U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
PUERTO RICO DEPARTMENT OF NATURAL AND ENVIRONMENTAL RESOURCES

SCIENTIFIC INVESTIGATION MAP 2008-3032

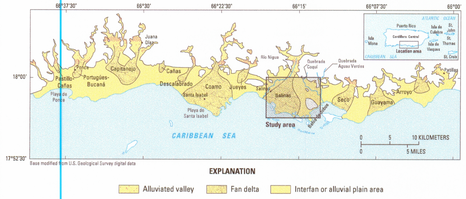
Historical ground-water development in the Salinas alluvial fan area, Salinas, Puerto Rico, 1900-2005

by José M. Rodríguez and Fernando Gómez-Gómez

INTRODUCTION

The Salinas alluvial fan area has historically been one of the most intensively used agricultural areas in the South Coastal Plain of Puerto Rico. Changes in agricultural practices and land use in the Salinas alluvial fan have also caused changes in the geographic distribution of ground-water withdrawals from the alluvial aquifer. As a result, the ground-water balance and ground-water flow pattern have changed throughout the years and may explain the presence of saline ground water along parts of the coast at present. By providing a reconstruction of historical ground-water development in the Salinas alluvial fan area, from the initial years of aquifer development at about 1900 to the most recent conditions existing in 2005, water-resources managers and planners can use the results of the analysis for a more complete understanding of aquifer conditions especially pertaining to water quality. This study effort was conducted by the U.S. Geological Survey in cooperation with the Puerto Rico Department of Natural and Environmental Resources as a contribution in the management of the Jobos Bay National Estuarine Research Reserve.

The study area encompasses about 20 mi² (square miles) of the extensive South Coastal Plain alluvial aquifer system (fig. 1). The study area is bounded to the north by foothills of the Cordillera Central mountain chain, to the south by the Caribbean Sea, and to the east and west by the Río Nigua de Salinas and the Quebrada Aguas Verdes, respectively. Fan-delta and alluvial deposits contain the principal aquifers in the study area.



EXPLANATION

Alluviated valley | Fan delta | Interfan or alluvial plain area

Figure 1. Location study area and extent of fan deltas of the South Coastal Plain alluvial aquifer system, Puerto Rico.

Table 1. Ground-water withdrawals, in million gallons per day, in the Salinas alluvial fan area from 1900 to 2005.

NUMBER IN MAP	USGS SITE IDENTIFICATION	1900-1909	1910-1919	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2005
TOTALS		6.14	10.05	13.08	17.30	21.60	23.20	26.90	21.87	18.77	10.09	10.45
1	175822006165400	0.35	0.87	0.87	0.87	0.87	0.87	0.87				
2	175906006171600	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87			
3	175817066145000	0.43	0.87	1.30	1.30	1.30	1.30	1.30				
4	175809006145300	0.43	0.52	0.52	0.98	2.01	2.01	2.01	2.01			
5	175810066153500	0.87	0.87	0.87	0.87	0.87	0.87	0.87				
6	175826066181600	0.28	0.28	0.28	0.28	0.28	0.28	0.28				
7	175837066173500	0.43	0.43	0.28	0.28	0.28	0.28	0.28				
8	175902066163800	1.17	1.17	1.17	1.17	1.17	1.17	1.17				
9	175850066154000	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	0.65	0.65	0.10
10	175857066175000		0.22	0.22	0.22	0.22	0.22	0.22				
11	175911066173700		0.22	0.22	0.22	0.22	0.22	0.22				
12	175829066163000		0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69		
13	175801066154700		0.69	0.87	0.87	0.87	0.87	0.87	0.87	0.87		
14	175748066155800		0.87	0.87	0.87	0.87	0.87	0.87	0.87			
15	175823066144200		0.19	0.05	0.05	0.05	0.05	0.05				
16	175748066132600			0.13	0.13	0.13	0.13	0.13				
17	175737066144700			0.77	0.98	0.98	0.98	0.98				
18	175916066164000			0.50	0.50	0.50	0.50	0.50	0.50	0.50		
19	175816066125400			0.05	0.05	0.05	0.05	0.05	0.05	0.05		
20	175917066162000			0.64								
21	175851066163000			0.19								
22	175810066145100			0.44								
23	175858066151600				0.59	0.59	0.78	0.78	0.78	0.78	0.78	
24	175851066145700				0.98	0.98	0.98	0.98	0.98	0.98	0.58	0.41
25	175849066145700										0.40	
26	175925066165100				0.43	0.43	0.43	0.43				
27	175821066182100				0.17	0.17	0.17	0.17				
28	175855066161400				0.19	0.19	0.19	0.19				0.10
29	175835066162600				0.59	0.59	0.59	0.59	0.59			
30	175913066163500				0.25	0.25	0.25	0.25	0.25			
31	175804066150700				0.71	0.71	0.96	0.87			0.70	0.70
32	175850066174400				0.17	0.17	0.17	0.17	0.17	0.17	1.01	0.59
33	175851066174600										0.86	0.86
34	175809066145300				0.44	0.35	0.35	0.35	0.35	0.35		
35	175823066164600				0.29	0.29	0.29	0.29				0.23
36	175928066171500					0.23	0.23	0.23	0.23	0.23		
37	175921066165500					0.62	0.62	0.62	0.62	0.62		
38	175905066172000					0.21	0.21	0.21				
39	175854066143100					0.48	0.48	0.48				
40	175910066143200					0.13	0.13	0.13	0.13	0.13		
41	175933066161800					0.19	0.19	0.19			0.50	0.50
42	175859066162200					0.47						0.10
43	175840066181200					0.09						
44	175748066160400					0.33	0.33	0.33		1.42		1.2
45	175756066133300					0.24						
46	175928066174000					0.36						
47	175856066151000						0.78	0.78	0.78	0.78	0.32	0.40
48	175931066160100						0.19	0.19	0.19	0.19		
49	175659066155400						0.08	0.08	0.08			
50	175839066180700						0.29	0.29				
51	175830066135400						0.66	0.66	0.66	0.66		
52	175813066133100						0.33	0.33	0.33	0.47	0.46	0.46
53	175822066134800							0.07	0.07	0.07	0.18	0.27
54	175922066170800							1.01	1.01	1.01	0.28	0.21
55	175913066171900							0.79	0.79	0.79	0.36	0.36
56	175816066133100							0.71	0.71	0.57		
57	175837066165400							0.66	0.66	0.71		
58	175826066181600							0.32	0.32	0.32		
59	175757066131800							0.23	0.23	0.23		
60	175931066165800								0.28	0.28		
61	175835066145700								1.25	1.25		
62	175825066142500								1.38	1.38	0.24	0.24
63	175833066151600								1.41	1.41	0.20	0.20
64	175845066142800								0.68	0.68	0.40	0.40
65	175828066142200								0.43	0.43	0.41	0.41
66	175739066155600									0.09	0.15	0.15
67	175826066180600										0.29	0.29
68	175924066170400										0.42	0.39
69	175924066170400										0.44	0.35
70	175810066152700										0.47	0.47
71	175915066143600										0.06	
72	175823066162400										0.07	0.07
73	175823066130900										0.21	0.21
74	175911066155800											0.08
75	175859066155300											0.08
76	175819066144400											0.08
77	175851066153000										0.17	0.17
78	175811066151000										0.13	0.13
79	175858066152800											0.13
80	175854066155200											0.11

DATA COMPILATION

The locations of wells were obtained from records available at the U.S. Geological Survey (USGS), Caribbean Water Science Center. Historical pumpage data were compiled from reports by McGuinness (1946), Ward and Truxes (1964), and Quiñones-Aponte and others (1997) in addition to records available at the former Engineering Department of the Central Aguirre Sugar Mill operated by Luce and Co., and from field visits made during 2002 and 2004. Data compilation from Quiñones-Aponte and others (1997) was part of the USGS Regional Aquifer-System Analysis (RASA) program. Historical ground-water levels were compiled by Quiñones-Aponte and others (1997). Well location and pumpage data are summarized in table 1 and figure 2. The historical geographic distribution of wells is shown in figures 3 through 11.

GROUND-WATER DEVELOPMENT HISTORY

Historical pumpage records indicate that between 1900 and 1909, about 6 Mgal/d (million gallons per day) of ground water were withdrawn from the Salinas fan-delta aquifer by steam-driven centrifugal pumps (table 1 and fig. 2) and used in furrow irrigation of sugarcane fields. In 1900, the Central Aguirre Sugar Mill cultivated 3,651 acres and produced 6,000 tons of sugarcane (http://ctp.uprm.edu/jobos/sobre_reserva/aguirre.pdf, accessed September 19, 2006). Historical USGS records indicate that between 1900 and 1909, nine well batteries were active in the Salinas alluvial fan area (fig. 3). Well batteries consisted of several relatively shallow wells connected by a header to a centrifugal pump typically installed in an excavated pit 20 ft (feet) below land surface (Quiñones-Aponte and others, 1997). Instantaneous discharge of these well batteries ranged from 300 to 3,000 gal/min (gallons per minute). A list of documented well batteries located in the study area in the early 1900s is presented in table 2 and the photo of the ruins of the Esperanza 2 battery well is shown in figure 12.

During the 1920s, ground-water withdrawals increased to about 13 Mgal/d (table 1 and fig. 2) when the steam-driven pumps were replaced by more efficient kerosene-driven pumps and active wells totaled 22. In the 1930s, the kerosene-driven pumps were replaced by electrically-powered deep turbine pumps. During the 1930 to 1939 period, the number of active wells in the Salinas alluvial fan area increased to 30 and the ground-water withdrawals increased to about 17 Mgal/d (figs. 2 and 5). Analyses of aerial photos from 1930 indicate that about 7,500 acres of sugarcane were under cultivation at that time.

Ground-water withdrawals remained relatively unchanged during the1940s to late 1950s, averaging about 23 Mgal/d (table 1, figs. 2, 5, and 6). Analyses of aerial photos from 1950 indicate that about 7,850 acres of sugarcane were under cultivation at that time. During the late 1950s and early 1960s, the Puerto Rico Aqueduct and Sewer Authority (PRASA) began installing wells as part of an islandwide effort to expand the public-supply water systems. The construction of new wells and the development of ground-water resources in the area peaked during the 1960s, when about 27 Mgal/d of ground water were pumped and 50 wells were active in the area (table 1, figs. 2 and 7).

Ground-water withdrawals decreased from about 22 Mgal/d during the 1970s to about 10 Mgal/d during the 1990s (fig. 2), primarily in response to declining sugarcane monoculture in the area. About 5,100 acres of sugarcane were under cultivation in the area during a survey of hydrologic conditions conducted in 1986 (Quiñones-Aponte and Gómez-Gómez, 1987, and Torres-González and Gómez-Gómez, 1987).

In 1990 the Central Aguirre Sugar Mill ceased operations (http://ctp.uprm.edu / jobos / sobre_reserva / aguirre.pdf, accessed September 19, 2006) and ground-water withdrawals decreased even further as sugarcane monoculture was replaced by truck-farm crops and the implementation of drip irrigation. The effect of parceling the land into smaller farms increased the number of active wells with no substantial change in ground-water withdrawals from 1990 to 2005 (figs. 10, 11 and 12). In 2004, about 3,500 acres were under cultivation in the area.

A reconstruction of the ground-water levels in the Esperanza 1 well battery (well 5 in figure 3) is presented in figure 13 (Quiñones-Aponte and others, 1997), and indicates a major rise in ground-water levels during a period of increased withdrawals reflects an increase in aquifer recharge resulting from the use of furrow irrigation for sugarcane cultivation. Large-scale surface-water irrigation commenced in the area in 1914 when water was made available by the Guayama Irrigation District through the Canal de Patillas and the Canal de Guamaní Oeste. The minimum water level recorded at the Esperanza 1 well battery (fig. 13) in 1970 can be ascribed to the effects of a severe drought that affected the area in the late 1960s.

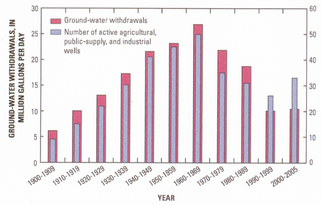


Figure 2. Historic ground-water withdrawals and number of wells in the Salinas alluvial fan area, Salinas, Puerto Rico, 1900 to 2005.

Table 2. Description of early 1900s well batteries in the Salinas alluvial fan area.

[NNE, north-northeast; SSW, south-southwest; E-W, east-west; N-S, north-south]

NUMBER IN MAP	WELL BATTERY NAME	USGS SITE IDENTIFICATION	YIELD (GALLONS PER MINUTE)	NUMBER OF WELLS PER BATTERY AND DESCRIPTION
1	MAGDALENA 5 BTR	175822066165400	560	4 wells
2	CARMEN BTR	175906066171600	2,250	14 wells in NNE-SSW line, depth 100 feet
4	COQUI 1 BTR	175809066133100	1,880	4 wells in E-W line (depth range 70-95 feet) and 4 wells in N-S line (depth range 74-83 feet)
5	ESPERANZA 1 BTR	175810066153500	2,400	8 wells in E-W line (depth range 104-148 feet) and 3 wells to the south
6	MARGARITA 2 BTR	175826066181600	900	7 wells in E-W line, depth range 83-140 feet
8	PROVIDENCIA BTR	175902066163800	3,000	6 wells in E-W line, depth range 70-80 feet
10	MUNDO 1 BTR	175857066175000	400	3 wells in E-W line, depth range 42-54 feet
11	SECOLA BTR	175911066173700	400-600	2 wells, depth range 40-60 feet
12	TERESA 1 BTR	175829066163000	2,000	11 wells in E-W line, depth range 83-140 feet
13	ESPERANZA 2 BTR	175801066154700	1,800	6 wells in E-W line, depth range 74-100 feet
14	SALICH BTR	175748066155800	400	4 wells in E-W line, depth range 80-92 feet
15	LANAUSSE BTR	175823066144200	N/A	3 wells, depth range 55-75 feet
16	MONTE SORIA 1 BTR	175748066132600	300	6 wells, depth range 70-80 feet
17	AGUIRRE 2A BTR	175759066144400	1,600	9 wells in E-W line, depth range 75-87 feet

REFERENCES CITED

McGuinness, C.L., 1946, Records of wells in Puerto Rico: U.S. Geological Survey Open-File Report, 267 p.

Quiñones-Aponte, Vicente, Gómez-Gómez, Fernando, and Renken, R.A., 1997, Geohydrology and simulation of ground-water flow in the Salinas to Patillas area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 95-4063, 37

Quiñones-Aponte, Vicente, and Gómez-Gómez, Fernando, 1987, Potentiometric surface of the alluvial aquifer and hydrologic conditions in the Salinas quadrangle, Puerto Rico, March 1986: U.S. Geological Survey Water-Resources Investigations Report 87-4161, 1 sheet.

Reserva Nacional Estuarina de Bahía de Jobos, Comunidad Aguirre, http://ctp.uprm.edu/jobos/sobre_reserva/aguirre.pdf, accessed on September 19, 2006.

Torres-González, Sigfredo, and Gómez-Gómez, Fernando, 1987, Potentiometric surface of the alluvial aquifer and hydrologic conditions in the Central Aguirre quadrangle, Puerto Rico, March 1986: U.S. Geological Survey Water-Resources Investigations Report 87-4160, 1 sheet.

Ward, P.E., and Truxes, C.S., 1964, Water wells in Puerto Rico: U.S. Geological Survey Water-Resources Bulletin 3, 249 p.

Figure 12. Ruins of the Esperanza 2 battery well (well 13 in figure 4).

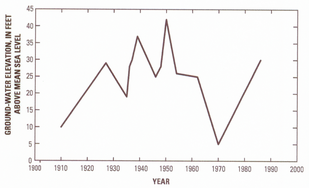


Figure 13. Ground-water levels at Esperanza 1 well battery, Salinas, Puerto Rico. (modified from Quiñones-Aponte and others, 1997)

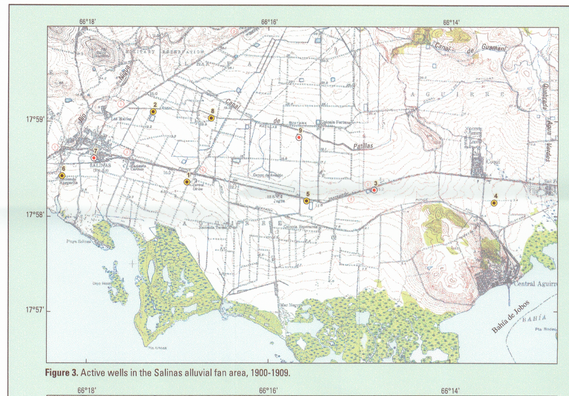


Figure 3. Active wells in the Salinas alluvial fan area, 1900-1909.

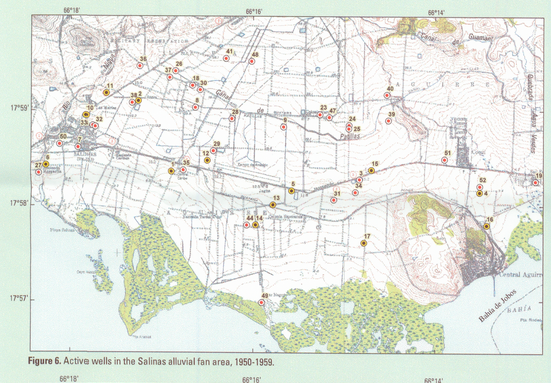


Figure 6. Active wells in the Salinas alluvial fan area, 1950-1959.

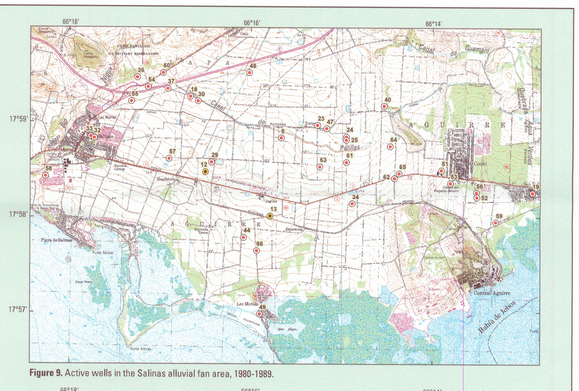


Figure 9. Active wells in the Salinas alluvial fan area, 1980-1989.

Figure 4. Active wells in the Salinas alluvial fan area, 1910-1929.

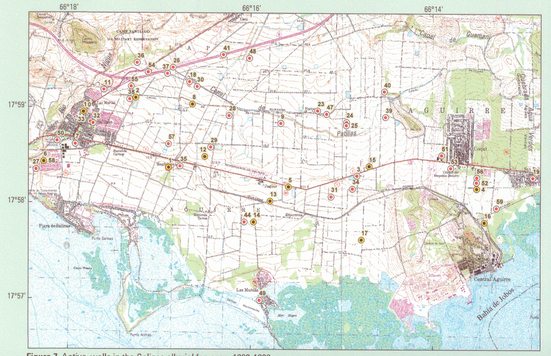


Figure 7. Active wells in the Salinas alluvial fan area, 1960-1969.

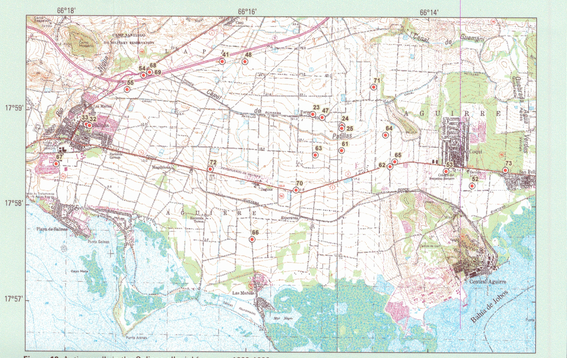


Figure 10. Active wells in the Salinas alluvial fan area, 1990-1999.

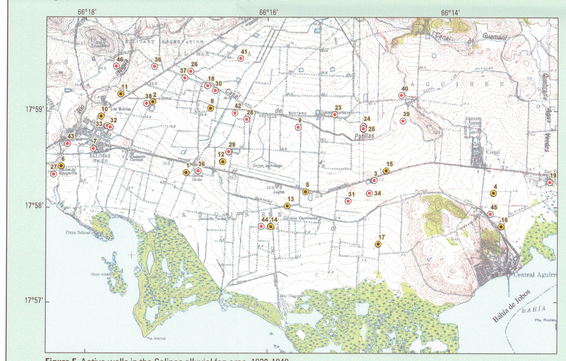


Figure 5. Active wells in the Salinas alluvial fan area, 1930-1949.

Figure 8. Active wells in the Salinas alluvial fan area, 1970-1979.

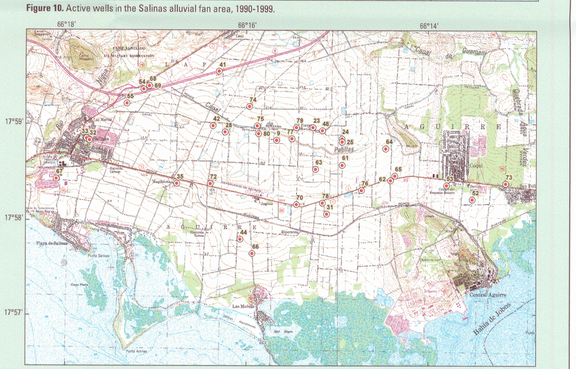


Figure 11. Active wells in the Salinas alluvial fan area, 2000-2005.

Base maps for figures 3-6 are from U.S. Geological Survey topographic maps for the quadrangles of Salinas (1952) and Central Aguirre (1952).
Base maps for figures 7-11 are from U.S. Geological Survey Digital Raster Graphic (DRG) files for the quadrangles of Salinas (1982) and Central Aguirre (1982).
Lambert conformal conic projection, NAD 1927

EXPLANATION

12 Well battery and map number | 49 Well and map number

0 0.5 1 MILES
0 0.5 1 KILOMETERS
Topographic map scale

HISTORICAL GROUND-WATER DEVELOPMENT IN THE SALINAS ALLUVIAL FAN AREA, SALINAS, PUERTO RICO, 1900-2005

by José M. Rodríguez and Fernando Gómez-Gómez

2008