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HYDROLOGY OF WATLING'S BLUE HOLE: SAN SALVADOR, BAHAMAS

Stephen Vermette
Geography and Planning
Vermetsj@buffalostate.edu
and
Rebecca Hudson
Earth Sciences and Science Education
Fatcat20us@yahoo.com
Buffalo State College
Buffalo, NY 14222

ABSTRACT: *Watling's blue hole is a karst feature located on the Bahamian island of San Salvador. The blue hole's physiography and hydrology were studied in April 2001. Watling's blue hole was compared with other Bahamian inland blue holes. Unlike typical blue holes, Watling's blue hole did not have a fresh water lens, and therefore did not exhibit a halocline. The impact of groundwater pumpage, drought conditions, and the island's geology were assessed to explain the absence of the fresh water lens. The absence of any significant stratification of the blue hole's water chemistry, the clarity of the water, and* Mg^{++}/Ca^{++} *ratios support a structural explanation (conduits connecting the blue hole to sea water) for the absence of a fresh water lens. Watling's blue hole can offer only a limited response in water chemistry to either climatic or human-induced changes to the island's availability of fresh water.*

INTRODUCTION

Island blue holes provide an opportunity to study island hydrology, and to assess the impacts of changing climates and island development on fresh water availability. The intent of this paper is to characterize the physical morphology and water chemistry of Watling's blue hole, and to compare these parameters with those of typical Bahamian blue holes. A growing scarcity of fresh water on the island of San Salvador may be reflected in changes to the water chemistry of Watling's blue hole. The validity of using Watling's blue hole as an indictor of fresh water availability is assessed.

BACKGROUND

The island of San Salvador is part of the Bahamian archipelago, located at 24°N and 74° 30'W (Figure 1A). The island's dimensions are approximately 10 miles (16 km) north-south and 5 miles (8 km) east-west. San Salvador is built on a limestone carbonate platform and exhibits a topography of petrified sand dunes, hypersaline lakes, and karst geomorphology (Carew and Mylroie, 1994). The largest settlement is Cockburn Town (population 950), located along the west shore of the island. The Bahamian Field Station is located along the north shore of the island. Watling's blue hole is located on Sandy Point, on the southwest corner of the island (Figure 1B).

Pit caves are features associated with the island's karst geomorphology. Water-filled pit caves are termed 'blue holes'. During periods of low sea level (low-stands), as during Pleistocene glaciation, pit caves form by dissolution of limestone attributed to the rapid percolation of rainfall. There are no streams on the island. A vertical shaft is produced through the bedrock. During periods of high-stands the pit caves flood (Carew and Mylroie, 1994). Inland blue holes refer to flooded pit caves that open onto land, whereas ocean holes are completely flooded, and open into a lagoon or ocean (Burkeen and Mylroie, 1992). Watling's blue hole is an example of an inland blue hole.

The morphology of inland blue holes is typically circular, as the limestone is pure and water entering or within the blue hole will erode any

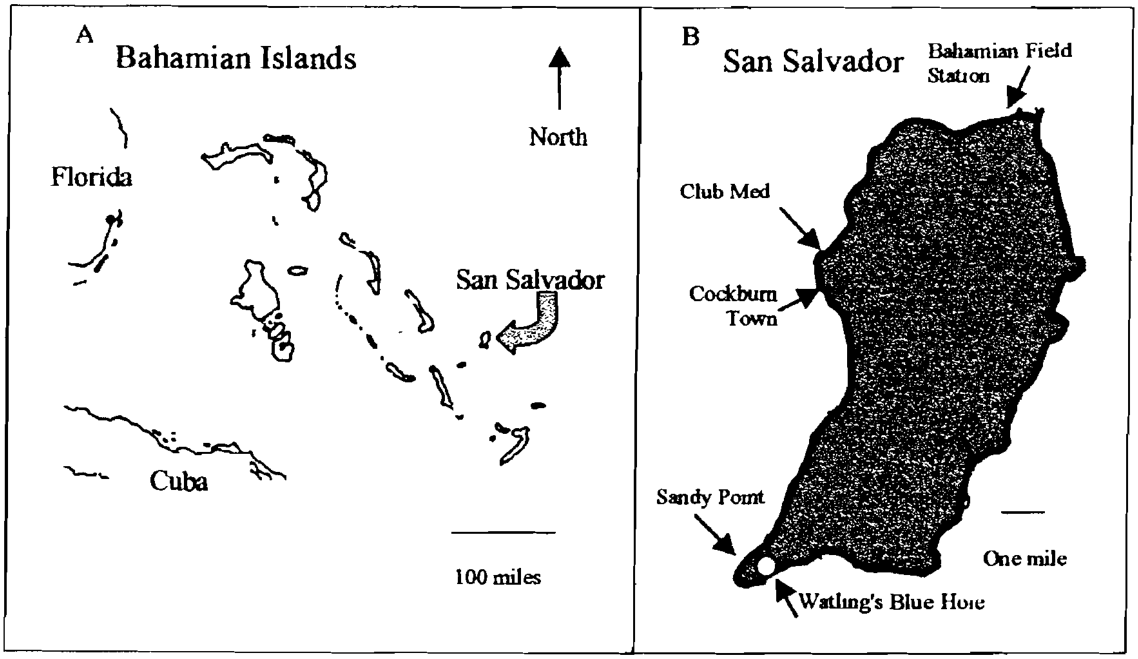

Figure 1. Location of the Bahamas and the island of San Salvador.

projections. Blue holes traditionally exhibit a water salinity from fresh to marine, with a freshwater lens floating on underlying denser seawater. The freshwater lens is a manifestation of the island's fresh water aquifer. Temporary freshwater lenses are also possible after a large storm. The boundary between the two water layers is usually well defined and is referred to as a halocline (Carew and Mylroie, 1994). Water chemistry usually exhibits a marked change at the halocline, which includes dramatic shifts in salinity, pH, clarity, and dissolved oxygen (The Blue Holes Foundation, 1999).

METHODS

Watling's blue hole was mapped and sampled on April 11, 2001. Weather data were acquired using a portable hand-held weather station. Two transects were taken across the blue hole, following approximate northwest-southeast and southwest-northeast orientations. Water depth was determined using a graduated pole, to a maximum depth of 7ft (2.1 m), and a secchi disk (using the weight) for deeper measurements. The center of the blue hole was identified by water colour: a darker blue indicating greater depth. These measurements were re-examined using photographs taken from a ridge overlooking the blue hole.

A vertical profile of the blue hole's water column was taken using a Van Doren bottle at set intervals of 3 ft (0.9 m), 9 ft (2.8 m), 18 f t (5.5 m), and 27 ft (8.2 m). The Van Doren bottle was lowered from two inner tubes floating over the deepest section of the blue hole. A secchi disk was used to measure the depth of the blue hole and again used to determine a secchi depth (a measure of water clarity). Water samples were collected in Nalgene bottles and returned to shore for immediate chemical analysis. Water temperature was taken immediately upon collection. The air temperature on the day of sampling was 81.7°F (27.6°C). Air temperatures had minimal effect on the collected water samples, as the ambient air temperature was comparable to the water temperature. All samples were protected from direct sunlight. Parameters measured included salinity (conductivity meter), temperature (digital thermometer), pH (meter and drop solution),

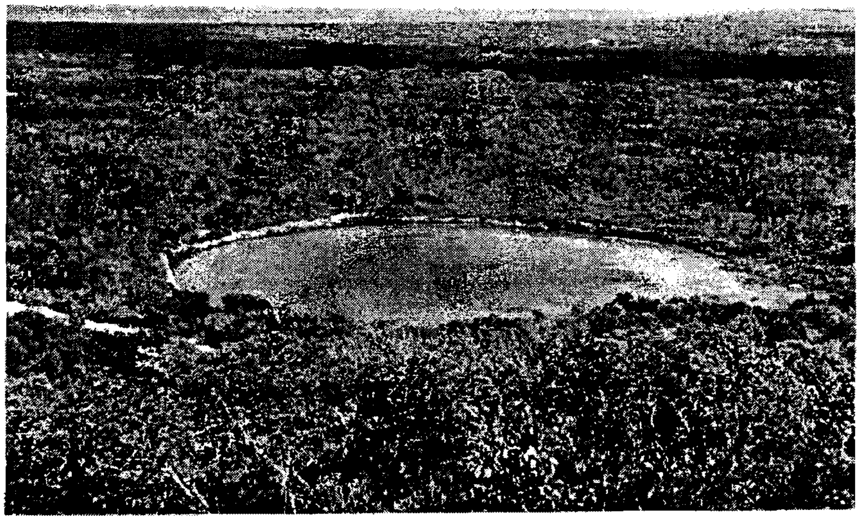

Figure 2. Watling's blue hole, as photographed from a nearby petrified sand dune (looking northwest).

hardness (titration method for calcium and magnesium), and dissolved oxygen (meter). Manufacturer recommended procedures were followed for all tests. All probes and vials were conditioned between measurements to avoid cross contamination of samples. The conductivity meter was designed for "fresh" water and thus any "salt" water measurements required that water collected from the blue hole be diluted with a prepared standard. The standard was made up of tap water (0.913 ppt salinity) taken from the Bahamian Field Station. The collected blue hole water was diluted 50mL into 150 mL of the prepared standard. Salinity was determined by multiplying the diluted sample by four and subtracting the salinity contributed to the sample from the tap water.

Biochemical Oxygen Demand (BOD_5) is a measure of the oxygen demand of bacteria used for the decomposition of decaying organic material after a five-day period. Samples for the BOD_5 test were taken from the surface and at a 27 ft (8.2 m) depth and secured in opaque Nalgene bottles. After a waiting period of five days the dissolved oxygen was determined. The BOD_5 was calculated as the difference between the dissolved oxygen measured at the blue hole and that of the dissolved oxygen measured five days later in a laboratory.

A sediment sample was taken within 3 ft (0.9 m) of shore. Shells were removed for identification. A loss-on-ignition test was conducted in the laboratory to determine the organic content of the sediment. Samples were placed in a crucible and excess water was allowed to evaporate overnight (about eight hours) in an oven set at 221°F (105°C). The sample was weighed and then heated to 1,022°F (550°C) for two hours. The sample was again weighed and the difference was taken to be sediment loss due to the ignition of organic matter.

RESULTS

At the surface, Watling's blue hole takes on the rounded shape typical of blue holes (Figures 2 and 3). It is slightly oval with its northwest-southeast dimension of 210 ft (64.1 m) and southwest-northeast dimension of 195 ft (59.5 m). A smaller vertical shaft extends down to 30 ft (9.2 m). The shaft is off-center, with most of the blue hole's surface area made up of a ring of shallow water, lined with fine sediment to an average depth of 2 ft (0.6 m). The sediment ring is atypical of blue holes on other Bahamian islands (Wehn, Personal Communication). The blue hole is outlined by an artificial rock wall ranging between 2 and 3 ft (0.6 and 0.9 m) in height. It is said that this rock wall, as well as rock structures on the northeast side of the blue hole, was built as a holding pen for sea turtles brought to the blue hole by residents inhabiting the island in the 1800's (Carew and Mylroie, 1994). The sediment is made up of 65%

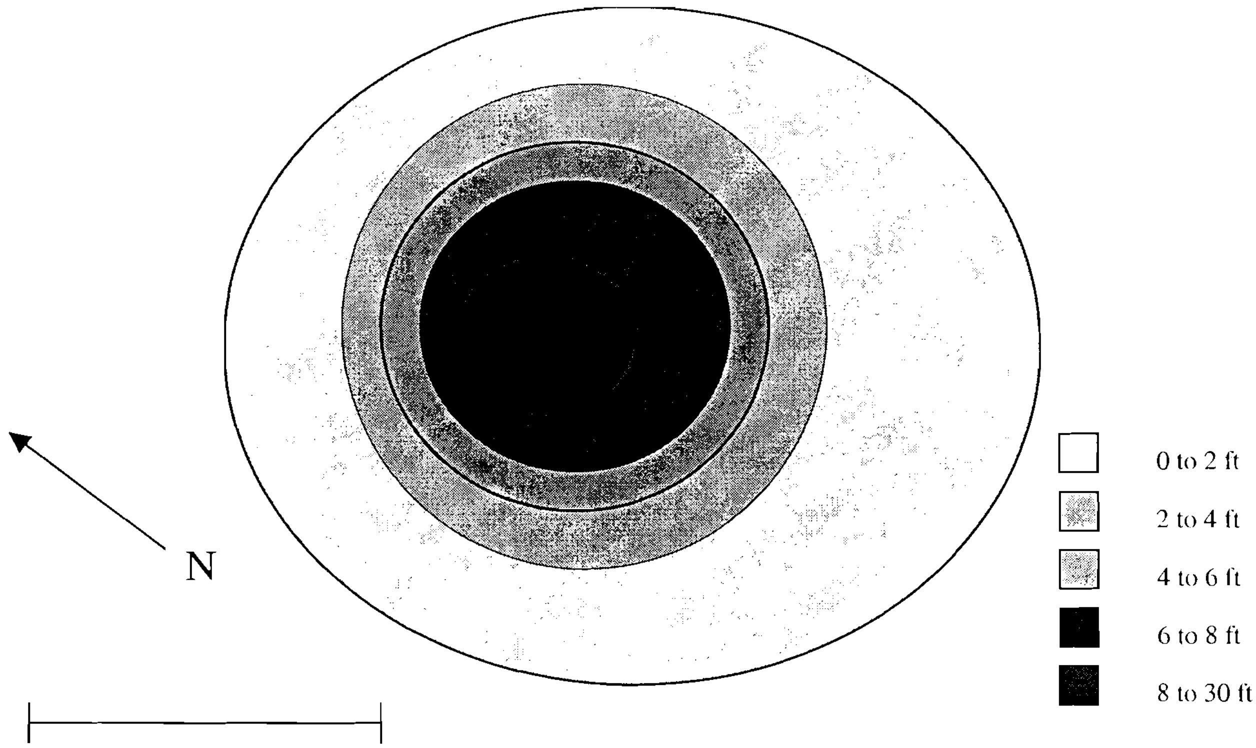

Figure 3. Morphology and water depth of Watling's blue hole (April, 2001).

organic matter, which in the shallow waters supports patches of Manatee and Turtle grass, as well as Fuzzy Finger algae. Numerous shells were found in the sediment. These have been identified as Rough Cerith gastropods and Smooth Tellin bivalves, both described as abundant in sands of shallow marine water (Dance, 1992). These observations indicate a brackish/saline environment.

A secchi depth of 16.5 ft (5 m) indicated excellent clarity, with no suspended solids or visible algae in the water. The BOD_5 measurements (surface and 27 ft (8.2 m)) were zero, indicating no significant oxygen demands (e.g. from bacteria decomposing organic matter). The vertical profile of the blue hole water column failed to show a fresh water (or even brackish) lens. The salinity measurements were comparable to those typical of water sampled below a halocline or the ocean (Figure 4). Results from other blue holes have been added for comparison.

Values for the other water chemistry measurements showed no significant chemical stratification within the water column, exhibiting only slight decreases with depth (Figure 5). Dissolved oxygen values were at saturation near the surface and at 85% near the bottom of the shaft, suggesting mixing of the water column.

DISCUSSION

Roadman (1974) documented the presence of a halocline in an unidentified blue hole at Sandy Point. A review of the author's map suggests that the blue hole may be Ink Well. Ink Well is described by Carew and Mylroie (1994) as having a fresh/brackish water lens of about 10 feet thick. Crotty and Teater (1984) described water in nearby Watling's blue hole as brackish (no data reported), and they noted the absence of a well-defined halocline. Profiles of Stargate and Black Hole blue holes from Andros Island (Figure 4) show a fresh water lens that is better

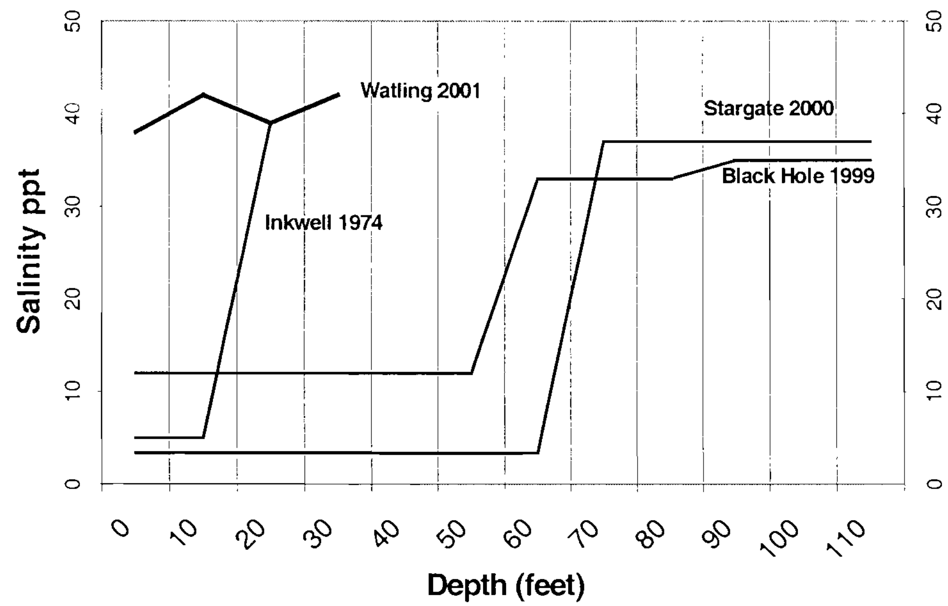

Figure 4. Water column salinity as measured at Watling's blue hole and compared to other Bahamian blue holes.

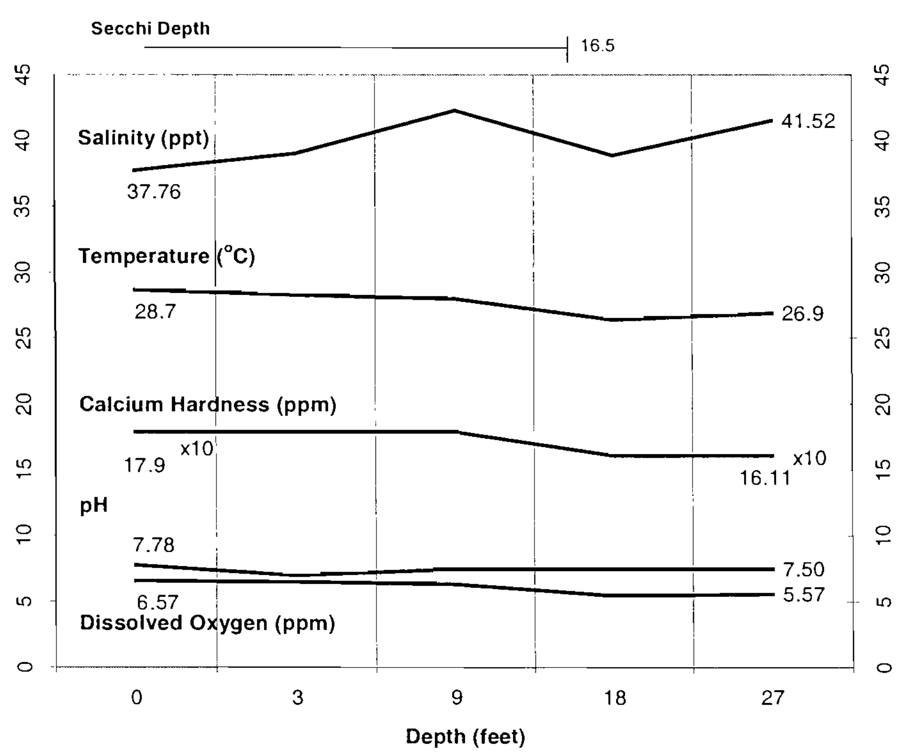

Figure 5. Water chemistry of Watling's blue hole (April 2001).

described as brackish. Our sampling of Watling's blue hole showed no evidence of a brackish lens.

Three explanations are explored to explain the absence of a fresh water lens (even brackish water) and the high salinity of Watling's blue hole.

Over Pumping

Groundwater does occur on the larger Bahamian islands. Andros, the largest island of the Bahamian archepalego, has sufficient groundwater resources to export its water to other islands. San Salvador supports a lens of groundwater (Davis and Johnson, 1989) but the availability of fresh water has always been a concern. The Bahamian Field Station (a former naval base) collects drinking water from a cement catchment built on the side of a dune.

Drinking water wells across the island do tap into fresh water, but they are susceptible to over pumping. The arrival of Club Med in 1994 and a growing population in Cockburn Town increased pumpage rates by 400%. The result was the loss of fresh water from the Cockburn Town aquifer (Davis, 2001). Other areas, especially the northern half of the island, have also lost their fresh water due to over pumping. While over pumping does have a local impact, the work of Davis and Johnson (1989) show that fresh water lenses are not continuous. This suggests that pumping one aquifer is unlikely to affect another. There is likely no hydrological connection between the northern well fields and the area around Watling's blue hole. There is no evidence to suggest excessive pumpage in the vicinity of Sandy Point.

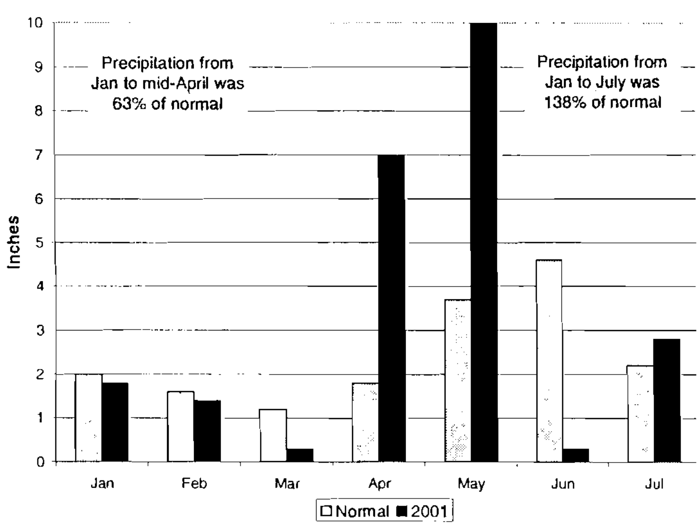

Figure 6. San Salvador islands precipitation from January to July 2001 as compared to the normal.

Drought Conditions

Our sampling of Watling's blue hole in April, 2001 occurred during a period, described by local residents, as a drought. Clearly, the absence of precipitation would lessen the availability of fresh water on the island but was it of sufficient length and magnitude to remove a fresh/brackish water lens? Precipitation data collected at the airport (near Cockburn Town) provides a 60 year average (normal) for San Salvador (Shaklee, 1996). The Koppen climate classification is Aw (tropical savanna) with most of the precipitation falling during the summer months. The period from June to November is also susceptible to heavy precipitation associated with hurricanes. While airport precipitation data were not available for our study period and the months previous, a recently installed meteorological station at the Bahamian Field Station provided data for the January to July period (Gerace Field Station, 2001). The data are summarized in Figure 6. The precipitation for April occurred in the last days of the month, thus the month of March and most of April recorded precipitation well below the normal. However, the drought does not appear to have been prolonged, as precipitation in the months of January and February were close to normal. Taken together, the period January to mid-April received 63% of normal precipitation. The high precipitation totals for the latter part of April and into May highlight the variability of San Salvador's precipitation. The six-month period from January to July experienced 138% of normal precipitation. While the climatological data are limited, there is no clear indication of a drought of sufficient duration or severity to account for the absence of a fresh/brackish water lens at Watling's blue hole.

The presence of a brackish water lens may be possible during flooding conditions. In the weeks following our sampling of Watling's blue hole, a storm passed over the island dumping 10 inches (250 mm) of rain in a period of a few days (Gerace Research Center, 2001). The brackish water lens with an ill-defined halocline, as measured by Crotty and Teater (1984), may be attributed to periods of excess rainfall.

Island Hydrology

Davis and Johnson (1989) found that fresh water aquifers on San Salvador exist under the petrified dunes and can exist near shorelines. However, the presence of conduits allows for mixing of marine and fresh water. In areas with connecting conduits a fresh/brackish water lens may be absent. Observations of surface water levels at Watling's Blue Hole indicated that the water level in the blue hole fluctuated a minimum of 2 ft (0.6 m) with the changing tide. Carew and Mylroie (1989) describe a tidal range of a little over 3 ft (0.9 m). The absence of a fresh/brackish water lens and a halocline is consistent with the existence of a conduit connecting the blue hole with the ocean. This influx of marine water could account for mixing of the water column and the absence of a significant chemical stratification. As further evidence, the clarity of the water and the low BOD_5 are consistent with the findings of Davis and Johnson (1989) who found that lakes with connecting conduits are clear, and free of algae. The physical evidence, including the grasses and shelled organisms, suggest a marine environment.

Davis and Johnson (1989) used Mg^{++}/Ca^{++} ratios to distinguish the sources of ground water on San Salvador. Ratios of < 0.16 were found to indicate that the ground water was derived only from precipitation, whereas higher values indicate marine/fresh water mixing. While our Ca^{++} values (179 ppm) appear comparable to well water derived from precipitation, our Mg^{++}/Ca^{++} ratios of 8 are more typical of ocean water and saline lakes (2.80 - 32.42), and support the absence of a fresh/brackish water lens at Watling's blue hole.

CONCLUSION

Watling's blue hole exhibits a typical rounded morphology. Most of the blue hole's area consisted of shallow waters, with a smaller shaft (slightly off center) extending down 30 ft (9.2 m). The bottom of the blue hole (in shallow waters) was made up of a highly organic sediment ring which supported grass patches, common gastropod and bi-valve organisms. The water's salinity was consistent to that of marine waters. A fresh/brackish water lens and a halocline were not observed. Other chemical parameters showed no significant stratification with depth, suggesting mixing of the water column. The high salinity of the water, apparent mixing of the water column, high Mg^{++}/Ca^{++} ratios, and water clarity are consistent with a conduit connecting Watling's blue hole to marine waters. The absence of a fresh or brackish lens and a halocline appears attributed to the island's geology, rather than to drought or over pumping of fresh water. Watling's blue hole can only offer a limited response to either climatic or human-induced changes to the island's availability of fresh water.

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REFERENCES

Burkeen, B. and Mylroie, J.E. 1992. *Bahamian Blue Holes: Description and Definition.* National Speleological Society Annual Convention, Huntsville, Alabama.

Carew, J.L. and Mylorie, J.E. 1994. *Geology and Karst of San Salvador Island, Bahamas: A Field Trip Guidebook*, Bahamian Field Station, San Salvador, Bahamas.

Crotty, K.J., and Teeter, J.W. 1984. Post-Pleistocene Salinity Variations in a Blue Hole, San Salvador Island, Bahamas, as Interpreted from the Ostracod Fauna. In *Proceedings of the Second Symposium on the Geology of the Bahamas: Fort Lauderdale, Florida*, ed. J.W. Teeter, pp. 3-16. CCFL Bahamian Field Station.

Dance, S.P. 1992. *Shells*, London: Dorling Kindersley Limited.

Davis, R.L. and Johnson, C.R. 1989. Karst Hydrology of San Salvador. In *Proceedings of the Fourth Symposium on the Geology of the Bahamas: Port Charlette, Florida*, ed. J.E. Mylroie. Bahamian Field Station.

Davis, R.L., 2001. Personal Communication. Gerace Field Station, 2001. *Weather Summary for San Salvador January - July 2001.* Gerace Field Station, San Salvador, Bahamas.

Roadman, K. 1974. *Soil and Water Conductivity*, Environmental Chemistry Notes, Bahamian Field Station, San Salvador Bahamas.

Shaklee, R.V. 1996. *Weather and Climate, San Salvador Island Bahamas.* Bahamian Field Station, San Salvador, Bahamas.

The Blue Holes Foundation. 1999. (http://www.blueholes.org), St. Lucia, Brisbane Australia.

Wehn, K. 2001. Assistant Visiting Professor. Buffalo State College. Personal Communication.