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Aquifer study: Preliminary results of the Hydrogeology Project (HGP)
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Bald Head Island, North Carolina

A report to the Village of Bald Head Island

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BHI CONSERVANCY

I. Strategy and Approach of well head survey and drilling program for the Aquifer Study

a. *Statement (excerpted from Dr. Hearty's white paper to Village 10 Dec 2008):* Bald Head Island's potable water supply is produced from a very sensitive, and very finite series of semi-confined aquifer zones completely surrounded by salt water. Over-production, contaminant impacts, and salt-water intrusion are among the largest of concerns for current island health, as well as future island growth. Knowledge of the precise elevation (0.01 ft.) of well heads, ground surfaces, and pond levels will allow the accurate measurement of the phreatic (saturated groundwater zone) surface of the ground water table at each production and monitoring well. With a number of such measurements across the grid of dozens of wells and ponds on BHI, the geometric shape of the surface of the lens of the *upper* aquifer can be accurately reconstructed. Periodic (preferably monthly during peak production) measurement of the specific aquifer water/head levels will reveal changes in the balance between extraction and seasonal rainfall, and thus provide an early warning system to indicate excessive drawdown and consequent danger of salt-water intrusion. Sampling the wells for pH, temperature, total dissolved solids, chlorides, salinity, and conductance will also help us to understand our salt to fresh water interface.

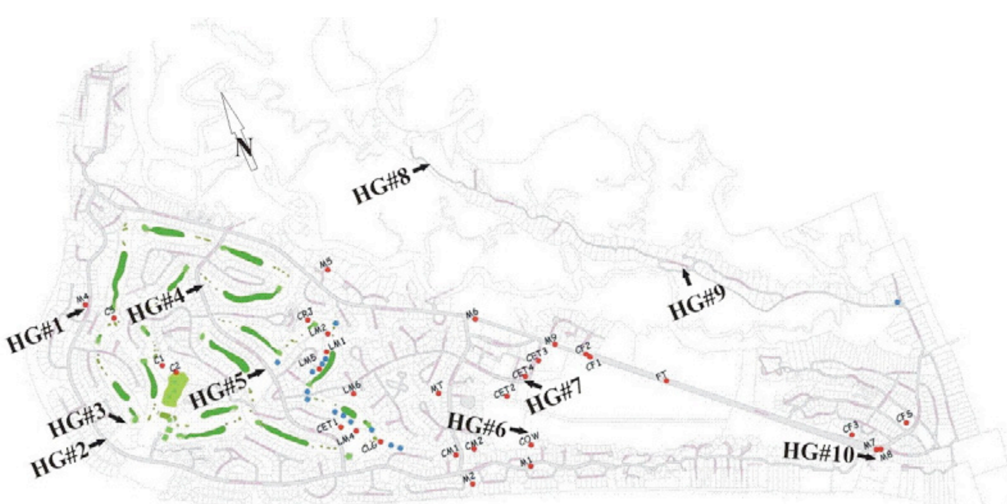
b. The surficial aquifer geometry is critical because it is the driving head behind the deeper aquifer recharge. Without surficial aquifer geometry, it is not possible to accurately determine deeper aquifer sustainability through recharge. On BHI, the surficial aquifer is the main freshwater recharge to the deeper aquifer, which is the primary source of freshwater production on the island. The surrounding, denser saltwater supports and buoys up the freshwater lens, which is recharged through rainfall, stormwater consolidation, and the recycled water discharge into the ponds above the semi-confining unit.

This cost-effective approach will also provide a simple and first order means to determine beneficial times when groundwater production can be safely increased, and will also help us to understand the island's ability to supply future water needs. This approach is a relatively inexpensive, stopgap measure that will allow some *preliminary* determinations of the geometry of the upper surface of the lens.

c. *Geological investigation of the subsurface of BHI.* There was a clear need for a comprehensive drilling, sediment coring, and well-monitoring program on the Smith Island complex (SIC); the latter with the clear objectives of defining the geometry and volume of the freshwater aquifers and other essential factors necessary for continued water production on the islands. Hearty proposed (10 Dec 2008) that the various entities on BHI consider a geological investigation during the 2009-2010 fiscal year consisting of ten 100 foot deep exploratory borings (each with a shallow and a deep well) distributed strategically across the primary aquifer of BHI (8 cores) and 2 on Middle Island. Each core will be sampled for sediment/rock at 5-foot intervals in order to reconstruct the subsurface geology associated with the aquifers. This will provide data on the extent, configuration, depth, recharge rates, water quality (WQ), and other essential information about the groundwater resources on BHI. Several of the most optimal holes are to be developed as production and monitor wells for future use on BHI. The cost of this geological investigation, pumping tests, and follow up water quality testing is $143,000, paid by the Village of BHI.

II. Objectives of drilling and monitoring programs

a. For McKim and Creed to conduct a precise survey of all production, irrigation, and monitoring wells on BHI as well as the placement of surveying benchmarks on all ponds on the island. With the known precise elevation relative to mean sea level of the ponds, well heads and ground levels, the depth to water can be measured at each of the over 50 wells on BHI. From this, the exact elevation and configuration of the upper surface of the groundwater lens can be constructed. Periodic measurements of this type will show changes in the groundwater lens that may be due to natural or human discharge (by

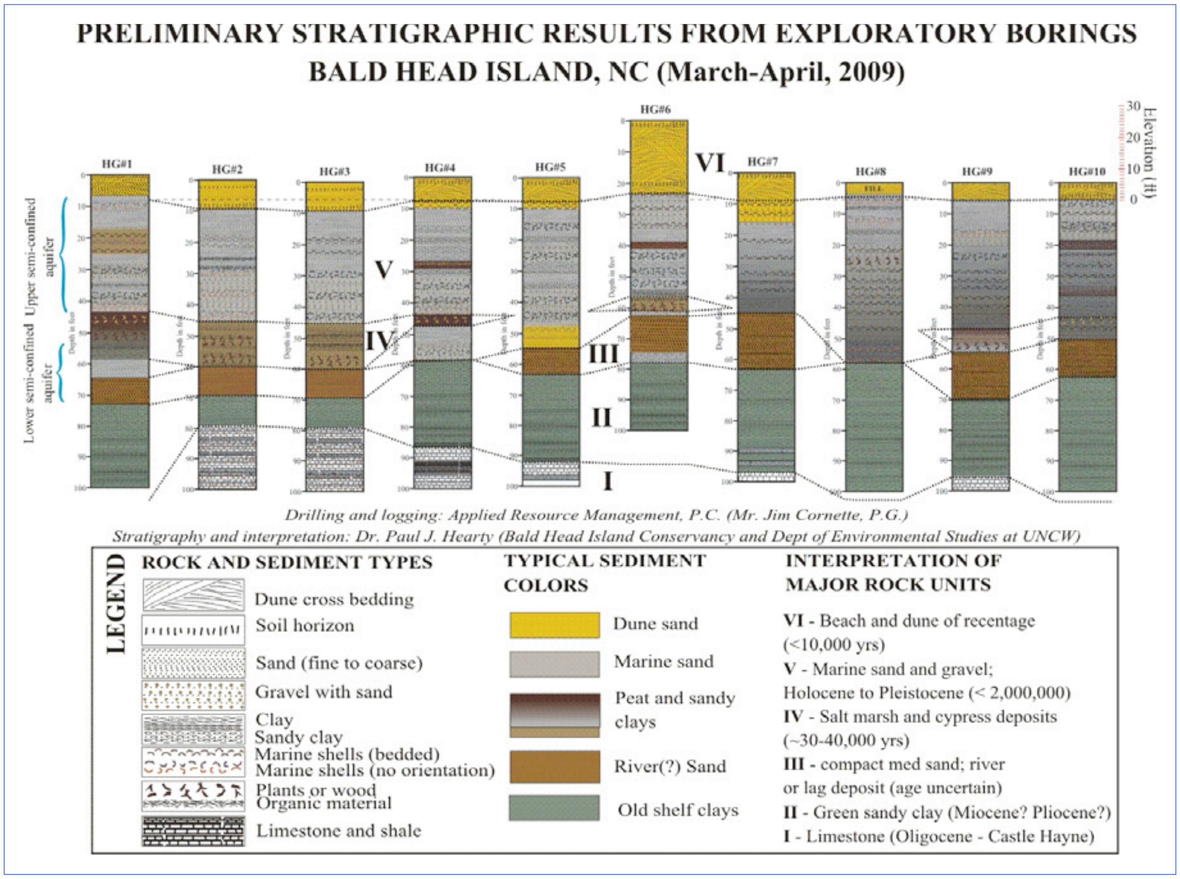


evapotranspiration, evaporation, leakage, production) or recharge (by rainfall or infiltration ponds).

b. To effectively distribute the ten drilling locations to optimize the distribution of new and existing well sites across the island and aquifers (Figure 1).
c. To determine the thickness and depth of the water-bearing geologic units which define the aquifers of Bald Head Island.
d. To determine the thickness, depth, and composition of the sedimentary units that restrict or prohibit the movement of water either vertically or laterally. These are called aquacludes (prevent water movement) or aquatards (slow groundwater movement). Understanding and revealing the geologic history of the island is a beneficial by-product of the exploratory borings. Once analysis and dating is completed, this information will be published in scholarly journals as well as local magazines and newsletters.
e. To discover the grainsize and porosity of the sediment or rock composing the aquifers from which estimates of the groundwater, reserve, yield, and production rates and sustainability can be determined.
f. To conduct pumping tests in established aquifers to determine aquifer characteristics for long-term water production.
g. To initiate a WQ testing program that will establish baseline data for physical and chemical groundwater parameters. At each well, these measurements will include: depth to water, pH, temperature, conductivity, salinity, and total dissolved solids. Other tests will be considered as the database is developed.
h. *Testing for biologicals.* Bacteria and microorganisms occur naturally even at depths of thousands of feet throughout the subsurface of the earth. Bacterial are also found in boiling hot springs, and beneath polar ice sheets. Therefore, accurate testing for human introduced biological material in the groundwater may be difficult. This requires extensive and time-consuming preparation of the wells and sampling materials. Wells must be sanitized first by introduction of chlorine, purged of all traces of this chemical by pumping, and the well sealed from any possible outside contamination. Testing equipment must be similarly rendered sterile: pump, cords, vials, gloves, etc., during each sampling event.

III. Results of exploratory borings – the stratigraphic record and geologic history of BHI

Six major geologic units were identified to a depth of 100 feet through the exploratory borings (See Figure 2 and Legend below). From *deep to shallow* these are: (I) a highly porous moldic coquina white, green, or black limestone at 80-100 feet (depths vary from hole to hole). Saltwater was observed in this unit; (II) a dense, green, impervious sandy clay with no preserved fossils, generally between 60 to 90 feet depth. This is the major **basal aquaclude** for BHI; (III) brown to grey coarse sand with few fossils generally between 50 and 70 feet. This unit comprises the **lower aquifer**; (IV) dense black to grey clay grading below to low density peat with plant traces and wood at 45-55 feet. This unit is discontinuous across the island but where present, is an effective **intermediate aquatard**; (5) fine to coarse grey sand to gravel with abundant marine fossils from 0 to 50 feet depth. This unit constitutes the primary **upper unconfined aquifer** for BHI; and (6) yellow, orange, to brown, sorted dune sand at 0 to +25 feet.



IV. Water Wells

At each of ten drilling sites of this Aquifer Study both shallow and deep wells were installed. Upon determination of the best geological units (high porosity and permeability) for water production, 4" PVC screen was set, usually in either 10- or 20-foot sections, in the augered boring at the appropriate optimal depth from the lower and upper aquifers. The PVC screen was then backfilled with coarse sand to allow water to easily infiltrate the well. All other levels of the same well were set with a solid PVC pipe and infilled with impermeable grout. In this manner, water can be monitored, tested, and produced (if necessary) isolated in both the shallow or deep semi-confined aquifers. The geological well logs and screened well depths of each well are recorded with the State of North Carolina.

V. Pumping tests

The function of pumping tests is to determine site specific aquifer characteristics including the approximate production rate of the water wells. The setup requires at least two wells (but preferably more) spaced in increasing radii from the central well. The central well is pumped at various rates 20/40/60 gal/min until it is determine a maximum/optimal rate at which the water can be removed. Pumping generally takes place over a 24-hour period. Water levels from the outlying wells are measured incrementally at 20, 40, 60, and 120-minute intervals. The amount of drawdown of the wells should stabilize some minutes or hours after the initiation of the test. Drawdown of the wells is the result of the formation of a cone or depression of the water table extending outward from the central well. The pumping test took place the site HG#7 near the Utilities complex (Figure 1). The well indicated a production capacity of approximately 130 gal/min (J. Cornette, personal communication). Another pumping test, not part of this Aquifer Study, took place at the Cape Fear Commons. These results can also be obtained from Mr. Cornette. Site HG#4 on northern Stede Bonnet is also designed for pumping tests, which will be conducted in the coming weeks.

VI. Defining the reserves and concerns for sustainable use of groundwater on BHI.

If we consider the overall findings related to the Aquifer Study, it is possible to make broad but very conservative estimates of the approximate volume or reserve of potable water lying beneath BHI. This estimate is highly dependent on the quality of water, which will be determined in a series of upcoming WQ testing "events". However, it is critically important to note that only a fraction of this water located well above sea level is available for production. At any time the water table drops toward sea level there is a greatly increased threat of saltwater intrusion. This threat could be expressed in a dramatic way by overtopping of the island during a hurricane storm surge, or more innocuously by the seepage of salt water underground into areas where the water table has been excessively lowered by over-production or natural causes. This emphasized the need to continually monitor the condition of the groundwater resource.

Estimated total volume of aquifer: Given that 1 cubic foot (1 ft^3) equals 7.5 gallons of water, and 1 ft^3 of saturated sediment may contain only 20% of water (1.5 gal/ft^3), and that perhaps 2 of BHI's 4.3 mi^2 area and a minimum aquifer thickness of 40 feet can produce potable water ($2 \times 5280^2 = 55{,}756{,}800$ ft^2 x 40 ft = 2.2 billion ft^3 of water-producing sediment x 1.5 gal/ft^3 = 3.3 billion gallons). A conservative estimate is that BHI's aquifer contains a volume of potable water equaling approximately 3.3 billion gallons. This is a significant amount of water, but again, it must be emphasized that only a small fraction of this volume can be used for production. The approximate amount that is available for production will be determined in the coming months and years as monitoring and WQ data are synthesized.

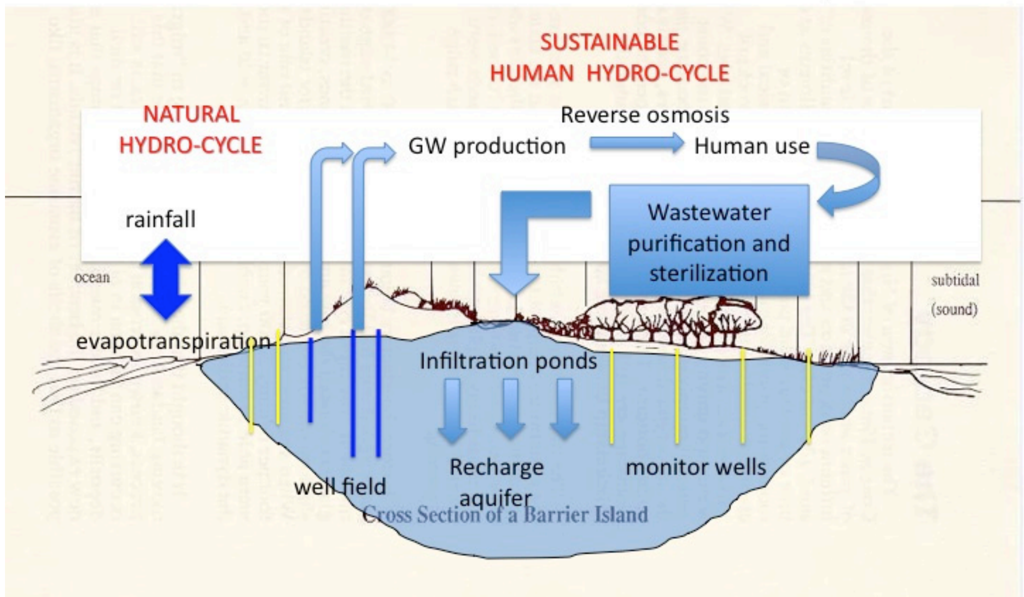
VII. Water Quality (WQ) testing: short and long term assessments.

The Utilities Department of the Village of BHI has regularly conducted WQ testing over the past years to ascertain that only the highest quality of water is available for use by the community. As part of the Aquifer study, there are numerous additional WQ testing events planned as well as a more specific scientific study that will seek to more clearly understand the nature and quality of the island's water resources. One event has been completed (June 2009) and three additional island-wide events will take place approximately in July, October, and January 2010. Approximately 50 water samples will be collected from shallow and deep wells distributed around the island, as well as from selected natural and artificial ponds. Samples will be placed in sterile jars, protected from the elements in coolers during transfer, and analyzed at Environmental Chemists in Wilmington. A more specific scientific investigation, overseen by Dr. Hearty, will be conducted by Mr. Ben Kearns and Ms. Michelle Stuart, both Masters degree candidates at UNCW. Over the next several months, this study will seek to understand the finer details of the aquifer, the mechanics of how the water moves underground, and its variable water quality.

VIII. Sustainable groundwater resources on barrier islands – The Concept (Figure 3):

BHI has achieved one of the more comprehensive subsurface aquifer investigations known from oceanic or barrier islands. The purpose of the Aquifer Study is to map the geology of the subsurface and to identify and characterize the nature of the sediments and rocks that form the aquifers beneath BHI. At this time, the geology of the aquifers is fairly well understood, but further sedimentological analyses and sample dating will clarify the geologic history of the island. Our initial findings indicate that bits and pieces of events are preserved from the period between the present at about 35 million years. This aspect of the natural history of BHI will enhance and enrich what is known about the island for the local community and visitors alike.

Sustainable groundwater resources on barrier and oceanic islands: *The Concept*



We have determined generally where potable water is, and where it is not; where fresh water travels, and where it cannot travel beneath the island. Pumping tests indicate that we have a high-quality aquifer with extensive permeable gravels and sands that are capable of producing over 100 gal/min from a single well. Hydrological studies will map the shape of the groundwater lens as it rises above sea level on the top, and as it mixes with saltwater on its sides. WQ testing will similarly identify the areas of most abundant and highest quality water. With over 50 wells in place over an area of about 4 square miles, it is possible *and necessary* to conduct periodic monitoring of the physical, chemical, and perhaps biological characteristics of the groundwater resources over time: wet and dry seasons, and peaks and troughs of island visitors.

At our hands, we have available the necessary tools to monitor, protect, and understand the water resources and its changes over time. Recycling purified and sterilized wastewater more or less guarantees sustainable use of the water resources over the long term. It is expected this Aquifer Study on BHI will serve as a model of sustainability for oceanic and barrier islands alike.

With regards,

Dr. Paul J. Hearty