PROCEEDINGS OF THE EIGHTH SYMPOSIUM ON THE GEOLOGY OF THE BAHAMAS AND OTHER CARBONATE REGIONS

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<u>Front Cover</u>: View to the SSE on White Cay in Grahams Harbour off the north coast of San Salvador, Bahamas. At this spectacularly scenic site one can see that marine erosion has removed the entire windward portion of these early Holocene eolianites (North Point Member, with an alochem age of ~5000 radiocarbon years B.P.) that were deposited when sea level was at least 2 meters below its present position.

<u>Back Cover</u>: Stephen Jay Gould, keynote speaker for this symposium, holds a *Cerion rodregoi* at the Chicago Herald Tribune's 1891 monument to the landfall of Christopher Colombus, which is located on the windward coast of Crab Cay on the eastern side of San Salvador Island, Bahamas. The monument consists of an obelisk constructed from local limestone which houses a carved rock sphere depicting the globe with the continents. The inscription carved in a marble slab, reads: "On this spot, Christopher Columbus first set foot upon the soil of the New World."

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HYDROGEOLOGY OF THE COCKBURN TOWN AQUIFER, SAN SALVADOR ISLAND, BAHAMAS, AND THE CHANGE IN WATER QUALITY RESULTING FROM THE DEVELOPMENT OF A RESORT COMMUNITY

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ABSTRACT

According to many historians, Columbus landed in the New World in 1492, at what is now San Salvador Island in the Bahamas. Spurred by this event, five hundred years later, a large resort community opened on the island near Cockburn Town, the government seat. Water supply to both the town and the resort comes from a 105 head wellfield, located nearby. We examined the hydrogeology and water quality at the wellfield to determine what impact the opening of the resort, with its attendant increase in water demand, had on the aquifer.

The aquifer is in the Cockburn Town Member of the Pleistocene Grotto Beach Formation. The wellfield is located between the ocean and two inland, hypersaline lakes on a platform with an elevation of approximately 3 m above current sea level. The ocean is roughly 0.7 km west of the wellfield, Flamingo Pond is roughly 1.1 km east-northeast, and Little Lake is roughly 1.6 km southeast. There is a thin freshwater lens at the wellfield site, and groundwater elevations are tidally influenced.

We obtained 119 weeks of data on pumping rates, rainfall, and salinity, covering the period 9 October 1992 to 20 January 1995 from the Bahamian Water and Sewerage Corporation and the Bahamian Department of Meteorology. We also measured groundwater elevations and conductivity in 26 of the field's 105 wells over a 25 hour period on 16-17 January 1995.

The construction of the Club Med resort led to a 382% increase in groundwater pumping. There was also a 51% increase in the salinity of the water delivered from the wellfield. At 9 g/l, this salinity renders the water unusable. Thus, the combination of an historical quirk that encouraged resort development, and the island's complex karst hydrogeology, has resulted in the degradation of the aquifer and the water supply for both Cockburn Town and the resort.

Groundwater elevations did fluctuate with the tides, but their amplitude did not dampen with distance from the ocean. Conductivity measurements also showed a complex spatial pattern of fluctuations through the tidal cycle. Although relationships are weak, it is possible that this complex pattern reflects the influence of dissolutional conduits that connect the two lakes to the ocean and which probably pass through the aquifer. Because of this, and the thinness of the freshwater lens, the quality of the water supplied to Cockburn Town prior to the resort development was already marginal.

INTRODUCTION

San Salvador Island, Bahamas (formerly known as Watlings Island) is located approximately 620 km east-southeast of Fort Lauderdale, Florida (Figure 1). The island is 11 km wide (E-W) and 19 km long (N-S) (Figure 2). Inland hypersaline lakes occupy

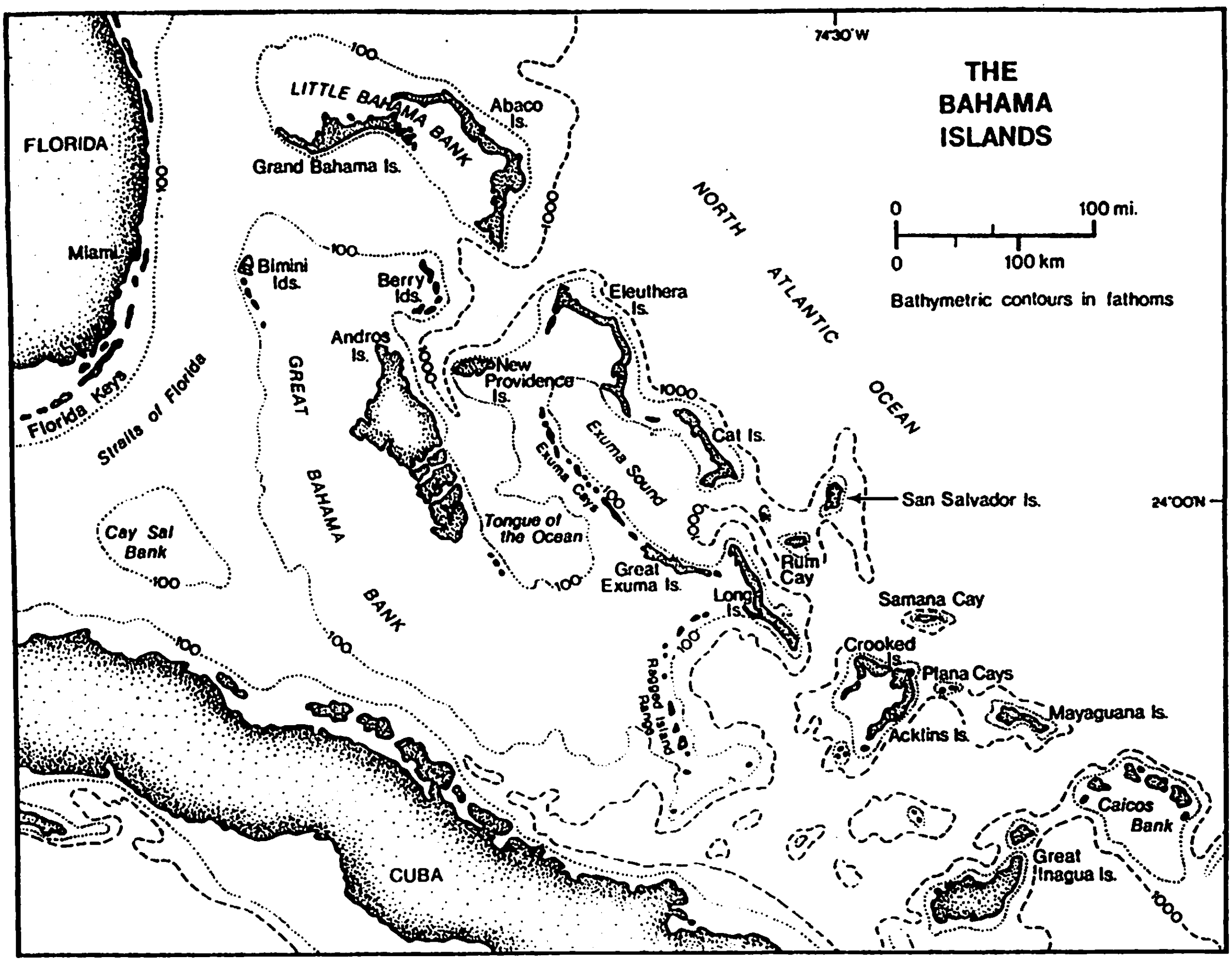

Figure 1. Map of the Bahamas and surrounding region (after Carew and Mylroie, 1995a).

the swales between the lithified Pleistocene and Holocene dune ridges that dominate the topography of the island.

According to many historians, San Salvador was the site of first landfall in the "new" world in October 1492 (Gerace, 1987). Five hundred years later, in 1992, Club Med's Columbus Isle resort opened. The resort created a large increase in the demand for freshwater on the island. The source of water for both the resort and Cockburn Town, the island's main town and government seat, is a wellfield located 1.5 km north of Cockburn Town and 0.5 km southeast of Club Med (Figure 2). The goal of our study was to determine the impact that Club Med's opening had on the water quality in the wellfield and to examine what role the island's karst hydrogeology might have played in the changes that took place. In the end, we hope that this information might help the people at Club Med and the Bahamian Water and Sewerage Corporation to better understand the nature of their water supply and perhaps, to develop management plans that would allow its continued use in the future.

San Salvador Geology

San Salvador Island is located on a small carbonate platform in the southeastern Bahamas (Figure 1). Mullins et al. (1992) suggest that these small platforms are the products of platform-margin collapse and retreat spurred by tectonics along the North American and Caribbean plate boundary. The southeastern part of the Bahamas consists of many of these small platforms, most of which are exposed as single islands such as San Salvador (Carew and Mylroie, 1995a,b; Curran

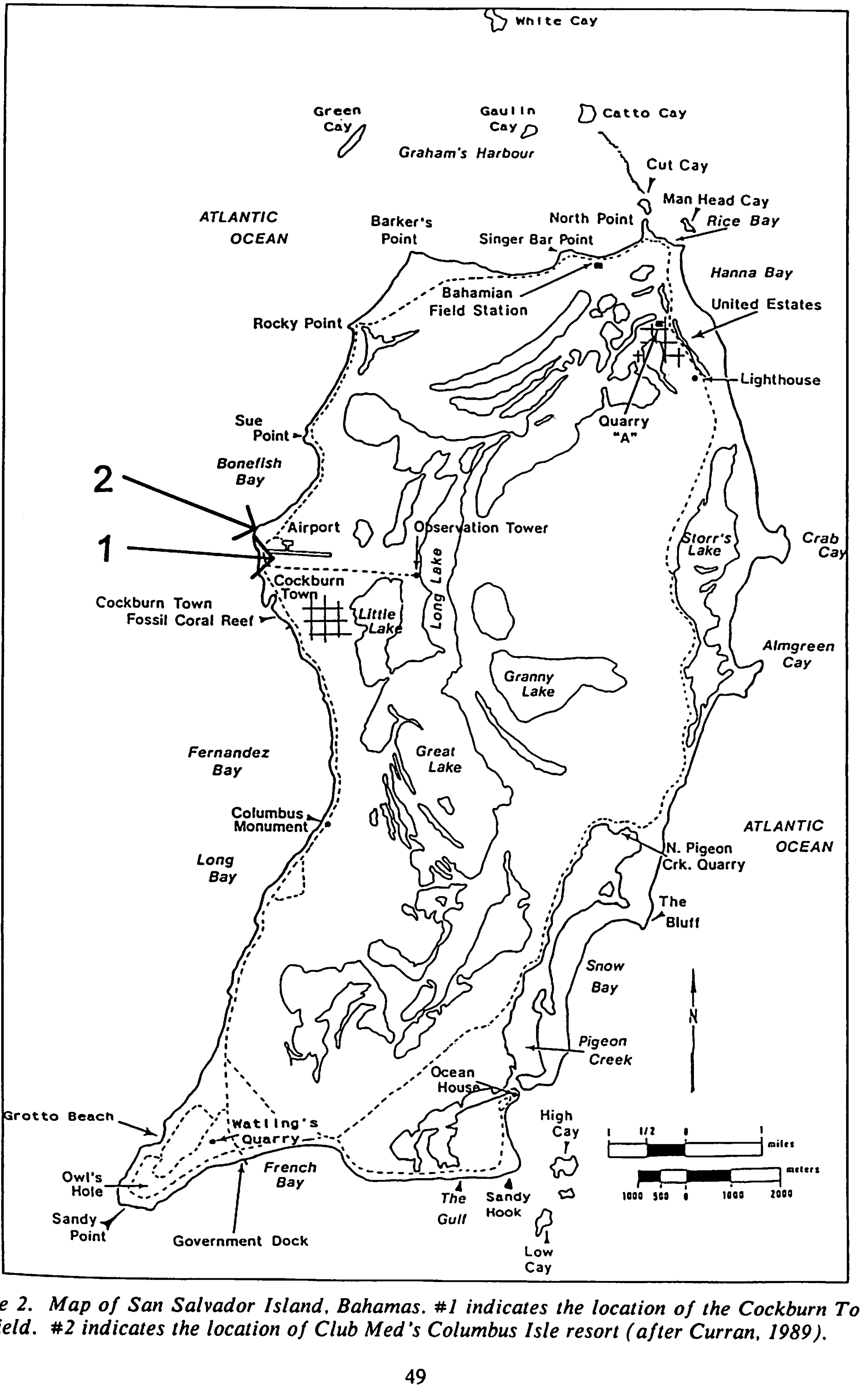

Figure 2. Map of San Salvador Island, Bahamas. #1 indicates the location of the Cockburn Town wellfield. #2 indicates the location of Club Med's Columbus Isle resort (after Curran, 1989).

and White, 1995).

Drilling data from the Bahamian Platform suggest that over 5 kilometers of carbonate sediment have accumulated on pre-Triassic crystalline bedrock (Sheridan et al., 1988). The upper units on San Salvador Island consist of Pleistocene and Holocene limestones including eolian calcarenite, beachrock, fossil coral reefrock, and minor paleosol and subtidal facies (Curran, 1985). Lithified eolian dune ridges, 10 to 20 m high, dominate the topography of the island, with shallow brackish to hypersaline lakes occupying the depressions between (Davis and Johnson, 1989). The shoreline is characterized by sand beaches, commonly containing Holocene beachrock, located between headlands composed of older, eroded eolianites (Curran, 1985).

Elevations on San Salvador reach 10 m in the area east of Club Med and southward toward Cockburn Town (Klein et al., 1958). This area contains several shallow sinkholes formed by the dissolution and collapse of the surface limestone (Klein et al., 1958). Drainage of the area is chiefly underground because the rainfall sinks into cracks and solution cavities, or collects in sinkhole depressions, and infiltrates into the subsurface (Klein et al., 1958).

San Salvador Hydrogeology

The climate on San Salvador is semi-tropical with a rainy season lasting from May to December. Mean annual precipitation (102.4 cm) is exceeded by mean annual potential evapotranspiration (142.8 cm) (Foos, 1994). Almost all precipitation immediately infiltrates into the rock so there is virtually no flowing fresh surface water on the island (Davis and Johnson, 1989).

The volume and geometry of the freshwater lenses beneath oceanic islands are largely determined by the climatic and hydrologic characteristics of the aquifer (Vacher, 1988). In homogenous, relatively unconsolidated and porous sediments, the downward infiltrating, less dense rainwater will displace the denser saltwater forming a lens-shaped body in accordance with the Dupuit-Ghyben-Herzberg relationship. In this model (Vacher, 1988), freshwater lenses float in hydrostatic equilibrium on the denser saltwater below. The shape of the lens is determined by the difference in the density of the fresh and saline waters, the amount of recharge, and the permeability of the aquifer. If the aquifer is extremely permeable, the freshwater will spread out on the surface of the saltwater and form a thin, brackish lens. However, if the aquifer lacks sufficient lateral permeability, water will move more quickly downward than it can move horizontally, resulting in a mound of freshwater that develops above the base elevation of sea level. The depth of the freshwater/saltwater interface below sea level will theoretically be approximately 40 times the height of the freshwater table above sea level. Field investigations and groundwater sampling on San Salvador, with its karstified limestones of varying permeability, have revealed that this relationship does not always hold true (Davis and Johnson, 1989).

In the interior of the island, fresh groundwater is found in discontinuous, isolated, lenses that lie beneath the consolidated carbonate dunes (Davis and Johnson, 1989). The interior freshwater lenses, fed by infiltrating rain water, drain to the brackish and hypersaline lakes, where the water evaporates. There are similar freshwater lenses near the coast that drain to the ocean; however, these are disrupted in many places by flow through caves and conduits. Most of the interior lakes and blueholes are connected to the sea by conduits, but some appear to be fed entirely by precipitation and groundwater seeps. The freshwater lenses on the island tend to be less than 20 m thick, irregular in shape, small, and fragmented (Davis and Johnson, 1989).

The ocean tides also play a role in the hydrology of San Salvador. Tides range from 0.3 m to nearly 1.0 m, varying with the time of day, lunar phases, and seasons (Davis and Johnson, 1989). This tidal action mixes the fresh groundwater with the sea water and moves this mixture through the dissolution conduits beneath the island's surface (Kunze and Quick, 1994). Phreatic conduits introduce sea water into the freshwater system with the incoming tides. Also, the conduits connect blue holes directly to the ocean, resulting in tidal fluctuations in the blue holes comparable to those in the ocean (Davis and Johnson, 1989).

The Cockburn Town wellfield is in the Cockburn Town Member of the Pleistocene Grotto Beach Formation (Carew and Mylroie, 1995a,b). The upper 7 m of the limestone in the Cockburn Town wellfield is composed of well cemented, crossbedded oolitic and fossiliferous limestone with low to moderate permeabilities (Klein et al., 1958). Below 9 m is a hard, highly fossiliferous, dissolution-riddled limestone (Klein et al., 1958).

According to Klein et al. (1958), there are two unconfined aquifers, of different lithologies, in the vicinity of the airport and Club Med. Both yield moderate quantities of freshwater from shallow wells. One aquifer is in the limestone area to the north and south of the airport where the Cockburn Town wellfield is located, and the second aquifer is in the unconsolidated, sands beneath the site of Club Med. The limestone aquifer is capable of a higher total yield than the sands aquifer.

MATERIALS AND METHODS

In January 1995, we undertook a study of the Cockburn Town wellfield and the underlying aquifer to examine the impact that Club Med's opening had on the water quality of the wellfield and to examine what role the island's karst hydrogeology might have played in the changes that took place. The Cockburn Town wellfield contains 105 wells in 11 well lines paralleling both sides of the airport runway (Figure 3). Each well line contains 8-12 wells with one centrally located pump per line. The wellfield is located: 0.7 km east of the ocean which has an average salinity of 32 g/l, 1.1 km west-southwest of Flamingo Pond which has an average salinity of 63 g/l, and 1.6 km northwest of Little Lake which has an

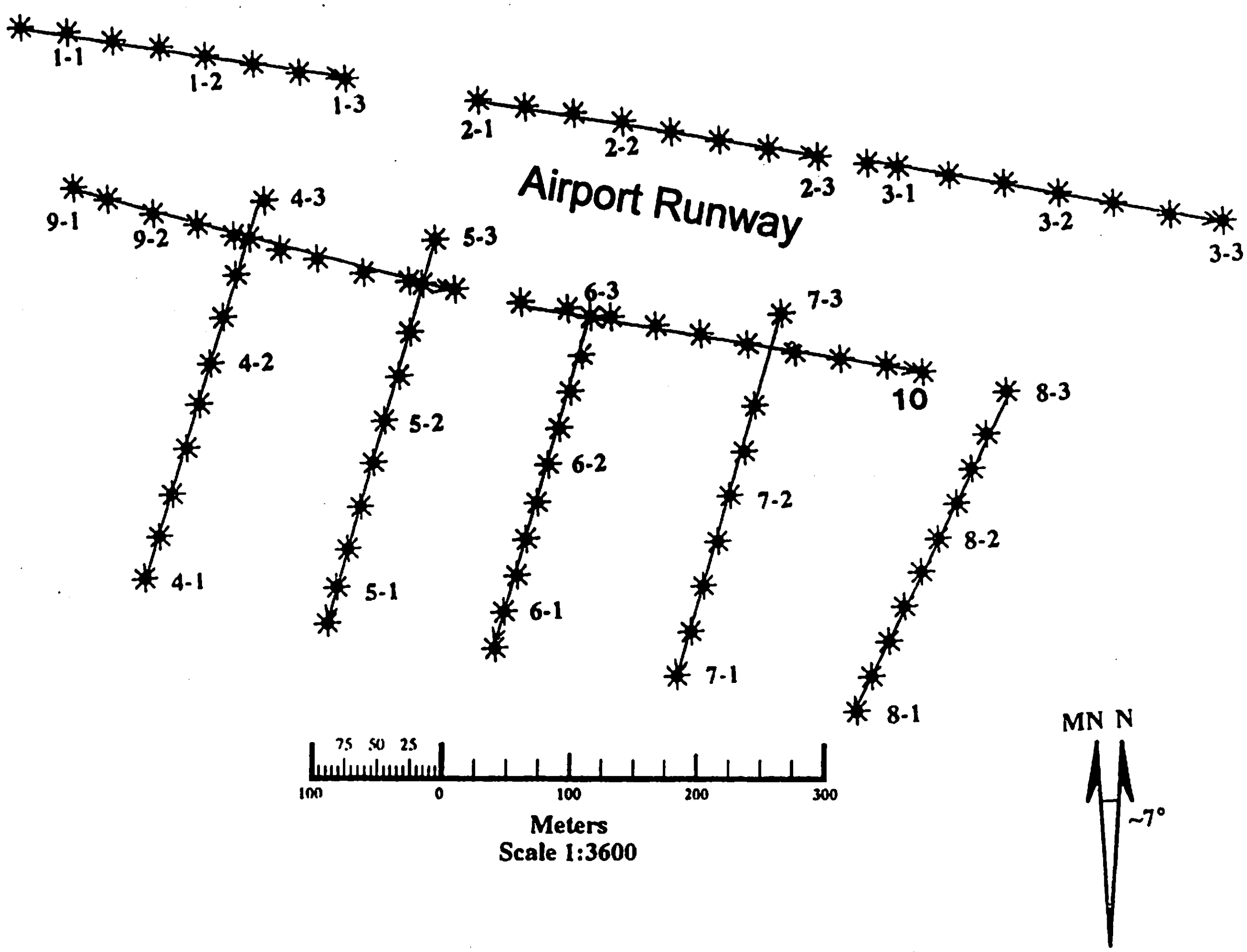

Figure 3. Map of Cockburn Town wellfield showing all wells in well lines 1-10. Wells sampled during the study are labeled A-B, with A indicating well line #, and B the well #.

average salinity of 48 g/l (Davis and Johnson, 1989; Davis unpublished data). Only well lines 1-9 (Figure 3) were included in this study due to the remote location of well line 11, and the overlap of well line 10 with the northern-most wells in well lines 6-8 (i.e., wells 6-3, 7-3, and 8-3).

The Bahamian Water and Sewerage Corporation (WSC) on San Salvador records water consumption and chlorinity for both Club Med and Cockburn Town at the end of each calendar week. We obtained these data for the period 9 October 1992 to 20 January 1995. This record begins twelve weeks before Club Med came on-line on 25 June 1993 and ends 79 weeks later. The chlorinity data were only available for well lines 4-10, located on the south side of the airport (Figure 3). Chlorinity was measured by the staff of the WSC using a Hach Kit (Model 8-P) employing the drop count titration method. These chlorinity data were converted to salinity using the formula: Salinity (g/l) = 1.80655 x Chlorinity (g/l) (Eaton et al., 1995). To verify their accuracy, we compared the WSC data to the salinity measurements we collected every other hour during the field portion of this study.

Climate information for the period 1 January 1993 to 30 September 1995 was obtained from the Bahamian Department of Meteorology in Nassau. These data include the daily amount of precipitation in inches at Cockburn Town. The meteorological station is located 1.5 km south of the wellfield (Figure 2).

Between 14:00 on 16 January 1995 and 15:00 on 17 January 1995, we measured depth to groundwater and salinity fluctuations in 26 of the 105 wells. We measured depth to water hourly at each of the 26 wells, and measured salinity every other hour. On the north side of the airport runway, we sampled three wells in each of the three well lines (1-3) (Figure 3). On the south side of the airport runway, we sampled three wells each in well lines 4-8, and two wells in line 9. During the study, pumping was occurring from lines 1, 2, 5, 7, 8, and 9. When a well line is being pumped, all wells in that well line are producing. We sampled the wells south of the runway over a 13 hour period from 14:00 on 16 January 1995 to 03:00 on 17 January 1995, and north of the runway for a 12 hour period, from 03:00 on 17 January 1995 to 15:00 on 17 January 1995. Safety considerations dictated the sampling of these two areas separately.

We measured depth to groundwater using two separate methods. The first method involved lowering a "kerplunker", attached to the end of a tape measure, into each well. The "kerplunker" was lowered down the well until the distinct sound of the "kerplunker" contacting the water was heard. At this point, the distance between the top of the well casing and the top of the water table was measured to the nearest centimeter using the attached tape measure. The second method involved lowering the probe of a YSI Model 33 Salinity Meter into the well until the salinity meter began to produce a reading. At this point both salinity, measured to the nearest 0.01 g/l, and depth to the water table, measured to the nearest centimeter, were recorded. The true elevations of the tops of the well casings were surveyed in on 10 January 1996.

RESULTS

Temporal Data

We examined the weekly water consumption data from 7 April 1993 to 13 January 1995 for temporal trends. Weekly water consumption for Cockburn Town ranged from 21,325 l on 24 June 1994 to 105,420 l on 16 July 1993 (mean = 40,220 l). There was a zero water consumption value on 14 May 1993 that was probably due to an electrical or mechanical failure, and that datum was not included in the following analyses. The weekly water consumption for Club Med ranged from 65,343 l on 16 July 1993 to 234,590 l on 30 December 1994 (mean = 134,880 l). The weekly water consumption for Cockburn Town plus Club Med ranged from 105,770 l on 28 January 1994 to 299,180 l on 30 December 1994 (mean = 174,410 l). A regression analysis of weekly water consumption over time for Cockburn Town ($R^2 = 0.02$) revealed no significant correlation ($\underline{P}>0.05$). However, regression analyses for weekly water consumption over time for Club Med ($R^2 = 0.10$) and Club Med plus Cockburn Town ($R^2 = 0.42$) both revealed very significant positive correlations ($\underline{P}<0.01$)

(Figure 4). A t-test revealed no significant change ($P>0.05$) in water consumption by Cockburn Town before Club Med came on line (mean = 45,669 l per week) and after Club Med came on line (mean = 39,530 l per week). A t-test revealed a very significant increase ($P<0.01$) from a mean of 45,669 l per week to 174,406 l per week in mean weekly water consumption when Club Med came on-line. This represents a 382% increase in mean weekly water consumption.

We also examined the salinity data collected from 7 April 1993 to 13 January 1995 for well lines 4 through 10 for temporal trends (Figure 5). Salinities ranged from a low of 5.24 g/l on 17 June 1994 to a high of 15.45 g/l on 17 September 1993 (mean = 8.70 g/l). We performed a regression analysis for well lines 4 through 10 combined ($R^2 = 0.05$) for mean salinity over time, and it revealed a significant increase ($P<0.05$). When examining the individual well lines, all but well lines 5 and 7 (positive but insignificant) revealed a significant ($P<0.05$) increase of mean salinity over time. A t-test revealed a very significant increase ($P<0.01$) in the salinity of the water consumed by Cockburn Town residents before (mean = 6.01 g/l) and after Club Med came on-line (mean = 9.07 g/l). This represents a 51% increase in the mean salinity of the water consumed by the residents of Cockburn Town.

We examined daily precipitation trends

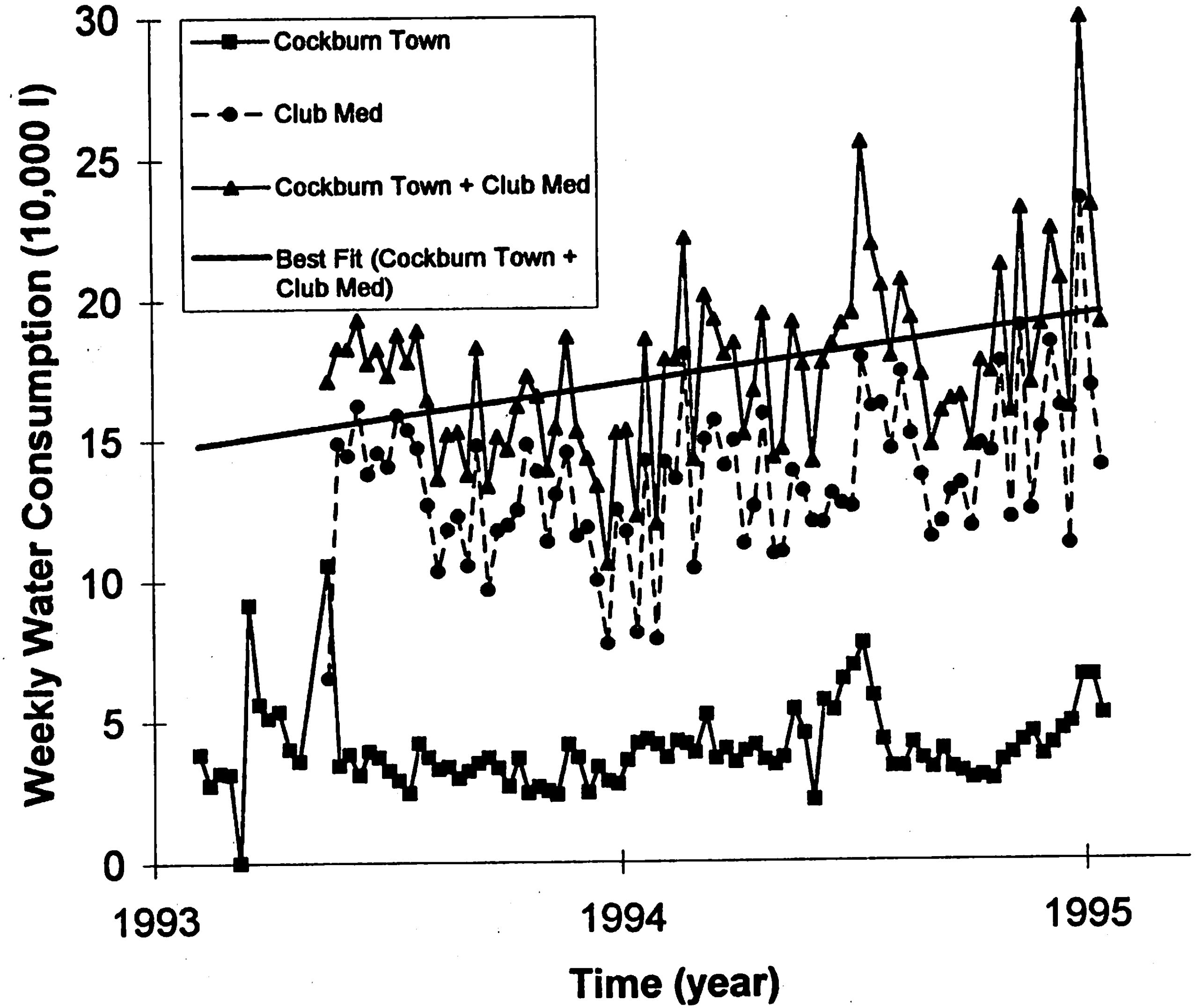

Figure 4. Weekly water consumption of Cockburn Town, Club Med, and Cockburn Town plus Club Med from 9 October 1992 to 20 January 1995. Line indicates best fit linear regression.

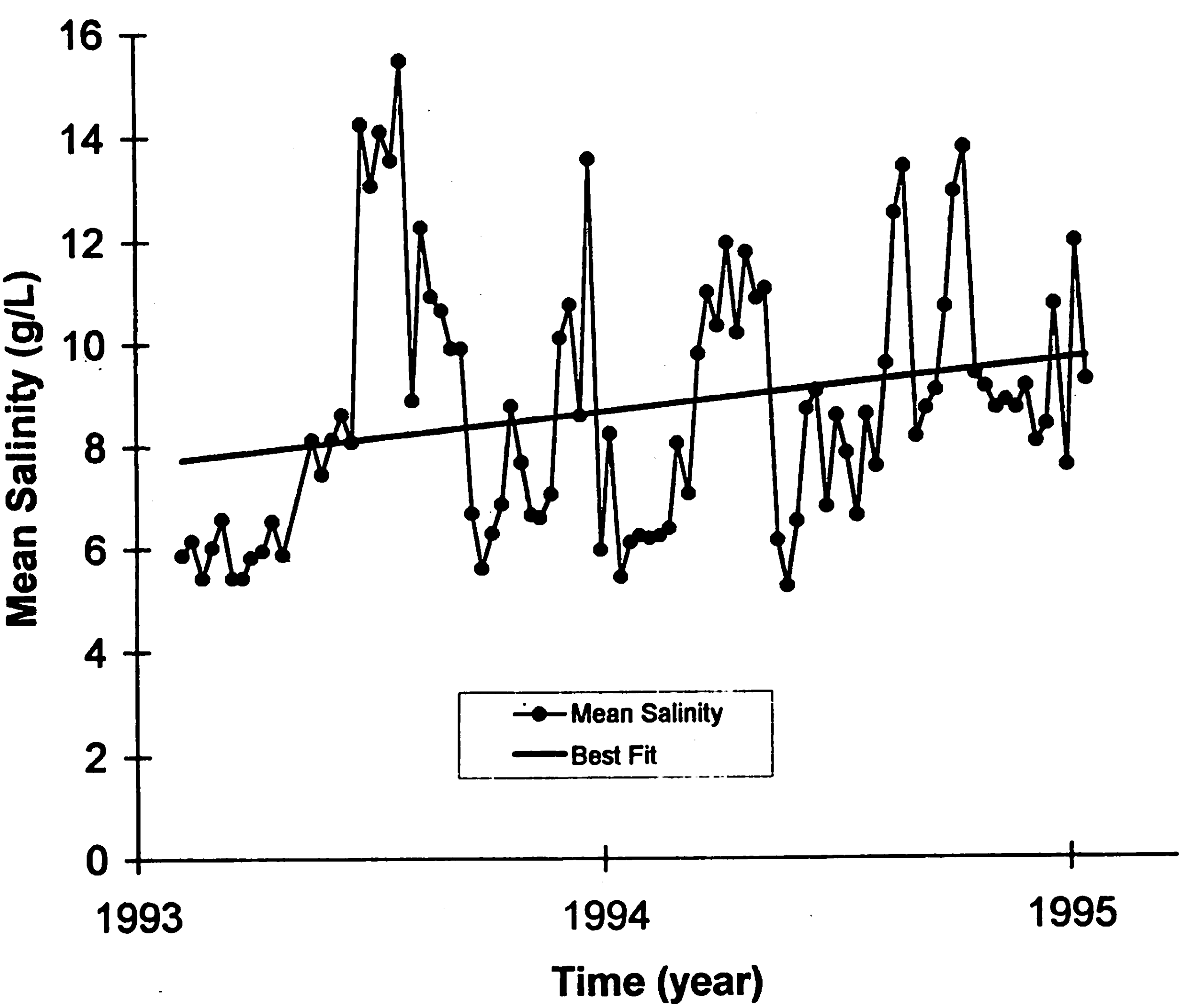

Figure 5. Mean weekly salinity of well lines 4-10 combined, from 9 October 1992 to 20 January 1995. Line indicates best fit linear regression.

to determine if a change in the precipitation rate may have influenced the increase in salinity. A minimum of 0.00 mm of precipitation occurred multiple times throughout the study period of 7 April 1993 to 13 January 1995. The maximum daily precipitation of 135.4 mm occurred on 22 November 1993. The mean daily precipitation rate for this period was 3.3 mm. A regression analysis of daily precipitation over time (R^2 = 0.00) revealed no significant correlation ($P>0.05$). A regression analysis of total weekly precipitation versus mean weekly salinity (R^2 = 0.01) also revealed no significant correlation ($P>0.05$). A second regression analysis of total weekly precipitation versus mean weekly salinity (R^2 = 0.00), using a one week delay to allow the precipitation to infiltrate the groundwater, also revealed no significant correlation ($P>0.05$). Regression analysis of weekly water consumption of Cockburn Town plus Club Med versus mean salinity (R^2 = 0.10) reveals a very significant positive correlation ($P<0.01$).

Spatial Data

The field studies examined groundwater elevations and salinities in the wellfield. Groundwater elevations ranged from -1.82 to +3.16 m (mean = 0.43 m) relative to mean sea level. We predicted that the groundwater elevation would increase as distance from the surrounding surface water bodies increased. Regression analyses were performed to test whether the mean groundwater elevations in each well were related to distance from the ocean (mean = 0.7 km) ($R^2 = 0.00$), Flamingo Pond (mean = 1.1 km) ($R^2 = 0.00$), or Little Lake (mean = 1.6 km) ($R^2 = 0.07$). The results indicated no significant correlation ($P>0.05$) for any. These elevations do not exhibit a simple spatial pattern of increased elevation with increased distance from the discharge points.

Over the 25 hour study period, the tidally induced groundwater level amplitudes (i.e., the fluctuations between low and high tide) ranged from 27 to 67 cm (mean = 51 cm). These data represent minimum amplitudes as each well was measured once per hour and not continuously. We predicted that the amplitude of tidal groundwater elevations would be dampened with increasing distance from the ocean. A regression analysis ($R^2 = 0.03$) revealed no significant correlation ($P>0.05$) between the amplitude of tidal groundwater elevations and distance from the ocean. These fluctuations do not exhibit a simple spatial distribution.

Values for mean salinity in each well ranged from 1.80 to 11.10 g/l (mean = 6.74 g/l). We predicted that mean salinity in each well would decrease as distance from the ocean and/or the hypersaline lakes increased. A regression analysis for mean salinity versus distance from the ocean ($R^2 = 0.00$), Flamingo Pond ($R^2 = 0.00$), and Little Lake ($R^2 = 0.04$), revealed no significant correlation ($P>0.05$).

It was predicted that there would be higher groundwater salinities at the lower groundwater elevations. A regression analysis of mean salinity versus the elevation of the groundwater table ($R^2 = 0.08$) revealed no significant correlation ($P>0.05$). These mean salinities do not exhibit a simple spatial distribution.

Over the 25 hour study period, the measured tidally-induced salinity fluctuations between low and high tide ranged from 0.00 to 3.22 g/l (mean = 0.70 g/l). These are the minimum salinity fluctuations as each well was measured every other hour and not continuously. It was predicted that salinity fluctuations would decrease as distance from the ocean and/or the hypersaline lakes increased. The salinity fluctuations do not significantly ($P>0.05$) decrease as distance from the ocean ($R^2 = 0.03$), Flamingo Pond ($R^2 = 0.02$), or Little Lake ($R^2 = 0.06$) increases. Again, these fluctuations do not exhibit a simple spatial distribution.

DISCUSSION

Beneath small, oceanic islands, fresh groundwater usually occurs as a lens overlying the saline groundwater which seeps in from the surrounding sea (Volker et al., 1985). Such islands usually lack significant freshwater. Therefore, the freshwater lens is an important source of water for human consumption. Pumping from the freshwater zone reduces the thickness of the freshwater lens and, as a consequence, the depth of the freshwater-saltwater interface. This results in local upconing of saltwater at the pumping site (Volker et al., 1985).

The intrusion of saltwater into a freshwater aquifer can be seen, in the Cockburn Town wellfield, as an increase in the salinity of the water being pumped from the aquifer, which has increased due to the development of the resort. The degradation of the Cockburn Town aquifer is confirmed by comparing current salinity values with those prior to major groundwater withdrawals. A 1958 U.S. Air Force study obtained data from test wells in this same area (Klein et al., 1958). At that time, salinities ranged from 0.21 to 1.81 g/l (Klein et al., 1958), which are much lower than the latest value of 9.85 g/l (mean of the last four weeks of data).

Standard groundwater theory (Fetter, 1994) suggests groundwater elevation should increase with increasing distance from the discharge points, the ocean or lakes in this case; and groundwater salinity, salinity fluctuation, and tidal amplitude should decrease with increasing distance. The lack of correlation between these groundwater parameters and distance from the ocean, Flamingo Pond, and Little Lake requires an explanation. There are three possible explanations for the lack of the predicted correlations. These hypotheses suggest that there are more complex subsurface controls on the groundwater table than just distance from the discharge points.

First, all but well lines 3 and 4 were being pumped during the field phase of the study. Pumping creates cones of depression around the wells, which would alter the elevation of the groundwater table. The second explanation has to do with the depth of each individual well. If a well is deeper than 9 m, then it is connected to the dissolution-riddled deep zone of the aquifer (Klein et al., 1958). Therefore, it may exhibit greater fluctuations than a well drilled shallower than 7 m due to more ocean tide influence. The effects of the tides on groundwater fluctuations, as measured by Klein et al. (1958), were greatest in wells that penetrated the highly permeable deep zone, which indicates a good hydraulic connection between the deep zone and the ocean. Groundwater fluctuations in wells penetrating only the shallow parts of the aquifer are much smaller in comparison to those of the deep zone wells.

The third explanation is that there may be subsurface conduits that pass beneath the wellfield. On carbonate islands, conduits are often caused by dissolution of exposed limestone during subaerial exposure. San Salvador was repeatedly subjected to subaerial exposure during low sea level stands throughout the Pleistocene Epoch (Carew and Mylroie, 1985, 1995a,b). Dissolution of the limestones at the groundwater table and at the halocline has produced subsurface rocks with high and variable permeabilities (Oberdorfer et al., 1990). The result of this is that the Pleistocene lithofacies on San Salvador, and most other Bahamian islands, are honeycombed with an extensive system of caves, conduits, and deep sinkholes (Mylroie and Carew, 1988; Eckstein and Maurath, 1995). Many of these extend from the coast all the way to ponds far in the interior. Both Little Lake and Flamingo Pond obtain sea water through such conduits.

Dissolution conduits in the aquifer can change the shape of the ideal freshwater lens by changing the effective hydraulic conductivity of the aquifer, thereby reducing the resistance to groundwater movement in preferred directions (Tarbox, 1987). In addition to the major controlling parameters including landmass width, hydraulic conductivity, and groundwater recharge, the dynamics of the ocean also play an important role in the thickness of the transition zone between the fresh and saltwater, groundwater level fluctuations, and salinity fluctuations (Vacher, 1988). Many dissolution features have distinctly horizontal orientations and are related to changes in sea level and to ancient buried soil horizons (Tarbox, 1987). The distribution of conduits is neither lithologically, stratigraphically, nor structurally controlled, suggesting a process unique to conduit formation in the Bahamas and geologically similar islands (Mylroie and Carew, 1988). As the ocean tides rise and fall, the conduits serve as an exchange for ocean water, groundwater, and inland lake water, and in the process, cause fluctuations in both the elevation and the salinity of the groundwater.

CONCLUSIONS

The development of the new Club Med resort, supported by the Bahamian government as a means of increasing the economic well being of San Salvador, has increased the rate of freshwater withdrawal from the Cockburn Town aquifer. The salinity has increased to over 9 g/l, which renders the water unusable for human consumption, and requires a new assessment of the local groundwater resources. Therefore, the combination of an historical quirk that encouraged resort development, and the island's complex karst hydrogeology, have created the need for this study.

The most significant findings of this study are the 382% increase in water consumption from the wellfield, and the resulting 51% increase in the salinity of this water, which are a direct result of nearly quadrupling the pumping rates from the wellfield by Club Med's Columbus Isle Resort. The data also show that the amount of water consumed by Cockburn Town residents has not significantly increased during this period; yet the residents of Cockburn Town have experienced an enormous degradation of what was an already borderline water supply.

Summarizing the spatially complex patterns of groundwater elevations, tidal groundwater amplitude, and salinity fluctuations is probably impossible. The effects of pumping, varying well depths, and the presence of subsurface conduits can effectively overprint patterns expected in homogenous, isotropic aquifers. In heterogeneous, anisotropic aquifers any of these three parameters can render nearly all types of patterns unrecognizable.

The increase in mean salinity in the water supply may have detrimental health effects on the population of San Salvador. Sodium hypertension is a direct health effect of increased salt intake, and its medical effects include coronary, neurological, and renal problems (Isselbacher, 1994). Importantly, sodium hypertension is twice as likely to occur among people of African descent (Isselbacher, 1994), and most of the population of San Salvador belongs to that ethnic group.

San Salvador needs groundwater supply management. One possible approach could be the construction of recharge basins, which frequently used to recharge unconfined aquifers like those found on San Salvador. Basins create a substantial hydraulic head that can be maintained to increase infiltration rates. Because of the large concentration of water in a small area, a large groundwater mound forms beneath these basins; then, when recharge ceases, the mound spreads throughout the aquifer (Fetter, 1994). Another solution could be the installation of a pressure-ridge system. In such a system, a line of pumping wells, parallel to the coast, pumps saltwater back into the ocean, which creates a ridge in the potentiometric surface. As a result, wells behind the trough could be drawn down substantially, even below sea level, with no fear of saltwater infiltration (Fetter, 1994). Alternatively, pumping of the wellfield could be reduced by reactivating the now inactive rainfall catchment near the airport. This and the construction of new catchments could substantially lessen the pressure on the aquifer.

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