Water-resources reconnaissance of Île de la Gonâve, Haiti

Joseph W. Troester · Michael D. Turvey

Abstract Île de la Gonâve is a 750-km^2 island off the coast of Haiti. The depth to the water table ranges from less than 30 m in the Eocene and Upper Miocene limestones to over 60 m in the 300-m-thick Quaternary limestone. Annual precipitation ranges from 800–1,400 mm. Most precipitation is lost through evapotranspiration and there is virtually no surface water. Roughly estimated from chloride mass balance, about 4% of the precipitation recharges the karst aquifer. Cave pools and springs are a common source for water. Hand-dug wells provide water in coastal areas. Few productive wells have been drilled deeper than 60 m. Reconnaissance field analyses indicate that groundwater in the interior is a calcium-bicarbonate type, whereas water at the coast is a sodium-chloride type that exceeds World Health Organization recommended values for sodium and chloride. Tests for the presence of hydrogen sulfide-producing bacteria were negative in most drilled wells, but positive in cave pools, hand-dug wells, and most springs, indicating bacterial contamination of most water sources. Because of the difficulties in obtaining freshwater, the 110,000 inhabitants use an average of only 7 L per person per day.

Résumé L'Île de la Gonâve est une île de 750 km^2 au large de la côte d'Haïti. La profondeur de la nappe varie entre moins de 30 m dans les calcaires de l'Éocène et du Miocène supérieur à plus de 60 m dans les calcaires quaternaires épais de 300 m. Les précipitations annuelles sont comprises entre 800–1.400 mm. La plus grande partie des précipitations est perdue par évapotranspiration et il n'y a pratiquement pas d'eau de surface. Le bilan de masse des chlorures permet d'estimer à 4% des précipitations le montant de la recharge de l'aquifère karstique. Des bassins dans les grottes et des sources sont la source d'eau courante. Des puits creusés à la main fournissent de l'eau dans les zones côtières. Quelques puits productifs ont été forés dépassant 60 m de profondeur. L'analyse des reconnaissances de terrain indique que les eaux souterraines à l'intérieur de l'île sont de faciès bicarbonaté calcique, tandis que l'eau près de la côte a un faciès chloruré sodique dépassant les valeurs recommandées par l'OMS pour le sodium et les chlorures. Des tests pour la présence de bactéries productrices d'hydrogène sulfuré se sont révélés négatifs dans la plupart des forages, mais positifs dans la plupart des sources captées et tous les autres sources, bassins de grottes et puits creusés à la main, ce qui indique une contamination bactérienne de la plupart des sources d'eau. Du fait des difficultés pour s'approvisionner en eau douce, les 110.000 habitants utilisent en moyenne seulement 7 L par personne et par jour.

Resumen La Isla de la Gonavê, cercana a la costa de Haití, tiene 750 km^2. La profundidad al nivel freático está comprendida entre menos de 30 m para las calcitas del Eoceno y Mioceno Superior y más de 60 m en el acuífero de calcitas cuaternarias, el cual posee 300 m de espesor. La precipitación anual varía entre 800–1.400 mm, si bien la mayor parte se pierde por evapotranspiración y prácticamente no hay aguas superficiales. Según un balance de masas de cloruros, alrededor del 4% de la precipitación recarga el acuífero kárstico. Las cavidades y manantiales son una fuente habitual de agua. Los pozos excavados proporcionan agua en las áreas costeras. Pocos pozos productivos se han perforado a más de 60 m. El reconocimiento de los análisis de campo indica que las aguas subterráneas son de tipo bicarbonatado-cálcico en el interior, mientras que es de tipo clorurado-sódico en la costa, donde se sobrepasan las concentraciones recomendadas por la Organización Mundial de la Salud para sodio y cloruro. Los ensayos efectuados para detectar la presencia de bacterias productoras de sulfuro de hidrógeno resultaron negativos en la mayoría de los pozos perforados, pero fueron positivos en la muchos manantiales explotados y en todos los manantiales, cavidades y pozos excavados, hecho que indica la contaminación bacteriana

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de la mayor parte de fuentes de agua. Debido a las dificultades para obtener agua dulce, los 110.000 habitantes utilizan una media de sólo 7 L por persona al día.

Keywords Carbonate rocks · Coastal aquifers · Equipment/field techniques · General hydrogeology · Groundwater exploration · Karst · Salt-water/fresh-water relations · Bacterial contamination

Introduction

Île de la Gonâve is a 750- km^2 island situated between the northern and southern peninsulas of Haiti in the Golfe de le Gonâve (Fig. 1) about 50 km west of Port-au-Prince. The island is a remote portion of Haiti, which in 1998 had a GDP (Gross Domestic Product) per capita of only \$510, the lowest GDP per capita in the western hemisphere (World Bank 2000). According to the Food and Agriculture Organization of the United Nations (2000b), Haiti is the third hungriest country in the world. Safe drinking water generally is unavailable to the majority of the population of Haiti. Data published by Gleick (2002) indicates that domestic water use in Haiti averages only 17 L per person per day, the lowest domestic water use in the western hemisphere. Sullivan (2002) and Sullivan et al. (2002) developed a Water Poverty Index (WPI) to compare the countries of the world using several indices that relate to water. According to their preliminary results, Haiti has the lowest WPI of any country in the world.

Three reconnaissance expeditions to Île de la Gonâve were conducted in April 2000, May to June 2001, and in June 2002 to test inexpensive methods of determining water quality and to assess the availability of clean freshwater on the island. The island was chosen as a field area for study because of difficulties experienced by several government agencies and nongovernmental organizations in obtaining water for the people living on this limestone island. Problems previously experienced include the lack of maintenance of drill rigs and pumps and the difficulties experienced in transporting a drill rig from Port-au-Prince to Île de la Gonâve, finding skilled well drillers to work on the island, and in drilling wells because of the hardness of the rocks, the numerous fractures and solution features and the depth to the water table. Lindegger (2002) writes in his report about water resources on Île de la Gonâve, "In all my years of consultancy and teaching work, I have seen poorer people, less healthy people, and more hungry people, but never a people with such limited access to water." At times, people on the island are literally starving because they do not have sufficient water to cook the basic staples of rice and beans. In a country where it is difficult for most people to obtain clean water, Île de la Gonâve is considered to be one of the worst areas for access to clean water.

This study is an example of work that can be done by nongovernmental organizations or private volunteer organizations in remote areas of the world, where the need

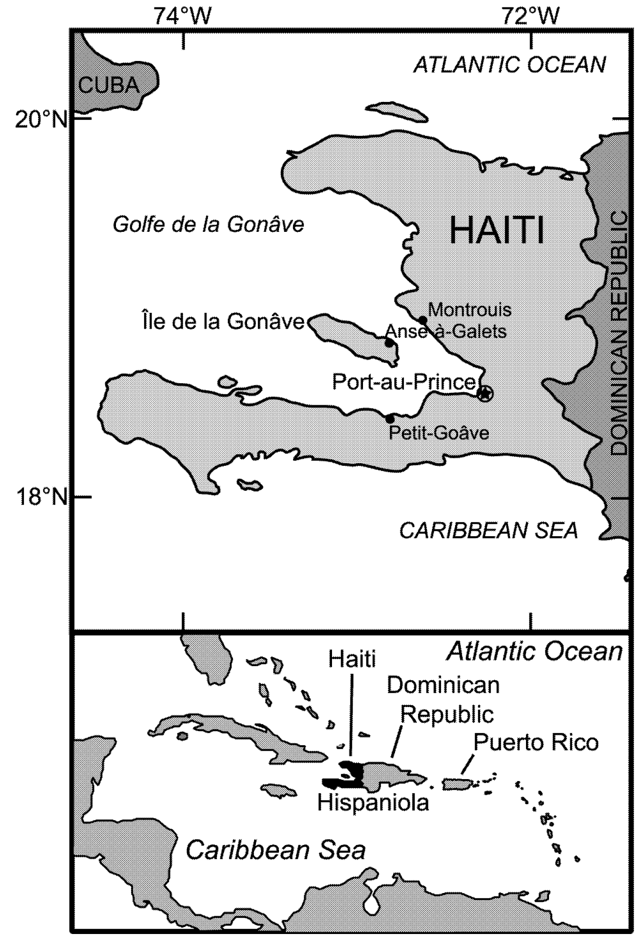

Fig. 1 Location of Haiti, Île de la Gonâve, and population centers

to obtain clean freshwater is great; however, the ability to conduct such work is limited by the lack of infrastructure within the area of concern, a scarcity of funds to conduct water-quality and water-resource assessments, the inability to preserve water samples, and the lack of access to a qualified water-quality laboratory. Standard laboratory methods were not used to determine water-quality conditions and characteristics because there were no funds available to cover the expenses of such methods and there were no adequate means available to preserve water samples for later laboratory analysis. No ice or refrigeration was available on the island. Acids used to preserve water samples were not available in Haiti, and could not legally be transported on airplanes to the island. Reconnaissance methods were deemed adequate to roughly characterize the water quality for the nongovernmental organizations trying to provide water for the island population. The authors of this paper collected the data as volunteers, and not as part of their official duties with their respective government agencies.

Geographic locations in Haiti commonly have several names with a variety of spellings. The place names and spellings used in this paper are taken from the 1:50,000-scale topographic maps published by the U.S. National

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Imagery and Mapping Agency, formerly the U.S. Defense Mapping Agency. Where location names were not referenced on the topographic maps, the most common spelling of the local Haitian Creole name was used. Some locations also have been identified by their commonly used English names. In this paper, common English names are shown in parenthesis following the Creole names.

Physical Setting and Climate

Île de la Gonâve has a length of 57 km and a maximum width of 15 km. The island is usually reached by ferry from near the town of Montrouis, which is about 20 km north of the island's main settlement, Anse-à-Galets (population about 40,000). Approximately 110,000 people inhabit the island, which has a population density of about 150 people per km^2 (Hermon Rigau Jr., Institut Haitien de Statistique et d'Information, written communication, 1999). The highest point on the island is about 778 m above mean sea level. The island is thinly forested and much of the land is cultivated by hand for various crops including peanuts, coffee, and tropical fruits. Land that is not cultivated is commonly used for grazing goats, burros, cows, and horses. The remaining trees, including many fruit trees, are being cut for lumber or charcoal. Transportation on the island is difficult. All roads outside of Anse-à-Galets require 4-wheel-drive vehicles; however, few vehicles are available. Most goods are transported either along the coast by sailboat or on land by burro.

Mean annual precipitation at Anse-à-Galets is 870 mm, based on continuous records from 1931 to 1956 and discontinuous records from 1956 to 1968 (Lindegger 2002). The driest months are from November to April and the wettest months are May, August, September, and October. Mean annual precipitation across the island ranges from about 800 to 1,400 mm (Haiti Foratech 1989). Mean annual rainfall normally is greater in the eastern portion of the island than in the western portion due to the orographic effect of the higher elevations. Long droughts and frequent crop failures due to droughts have been reported. The average annual precipitation at Port au-Prince (50 km to the east and on the main island of Hispaniola) has decreased from about 1,600 mm in the 1860s to about 1,300 mm in the 1950s. Precipitation data from Port-au-Prince after the 1950s are sporadic, making further comments about climate change difficult (National Oceanic and Atmospheric Administration, National Climatic Data Center, Global Historical Climatology Network, written communication, 2002). No data are available on potential evaporation from the Île de la Gonâve; however, two stations located on the southern coast of Puerto Rico (the first island east of Hispaniola) have average potential evaporation values of 2,028 and 2,072 mm, whereas stations at higher elevations have less potential evaporation with values ranging from 1,294 to 1,588 mm (Calvesbert 1970). Potential evaporation on Île de la Gonâve is estimated to be about 2,000 mm on the coast, and less at higher elevations. Consequently, most rain is lost through evapotranspiration.

Geology

The geology of Île de la Gonâve was first described by Woodring et al. (1924). The Centre d'Etudes et de Réalisations Cartographiques Géographiques produced a geologic map of Haiti in 1989. The geologic map shown in Fig. 2A is adapted from the portion of the geologic map that contains Île de la Gonâve. Lewis and Draper (1990), Mann et al. (1995), and Dolan and Mann (1998) describe the general tectonic setting in this area of the northern Caribbean.

The overall geologic structure of the island consists of a northwest-trending, doubly plunging anticline exposing a core of Eocene, thickly bedded limestone, overlain by an Upper Miocene sequence of thinly bedded limestone. The axis of the anticline is near the southern edge of the island, where elevations are the highest. Dips throughout the sequence are variable (usually less than 20 degrees), with numerous minor folds and faults seen in outcrops (Lewis and Draper 1990).

The Eocene and Upper Miocene limestones are exposed in the eastern portion of the island where the relief is higher and more rugged than the western portion of the island. In addition, precipitation is higher; soils are thicker, and, consequently, there is more agriculture practiced on the eastern portion of the island than on the western portion. The Eocene limestone is exposed on about 27% of the island, while the Upper Miocene limestone is exposed on only about 10% of the island.

A 300-m-thick sequence of Quaternary limestone marine terraces exposed in the western portion of the island indicates recent uplift (Lewis and Draper 1990). The Quaternary limestone is exposed on about 53% of the island and is poorly bedded and most exposures are rubbly. Numerous faults and reef crests determine the physiography of these terraces. Soils on the Quaternary limestone are thin and rocky except where the red soil, an oxisol, has collected in broad, shallow sinkholes. A small fringe of Quaternary alluvium and beach deposits surround much of the island, but are exposed in only about 10% of the area.

Karst Landforms

The Eocene limestone has been partially eroded into a rugged karst landscape. Some large cave openings can be seen in bare hillsides, but none were explored as part of this study. Although some caves in the vicinity of Nan Café (site number 18 in Table 1 and Fig. 2) have been examined by previous researchers for vertebrate remains (Miller 1930; Poole 1930; Koopman 1955), no known subsequent explorations have been documented. The caves are known to many of the inhabitants, who obtain water from various cave pools around the island.

Most people who live on or near outcrops of the Eocene limestone obtain water from large karst springs,

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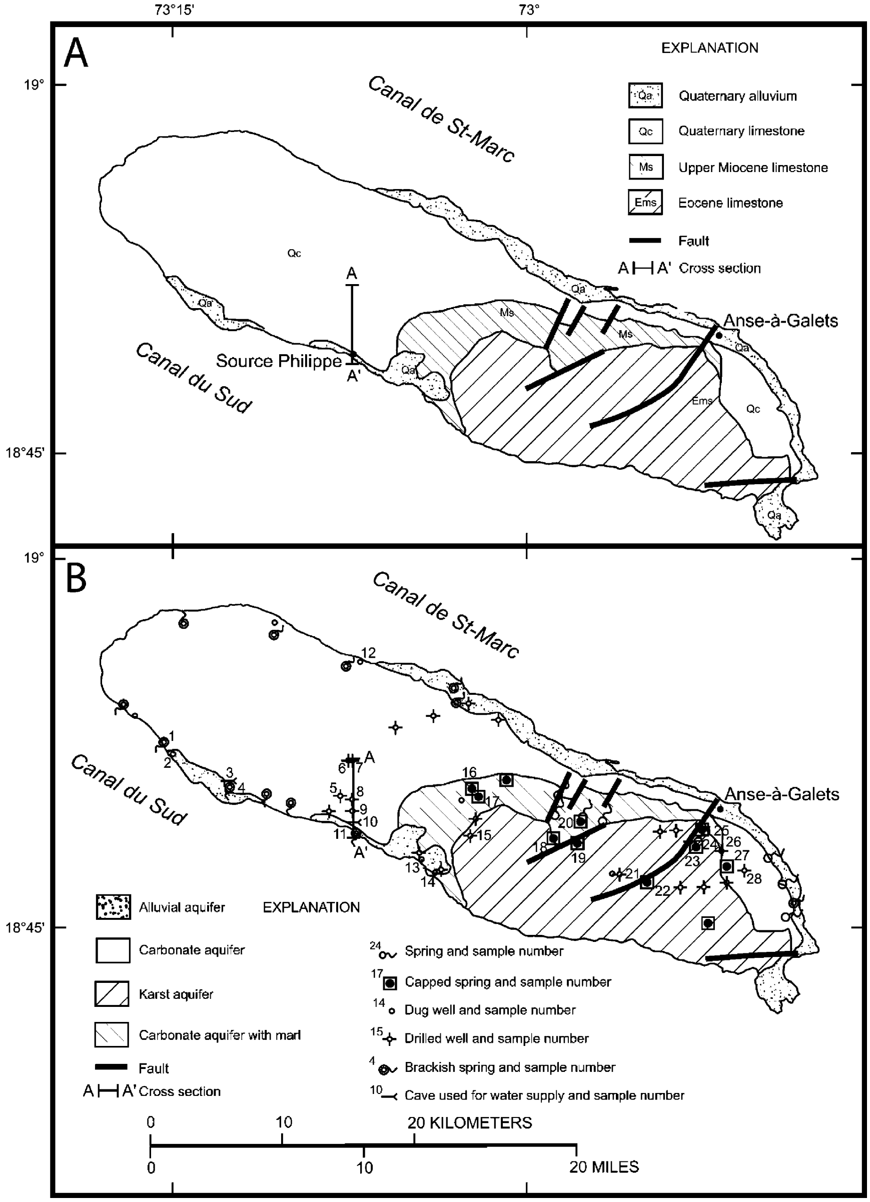

Fig. 2 A Geologic map of Île de la Gonâve, Haiti (adapted from Centre d'Etudes et de Réalisations Cartographiques Géographiques 1989). **B** Hydrogeologic map of Île de la Gonâve, Haiti (adapted from United Nations Development Program, 1990)

such as Gros Man Man and Nan Café (site numbers 17 and 18, respectively, in Table 1 and Fig. 2), where groundwater rises to the surface at the contact between the Eocene limestone and the overlying thinner-bedded Upper Miocene limestone. These springs form streams that flow for no more than 100 m before the water seeps back into the ground. These large springs are probably fed by rainwater that drains into sinkholes to the south, which have developed in the Eocene limestone near the center of the anticline. Woodring et al. (1924) described the largest of these sinkholes, Plaine Des Mapous, which is about 4 km long and 1 km wide with the long sides parallel to the axis of the anticline, about N. 70°W. The rectangular shape of the sinkhole is indicative of structural control. Nan Ida is the lowest point in Plaine Des Mapous and is located about 3 km southeast and 120 m above the spring at Nan Café (site number 18 in Table 1 and Fig. 2). Plaine Des Mapous probably drains to this large spring. The discharge from the large springs that drain the Eocene limestone cannot be gauged because almost all of them are capped and flow into a series of pipes that distribute the water by gravity to the area below the springs.

Karst features in the 300-m-thick Quaternary limestone section in the western portion of the island include closed depressions, caves, and springs and seeps along the coast. Most closed depressions in the Quaternary limestone are broad and shallow. Their shape probably reflects original depositional morphology. These depressions collect soil and are commonly farmed. Pit caves were observed on the plateau, but were not explored during this study.

Several short caves have been dissolved in the Quaternary limestone near the coast. Small pools in these caves are used as a source for drinking water, even though

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Table 1 Selected physical and chemical properties of water samples from Île de La Gonâve, Haiti: *LSD* land surface elevation in meters above mean sea level; *SC* specific conductivity in microsiemens per centimeter; *TDS* total dissolved solids; all concentrations in milligrams per liter (mg/L); hardness and alkalinity are measured in mg/L as $CaCO_3$; nitrate is in mg/L as N; < less than; *nd* not determined; *pNa* the logarithm of the reciprocal of the sodium ion activity; PathoScreen™ tests used to determine the presence or absence of hydrogen sulfide-producing bacteria; *P* hydrogen sulfide-producing bacteria present; *A* hydrogen sulfide-producing bacteria absent

Site number	Site name	Site type	Latitude and longitude	LSD	Sample date	SC	TDS	pH meter	pNa	pH strip	Hardness	Alkalinity strip	NO_3	Cl strip	Fe	Cl titrater	Alk.	SO_4	Ca	Mg	PathoScreen™
1	Grand Vide Spring	Coastal spring	Latitude 18°52′37″N, longitude 73°15′27″W	<1	4/6/00	nd	850	nd	nd	8	250	80	5	nd	0	400	nd	nd	nd	nd	P
2	Grand Vide Well	Coastal hand-dug well	Latitude 18°52′3″N, longitude 73°15′2″W	1	4/6/00	nd	870	nd	nd	8	425	180	5	nd	0	400	nd	nd	nd	nd	P[1]
3	Trou Luis	Coastal spring	Latitude 18°50′47″N, longitude 73°12′39″W	<1	4/6/00	nd	1,940	nd	nd	8	250	120	3	nd	0	>650	nd	nd	nd	nd	P[1]
					5/28/01	7,630	>1,000	8.3	1.3	8.5	250	180	5	500	0	2,360	210	230	46	210	P
4	Trou Vital	Coastal cave pool	Latitude 18°50′50″N, longitude 73°12′37″W	2	4/6/00	nd	1,090	nd		7.5	250	180	5	nd	0	223	nd	nd	nd	nd	P[1]
					5/28/01	2,930	>1,000	8.2	1.6	8	250	180	5	500	0	735	240	100	92	90	P
5	Port de Bonhair	Drilled well	Latitude 18°50′21″N, longitude 73°7′57″W	75	6/29/02	570	293	8.2	2.5	7.5	250	240	nd	nd	nd	52	nd	nd	nd	nd	P
6	Dent Grignin No. 1	Drilled well	Latitude 18°51′48″N, longitude 73°7′32″W	212	4/5/00	nd	260	nd	nd	8	425	120	0.5	nd	0	162	nd	nd	nd	nd	A
					5/29/01	501	256	8.2	2.9	8	250	180	2	50	0	32	237	3	60	4	A
9	Nan Fonnise (Two Trees)	Drilled well	Latitude 18°49′45″N, longitude 73°7′25″W	57	5/29/01	1017	479	8.4	2.3	8.5	250	180	5	250	0	219	207	34	73	17	A
10	Trou Nastan (Source Philippe)	Coastal cave pool	Latitude 18°49′11″N, longitude 73°7′22″W	8	4/4/00	nd	>7,000	nd	nd	7	425	80	0.5	nd	0	>800	nd	nd	nd	nd	P
					5/27/01	11,060	>1,000	8.2	1.3	8.5	250	240	2	500	0	3,920	240	87	54	255	P
11	Trou Beuf	Coastal hand-dug well	Latitude 18°49′3″N, longitude 73°7′19″W	<1	5/27/01	13,500	>1,000	8.2	1	8	250	240	20	500	0	4,900	369	276	116	195	P
12	St. Esprit (Gros Mangle)	Coastal hand-dug well	Latitude 18°55′49″N, longitude 73°7′6″W	2	6/28/02	2790	nd	8.3	2.2	8	250	240	nd	nd	nd	>622	nd	nd	nd	nd	P
13	Mahotière	Coastal hand-dug well	Latitude 18°47′47″N, longitude 73°4′30″W	<1	4/7/00	nd	900	nd	nd	7.5	425	240	0	nd	0	300	nd	nd	nd	nd	P[1]
					6/2/01	1969	920	8.1	2.3	8	250	240	0.5	500	0.02	490	570	77	90	28	P
14	Pointe A Raquettes	Coastal hand-dug well	Latitude 18°47′14″N, longitude 73°3′55″W	10	4/7/00	nd	1,320	nd	nd	7.5	425	180	0.2	nd	0	279	nd	nd	nd	nd	P[1]
					6/2/01	3,180	>1,000	7.9	2.2	8	250	180	0.5	500	0	454	213	50	204	38	P
15	La Palmiste	Drilled well	Latitude 18°48′44″N, longitude 73°2′26″W	350	4/7/00	nd	250	nd	nd	8	425	80	0	nd	0	52	nd	nd	nd	nd	A
16	Ca Léon	Capped Spring	Latitude 18°50′38″N, longitude 73°2′23″W	270	4/4/00	nd	320	nd	nd	8.5	425	120	0	nd	0	240	nd	nd	nd	nd	P
					5/31/01	708	358	7.8	3.1	8	250	180	0	50	0	45	474	10	149	7	P
17	Gros Man Man	Capped Spring	Latitude 18°50′22″N, longitude 73°2′7″W	300	4/4/00	nd	270	nd	nd	7.5	425	180	0.5	nd	0	60	nd	nd	nd	nd	P
					5/31/01	629	319	7.9	2.5	8	250	180	2	50	0	52	291	0	61	4	P
18	Nan Café	Capped Spring	Latitude 18°48′38″N, longitude 72°58′54″W	400	4/7/00	nd	280	nd	nd	8	425	360	5	nd	0	60	nd	nd	nd	nd	P
					6/1/01	643	321	8	2.8	8	250	180	5	50	0	45	273	7	133	4	P
					6/25/02	630	313	7.7	3.2	7	250	180	2	50	nd	<26	nd	nd	nd	nd	P
19	Nan Jozin	Capped spring	Latitude 18°48′27″N, longitude 72°57′53″W	435	6/27/02	498	260	8	2.7	7.5	250	240	5	nd	nd	<26	nd	nd	nd	nd	A
20	Grande Source	Capped Spring	LLatitude 18°49′18″N, longitude 72°5745”W	335	4/8/00	nd	230	nd	nd	8	425	180	10	nd	0	162	nd	nd	nd	nd	P
					6/27/02	520	263	7.9	3.5	7.5	250	180	5	nd	nd	26	nd	nd	nd	nd	P
21	Mare Súcrin	Drilled well	Latitude 18°47′9″N, longitude 72°56′10″W	525	6/25/02	689	366	7.7	3	7.5	250	180	2	50	0	32	nd	nd	nd	nd	A
22	Cais	Capped spring	Latitude 18°46′50″N, longitude 72°54′55″W	520	6/26/02	613	316	8.1	3.1	7.5	250	240	2	50	nd	32	nd	nd	nd	nd	P

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Table 1 (continued)

Site number	Site name	Site type	Latitude and longitude	LSD	Sample date	SC	TDS	pH meter	pNa	pH strip	Hardness	Alkalinity strip	NO_3	Cl strip	Fe	Cl titrater	Alk.	SO_4	Ca	Mg	PathoScreen™
23	Spring Box above Tête Source	Capped Spring	Latitude 18°48′18″N, longitude 72°52′50″W	210	4/11/00	nd	260	nd	nd	8	425	nd	3	nd	0	32	nd	nd	nd	nd	P
24	spring above Tête Source	Spring	Latitude 18°48′29″N, longitude 72°52′43″W	180	4/11/00	nd	220	nd	nd	8	225	180	5	nd	0	52	nd	nd	nd	nd	P[1]
25	Tête Source	Capped Spring	Latitude 18°49′0″N, longitude 72°52′36″W	90	6/26/02	524	271	8.1	3.3	7.5	250	240	2	50	nd	52	nd	nd	nd	nd	P
					4/11/00	nd	330	nd	nd	8.5	250	nd	2.5	nd	0	52	nd	nd	nd	nd	P
26	Mésalis	Drilled well	Latitude 18°48′6″N, longitude 72°51′45″W	310	6/27/02	660	339	7.9	3.2	7	250	240	nd	nd	nd	75	nd	nd	nd	nd	A
					6/24/02	590	315	8	3.1	7.5	250	180	nd	50	0	93	nd	nd	nd	nd	A
27	Morne Chandelle	Capped spring	Latitude 18°47′29″N, longitude 72°51′32″W	390	6/24/02	680	343	8.2	3.4	8	250	180	nd	50	0	52	nd	nd	nd	nd	P
28	Nouvelle Cite	Drilled well	Latitude 18°47′18″N, longitude 72°50′48″W	340	6/24/02	530	291	8.2	3.7	7.5	250	240	nd	50	0	<26	nd	nd	nd	nd	A

[1] Assumed to test positive for the presence of hydrogen sulfide-producing bacteria, because of the presence of animal fecal material

some are saline, such as Trou Nastan (site number 10 in Table 1 and Fig. 2) at Source Philippe. The caves observed along the coast are typical of small flank-margin caves described from other tropical islands by Mylroie and Carew (1990) and Mylroie et al. (2001).

Small springs and seeps along the coast that are not too saline, are used for sources of drinking water. These discharge features are only slightly above sea level and are less numerous, but similar in morphology to springs and seeps on Guam that are described by Mylroie et al. (2001). Some, such as the Grand Vide Spring and Trou Luis (site numbers 1 and 3, respectively, in Table 1 and Fig. 2) flow directly into lagoons. Other discharge points were observed on the edges of mud flats. None of these points were sampled, however, because free ranging livestock wallow in them and they have become large mud holes. Some shallow, hand-dug wells have been constructed on these seeps. The well at Trou Beuf (site number 11 in Tables 1, 2 and Fig. 2) was constructed in January 2001 on a seep in a low spot near the coast. Other hand-dug wells such as Mahotière (site number 13 in Table 1 and Fig. 2) near the coast, appear to have been built on top of pronounced seeps. Discharge could not be measure at any of these small springs and seeps along the coast because of the lack of a defined flow channel, or else the freshwater discharged as a thin layer on top of saline water.

Hydrogeology

A hydrogeologic map of Haiti was produced by the United Nations Development Program (UNDP), Department of Technical Cooperation for Development in 1990. The hydrogeologic map shown in Fig. 2B is adapted from the portion of the map that contains Île de la Gonâve. No transmissivity or permeability data are available for any of the rock units on La Gonâve. There is no previous measurement of aquifer recharge and few discharge measurements from wells or springs. Because evapotranspiration exceeds precipitation, groundwater recharge usually only occurs during intense storms. Otherwise the vegetation consumes all the water that does not immediately evaporate from the hot, dry surface. Additional data are available from reports by Spruijt (1984) and Haiti Foratech (1989).

The depth to the water table in the Eocene limestone commonly ranges from less than 30 m to not more than 60 m below land surface. Some productive wells have been drilled into the limestone. Unfortunately, many pumps installed in wells have failed and have not been repaired or replaced. Discharge measured from two drilled wells that are still working, site numbers 21 and 26 (Table 1 and Fig. 2), yielded 0.2 and 0.3 L/s, respectively. Discharge from the two wells was measured using hand pumps. These types of pumps were installed because they are inexpensive and easy to repair. The low well yields reflect the type of pump and probably do not indicate aquifer yield.

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Table 2 Characteristics of selected drilled wells and other hydrologic features shown in Fig. 3: < less than; *nd* not determined; *μS/cm* microsiemens per centimeter

Site number	Site name	Site type	Latitude and longitude	Land surface elevation in meters above mean sea level	Water table elevation in meters above mean sea level	Total depth of well in meters	Sample date	Pumping rate in liters per second	Conductivity in μS/cm
5	Port de Bonhair	Drilled well	Latitude 18°50′21″N, longitude 73°7′57″W	75	75	80	6/29/02	0.63	570
6	Dent Grignin No. 1	Drilled well	Latitude 18°51′48″N, longitude 73°7′32″W	212	131	90	4/5/00	0.44	nd
7	Dent Grignin No. 2	Drilled well	Latitude 18°51′48″N, longitude 73°7′32″W	212	131	162	5/29/01	0.59	501
							11/17/02	0.13	nd
8	Morne Cean (Glens Well)	Drilled well	Latitude 18°50′13″N, longitude 73°7′27″W	116	39	91	5/25/01	nd	nd
9	Nan Fonnise (Two Trees)	Drilled well	Latitude 18°49′45″N, longitude 73°7′25″W	57	1	57	5/29/01	0.13	1017
10	Trou Nastan (Source Philippe)	Cave pool	Latitude 18°49′11″N, longitude 73°7′22″W	8	<1	8	5/27/01	nd	11,060
11	Trou Beuf	Hand-dug well	Latitude 18°49′3″N, longitude 73°7′19″W	<1	<1	1	5/27/01	nd	13,500

Wells drilled in the Upper Miocene limestone generally have poorer yields than wells drilled in other limestones on the island (United Nations Development Program 1990). Solution features in the Upper Miocene limestone are few and many of the valleys in this unit appear to be fluvial in origin, although none presently have flowing streams except immediately after large storms.

Shallow, hand-dug wells in the Quaternary limestone supply water to people along the coast where the water table is close to the land surface. On the plateau, the water table is commonly greater than 60 m below the land surface. Because of the great depth to the water table, few productive wells have been drilled in this area.

Yield from hand pumps and small submersible pumps installed in wells drilled into the Quaternary limestone ranges from 0.1–0.6 L/s with an average of 0.4 L/s. Again, however, hand pumps were installed because they are inexpensive to operate and repair; consequently, the low well-yields likely reflect the type of pump and do not indicate true aquifer yield.

Since 1994, the Église Méthodiste d'Haïti (Methodist Church of Haiti) with the help of the United Methodist Committee on Relief (UMCOR) and the Kansas East Conference of the United Methodist Church using a cable-tool drilling rig has drilled a series of wells in the Quaternary limestone near Source Philippe, a small fishing village on the southern coast of the western portion of the island. Four wells—Dent Girgnin No. 1, Dent Girgnin No. 2, Morne Cean (Glen's Well), and Nan Fonnise (Two Trees; site numbers 6, 7, 8, and 9, respectively, in Table 2, and Fig. 2)—are included along cross section A-A′, which runs south from the village of Dent Girgnin to Source Philippe (Fig. 3, Table 2). Geologic logs are not available for all of the drilled wells, but some details are known. At Nan Fonnise (Two Trees), most of the rock fragments returned by the bailer to the surface consisted of porous, very pale orange, fossiliferous limestone. While drilling at this site, numerous small cavities were found, as evidenced by frequent, sudden drops of the drill bit and the inability to circulate water in the borehole to make a slurry with the crushed rock at the bottom of the hole. Drilling at Morne Cean (Glen's Well) and Port de Bonhair (site number 5; Table 2 and Fig. 2) was similar to drilling at Nan Fonnise (Two Trees). Rock fragments returned to the surface also were porous, light-colored limestone. During drilling, bit drops were frequent and water could not be maintained in the borehole. From the land surface to 90 m below land surface at Dent Girgnin No. 1 and Dent Girgnin No. 2, the rock fragments returned to the surface consisted of a light-colored limestone similar to that described for the other drilling sites. From 90 m downward to the bottom of the borehole at 162 m below land surface, the material returned was a soft, plastic clay that was difficult to bail from the borehole.

Also along the cross section (Fig. 3, Table 2), but closer to the coast than the drilled wells are Trou Nastan, an 8-m-deep cave containing a small cave pool that is

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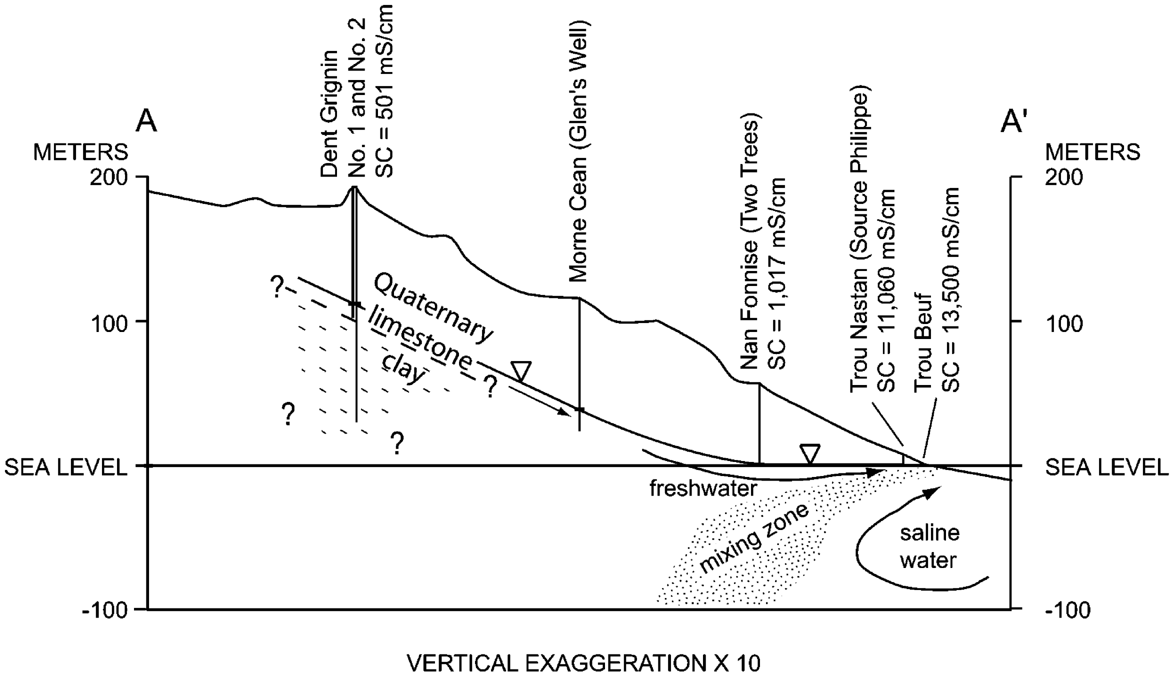

Fig. 3 Hydrogeologic cross section of Île de la Gonâve. *SC* - specific conductivity; μS/cm - microsiemens per centimeter; ∇ - water table; *arrows* represent flowlines

Table 3 Estimated domestic water use on Île de la Gonâve, in Haiti, and in other nearby islands and countries

Area	References	Domestic water use in liters per capita per day
Haiti	Gleick (2002)	17
Anse-à-Galets, Île de la Gonâve	This paper	7.4
Rural villages, Île de la Gonâve	Lindegger (2002)	7.7
Rural villages, Île de la Gonâve	This paper	6.1
Dominican Republic	Gleick (1999)	48
Puerto Rico	Molina-Rivera (1998)	200
USA	Solley et al. (1998)	370

used for drinking water, and Trou Beuf, a diffuse seep that has been modified into a hand-dug well, which is used to water livestock. In this area, groundwater in the Quaternary limestone is assumed to be flowing perpendicular to the long axis of the island (down the southern flank of the anticline) and towards the ocean. Consequently, the cross section shown in Fig. 3 should be aligned parallel with flow lines in the aquifer.

Water Use in Haiti

Water-use data for most rural areas in the underdeveloped world, where water meter and record keeping seldom exist, are difficult to obtain. Some data, however, have been published for Haiti and a few people have made observations on Île de la Gonâve. Data published in Gleick (2002), which was obtained from the Food and Agriculture Organization of the United Nations (2000a), indicates that the estimated domestic water use in the year 2000 for Haiti is 17 L per person per day. Gleick (2002) lists Haiti as having the lowest domestic water use in the western hemisphere (Table 3).

Water Use on Île de la Gonâve

On April 11, 2000, the discharge from Tête Source was volumetrically measured at 3.4 L/s as it entered the water distribution system for Anse-à-Galets (estimated population of 40,000). Although this measurement took place in the dry season, the discharge entering the distribution system remains close to this amount throughout the year. These numbers would indicate that the people in Anse-à-Galets use about 7.4 L per person per day. The actual use is less because of leaks in the distribution system and the export of water from Anse-à-Galets to the surrounding villages.

In Haiti, water use in individual homes is relatively easy to estimate because the people know the size of the bucket they use and they know how many buckets they carry home each day. Lindegger (2002) interviewed 15 people in three villages on Île de la Gonâve. The water

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use reported by these individuals averaged 7.7 L per person per day. The one-way distance traveled averaged about 2.7 m. The average length of time spent collecting water for a family was 2 h and 45 min per day.

During the third reconnaissance expedition, one woman in each of four villages (Nan Mangot, Plaine Des Mapous, Bois Brulé, and Lotorre) that are at a long distance from water sources was interviewed. The water use reported by these individuals ranged from 1.9 to 14 L per person per day and averaged 6.1 L per person per day. The one-way distance traveled ranged from about 1.6 to about 6 km and averaged about 4.6 km. The length of time spent obtaining water each day ranged from 1.3 to 5 h per family per day. The average length of time spent collecting water for a family was almost 3 h per day. These average numbers are similar to averages obtained by Lindegger (2002). Data in neither study indicate a correlation between time of travel and amount of water used. This lack of correlation is partly because some people have burros to carry their water, whereas others carry water in 20-L buckets on their heads.

By combining the data set from Lindegger (2002) with the data set from this study, the average rural domestic water use is calculated to be 7.4 L per person per day for the 70,000 people living on the island. This is the same as the average domestic water use for the town of Anse-à-Galets. However, these estimates do not include rainwater harvesting or in-stream use, such as bathing and washing clothes. Rainwater harvesting is expected to be small due to the length of the dry season and the small size of the available roofs and the cisterns.

The Price of Water on Île de la Gonâve

The price of water on the island varies. There is no charge for water in most places, but a few wells and distribution systems charge 0.10–0.20 Haitian Gourde for a 20-L bucket to cover fuel expenses; this would be equivalent to about 0.20–0.40 U.S. dollars per m^3. In times of drought, prices can go much higher. During the first expedition, water was so scarce in Source Philippe that people were taking small boats 50 km across the channel to the Petit-Goâve on the southern peninsula to bring back water of dubious quality and selling 27-L buckets for 6 Haitian Gourdes (or about 8 U.S. dollars per m^3). Even at that highly inflated price, not enough water could be brought in by boat to supply the paying customers. The price of water provided by Centrale Autonome Métropolitaine d'Eau Potable (the public utility in Port-au-Prince) is about 0.50 U.S. dollars per m^3, while trucked water sells for 3–5 U.S. dollars per m^3 (Constance 1999). Among others, according to Gleick (2002), most municipalities and industries in industrialized countries pay about 0.75 U.S. dollar per m^3 for reliable water supply in urban areas and costs of transporting water by ship usually range between 2–4 U.S. dollars per m^3.

For comparison with the estimated per-capita domestic water use in Haiti (Table 3), the estimated average domestic water use for 2000 in the Dominican Republic, which shares the island of Hispaniola with Haiti, is 48 L per person per day (Gleick 1999). Average domestic water use for 1995 in Puerto Rico, the island directly east of Hispaniola, is 200 L per person per day (Molina-Rivera 1998). Average domestic water use for 1995 in the United States is about 370 L per person per day (Solley et al. 1998).

Water Needs on Île de la Gonâve

The Sphere Project (2000) developed a set of universal minimum standards in core areas of humanitarian assistance, including water supply and sanitation. Their minimum water requirement for drinking, cooking, and personal and domestic hygiene is at least 15 L per person per day. In addition, the maximum distance from any shelter to the nearest water point should be no more than 500 m to allow use of the minimum water requirement.

The United Nations defines "reasonable access" as the availability of at least 20 L per person per day from a source within 1 km of the user's dwelling (WHO and UNICEF 2000; UNESCO 2003).

Gleick (1996) defines the basic water requirement as 50 L per person per day. This requirement can be subdivided as follows: drinking water (5 L per person per day), sanitation (20 L per person per day), bathing (15 L per person per day), and cooking (10 L per person per day).

By any of these standards (15, 20, or 50 L per person per day), the average estimated water use by the people on Île de la Gonâve (7.4 L per person per day) is insufficient for drinking, cooking, and rudimentary hygiene. In addition, the distance traveled and the time spent collecting water generally is too great to allow for additional water use.

Solving the water-supply problem for the island requires the disinfection of water from contaminated sources, repair and replacement of broken pumps, additional water sources, improved distribution, and continued maintenance. All of these are obtainable goals, but they require substantial expenditures.

The simplest method for disinfecting drinking water is by chlorination, either by adding drops of household bleach to individual buckets or by providing in-line chlorination of the water distributed by pipes from the capped springs. In the few areas where generators provide electricity, water can be treated by ozonation, ultraviolet light, or reverse osmosis.

About 840,000 L of additional water per day would be required to raise the average domestic water use on the island from the current estimate, 7.4 L per person per day, to a minimum of 15 L per person per day. The wells on the island observed during this study pumped an average of 0.4 L/s and probably operate for about 12 h per day. At that rate, about 50 wells would be required to produce the additional 840,000 L per day. If the additional wells average 60 m in depth and cost 100 U.S. dollars per meter to drill, then the additional water could be obtained for about 300,000 U.S. dollars. The cost of providing these

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wells would be about 3 U.S. dollars per person on the island.

Even with 50 additional wells, water distribution would remain a problem. The Sphere Project (2000) sets the maximum distance from any house to the nearest water source at 500 m. The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2000) defines "reasonable access" as within 1 km of the user's dwelling. To meet either standard (500 m or 1 km) for the largely rural population of Île de la Gonâve would require the addition of hundreds of water distribution points and hundreds of kilometers of pipe scattered across the 750-km^2 island.

Water-quality Evaluation Methods

Groundwater samples from various cave pools, springs, capped springs, coastal springs, drilled wells, and hand-dug wells on Île de la Gonâve were analyzed by inexpensive means. Total dissolved solids (TDS) were estimated in the field using a Hanna Instruments TDS1 pocket electrical probe (the use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey or the U.S. Environmental Protection Agency). On the first reconnaissance expedition, when the reading from the TDS probe exceeded 1,000 mg per kg, the sample was diluted with drinking water because no distilled water was available. This method yielded only a crude measurement of total dissolved solids. On the second reconnaissance expedition, field demineralized water was used for dilution. This water was obtained by pouring drinking water into a small (177 ml) bottle partially filled with monobed resin (Hach catalog number 14299-00) and shaking.

Iron, nitrate, nitrite, chloride, total hardness, alkalinity, and pH were determined in the field using simple test strips manufactured by Industrial Test Systems (ITS). In all cases, the test strips were matched to the nearest color. No attempt was made to extrapolate between values. These test strips provided only a gross estimate of the chemical composition of the water, but were used because of the difficulty and expense of transporting samples to a water-quality laboratory.

Chloride also was determined using Hach Quantab® titrator strips. When the chloride concentration of a sample exceeded the range of the titrator strip, the sample was diluted with field-demineralized water to estimate the chloride concentration. Although more accurate than simple test strips, the Quantab titrator is only an indication of the chemical composition of the water sample.

The presence of hydrogen sulfide-producing bacteria was checked using the Hach PathoScreen™ test. This test, described by Manja et al. (1982), Kromoredjo and Fujioka (1991), and Grant and Ziel (1996), provides a simple screening test to ascertain if hydrogen sulfide-producing bacteria are present in the water. In places where a water-quality laboratory is unavailable, the PathoScreen test has been used as a proxy for the possible presence of harmful bacteria. An antibacterial gel was used to clean hands prior to collecting the sample for the PathoScreen test and a pocketknife was cleaned with an alcohol wipe. A sterile Nasco Whirl-Pak® plastic bag was filled to the 100-ml line that is preprinted on the bag. The clean knife was used to cut open a PathoScreen pillow and the reducing bacterial media was added to the sample. The sample was incubated at room temperature (about 25°C or above) for 24–30 h. If the sample turned black after that length of time, then the presence hydrogen sulfide-producing bacteria was indicated. According to the manufacturer of the PathoScreen test, bacteria that produce hydrogen sulfide are associated with those bacteria in the human gut, although the test does not differentiate between sources of bacteria. Several pathogenic bacteria produce hydrogen sulfide.

Wet chemical methods were used on the second expedition to determine the concentration of alkalinity, sulfate, calcium, and magnesium. Alkalinity was determined by titration using an alkalinity test kit from Hanna Instruments (HI 3811). Sulfate concentration was determined by the turbidimetric method using a test kit from Hanna Instruments (HI 93751). Calcium and magnesium concentrations were determined using a test kit from Hanna Instruments (HI 93752). The chemical procedures used to determine alkalinity, sulfate, calcium, and magnesium in the field were time consuming and complicated. In addition, they required more water than could easily be produced from the small field demineralizer bottle. Consequently, it was not possible to test duplicate samples at each site. Because of the difficulty in using these test kits, they were not used on the third reconnaissance expedition.

On the second and third reconnaissance expeditions to Île de la Gonâve (May toJune 2001 and June 2002), several additional meters were used to examine the water chemistry. These included two pocket conductivity meters (Hanna Instruments DiSTWP3 and DiSTWP4), a Hanna pocket pH probe (HI 98106), and a Hanna pocket sodium meter (HI 98202).

Water-quality Results

The results of the reconnaissance field analyses of water in wells, caves, and springs are listed in Table 1. Due to the limitations of the water-quality methods used, the values presented can only be used to provide a gross estimate of the chemical composition of the water on the island. However, the analyses appear to be typical of groundwater in karst and coastal karst terrains.

The conductivity observed in water from the interior part of the island ranged from 498 to 1,017 μS/cm. Near the coast, conductivity rose sharply and ranged from 1,969 to 13,500 μS/cm. The high number, 13,500 μS/cm, is equivalent to about 30% of the conductivity of seawater. The water-quality standard set by the Sphere Project (2000) is no more than 1,000 mg/L total dissolved

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solids (approximately 2,000 μS/cm electrical conductivity). The water in most coastal locations exceeds this water-quality standard.

Using the pocket pH meter, pH ranged from 7.7 to 8.4, and the pH test strips reported values that ranged from 7 to 8.5. The two methods gave similar results, and both methods indicate, that the waters are neutral to slightly basic.

Calcium concentrations ranged from 46 to 204 mg/L, with most of the higher values in water obtained from the interior of the island. Magnesium concentrations ranged from 4 to 255 mg/L. Magnesium concentrations in water from the interior of the island ranged from 4 to 17 mg/L, but water from near the coast ranged from 28 to 255 mg/L. The highest magnesium concentration, 255 mg/L, is 19% of the magnesium concentration found in seawater. Hardness, calculated from these values, ranged from 166 to 1,185 mg/L as $CaCO_3$, with the higher values being reported from the coast. Hardness, as determined with test strips, was either of the two top values on the test strip, 250 or 425 mg/L as $CaCO_3$. The test strips and the chemical kits both indicated that water on the island is hard to very hard.

Alkalinity, as determined by the test kit, ranged from 207 to 570 mg/L as $CaCO_3$. Alkalinity, as determined by the test strips, ranged from 80 to 360 mg/L as $CaCO_3$ for all of the samples, but was either 180 or 240 mg/L as $CaCO_3$ for the 11 samples that were also analyzed using the test kit. The chemical test kit reported alkalinity concentrations that ranged from 1 to 2.6 times the alkalinity concentration determined from the test strips.

Values of pNa ranged from 1.0 to 3.7, which is comparable to a range of 5 to 2,300 mg/L when converted to sodium concentration. Values for samples from the interior of the island (5–120 mg/L) were generally lower than values for samples from near the coast (120–2,300 mg/L). The highest sodium concentration, 2,300 mg/L, is 22% of the sodium concentration found in seawater. The World Health Organization (1993, p. 55) has not proposed a health-based guideline value for sodium, but they do warn that sodium concentrations in excess of 200 mg/L may give rise to an unacceptable taste in water. The World Health Organization states "No firm conclusion can be drawn concerning the possible association between sodium in drinking water and the occurrence of hypertension. However, chronic arterial hypertension constitutes a major public health problem on Île de la Gonâve and it has been attributed to drinking brackish water" (Paul Carrendard, MD, Methodist Church of Haiti, written communication, 1998).

The concentration of chloride, as determined with the chloride titrator, ranged from less than 26 to 4,900 mg/L. The highest chloride concentration, 4,900 mg/L, is 26% of the chloride concentration found in seawater. Values for samples from the interior of the island (less than 26–240 mg/L) generally were lower than values for samples from near the coast (223–4,900 mg/L). Although the average chloride concentration for samples from the interior was about 70 mg/L, variation in chloride concentration was observed in three springs issuing from the Eocene limestone (site numbers 16, 18, and 20, respectively, in Table 1 and Fig. 2) and in one well in the Quaternary limestone (site number 6 in Table 1 and Fig. 2). In all these cases, the chloride concentration was 2–6 times higher in April 2000 (near the end of the dry season) than the concentration observed on subsequent trips when it was wetter. Almost all of the sources of drinking water near the coast exceeded the recommended value of 250 mg/L (The World Health Organization 1993, p. 45).

The average chloride composition of precipitation measured by the National Atmospheric Deposition Program site in Puerto Rico is 2.61 mg/L (National Atmospheric Deposition Program/National Trends Network, written communication, 2002). If the average chloride concentration of precipitation on Île de la Gonâve is similar to that of Puerto Rico, then 96% of precipitation would have to be removed by evapotranspiration to yield the average chloride concentration of 70 mg/L, which is the concentration found in water from the interior of the island. Consequently, the recharge rate is roughly estimated to be only 4% of the mean annual precipitation based on a chloride mass balance; however, this estimate is probably not very reliable because of the variation in chloride in precipitation both within and between storms. This rough recharge estimate is slightly less than the 14% recharge that Hanshaw and Back (1980) estimated for the Yucatan Peninsula, a similar age carbonate terrain at the same latitude as Haiti and with a similar average annual precipitation (1,050 mm), but less relief.

There is a good correlation between sodium determine with the pNa meter and chloride determined using the chloride titrator (r^2=0.94), but the molar concentration of chloride obtained with the chloride titrator was about 1.5 times the molar concentration of sodium obtained with the pNa meter. The chloride test strip indicated values of chloride that ranged from 50 to 500 mg/L. Results from the chloride test strip were in good agreement with values obtained using the chloride titrator, although the test strip had fewer possible values and its maximum valued was only 500 mg/L.

An elevated nitrate concentration was observed in a water sample from only one hand-dug well. The nitrate test strip indicated that water from Trou Beuf (site number 11 in Table 1 and Table 2 and in Fig. 2) had a nitrate concentration of about 20 mg/L as nitrogen (or 82 mg/L as nitrate). This well apparently is used only to water livestock and the nitrate is probably from the high concentration of livestock manure that surrounds this shallow well. The World Health Organization (1998, pp. 8–10) has a guideline value for nitrate of 50 mg/L as nitrate (or 11 mg/L as nitrogen). Although the water at Trou Beuf exceeds this value, the water apparently is not used for human consumption.

Sulfate concentrations in water from the interior of the island ranged from 0 to 34 mg/L, whereas water from near the coast ranged from 50 to 276 mg/L. The highest sulfate

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concentration, 276 mg/L, is 10% of the sulfate concentration found in seawater.

Test strips were used to determine the concentration of nitrite and iron. Neither ion was found above the detection limit of their respective test strips, so the data are not presented in Table 1.

Tests for the presence of hydrogen sulfide-producing bacteria were negative for samples collected from six out of seven drilled wells that were tested. The only drilled well in which hydrogen sulfide-producing bacteria were present was Port de Bonhair (site number 5, Table 2 and Fig. 2); however, this well was not chlorinated after the well was completed.

Several of the springs that were sampled had been capped to prevent contamination of the water supply from surface runoff. Although this technique for improving access to water has been used elsewhere, six out of eight capped springs that were sampled tested positive for the presence of hydrogen sulfide-producing bacteria. This result may indicate (1) that the sampled springs have a component of conduit flow that does not allow for any filtration, (2) livestock grazing in the near vicinity of the spring may be affecting the water quality, or (3) there could be a contamination problem along the pipe between the spring box and the point where the system is sampled. The two capped springs where hydrogen sulfide-producing bacteria were absent were Nan Jozin and Tête Source (site numbers 19 and 25, respectively, in Table 1 and Fig. 2).

At Nan Jozin, thorn fences protect the spring and the PVC pipe that runs underground from the spring to the water distribution point. No evidence of livestock was observed between the spring and the water distribution point, and livestock could only obtain water downstream from the public water distribution point. A nearby resident indicated that there was an active local water committee that cleaned the spring area every 3 mo.

The spring box at Tête Source is buried in gravel more than 1 m below the dry stream valley. On the first expedition, the PathoScreen test indicated that water from Tête Source did contain hydrogen sulfide-producing bacteria at the first location where the water could be sampled. On the third expedition, the water tested negative for the bacteria. Unfortunately, time did not permit additional tests. The spring box and water distribution system that takes the water to the Anse-à-Galets is the newest and largest of all the spring boxes observed on the island. Although the water at the spring does not contain hydrogen sulfide-producing bacteria, by the time the water flows through the pipe system to the Anse-à-Galets, it tests positive for bacteria.

With the exception of most of the drilled wells and two capped springs, all of the other sources of drinking water that were sampled during the three expeditions (springs, cave pools, and hand-dug wells) tested positive for the presence of hydrogen sulfide-producing bacteria. Few sources of safe drinking water exist for the population of the island. Veeken (1993) reported that typhoid (a water-borne disease) was common on the island. During a typhoid epidemic in 1999–2000, the hospital at Anse-à-Galets diagnosed an average of 49 new cases of typhoid per day, although the number of cases subsequently dropped to 10–15 per day (Dr. Kristi Ter Avest-Thede, Wesleyan World Missions, written communication, 2003). Widespread bacterial contamination of the water is not surprising, in that there are few latrines on the island and livestock graze freely, enabling waste to be washed into the drinking-water sources.

Although the accuracy of the water-quality methods is not sufficient for a detailed geochemical analysis, the data obtained by these methods indicate general trends in the chemical composition of the groundwater. In the interior of the island, for example at Dent Grignin No. 1 (site number 6 in Table 1 and Fig. 2), the water is a calcium-bicarbonate type. As the water moves downgradient along the flow path, as shown in Fig. 3, conductivity increases and concentrations of sodium, magnesium, chloride, and sulfate increase as the groundwater mixes with saline water from below the aquifer. Near the coast, for example at Trou Nastan and Trou Beuf (site numbers 10 and 11, respectively, in Table 1 and Fig. 2), the water is a sodium-chloride type and exceeds World Health Organization recommended values for both sodium and chloride. The water in this area is about 20% seawater.

Summary

The 110,000 inhabitants of Île de la Gonâve currently have few sources of clean, freshwater to meet basic human needs. Tests for the presence of hydrogen sulfide-producing bacteria were negative for six of the seven drilled wells that were tested, but bacteria were present in all but two samples collected from the capped springs and in all other drinking-water sources (springs, cave pools, and hand-dug wells) that were sampled. Consequently, most drinking-water sources are considered contaminated.

Average water use on Île de la Gonâve is estimated to be about 7 L per person per day, and many individuals in rural areas spend 2–3 h per day collecting water for their families. This amount of water is insufficient for drinking, cooking, and rudimentary hygiene.

The simple methods used in this study for testing the quality of water on Île de la Gonâve indicate that water from the interior of the island is a calcium-bicarbonate type, but water at the coast is a sodium-chloride type that exceeds World Health Organization recommended values for both sodium and chloride. Water at the coast is higher in sodium, magnesium, chloride, and sulfate than water from the interior of the island, and is about 20% seawater. The existence of chronic arterial hypertension as a major public health problem on Île de la Gonâve has been attributed to the consumption of brackish water.

The inexpensive reconnaissance methods used in this study to determine general water-quality conditions could be used effectively by nongovernmental organizations or private volunteer organizations in remote areas of the world, where the need for clean freshwater is great, but the ability to conduct work is limited by the lack of

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infrastructure within the area of concern, a scarcity of funds to conduct water-quality and water-resource assessments, the inability to preserve water samples, and the lack of access to a water-quality laboratory. Reconnaissance methods were deemed adequate to roughly characterize the water quality for the nongovernmental organizations that were trying to provide water for the population of the island.

Drilling wells to successfully produce clean drinking water is difficult, because of numerous difficulties, including the difficulties experienced in transporting a drill rig from Port-au-Prince to Île de la Gonâve, finding skilled well drillers to work on the island, and drilling because of the hardness of the rocks, the numerous fractures and solution features, and the depth to the water table.

Solving the water-supply problem for the island requires disinfection of water from contaminated sources, repair and replacement of broken pumps, additional water sources, improved distribution, and continued maintenance. These are obtainable goals, but will require substantial expenditures.

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