

**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 Jobs Bay National Estuarine Research Reserve.

The study area encompasses about 20 mi<sup>2</sup> (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.

**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 McGuiness (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/jobs/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 the 1940s 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/jobs/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 between 1910 and 1920. This increase 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.

**REFERENCES CITED**

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

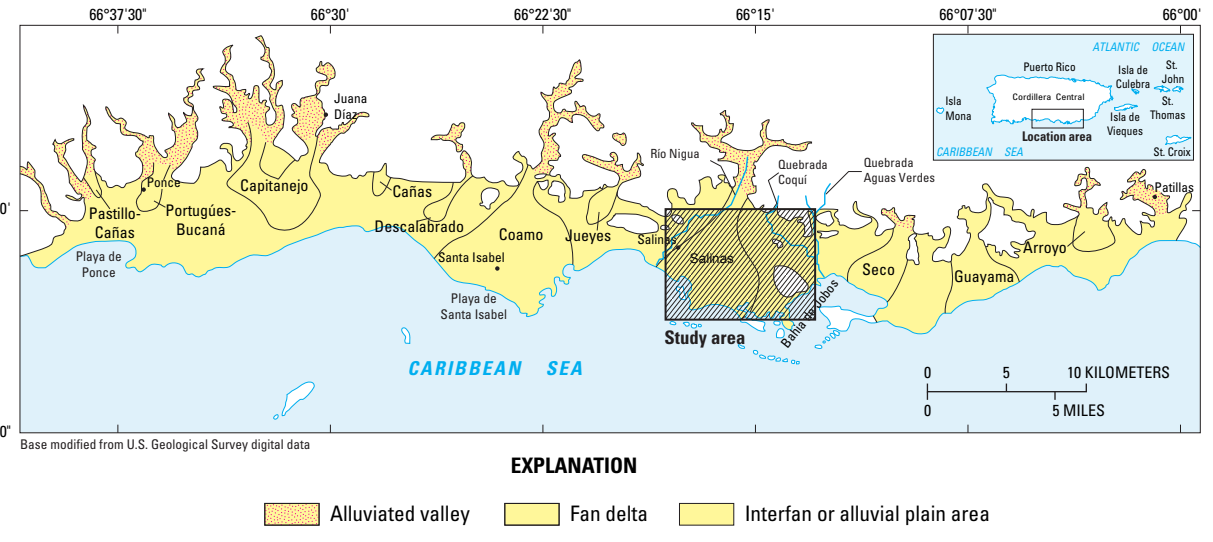
Quiñones-Aponte, Vicente, Gómez-Gómez, Fernando, and Renken, R.A., 1997, Geohydrology and simulation of ground-water flow in the Salinas to Patillas area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 95-4063, 37.

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

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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 87-4161, 1 sheet.



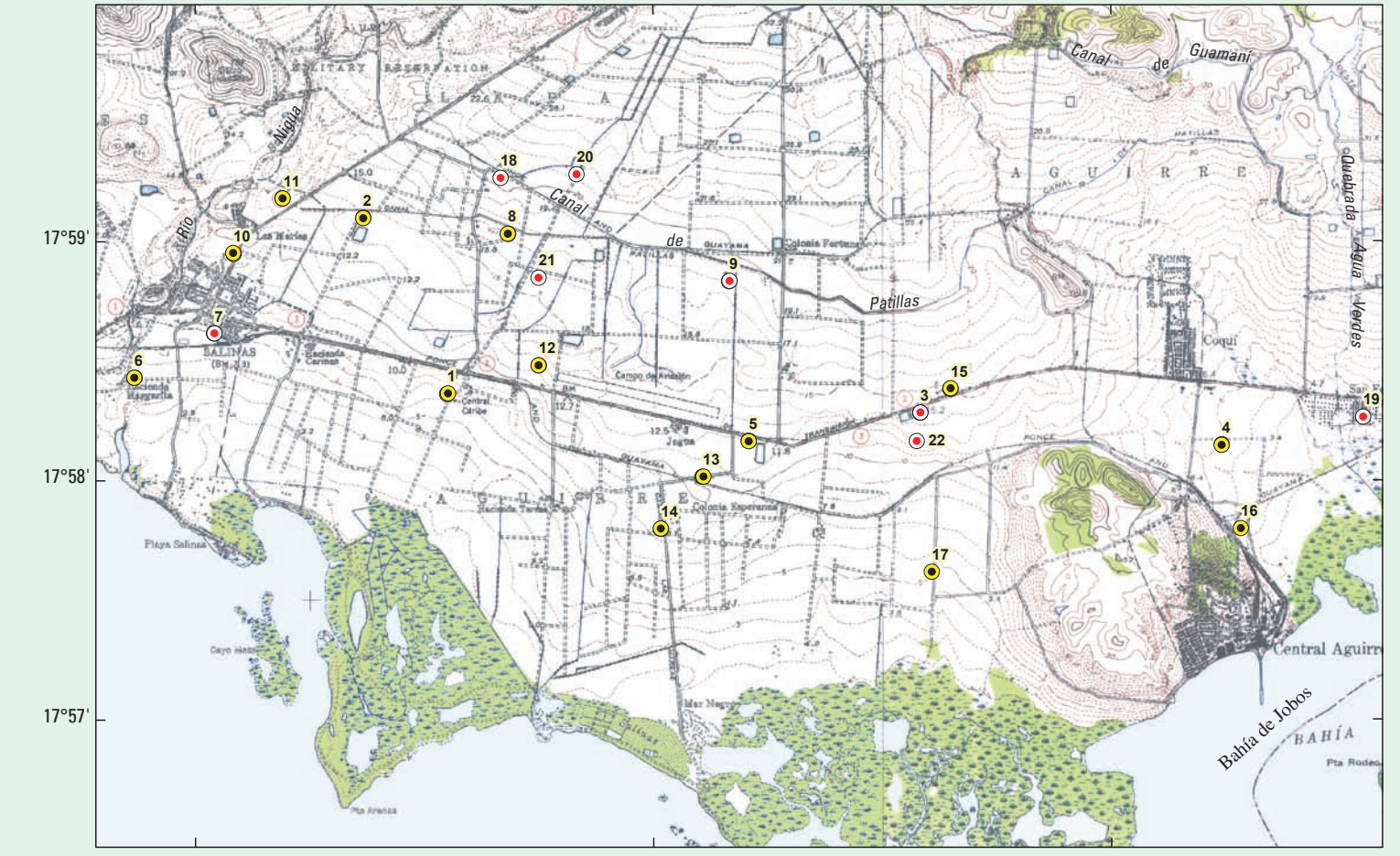
**Figure 1.** Location study area and extent of fan deltas of the South Coastal Plain alluvial aquifer system, Puerto Rico.

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

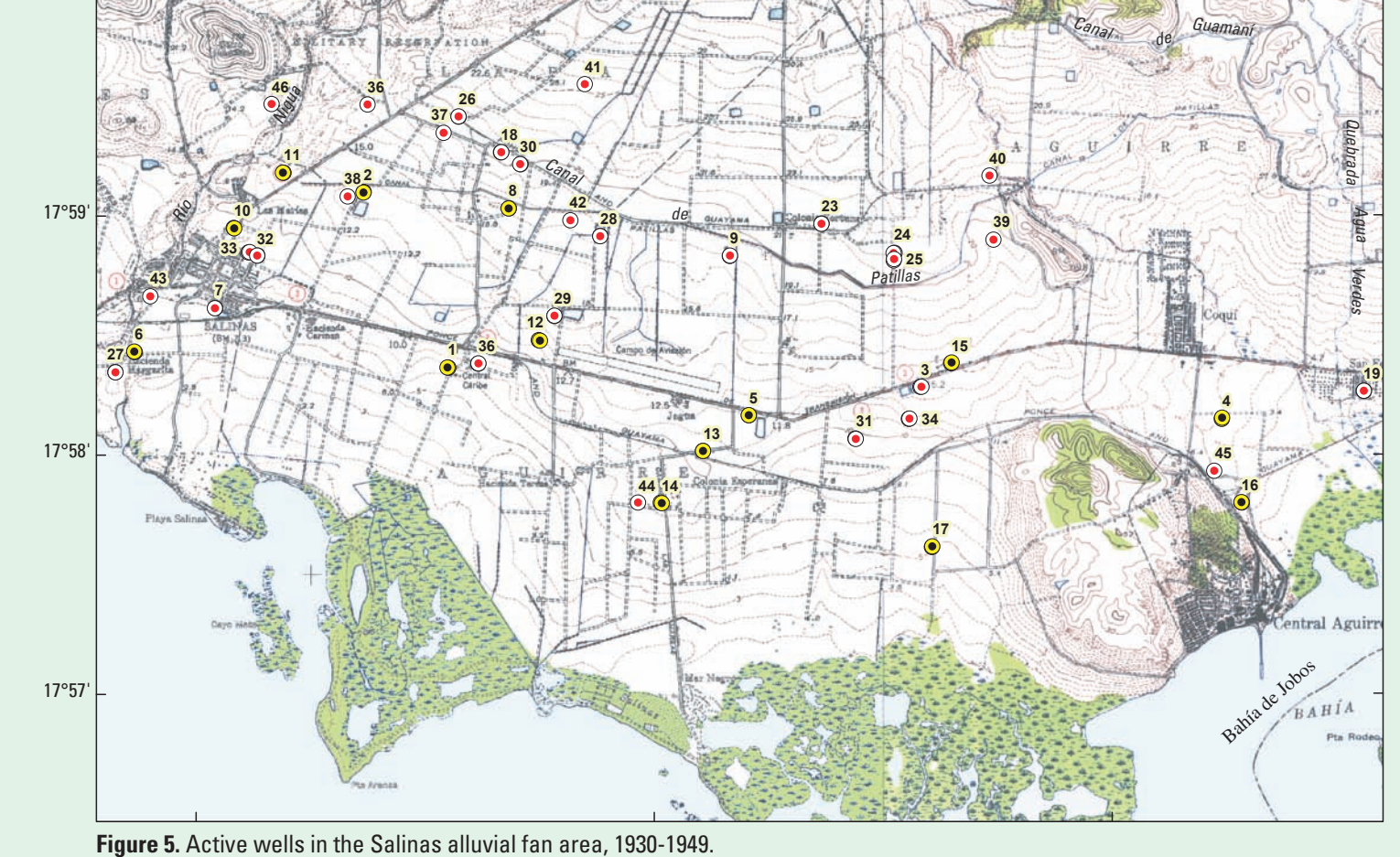
NUMBER IN MAP	USGS SITE IDENTIFICATION	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2005
		TOTALS	6.14	10.05	13.08	17.30	21.60	23.20	26.30	21.87	18.77	10.89	10.45
1	175822066165400	0.35	0.87	0.87	0.87	0.87	0.87	0.87					
2	17590066171600	0.87	0.87	0.87	0.87	0.87	0.87	0.87					
3	17581066145300	0.43	0.87	1.30	1.30	1.30	1.30						
4	17580066145300	0.43	0.52	0.52	0.98	2.01	2.01	2.01	2.01	2.01			
5	17581066153500	0.87	0.87	0.87	0.87	0.87	0.87	0.87					
6	17582066181600	0.28	0.28	0.28	0.28	0.28	0.28	0.28					
7	17583066175500	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	17585066154000	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	0.22					
11	17591066173700	0.22	0.22	0.22	0.22	0.22	0.22	0.22					
12	17582066163000	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	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	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	17581066161000	0.44											
23	17585066151600		0.59	0.59	0.78	0.78	0.78	0.78					
24	175851066145700	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.58	0.41			
25	17584066145700									0.40			
26	175925066165100		0.43	0.43	0.43								
27	175821066182100	0.17	0.17	0.17	0.17								
28	17585066161400	0.19	0.19	0.19	0.19							0.10	
29	17583066162600	0.59	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	17585066174400	0.17	0.17	0.17	0.17	0.17	0.17	0.17	1.01	0.59			
33	17585066174600									0.86	0.86		
34	17580066145300		0.44	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	17585066162200	0.47								0.10			
43	17584066181200	0.09											
44	175748066160400	0.33	0.33	0.33					1.42	1.2			
45	17575066133800	0.24											
46	175928066174000	0.36											
47	17585066151000		0.78	0.78	0.78	0.78	0.32	0.40					
48	175931066160100	0.19	0.19	0.19	0.19								
49	17569066155400	0.08	0.08	0.08									
50	17583066180700	0.29	0.29										
51	17583066135400	0.66	0.66	0.66	0.66								
52	17581306613100	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	1758106613100	0.71	0.71	0.57									
57	175837066165400	0.66	0.66	0.71									
58	17582066181600	0.32	0.32	0.32									
59	175757066131800	0.23	0.23	0.23									
60	175931066165800	0.28	0.28										
61	17583066145700	1.25	1.25										
62	175825066142500	1.38	1.38	0.24	0.24								
63	17583066151600	1.41	1.41	0.20	0.20								
64	17584066142800	0.68	0.68	0.40	0.40								
65	175828066142200	0.43	0.43	0.41	0.41								
66	17579066155600	0.09	0.15	0.15									
67	17582066180600	0.29	0.29										
68	175924066170400	0.42	0.39										
69	175924066170400	0.44	0.35										
70	17581066152700	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	17585066155300	0.08											
76	175819066144400	0.17											
77	17581066153000	0.17	0.17										
78	175811066151000	0.13	0.13										
79	17585066152800	0.13											
80	17584066155200	0.11											



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



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



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

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.

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

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	17590066171600	2,250	14 wells in NNE-SSW line, depth 100 feet
4	COQUI 1 BTR	17580066133100	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	17581066153500	2,400	8 wells in E-W line (depth range 104-148 feet) and 3 wells to the south
6	MARGARITA 2 BTR	17		