report 2005-1201 26 p. http://pubs.usgs.gov/of/2005/1201/.

Molina-Rivera, W.L., and Dopazo, Teresa, 1995, Estimated water use in Puerto Rico, 1986-87: U.S. Geological Survey Open- File Report 95-358, 31 p.

Mueller, D.K., Hamilton, P.A., Helsel, D.R., Hitt, K.J., and Ruddy, B.C., 1995, Nutrients in ground water and surface water of the United States—An analysis of data through 1992: U.S. Geological Survey Water Resources Investigations Report 95–4031, 74 p.

Piper, A.M., 1944, A graphic procedure in the geochemical interpretation of water-analyses, Eos Transactions, American Geophysical Union, v. 25, no. 6, p. 914--928, accessed November 2015 at http://dx.doi.org/10.1029/TR025i006p00914.

Renken, R.A., Ward, W.C., Gill, I.P, Gómez-Gómez, Fernando, Rodríguez-Martínez, Jesús, and others, 2002, Geology and hydrogeology of the Caribbean Islands aquifer system of the Commonwealth of Puerto Rico and the U.S. Virgin Islands: U.S. Geological Survey Professional Paper 1419, 139 p., 5 pls., accessed June 2015 at http://pubs.usgs.gov/pp/pp1419/.

Rodríguez, J.M., 2006, Evaluation of hydrologic conditions and nitrate concentrations in the Río Nigua de Salinas alluvial fan aquifer, Salinas, Puerto Rico, 2002–03: U.S. Geological Survey Scientific Investigations Report 2006–5062, 38 p.

Rodríguez, J.M., 2013, Evaluation of groundwater quality and selected hydrologic conditions in the South Coast aquifer, Santa Isabel area, Puerto Rico, 2008–09: U.S. Geological Survey Scientific Investigations Report 2012–5254, 36 p.

Rodríguez, J.M., and Gómez-Gómez, F., 2008, Groundwater-quality survey of the South Coast aquifer of Puerto Rico, April 2 through May 30, 2007: U.S. Geological Survey Scientific Investigations Map 3092, 1 sheet.

Torres-González, Sigfredo, 1991, Effects of aquifer overdevelopment within the Río Coamo alluvial fan, Santa Isabel, Puerto Rico, 1987: International Association of Hydrogeologists, XXIII International Congress, Canary Islands, Spain, p. 483–488.

U.S. Census Bureau, 1980-2013, U.S Census Bureau census population counts: U.S. Department of Commerce, Bureau of the Census, accessed May 2015 at http://www.census.gov/2010census/news/releases.

U.S. Department of Agriculture, Annual summary 1899-1954, Puerto Rico section Climate and Crop Service of the Weather Bureau: San Juan, P.R., Department of Agriculture, yearly publications, accessed May 2015 at http://www.ncdc.noaa.gov/cdo-web/#t=secondTabLink.

U.S. Department of Commerce, Climatological data annual summary Puerto Rico and Virgin Islands 1955-2014: Asheville, N.C., Department of Commerce, yearly publications, accessed May 2015 at http://www.ncdc.noaa.gov/cdo-web/#t=secondTabLink.

U.S. Environmental Protection Agency, 1995, Drinking water regulations and health advisories: Washington, D.C., Office of Water, 11 p.

U.S. Environmental Protection Agency, 2009, National primary drinking water regulations: EPA 816–F–09–004, accessed June 2015 at http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf.

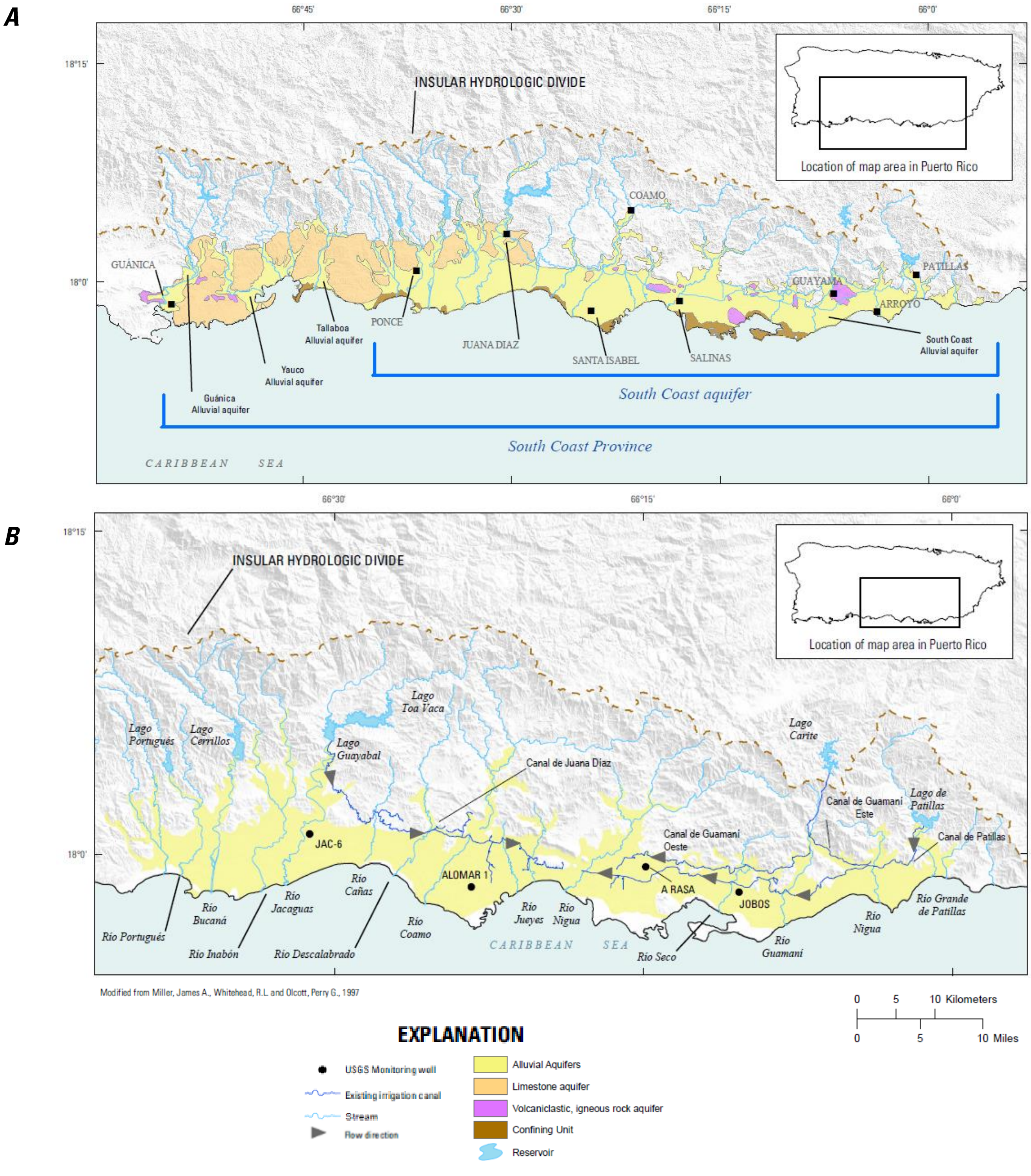
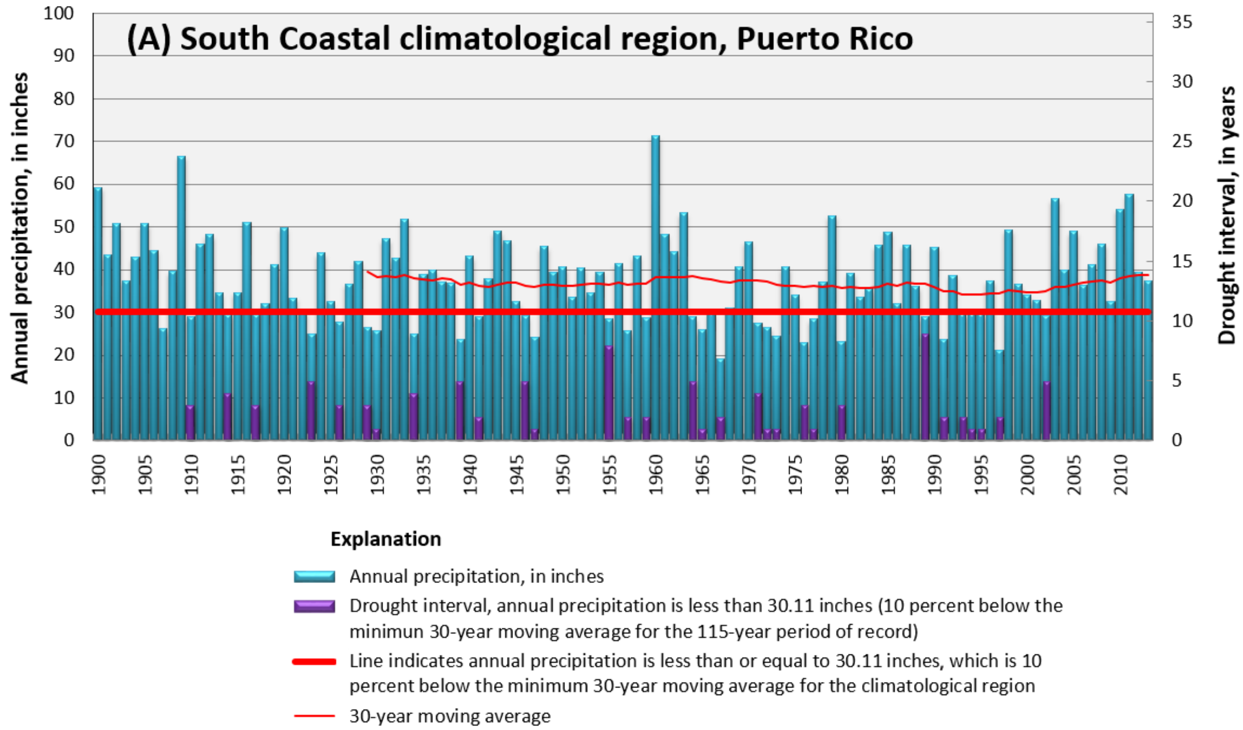



**Figure 1.** Location of (*A*) South Coast Province and South Coast aquifer, Puerto Rico, and (*B*) major irrigation infrastructure and selected USGS monitoring wells in the study area.


**Figure 2.** Climatological regions and location of National Weather Service rainfall stations operated by the National Oceanic and Atmospheric Administration in Puerto Rico [from Gómez-Gómez and others, 2014].



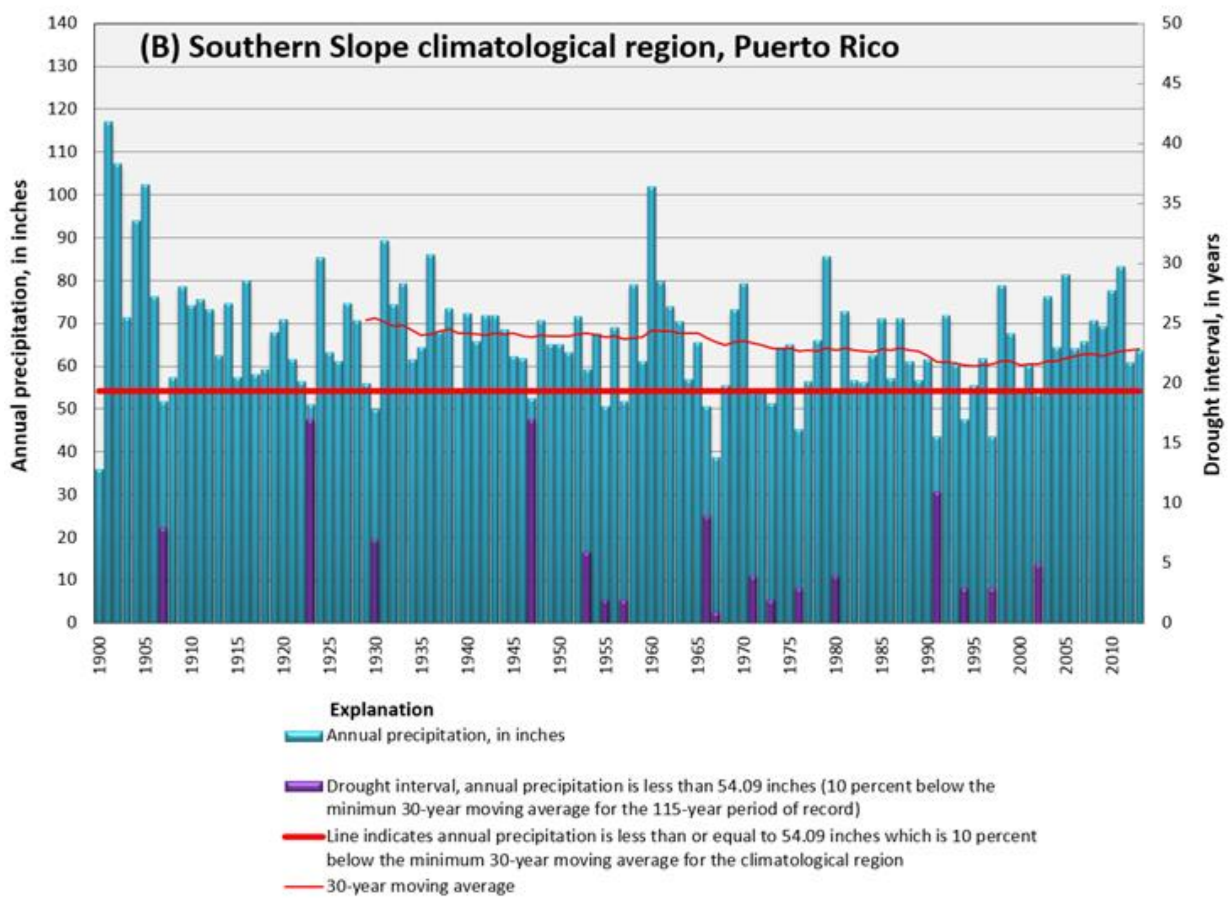




**Figure 3.** Annual precipitation accumulation, drought interval, and 30-year moving average precipitation trend for the (A) South Coastal and (B) Southern Slopes climatological regions, Puerto Rico (sources: U.S. Department of Agriculture, 1899–1954; U.S. Department of Commerce, 1955–2014).

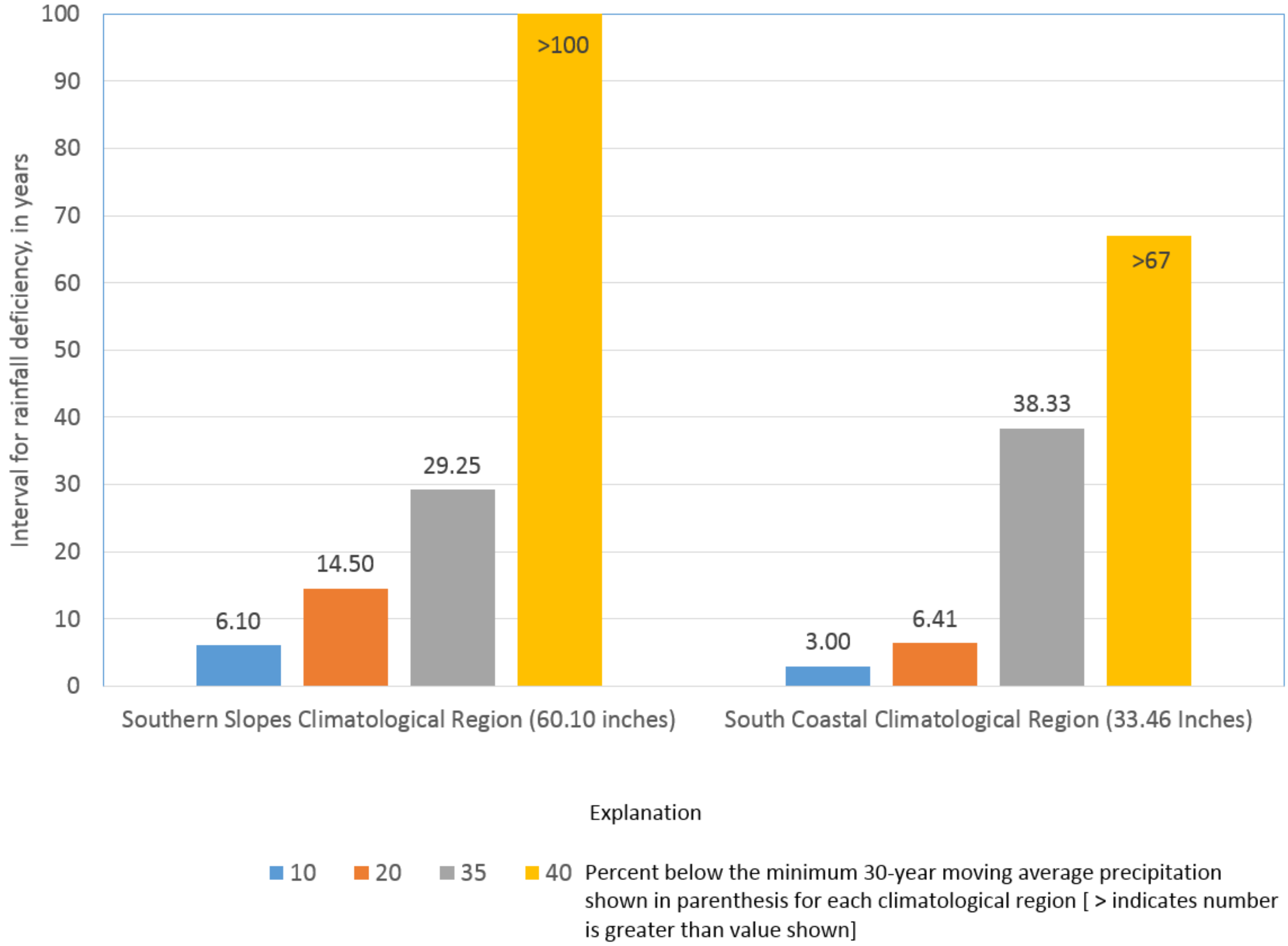



**Figure 4.** Rainfall deficiency intervals for the South Coastal and Southern Slopes climatological regions.

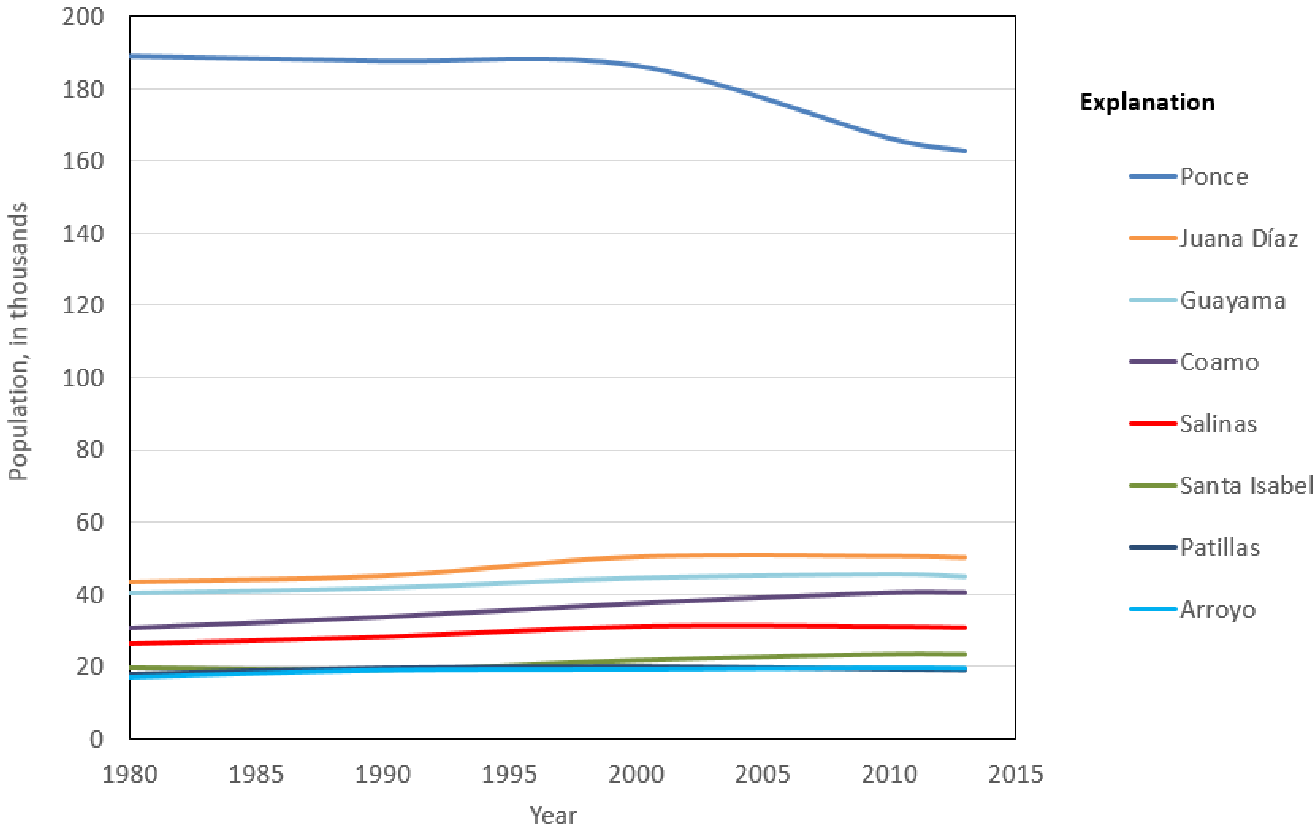



**Figure 5.** Population trends in municipalities along the South Coast aquifer, Puerto Rico, 1980 to 2013 (source: U.S. Census Bureau, 1980–2013).

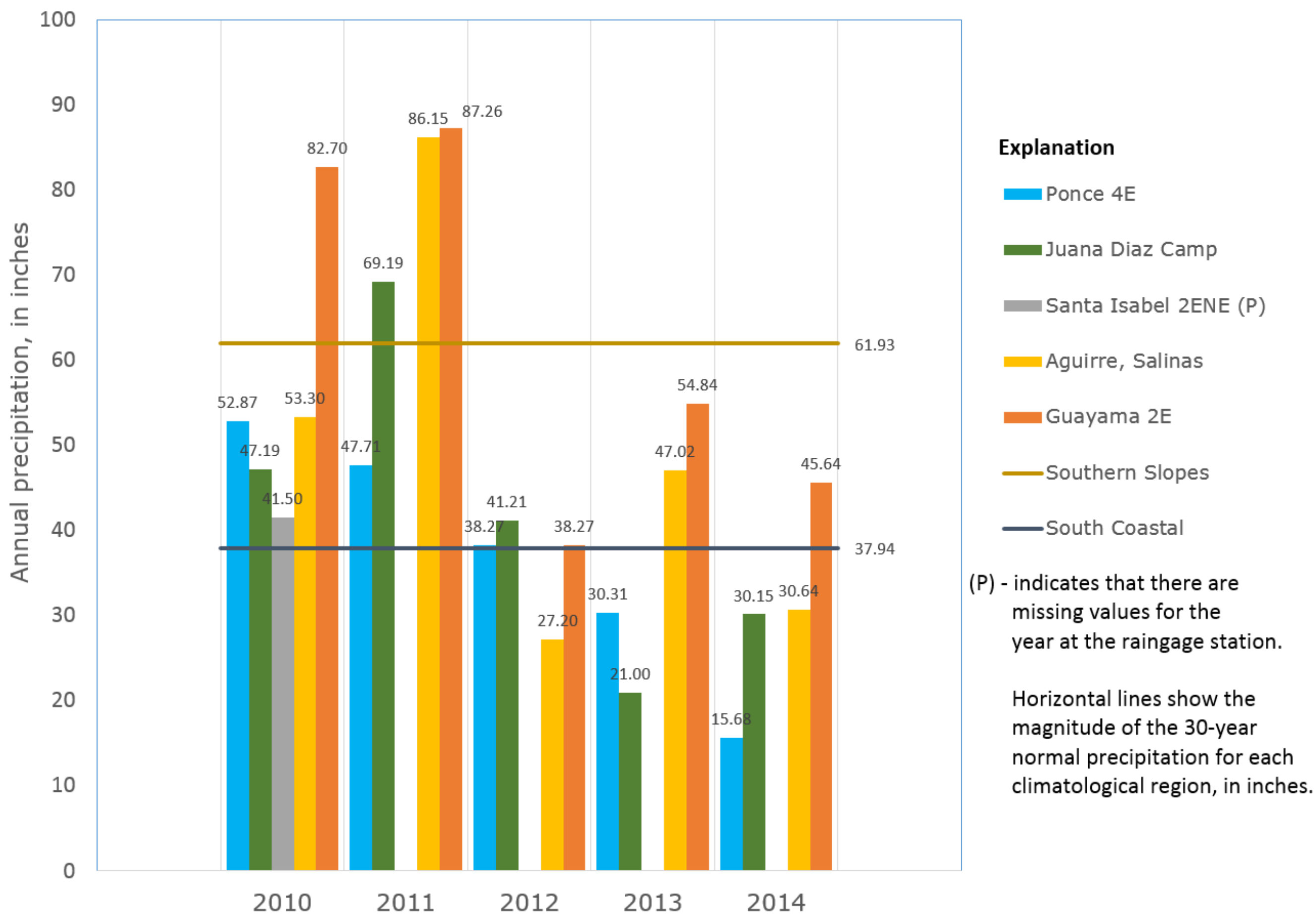
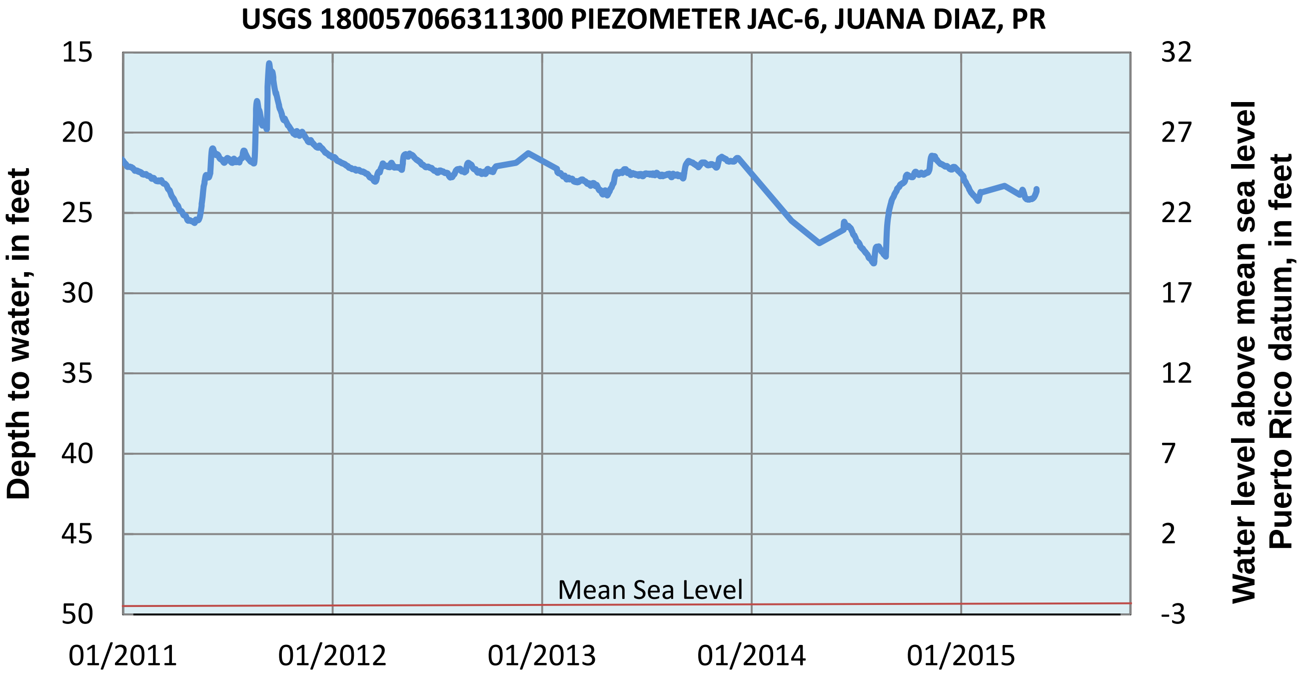



**Figure 6.** Annual precipitation measured at National Weather Service rainfall stations, and 30-year moving normal precipitation for the South Coastal and Southern Slopes climatological regions, South Coast aquifer, Puerto Rico, 2010–14.

***A.*** Ponce-Juana Díaz




***B.*** Santa Isabel

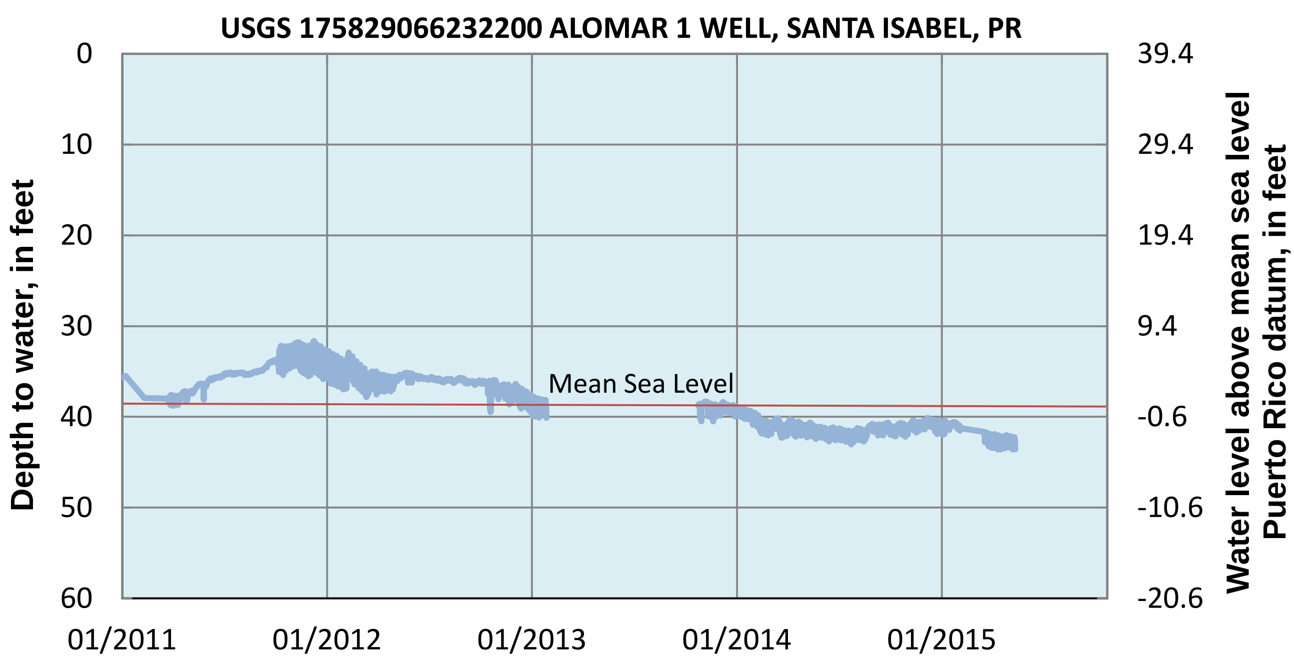
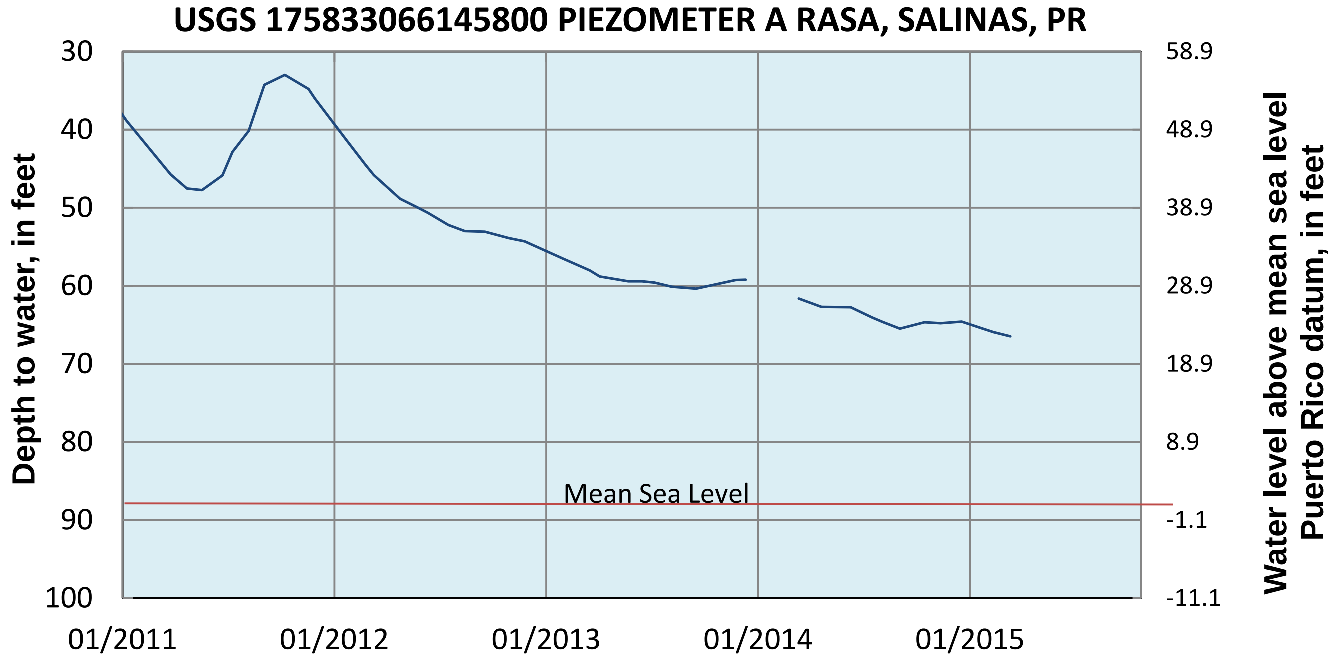



**Figure 7.** Measured water levels at USGS (A) Piezometer JAC-6, Juana Díaz, (B) Alomar 1 well, Santa Isabel, (C) Piezometer A RASA, Salinas, and (D) Jobos well, Guayama, 2011–15.

***C.*** Salinas




***D.*** Guayama

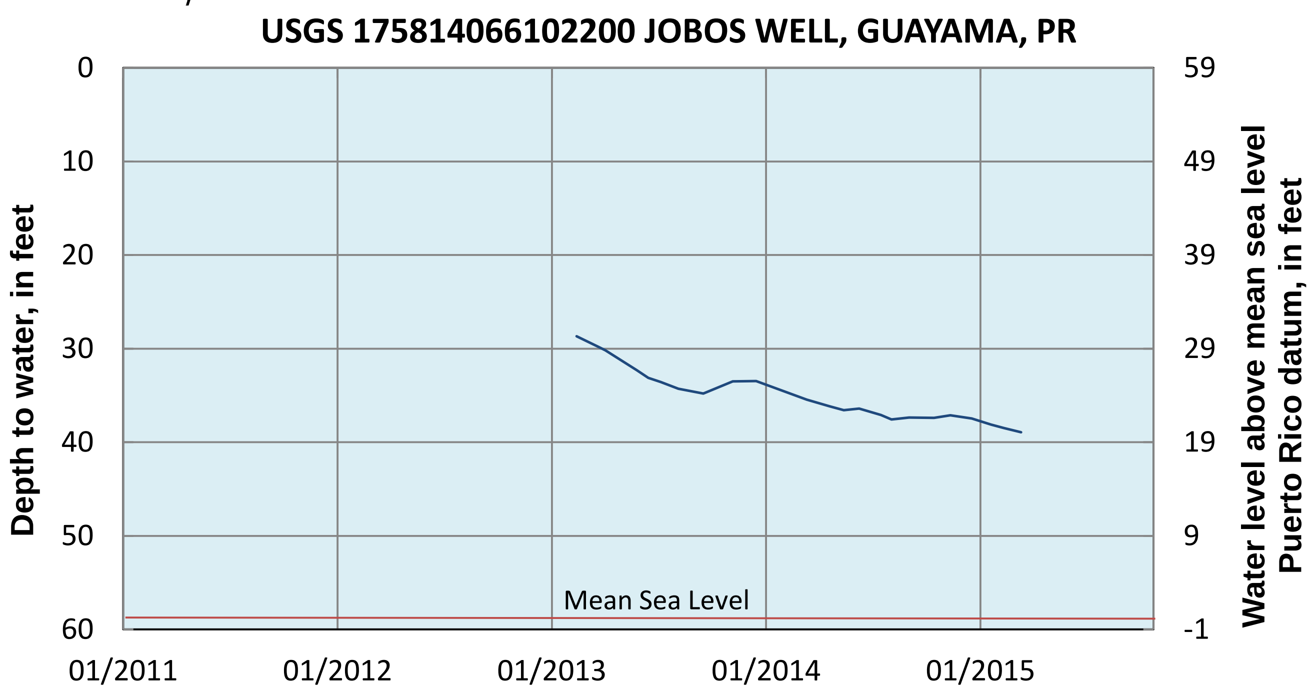



**Figure 7.** Measured water levels at USGS (A) Piezometer JAC-6, Juana Díaz, (B) Alomar 1 well, Santa Isabel, (C) Piezometer A RASA, Salinas, and (D) Jobos well, Guayama, 2011–15.—Continued

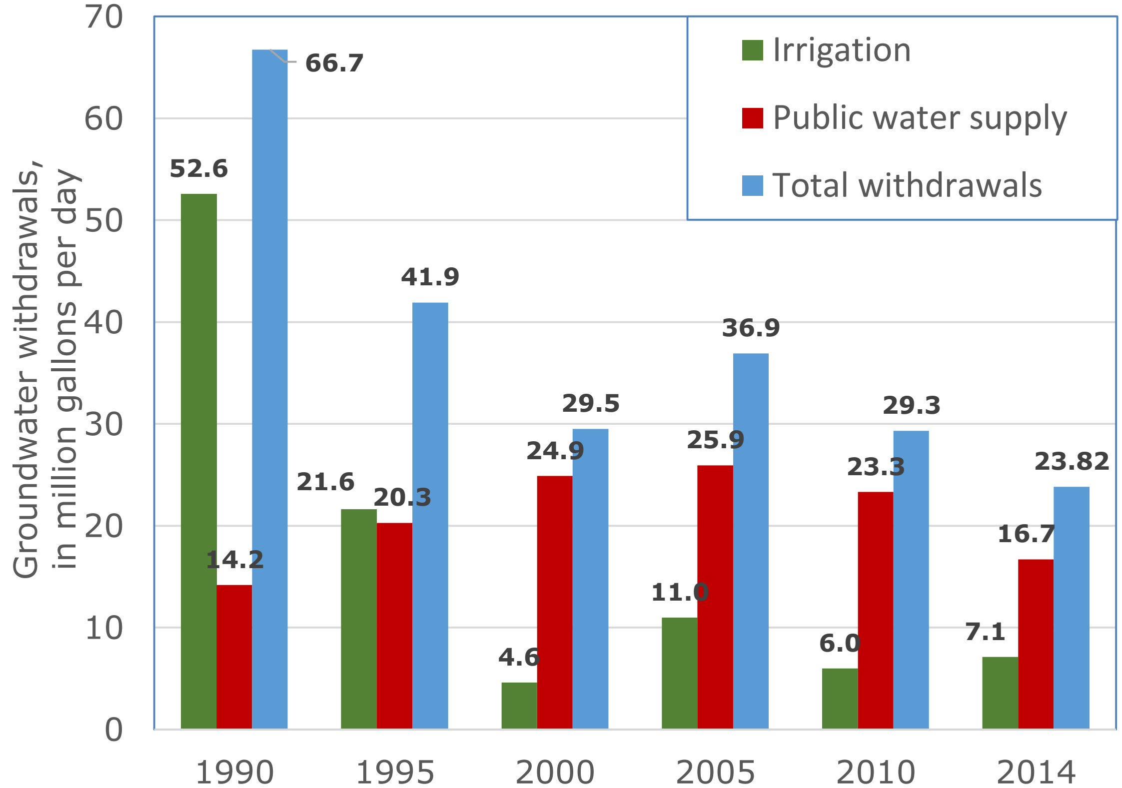



**Figure 8.** Groundwater withdrawals for irrigation and public water supply in the South Coast aquifer, in million gallons per day, 1990–2014 (source: W.L. Molina, U.S. Geological Survey, written commun., May 5, 2015).

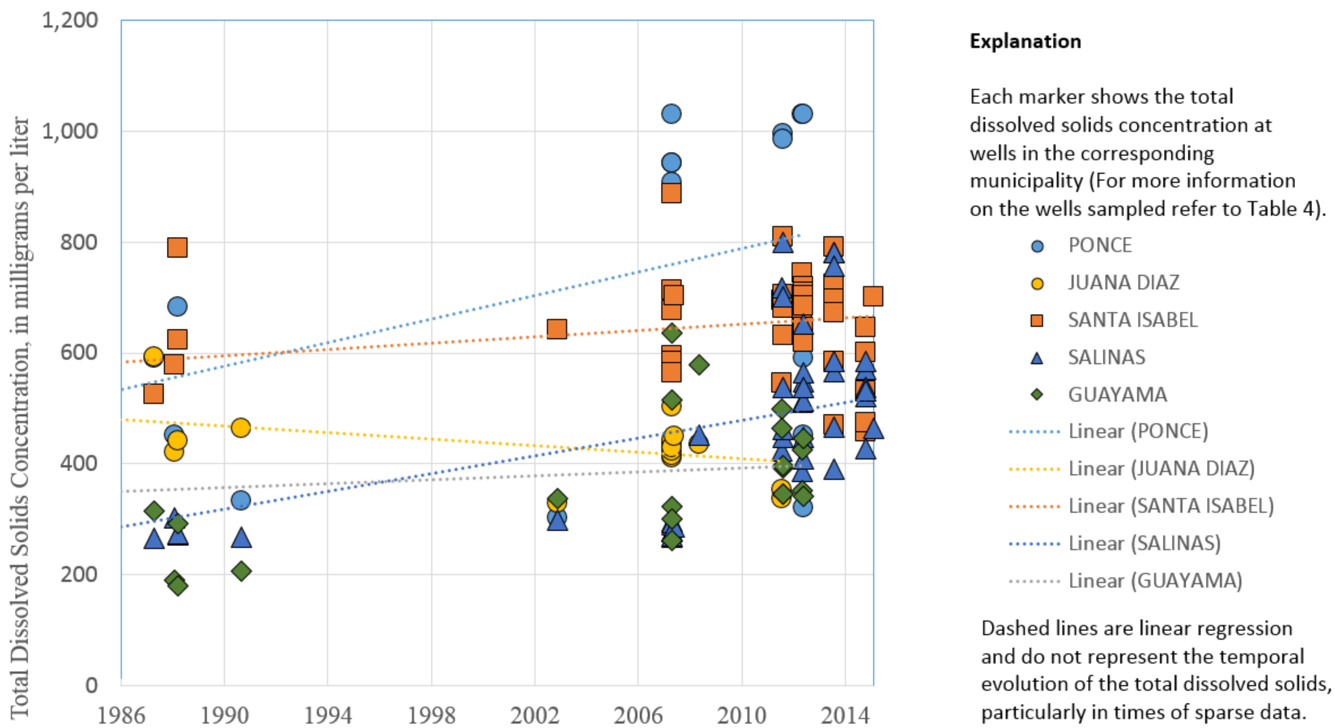



**Figure 9.** Total dissolved solids concentrations of the freshwater zone, South Coast aquifer, Puerto Rico.

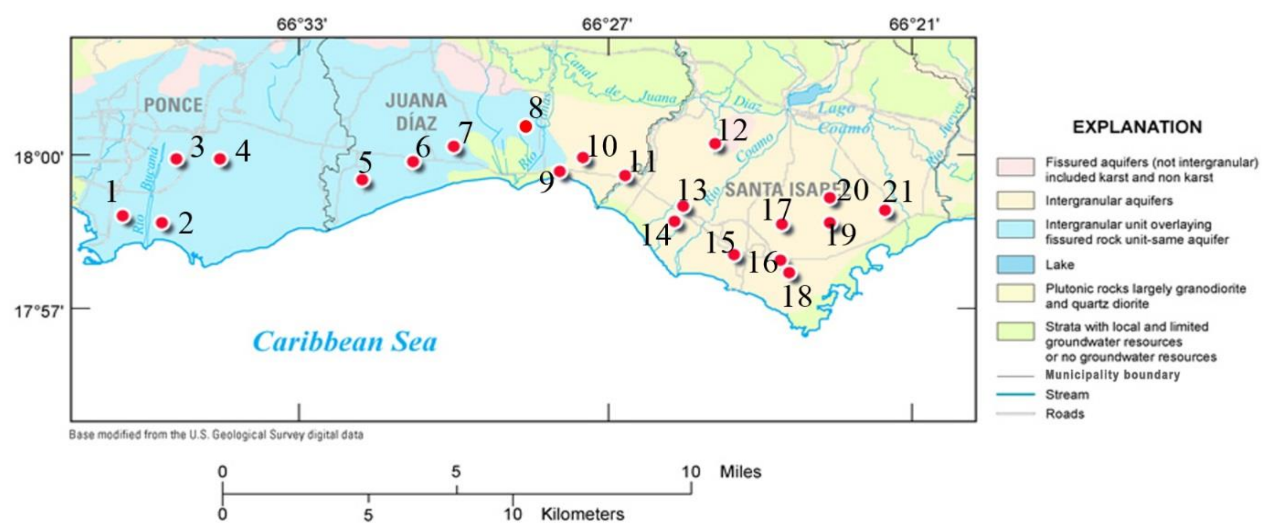



**Figure 10.** Location of wells sampled in the Ponce to Santa Isabel coastal areas, South Coast aquifer, Puerto Rico (see table 4 for additional site-specific information).

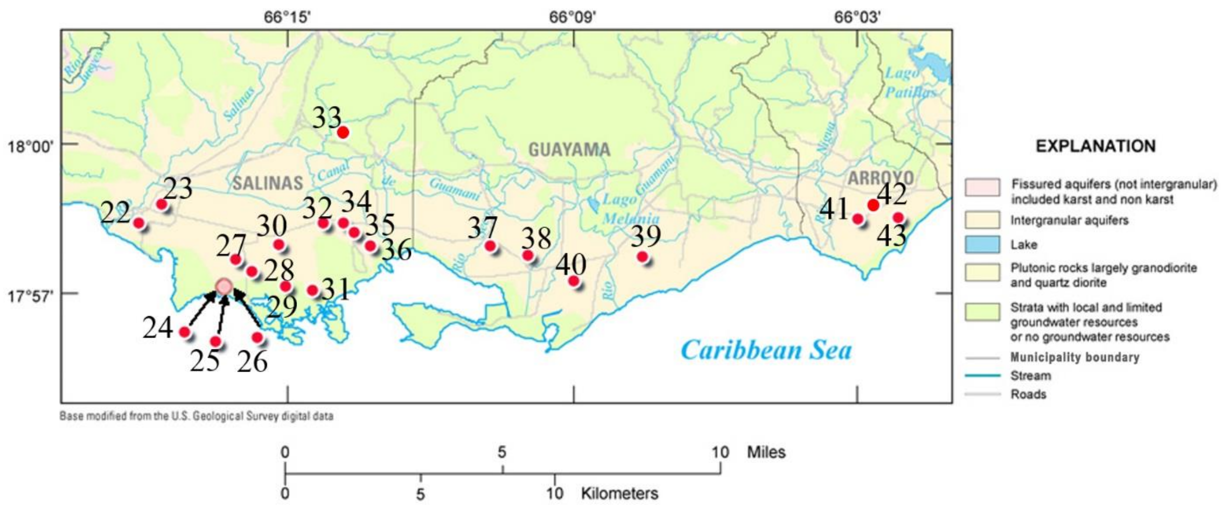



**Figure 11.** Location of wells sampled in the Salinas to Arroyo coastal areas, South Coast aquifer, Puerto Rico (see table 4 for additional site-specific information).

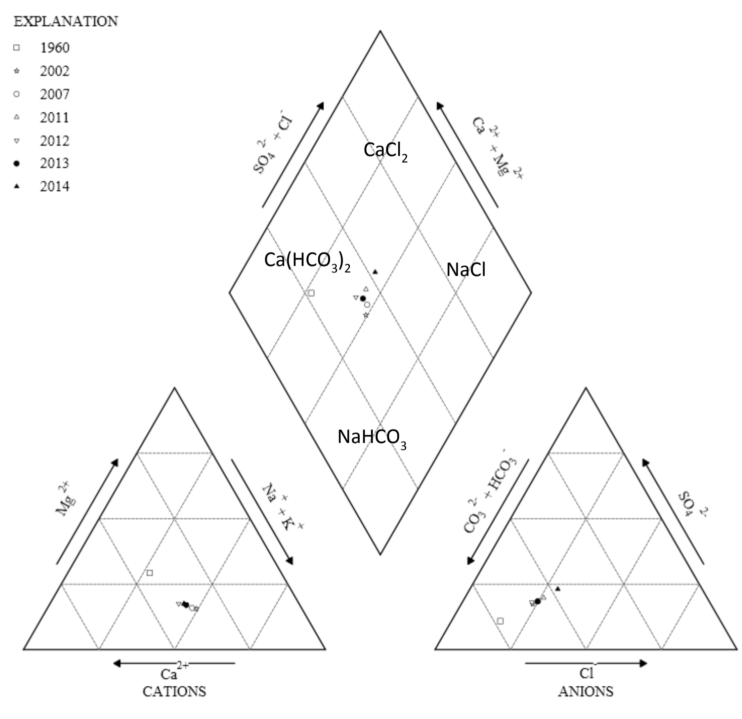



**Figure 12.** Groundwater ionic composition at well 32 (USGS 175804066150700), Salinas, Puerto Rico.

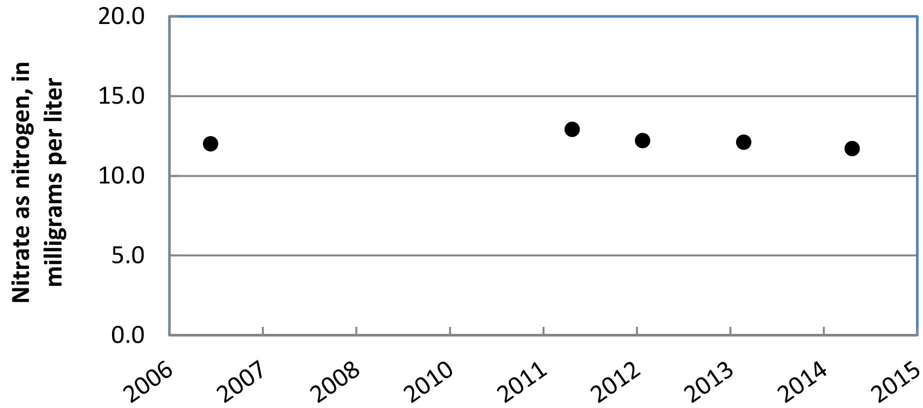



**Figure 13.** Nitrate-nitrogen concentration in groundwater from well 32 (USGS 175804066150700), Salinas, Puerto Rico.

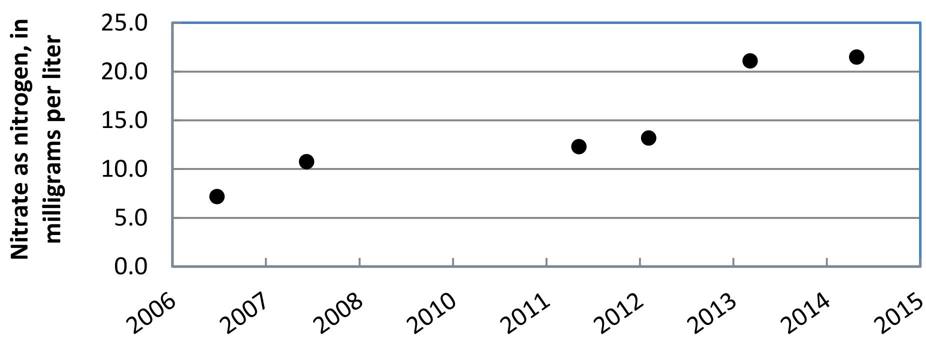



**Figure 14.** Nitrate-nitrogen concentration in groundwater from well 16 (USGS 175748066234200), Santa Isabel. Puerto Rico.

**Table 1.** Total annual rainfall, in percent above or below the 30-year average, at National Oceanic and Atmospheric Administration rainfall stations, South Coast aquifer, Puerto Rico, 2010–14.

[Positive values indicate above 30-year moving average rainfall; negative values indicate deficit in rainfall. NOAA, National Oceanic and Atmospheric Administration; NA, station was discontinued and data are not available]

| NOAA stations | Percentage above (+) or below (–) the 30-year moving average | | | | | | | | | | 30-year moving average, in inches | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | | |
| | Local | Regional | Local | Regional | Local | Regional | Local | Regional | Local | Regional | Local | Regional |
| Ponce 4E | 36.1 | 39.4 | 22.8 | 25.8 | –1.5 | 0.9 | –22.0 | –20.1 | –59.7 | –58.7 | 38.86 | 37.94 |
| Juana Díaz Camp | 12.3 | –23.8 | 64.7 | 11.7 | –1.9 | –33.4 | –50.0 | –66.1 | –28.2 | –51.3 | 42.01 | 61.93 |
| Santa Isabel 2ENE[P] | 16.1 | 9.4 | NA | NA | NA | NA | NA | NA | NA | NA | 35.74 | 37.94 |
| Aguirre Salinas | 31.3 | 40.5 | 112.2 | 127.1 | –33.0 | –28.3 | 15.8 | 23.9 | –24.5 | –19.2 | 40.60 | 37.94 |
| Guayama 2E | 37.3 | 33.5 | 44.9 | 40.9 | –36.5 | –38.2 | –9.0 | –11.4 | –24.2 | –26.3 | 60.24 | 61.93 |

[P]Partial record used for period of 2011 to 2014 for annual accumulation in precipitation at a local scale and for the estimated 30-year moving average for the South Coastal and Southern Slopes climatological regions at a regional scale.

**Table 2.** U.S. Geological Survey observation wells used in the evaluation of hydrologic conditions in the South Coast aquifer, Puerto Rico.

[nd, not determined]

| Station identification number | Well name | Aquifer area | Monitoring equipment | Measurement interval | Well depth, in feet |
|---|---|---|---|---|---|
| 175934066364800 | Constancia 3 well, Ponce, PR | Ponce-Juana Díaz | Transducer | Hourly | 144 |
| 175950066354200 | Restaurada P8A well, Ponce, PR | Ponce-Juana Díaz | Tapedown | Monthly | 165 |
| 180020066261500 | CAB 1 well, Juana Díaz, PR | Ponce-Juana Díaz | Transducer | Hourly | 71 |
| 180046066281700 | Amelia Domestic well, Juana Díaz, PR | Ponce-Juana Díaz | Tapedown | Monthly | nd |
| 180049066381200 | Canas well, Ponce, PR | Ponce-Juana Díaz | Tapedown | Monthly | 300 |
| 180057066311300 | Piezometer JAC-6 Juana Díaz, PR | Ponce-Juana Díaz | Transducer | Hourly | 49 |
| 180105066294800 | Ursula 7, Juana Díaz, PR | Ponce-Juana Díaz | Tapedown | Monthly | nd |
| 180138066323600 | Colones well, Ponce, PR | Ponce-Juana Díaz | Tapedown | Monthly | 227 |
| 180426066321100 | Cayabo well, Juana Díaz, PR | Ponce-Juana Díaz | Tapedown | Monthly | nd |
| 175734066233300 | Alomar Oeste well, Santa Isabel, PR | Santa Isabel | Transducer | Hourly | 70 |
| 175756066244001 | Playa 3 well, Santa Isabel, PR | Santa Isabel | Tapedown | Monthly | 250 |
| 175829066232200 | Alomar 1 well, Santa Isabel, PR | Santa Isabel | Transducer | Hourly | 112 |
| 175843066244100 | Jobitos BTR well, Santa Isabel, PR | Santa Isabel | Tapedown | Monthly | nd |
| 175943066224800 | Paso Seco 7 well, Santa Isabel, PR | Santa Isabel | Transducer | Hourly | 235 |
| 180151066220900 | Semidey well, Santa Isabel, PR | Santa Isabel | Tapedown | Monthly | nd |
| 175711066143600 | Piezometer JBNEER East 1, Salinas, PR | Salinas-Guayama | Tapedown | Monthly | 74 |
| 175719066085500 | PHILPET 13 well, Guayama, PR | Salinas-Guayama | Tapedown | Monthly | 99 |
| 175721066151400 | Piezometer JBNEER West 1, Salinas, PR | Salinas-Guayama | Tapedown | Monthly | 87 |
| 175814066102200 | Jobos well, Guayama, PR | Salinas-Guayama | Tapedown | Monthly | 166 |
| 175833066145800 | Piezometer A RASA, Salinas, PR | Salinas-Guayama | Tapedown | Monthly | 75 |
| 175858066100200 | JUA 5 well, Guayama, PR | Salinas-Guayama | Transducer | Hourly | 142 |
| 175910066155500 | Piezometer RASA D, Salinas, PR | Salinas-Guayama | Tapedown | Monthly | 87 |
| 175947066130601 | Piezometer Aguirre HW 5B, Salinas, PR | Salinas-Guayama | Transducer | Hourly | 51 |

**Table 3.** Summary of groundwater withdrawals for public water supply in the South Coast aquifer, Puerto Rico,1990–2014.
[From W.L. Molina, U.S. Geological Survey, written commun., 1990–2014. Numbers for each year may not add to totals shown due to rounding]

| Municipality | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| | Million gallons per day | | | | | |
| Ponce | 7.4 | 8.0 | 5.9 | 6.3 | 3.3 | 5.8[a] |
| Juana Díaz | 3.6 | 2.9 | 3.0 | 0.3 | [a] | [a] |
| Santa Isabel | 2.2 | 4.9 | 6.6 | 7.0 | 6.9 | 5.3[b] |
| Salinas | 3.0 | 1.4 | 2.5 | 4.4 | 3.9 | 4.4[c] |
| Guayama | 0.0 | 0.4 | 0.6 | 1.2 | 1.0 | [c] |
| Arroyo | 0.3 | 1.1 | 1.4 | 1.4 | 1.8 | 0.6 |
| Patillas | 0.3 | 0.4 | 0.6 | 1.1 | 0.8 | 0.7 |
| Total | 14.2 | 20.3 | 24.9 | 25.9 | 23.3 | 16.7 |

[a]Sum of Ponce to Juana Díaz.

[b]Sum of Juana Díaz and Santa Isabel.

[c]Sum of Salinas, Guayama, Arroyo, and Patillas.

**Table 4.** Map number, U.S. Geological Survey station identification number, municipality, and total dissolved solids concentrations for selected monitoring wells used to describe chemical conditions of the freshwater zone of the South Coast aquifer, Puerto Rico.

[mg/L, milligram per liter; E, estimated. Wells with a map number are part of the 2007–15 USGS Groundwater Quality Network; wells without a map number (NA, not applicable) are not, but site-specific data were available from the USGS National Water Information System; refer to figure 9 for time-series distribution]

| Map number (figs. 10, 11) | Station identification | Municipality | Date and time | Total dissolved solids concentration (mg/L) |
|---|---|---|---|---|
| 1 | 175839066361500 | Ponce | 12/10/2002; 1508 | 303E |
| 1 | 175839066361500 | Ponce | 12/11/2002; 0830 | 1,030E |
| 1 | 175839066361500 | Ponce | 12/11/2002; 1405 | 908E |
| 1 | 175839066361500 | Ponce | | |
| 2 | 175835066353900 | Ponce | 3/31/1989; 1015 | 683 |
| 2 | 175835066353900 | Ponce | 12/10/2002; 1450 | 333E |
| 2 | 175835066353900 | Ponce | | |
| 3 | 175948066351500 | Ponce | | |
| 4 | 175947066343200 | Ponce | 4/30/2007; 1315 | 942 |
| 4 | 175947066343200 | Ponce | 7/19/2011; 1320 | 1,000 |
| 4 | 175947066343200 | Ponce | 12/6/2013; 1330 | 1,520 |
| 4 | 175947066343200 | Juana Díaz | | |
| 5 | 175923066314300 | Juana Díaz | | |
| 5 | 175923066314300 | Juana Díaz | 5/2/2007; 1430 | 411 |
| 5 | 175923066314300 | Juana Díaz | 7/15/2011; 1020 | 424 |
| 5 | 175923066314300 | Juana Díaz | 1/24/2014; 1050 | 436 |
| 5 | 175923066314300 | Juana Díaz | 10/16/2014; 1100 | 337 |
| 6 | 175956066304500 | Juana Díaz | 7/21/2011; 1205 | 444 |
| 6 | 175956066304500 | Juana Díaz | 5/16/2012; 1130 | 429 |
| 6 | 175956066304500 | Juana Díaz | 12/3/2013; 1110 | 451 |
| 6 | 175956066304500 | Juana Díaz | 10/16/2014; 1200 | 354 |
| 6 | 175956066304500 | Juana Díaz | | |
| 7 | 175958066295200 | Juana Díaz | | |
| 8 | 180029066281700 | Juana Díaz | | |
| 9 | 175941066275100 | Juana Díaz | | |
| 9 | 175941066275100 | Juana Díaz | 7/21/2011; 1330 | 504 |
| 10 | 175952066272800 | Juana Díaz | | |
| 10 | 175952066272800 | Juana Díaz | 4/13/2007; 0830 | 441E |
| 10 | 175952066272800 | Juana Díaz | 7/15/2011; 0830 | 415 |
| 11 | 175931066264300 | Juana Díaz | | |
| 11 | 175931066264300 | Juana Díaz | 4/13/2007; 0950 | 465 |
| 11 | 175931066264300 | Juana Díaz | 7/14/2011; 1400 | 438 |
| 12 | 180007066245500 | Juana Diaz | | |
| 12 | 180007066245500 | Santa Isabel | 4/13/2007; 1100 | 1,110 |
| 12 | 180007066245500 | Santa Isabel | 8/11/2011; 1130 | 1,130 |
| 12 | 180007066245500 | Santa Isabel | 5/15/2012; 1015 | 1,150 |
| 12 | 180007066245500 | Santa Isabel | 7/17/2013; 1045 | 1,090 |
| 12 | 180007066245500 | Santa Isabel | 10/21/2014; 1040 | 1,080 |
| 13 | 175848066253100 | Santa Isabel | 4/11/2007; 1120 | 595 |
| 13 | 175848066253100 | Santa Isabel | 8/11/2011; 1320 | 631 |
| 13 | 175848066253100 | Santa Isabel | 5/15/2012; 1130 | 709 |
| 13 | 175848066253100 | Santa Isabel | 5/15/2012; 1135 | 704 |
| 13 | 175848066253100 | Santa Isabel | 7/17/2013; 1130 | 697 |
| 13 | 175848066253100 | Santa Isabel | 10/21/2014; 1005 | 475 |
| 13 | 175848066253100 | Juana Díaz | | |
| 14 | 175839066253900 | Santa Isabel | 2/10/1967; 1245 | 527 |
| 14 | 175839066253900 | Santa Isabel | 4/11/2007; 1040 | 677 |

**Table 4.** Map number, U.S. Geological Survey station identification number, municipality, and total dissolved solids concentrations for selected monitoring wells used to describe chemical conditions of the freshwater zone of the South Coast aquifer, Puerto Rico.—Continued

[mg/L, milligram per liter; E, estimated. Wells with a map number are part of the 2007–15 USGS Groundwater Quality Network; wells without a map number (NA, not applicable) are not, but site-specific data were available from the USGS National Water Information System; refer to figure 9 for time-series distribution]

| Map number (figs. 10, 11) | Station identification | Municipality | Date and time | Total dissolved solids concentration (mg/L) |
|---|---|---|---|---|
| 14 | 175839066253900 | Santa Isabel | 8/11/2011; 1245 | 681 |
| 14 | 175839066253900 | Santa Isabel | 5/15/2012; 1230 | 647 |
| 14 | 175839066253900 | Santa Isabel | 7/17/2013; 1145 | 791 |
| 14 | 175839066253900 | Santa Isabel | 7/17/2013; 1150 | 672 |
| 14 | 175839066253900 | Santa Isabel | 10/21/2014; 1130 | 602 |
| 14 | 175839066253900 | Juana Díaz | | |
| 15 | 175758066242700 | Santa Isabel | 8/14/1967; 1150 | 386 |
| 15 | 175758066242700 | Santa Isabel | 4/12/2007; 1115 | 564 |
| 15 | 175758066242700 | Santa Isabel | 7/14/2011; 1530 | 546 |
| 15 | 175758066242700 | Santa Isabel | 5/16/2012; 0845 | 684 |
| 15 | 175758066242700 | Santa Isabel | 7/16/2013; 1150 | 585 |
| 15 | 175758066242700 | Santa Isabel | 10/15/2014; 1020 | 532 |
| 15 | 175758066242700 | Santa Isabel | | |
| 16 | 175748066234200 | Santa Isabel | | |
| 17 | 175825066233900 | Santa Isabel | 4/11/2007; 1335 | 585 |
| 17 | 175825066233900 | Santa Isabel | 5/15/2012; 1500 | 620 |
| 17 | 175825066233900 | Santa Isabel | 7/18/2013; 1110 | 470 |
| 17 | 175825066233900 | Santa Isabel | 10/15/2014; 0905 | 458 |
| 17 | 175825066233900 | Santa Isabel | | |
| 18 | 175734066233300 | Santa Isabel | 5/18/2007; 1000 | 703 |
| 18 | 175734066233300 | Santa Isabel | 7/28/2011; 1245 | 706 |
| 18 | 175734066233300 | Santa Isabel | 5/11/2012; 1030 | 720 |
| 18 | 175734066233300 | Santa Isabel | 1/28/2015; 1510 | 701 |
| 18 | 175734066233300 | Santa Isabel | | |
| 19 | 175835066223600 | Santa Isabel | 4/12/2007; 1345 | 1,650 |
| 19 | 175835066223600 | Santa Isabel | | |
| 20 | 175857066223500 | Santa Isabel | 8/11/2011; 1015 | 810 |
| 20 | 175857066223500 | Santa Isabel | 5/8/2012; 1000 | 669 |
| 20 | 175857066223500 | Santa Isabel | | |
| 21 | 175848066213300 | Santa Isabel | 4/12/2007; 0915 | 713 |
| 21 | 175848066213300 | Santa Isabel | 7/12/2011; 1430 | 696 |
| 21 | 175848066213300 | Santa Isabel | 5/8/2012; 1440 | 745 |
| 21 | 175848066213300 | Santa Isabel | 7/16/2013; 0945 | 723 |
| 21 | 175848066213300 | Santa Isabel | 10/16/2014; 0930 | 647 |
| 21 | 175848066213300 | Santa Isabel | | |
| 22 | 175826066180600 | Salinas | | |
| 23 | 175851066174600 | Salinas | 4/4/2007; 1200 | 485 |
| 23 | 175851066174600 | Salinas | 5/22/2007; 1030 | 936 |
| 23 | 175851066174600 | Salinas | 6/27/2011; 1200 | 503 |
| 23 | 175851066174600 | Salinas | 5/1/2012; 0000 | 515 |
| 23 | 175851066174600 | Salinas | 7/1/2013; 1200 | 483 |
| 23 | 175851066174600 | Salinas | 10/7/2014; 1200 | 443 |
| 24 | 175708066163001 | Salinas | 3/11/2002; 1200 | 470 |
| 24 | 175708066163001 | Salinas | | |
| 25 | 175708066163000 | Salinas | 3/20/1986; 0915 | 565 |
| 25 | 175708066163000 | Salinas | | |

**Table 4.** Map number, U.S. Geological Survey station identification number, municipality, and total dissolved solids concentrations for selected monitoring wells used to describe chemical conditions of the freshwater zone of the South Coast aquifer, Puerto Rico.—Continued

[mg/L, milligram per liter; E, estimated. Wells with a map number are part of the 2007–15 USGS Groundwater Quality Network; wells without a map number (NA, not applicable) are not, but site-specific data were available from the USGS National Water Information System; refer to figure 9 for time-series distribution]

| Map number (figs. 10, 11) | Station identification | Municipality | Date and time | Total dissolved solids concentration (mg/L) |
|---|---|---|---|---|
| 26 | 175708066163002 | Salinas | 5/22/2007; 1200 | 19,900E |
| 26 | 175708066163002 | Salinas | 8/18/2011; 1530 | 19,500 |
| 26 | 175708066163002 | Salinas | 5/3/2012; 1445 | |
| 26 | 175708066163002 | Salinas | 12/11/2013; 1320 | 18,700 |
| 26 | 175708066163002 | Salinas | 1/27/2015; 1110 | 18,900 |
| 27 | 175748066160400 | Salinas | 4/1/1986; 1515 | 567 |
| 27 | 175748066160400 | Salinas | 8/13/1986; 0930 | 428 |
| 27 | 175748066160400 | Salinas | 3/5/2002; 1025 | 506 |
| 27 | 175748066160400 | Salinas | 4/4/2007; 0845 | 537 |
| 27 | 175748066160400 | Salinas | 6/30/2011; 1430 | 543 |
| 27 | 175748066160400 | Salinas | | |
| 28 | 175738066155400 | Salinas | | |
| 29 | 175721066151400 | Salinas | 5/16/2007; 1000 | 530E |
| 29 | 175721066151400 | Salinas | 8/18/2011; 1230 | 483 |
| 29 | 175721066151400 | Salinas | 5/3/2012; 1245 | 514 |
| 29 | 175721066151400 | Salinas | 1/28/2015; 1250 | 502 |
| 29 | 175721066151400 | Salinas | | |
| 30 | 175804066150700 | Salinas | 3/5/2002; 1255 | 663 |
| 30 | 175804066150700 | Salinas | 4/4/2007; 0945 | 717 |
| 30 | 175804066150700 | Salinas | 6/30/2011; 1130 | 666 |
| 30 | 175804066150700 | Salinas | 4/26/2012; 1015 | 685 |
| 30 | 175804066150700 | Salinas | 7/3/2013; 1025 | 717 |
| 30 | 175804066150700 | Salinas | 10/10/2014; 0950 | 580 |
| 30 | 175804066150700 | Salinas | | |
| 31 | 175711066143600 | Salinas | | |
| 32 | 175828066142200 | Salinas | | |
| 33 | 180008066135900 | Salinas | | |
| 33 | 180008066135900 | Salinas | 11/26/2002; 1230 | 572 |
| 33 | 180008066135900 | Salinas | 10/9/2014; 1000 | 636 |
| 34 | 175822066134800 | Salinas | | |
| 35 | 175820066133500 | Salinas | 4/25/2012; 1200 | 639 |
| 35 | 175820066133500 | Salinas | 7/1/2013; 1200 | 614 |
| 35 | 175820066133500 | Salinas | 10/7/2014; 1200 | 615 |
| 35 | 175820066133500 | Salinas | | |
| 36 | 175812066133200 | Salinas | 8/13/1986; 1200 | 531 |
| 36 | 175812066133200 | Salinas | 8/13/1986; 1200 | 537 |
| 36 | 175812066133200 | Salinas | 4/18/2007; 1430 | 757E |
| 36 | 175812066133200 | Salinas | 6/30/2011; 0800 | 689 |
| 36 | 175812066133200 | Salinas | | |
| 37 | 175755066105000 | Guayama | 3/25/1986; 1200 | 316 |
| 37 | 175755066105000 | Guayama | 4/3/2007; 0955 | 393 |
| 37 | 175755066105000 | Guayama | 6/29/2011; 1300 | 396 |
| 37 | 175755066105000 | Guayama | 7/3/2013; 1120 | 426 |
| 37 | 175755066105000 | Guayama | 10/14/2014; 1110 | 447 |
| 37 | 175755066105000 | Guayama | | |

**Table 4.** Map number, U.S. Geological Survey station identification number, municipality, and total dissolved solids concentrations for selected monitoring wells used to describe chemical conditions of the freshwater zone of the South Coast aquifer, Puerto Rico.—Continued

[mg/L, milligram per liter; E, estimated. Wells with a map number are part of the 2007–15 USGS Groundwater Quality Network; wells without a map number (NA, not applicable) are not, but site-specific data were available from the USGS National Water Information System; refer to figure 9 for time-series distribution]

| Map number (figs. 10, 11) | Station identification | Municipality | Date and time | Total dissolved solids concentration (mg/L) |
|---|---|---|---|---|
| 38 | 175747066101000 | Guayama | | |
| 39 | 175740066073200 | Guayama | | |
| 40 | 175719066085500 | Guayama | 5/17/2007; 1440 | 345E |
| 40 | 175719066085500 | Guayama | 7/28/2011; 1015 | 346 |
| 40 | 175719066085500 | Guayama | 12/11/2013; 1030 | 352 |
| 40 | 175719066085500 | Guayama | 1/27/2015; 1345 | 342 |
| 40 | 175719066085500 | Guayama | | |
| 41 | 175832066031300 | Guayama | | |
| 42 | 175848066024100 | Guayama | | |
| 43 | 175832066022000 | Guayama | | |
| NA | 175659066093600 | Guayama | 5/21/1987; 0915 | 515 |
| NA | 175710066092300 | Guayama | 4/1/1986; 1345 | 263 |
| NA | 175728066100900 | Guayama | 5/2/2007; 1130 | 744 |
| NA | 175728066225800 | Santa Isabel | 4/18/2007; 1330 | 887 |
| NA | 175729066160601 | Salinas | 3/20/1986; 0815 | 548 |
| NA | 175732066091900 | Guayama | 3/25/1986; 1630 | 292 |
| NA | 175732066091900 | Guayama | 8/13/1986; 1300 | 301 |
| NA | 175735066151800 | Salinas | 3/20/1986; 1100 | 538 |
| NA | 175735066151800 | Salinas | 5/17/2007; 1115 | 810E |
| NA | 175754066072200 | Guayama | 4/1/1986; 1145 | 337 |
| NA | 175754066072200 | Guayama | 8/12/1986; 1400 | 323 |
| NA | 175754066084100 | Guayama | 3/26/1986; 1115 | 207 |
| NA | 175805066105500 | Guayama | 3/21/1986; 0900 | 335 |
| NA | 175808066120600 | Guayama | 4/1/1986; 1445 | 838 |
| NA | 175808066120600 | Guayama | 8/14/1986; 0830 | 819 |
| NA | 175808066120600 | Guayama | 3/15/1988; 1230 | 797 |
| NA | 175816066183200 | Salinas | 8/7/1986; 1100 | 780 |
| NA | 175820066144800 | Salinas | 8/13/1986; 1100 | 584 |
| NA | 175821066144600 | Salinas | 3/12/2002; 1115 | 560 |
| NA | 175823066162400 | Salinas | 3/20/1986; 1030 | 513 |
| NA | 175823066164600 | Salinas | 4/17/2007; 1015 | 545E |
| NA | 175823066180500 | Salinas | 8/9/1986; 0815 | 522 |
| NA | 175824066360900 | Ponce | 4/29/1987; 1435 | 423 |
| NA | 175824066360900 | Ponce | 5/18/1987; 1500 | 322 |
| NA | 175825066142500 | Salinas | 4/25/1979; 0710 | 304 |
| NA | 175825066142500 | Salinas | 5/9/1979; 0715 | 304 |
| NA | 175825066142500 | Salinas | 7/24/1979; 0845 | 275 |
| NA | 175825066142500 | Salinas | 8/8/1979; 1200 | 299 |
| NA | 175825066142500 | Salinas | 8/21/1979; 1000 | 296 |
| NA | 175825066142500 | Salinas | 9/25/1979; 0900 | 279 |
| NA | 175825066142500 | Salinas | 10/10/1979; 1100 | 294 |
| NA | 175825066142500 | Salinas | 10/23/1979; 1030 | 287 |
| NA | 175825066142500 | Salinas | 11/28/1979; 1055 | 453 |
| NA | 175826066134400 | Salinas | 6/24/1982; 1000 | 717 |
| NA | 175826066173700 | Salinas | 8/8/1986; 1845 | 570 |
| NA | 175828066344400 | Ponce | 5/19/1987; 1630 | 590 |

**Table 4.** Map number, U.S. Geological Survey station identification number, municipality, and total dissolved solids concentrations for selected monitoring wells used to describe chemical conditions of the freshwater zone of the South Coast aquifer, Puerto Rico.—Continued

[mg/L, milligram per liter; E, estimated. Wells with a map number are part of the 2007–15 USGS Groundwater Quality Network; wells without a map number (NA, not applicable) are not, but site-specific data were available from the USGS National Water Information System; refer to figure 9 for time-series distribution]

| Map number (figs. 10, 11) | Station identification | Municipality | Date and time | Total dissolved solids concentration (mg/L) |
|---|---|---|---|---|
| NA | 175828066344401 | Ponce | 5/20/1987; 1015 | 452 |
| NA | 175833066145800 | Salinas | 3/20/1986; 1330 | 449 |
| NA | 175837066165400 | Salinas | 3/15/1988; 1115 | 498 |
| NA | 175838066161100 | Salinas | 3/19/1986; 1500 | 511 |
| NA | 175839066151500 | Salinas | 4/25/1979; 0640 | 262 |
| NA | 175839066151500 | Salinas | 5/9/1979; 0705 | 266 |
| NA | 175839066151500 | Salinas | 7/24/1979; 0800 | 272 |
| NA | 175839066151500 | Salinas | 8/8/1979; 1100 | 268 |
| NA | 175839066151500 | Salinas | 8/21/1979; 0845 | 268 |
| NA | 175839066151500 | Salinas | 9/11/1979; 0800 | 279 |
| NA | 175839066151500 | Salinas | 9/25/1979; 0800 | 278 |
| NA | 175839066151500 | Salinas | 10/10/1979; 1020 | 290 |
| NA | 175839066151500 | Salinas | 10/23/1979; 0930 | 270 |
| NA | 175839066151500 | Salinas | 11/28/1979; 1140 | 423 |
| NA | 175840066024200 | Arroyo | 3/26/1986; 1515 | 389 |
| NA | 175840066102100 | Guayama | 3/25/1986; 1300 | 191 |
| NA | 175845066164500 | Salinas | 3/12/2002; 1415 | 404 |
| NA | 175845066164500 | Salinas | 11/20/2002; 1130 | 412 |
| NA | 175848066145800 | Salinas | 8/8/1986; 1215 | 585 |
| NA | 175851066153000 | Salinas | 12/5/2002; 1030 | 458 |
| NA | 175854066144500 | Salinas | 11/22/2002; 1245 | 636 |
| NA | 175854066144500 | Salinas | 4/2/2007; 1130 | 688E |
| NA | 175855066161400 | Salinas | 3/19/2002; 1045 | 453 |
| NA | 175855066161400 | Salinas | 11/21/2002; 1200 | 455 |
| NA | 175858066123100 | Salinas | 8/14/1986; 0930 | 465 |
| NA | 175858066151600 | Salinas | 4/3/2007; 0845 | 527E |
| NA | 175902066354400 | Ponce | 6/3/2003; 0830 | 1,030 |
| NA | 175904066181800 | Salinas | 3/19/1986; 1100 | 702 |
| NA | 175904066181800 | Salinas | 8/7/1986; 1200 | 757 |
| NA | 175910066122300 | Salinas | 3/25/1986; 1030 | 466 |
| NA | 175910066155500 | Salinas | 3/19/1986; 1315 | 537 |
| NA | 175911066322500 | Ponce | 6/3/2003; 1130 | 942E |
| NA | 175912066120400 | Guayama | 3/20/1986; 1715 | 585 |
| NA | 175912066221500 | Santa Isabel | 5/7/2008; 1530 | 1,900 |
| NA | 175916066183200 | Salinas | 8/7/1986; 1100 | 780 |
| NA | 175920066175800 | Salinas | 3/19/1986; 1145 | 800 |
| NA | 175920066251700 | Salinas | 4/11/2007; 1220 | 703 |
| NA | 175921066144500 | Santa Isabel | 11/22/2002; 1100 | 641 |
| NA | 175921066165500 | Salinas | 3/19/1986; 0645 | 449 |
| NA | 175921066165500 | Salinas | 3/15/1988; 1030 | 439 |

**Table 4.** Map number, U.S. Geological Survey station identification number, municipality, and total dissolved solids concentrations for selected monitoring wells used to describe chemical conditions of the freshwater zone of the South Coast aquifer, Puerto Rico.—Continued

[mg/L, milligram per liter; E, estimated. Wells with a map number are part of the 2007–15 USGS Groundwater Quality Network; wells without a map number (NA, not applicable) are not, but site-specific data were available from the USGS National Water Information System; refer to figure 9 for time-series distribution]

| Map number (figs. 10, 11) | Station identification | Municipality | Date and time | Total dissolved solids concentration (mg/L) |
|---|---|---|---|---|
| NA | 175921066220100 | Santa Isabel | 3/15/1988; 1400 | 624 |
| NA | 175925066145400 | Salinas | 3/20/1986; 1200 | 652 |
| NA | 175931066160100 | Salinas | 3/19/1986; 1245 | 463 |
| NA | 175933066120400 | Guayama | 9/2/1988; 1345 | 499 |
| NA | 175933066161800 | Salinas | 3/6/2002; 0955 | 396 |
| NA | 175933066161800 | Salinas | 11/21/2002; 1430 | 402 |
| NA | 175939066121403 | Guayama | 7/13/1988; 1300 | 818 |
| NA | 175941066221400 | Santa Isabel | 1/26/1988; 1300 | 579 |
| NA | 175942066070700 | Guayama | 3/26/1986; 1000 | 180 |
| NA | 175942066251900 | Santa Isabel | 3/18/1988; 1345 | 788 |
| NA | 175946066102003 | Guayama | 7/29/1988; 1600 | 579 |
| NA | 175947066130604 | Salinas | 5/4/1988; 1610 | 662 |
| NA | 175950066125202 | Salinas | 4/27/1988; 1230 | 694 |
| NA | 175950066263900 | Juana Díaz | 4/9/1987; 1630 | 526 |
| NA | 175951066281400 | Juana Díaz | 4/9/1987; 1420 | 526 |
| NA | 175953066124400 | Salinas | 5/3/1988; 1155 | 927 |
| NA | 175954066210500 | Santa Isabel | 4/7/1987; 1750 | 526 |
| NA | 175955066103003 | Guayama | 9/8/1988; 1300 | 464 |
| NA | 175957066121500 | Guayama | 7/7/1988; 1530 | 636 |
| NA | 175958066131000 | Salinas | 6/23/1988; 1600 | 552 |
| NA | 175959066141500 | Salinas | 3/18/2002; 1045 | 876 |
| NA | 175959066141500 | Salinas | 11/27/2002; 1115 | 837 |
| NA | 180001066311200 | Juana Díaz | 4/17/2007; 1445 | 431 |
| NA | 180004066343200 | Ponce | 12/10/2013; 1110 | 996 |
| NA | 180005066322400 | Ponce | 10/24/2014; 1010 | 984 |
| NA | 180009066320100 | Ponce | 10/24/2014; 1115 | 1,440 |
| NA | 180013066375200 | Ponce | 12/11/2002; 0830 | 1,030 |
| NA | 180014066325600 | Ponce | 5/18/1987; 1500 | 322 |
| NA | 180016066261500 | Juana Díaz | 1/28/1988; 1120 | 593 |
| NA | 180024066140100 | Salinas | 3/14/2002; 1400 | 876 |
| NA | 180024066140100 | Salinas | 11/26/2002; 1430 | 856 |
| NA | 180027066313200 | Juana Díaz | 4/17/2007; 1400 | 330 |
| NA | 180031066350100 | Ponce | 6/3/2003; 0830 | 1,030 |
| NA | 180032066384500 | Ponce | 5/20/1987; 1015 | 452 |
| NA | 180033066140900 | Salinas | 11/19/2002; 1030 | 1,010 |
| NA | 180051066382200 | Ponce | 5/19/1987; 1630 | 590 |
| NA | 180054066152800 | Salinas | 3/19/1986; 1745 | 386 |
| NA | 180054066152800 | Salinas | 8/7/1986; 1620 | 390 |
| NA | 180105066294800 | Juana Díaz | 3/18/1988; 1300 | 422 |
| NA | 180201066133900 | Salinas | 4/18/1989; 1145 | 370 |
| NA | 180201066133900 | Salinas | 5/24/1989; 1230 | 371 |
| NA | 180201066133900 | Salinas | 6/27/1989; 1026 | 371 |
| NA | 180201066133900 | Salinas | 7/24/1989; 1036 | 382 |
| NA | 180201066133900 | Salinas | 12/18/1989; 1000 | 856 |

**Table 4.** Map number, U.S. Geological Survey station identification number, municipality, and total dissolved solids concentrations for selected monitoring wells used to describe chemical conditions of the freshwater zone of the South Coast aquifer, Puerto Rico.—Continued

[mg/L, milligram per liter; E, estimated. Wells with a map number are part of the 2007–15 USGS Groundwater Quality Network; wells without a map number (NA, not applicable) are not, but site-specific data were available from the USGS National Water Information System; refer to figure 9 for time-series distribution]

| Map number (figs. 10, 11) | Station identification | Municipality | Date and time | Total dissolved solids concentration (mg/L) |
|---|---|---|---|---|
| NA | 180217066141900 | Salinas | 7/19/1988; 1000 | 405 |
| NA | 180217066141900 | Salinas | 12/27/1988; 1030 | 395 |
| NA | 180217066141900 | Salinas | 1/24/1989; 1000 | 385 |
| NA | 180217066141900 | Salinas | 2/21/1989; 0930 | 383 |
| NA | 180217066141900 | Salinas | 3/20/1989; 0900 | 381 |
| NA | 180217066141900 | Salinas | 4/18/1989; 1400 | 383 |
| NA | 180217066141900 | Salinas | 5/23/1989; 1000 | 389 |
| NA | 180217066141900 | Salinas | 6/26/1989; 1210 | 400 |
| NA | 180217066141900 | Salinas | 7/24/1989; 1220 | 399 |
| NA | 180217066141900 | Salinas | 8/28/1989; 0953 | 394 |
| NA | 180217066141900 | Salinas | 10/16/1989; 1145 | 414 |
| NA | 180217066141900 | Salinas | 11/20/1989; 1021 | 420 |
| NA | 180217066141900 | Salinas | 12/18/1989; 1112 | 423 |
| NA | 180217066141900 | Salinas | 7/6/1990; 1425 | 416 |
| NA | 180217066141900 | Salinas | 12/5/1990; 1115 | 399 |
| NA | 180242066223400 | Coamo | 4/9/1986; 1830 | 381 |
| NA | 180403066224100 | Coamo | 4/9/1986; 1300 | 413 |