Freshwater Aquifer Monitoring Program
Report #1 (June 2009-December 2012)

Introduction
The BHI Conservancy in collaboration with the Village of BHI began an aquifer characterization program in 2008. The goals of the collaboration are:

1. Characterize the freshwater resources of Bald Head Island
2. Develop a monitoring protocol that will be used at regular intervals to assess water quality and quantity
3. Support the Village of BHI in developing a resource use plan with the NC Division of Water Quality.

Other questions posed by Bald Head Island stakeholders:

1. Can the BHI freshwater aquifer support build-out of the island's 2000+ platted lots?
2. What is the 'health' (water quality) of the freshwater aquifer at various sites throughout the island?
3. What is the impact of dredging activities on the freshwater aquifer?
4. What is the geometry of the freshwater aquifer (where are the ‘cleanest’, most productive wells and where are there potential water quality problems)?
5. What threats are there to the freshwater aquifer, can these threats be managed and how?

The initial drilling study determined that the aquifer on Bald Head Island is comprised of two layers; an upper (or unconfined surficial) aquifer and lower (semi-confined) aquifer. The upper aquifer ranges from ground elevation (including ponds) to a depth of 50 feet. The lower aquifer is contained between a semi-permeable clay layer near a depth of 50 feet and by a layer of marine clay at a depth of 70 feet. The semi-permeable clay layer forming the upper boundary is what defines the lower aquifer as semi-confined. This layer allows for infiltration from the upper aquifer.

“The upper aquifer is the main freshwater recharge to the lower 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, storm water consolidation and the recycled water discharge into the ponds above the lower aquifer (Figure 1). Pumping tests indicate that we have a high-quality aquifer with extensive permeable gravels and sand that are capable of producing over 100 gal/min from a single well. It is expected that the freshwater aquifer study and monitoring program will
provide the knowledge, tools and management strategies for the community of BHI to become a model of barrier island sustainability” (Hearty 2009).

![Diagram of a barrier island freshwater aquifer](image)

**Figure 1.** Generalized diagram of a barrier island freshwater aquifer (from Tronicke et al. 1999). MSL is mean sea level.

Current goals of the freshwater aquifer monitoring program are:

1. Assist the community in making wise decisions regarding water and land use planning.
2. Serve as an early warning system to identify threats to the island’s freshwater supply including saltwater intrusion via dredging activities.

**Deliverables (from the 2012-2013 environmental contract with The Village of BHI):**

“The BHI Conservancy will provide a year-end report on the status of BHI freshwater resources. If a potential threat to the freshwater supply is revealed by any of the sampling events or subsequent data analysis, the BHI Conservancy will notify the Village and other impacted parties.”

**Methods**

With the addition of twenty-seven new monitoring wells and the inclusion of twelve historic wells and eleven ponds, the aquifer monitoring network today totals fifty sampling locations.

Once per month, and in response to environmental emergencies (i.e. drought, storm events, oil spills, etc.), depth-to-water measurements are conducted at thirty-nine well/pond
locations. A field team travels to each well and pond location, records time, well or pond number, and water depth using an electronic water depth tape measure.

Once per quarter, water quality analysis is performed on all fifty sampling locations. Two field teams travel to each well location, record time, well number and water table depth. Using low flow pumps, three casing volumes are purged before samples are collected. This is in accordance with U.S. Environmental Protection Agency recommendations.

After purging, ten liters of well water are withdrawn and sampled for pH, temperature, conductivity, salinity and total dissolved solids (TDS). Additionally, 500 ml of sample are placed in a sterile, plastic screw capped bottle, appropriately labeled, placed on ice and transported within twenty-four hours to Environmental Chemist Laboratories (Wilmington, NC) for testing.

Figure 2. Brooks Avery and Bob Kieber (UNCW) taking water samples near 'the point'.
Results and Discussion

Depth-to-water

Figures 4 through 7 depict a series of depth-to-water measurements taken from July 15, 2009 through August 4, 2010. Figure 4 represents wells in the upper aquifer located on the golf course. As can be seen, water levels fluctuate up to 2.5 feet with the highest levels observed in late fall through early spring. Figure 5 depicts upper aquifer wells located close to ‘the point’ where West and South Beaches converge. This area is of importance due to potential effects of the shipping channel which is located in close proximity. As can be seen, water levels fluctuate from 1.0 to 2.3 feet, with individual wells varying to a greater extent than those on the golf course. Again the highest water levels were observed in late fall through early spring. Lower aquifer wells located on the golf course showed similar patterns to upper aquifer wells in the same area (Figure 6). Lower aquifer wells near the point also demonstrated similar patterns to upper aquifer wells in the same area (Figure 7).

These results make intuitive sense in that the greatest draw down of water on-island occurs during late spring through early fall, peaking in summer. This coincides with both the highest rates of evapotranspiration (plant water use) and the high point of ‘tourist season’. It also makes sense that water table fluctuations are greater on the golf course versus near the point because the golf course is located where the aquifer lens is highest (center of the island) and the point is located where the aquifer lens is the lowest (‘edge’ of the island).
Figure 4. Depth-to-water measurements of upper aquifer wells located on the golf course. Measurement dates are indicated. Note that the highest water tables were measured in late fall through early spring when plants are mostly dormant and human demand is low.

Figure 5. Depth-to-water measurements of upper aquifer wells located near ‘the point’ at the convergence of West and South Beaches. Measurement dates are indicated. Note that water levels fluctuated less at these wells versus those on the golf course.
Figure 6. Depth-to-water measurements of lower aquifer wells located on the golf course. Measurement dates are indicated. Note that patterns are similar to those found for upper aquifer wells located on the golf course.

Figure 7. Depth-to-water measurements of lower aquifer wells located near ‘the point’ at the convergence of West and South Beaches. Measurement dates are indicated. Note that patterns are similar to those found for upper aquifer wells located near ‘the point’.
**Water quality**

The areas that exhibit higher salinity, chlorides, and TDS levels are more often found in the lower aquifer than the upper aquifer (Figures 8-13). However, in some areas, wells located in both the upper and lower aquifers exhibited high concentrations of the parameters measured. At most well arrays, there is a shallow well that monitors the upper aquifer, and a deeper well that monitors the lower aquifer. The deeper wells normally have a “D” in their I.D. code, while the shallow wells typically have an “S” in their I.D. code. For example, the array closest to the SW point of BHI consists of a well in the upper aquifer, HG2S, and a well in the lower aquifer, HG2D.

For the upper aquifer, the following wells tended to exhibit higher levels for most parameters (salinity, chlorides, and TDS). These wells are HG2S, HG3S, HG8S, and HG9S. Note that HG2S and HG3S are from the same arrays on the southwestern corner of the island that exhibited higher levels in their deeper well counterparts (HG2D and HG3D, respectively). Similarly to HG8D, HG8S and HG9S are probably affected by Middle Island’s low profile and interaction with the surrounding salt marsh. In some areas, such as the western central side of BHI, the deeper well (M4) exhibits high levels of salinity, while the nearby shallow well counterpart (HG1S) does not. This is also evident in the arrays near the BHI Conservancy, where the deeper well M8 exhibits high levels of salinity whereas the shallow well HG10S does not. In both cases this could be due to the lower aquifer coming in contact with the freshwater-saltwater interface or transition zone (see Figure 1). It is important to note that the SW point of BHI and Middle Island are the areas that both shallow and deep wells exhibit higher levels of salinity, chlorides, and TDS.

The following wells, located in the lower aquifer, tended to exhibit higher levels for most parameters (salinity, chlorides, and TDS). These wells are: HG2D, HG3D, HG8D, HG11D, HG12D, M4, M5, and M8. HG2D, HG3D, and HG12D are located near the southwestern corner of BHI. The proximity to the ocean is likely a contributing factor to their high salinity levels. HG8 is located on Middle Island, and the level of salinity may be attributed to its low profile and salt marsh interaction with the water table. M4 (western side of BHI), M5 (northern side of BHI), and M8 (eastern side of the island) are all perimeter wells, located near the edge of the freshwater lens of the aquifer. Their proximity to the ocean most likely accounts for their higher levels of the parameters measured.

For both the lower and upper aquifer wells, the pH ranges appear to be stable, with most values falling between 7 and 8. All of the well pH values are in the ‘acceptable’ range for aquatic life according to the NC Division of Water Quality water standards. Most of the ponds on BHI, such as the Middle Island Ibis pond and golf course ponds have higher pH levels than the aquifer wells. This is to be expected due to pond depth, associated environmental factors and wildlife usage.

For overall depiction of island water quality, a series of three maps showing categorical ranges of three key parameters have been constructed (Figures 14-16). Maps are color-coded to represent standard (green), moderate (yellow), or high (red) levels of each parameter, relative to NC Division of Water Quality standards. Figure 14 depicts the range
of values for salinity. Figure 15 depicts the range of values for chlorides and Figure 16 depicts the range of values for TDS.

**Figure 8.** Wells located in the lower aquifer that consistently exhibited low salinity (top graph) and wells located in the lower aquifer that consistently exhibited high salinity (bottom graph).
Figure 9. Wells located in the upper aquifer that consistently exhibited low salinity (top graph) and wells located in the upper aquifer that consistently exhibited high salinity (bottom graph).
Figure 10. Wells located in the lower aquifer that consistently exhibited low chlorides (top graph) and wells located in the lower aquifer that consistently exhibited high chlorides (bottom graph).
Figure 11. Wells located in the upper aquifer that consistently exhibited low chlorides (top graph) and wells located in the upper aquifer that consistently exhibited high chlorides (bottom graph).
Figure 12. Wells located in the lower aquifer that consistently exhibited low TDS (top graph) and wells located in the lower aquifer that consistently exhibited high TDS (bottom graph).
Figure 13. Wells located in the upper aquifer that consistently exhibited low TDS (top graph) and wells located in the upper aquifer that consistently exhibited high TDS (bottom graph).
Figure 14. Average salinity concentration of wells on BHI. To create categories for illustrating salinity data, 0-5 ppt was considered ‘standard’, 5.1-10 ppt ‘moderate’ and greater than 10 ppt ‘high’. For the individual well I.D. labels on the map, green labels indicate a low or standard range for salinity, orange labels represent an elevated salinity level, and red labels are areas with the highest salinity. Note the areas on Middle Island and the southwestern point of BHI that exhibit the highest salinity concentrations.
Figure 15. Average chloride concentration of wells on BHI. To create categories for illustrating chloride data, the acceptable drinking water standard level of chlorides (250 mg/L), which is considered the safe level of chlorides in drinking water by the State of North Carolina, was used. This value was used to create the ‘standard’ category (0-250 mg/L). The moderate category ranged from 250.1 to 2500 mg/L while the high category was composed of values over 2500 mg/L. Notice the higher chloride concentrations were found near the southwestern point of BHI, the salt marsh and Middle Island.
Figure 16. Average total dissolved solid (TDS) concentration of wells on BHI. The ‘standard’ or low category is depicted in green and ranges from 0-500 mg/L, the ‘moderate’ category is shown in orange and ranges from 500.1-5000 mg/L and the ‘high’ category is shown in red and includes values over 5000 mg/L. Notice the large number of wells with high TDS concentration near the southwestern point of BHI as well as areas near the salt marsh and Middle Island.
Main Findings

• The upper aquifer is the main freshwater recharge to the lower aquifer, which is the primary source of freshwater production on the island.
• The surrounding, more dense saltwater supports and buoys up the freshwater lens, which is recharged through rainfall, storm water consolidation and recycled water discharge into the ponds above the lower aquifer.
• Pumping tests indicate that we have a high-quality aquifer with extensive permeable gravels and sand that are capable of producing over 100 gal/min from a single well.
• The water table is highest from late fall until early spring.
• The water table fluctuates to a greater degree throughout the year near the middle of BHI (versus the edges) because the freshwater lens is thickest in the middle.
• Water table height measured at various wells was more consistent near the middle of BHI versus the edges.
• In general, water quality parameters were ‘best’ near the middle of BHI and ‘worst’ near ‘the point’

Conclusions

• The freshwater aquifer appears to be of fairly significant size, at least 3.3 billion gallons (Hearty 2009)
• Water quality is very good over the majority of BHI, especially near the center
• Water quality is relatively poor near the edges of the island and especially near ‘the point’
• Saltwater intrusion could become a significant issue at wells located near ‘the point’
• Water quantity is least during late spring, summer and early fall when plants are actively removing water from the ground and when human water demand is at peak

Recommendations

1. Determine and characterize threats to the BHI water supply (e.g. increasing human population, sea-level rise, increasing intensity and frequency of storms, erosion at the ‘point’)
2. Continue to monitor freshwater aquifer (water quality and quantity)
3. Promote the wise use of water resources in the community
4. Regular testing of septic tank systems remaining on BHI, conversion to public waste water treatment as soon as feasible
5. Promote the use of rain barrels by homeowners and businesses
6. Promote planting of native (drought tolerant) vegetation

Future Studies

The BHI Conservancy suggests that the following data collection and analysis be performed in addition to monthly depth-to-water measurements and quarterly water quality measurements:

• Study of tide effects on wells located near the point – accomplished by taking depth-to-water and water quality measurements at selected wells during several twenty-four hour periods in relation to tides.
• Study of dredging effects on wells located near the point – accomplished by taking depth-to-water and water quality measurements at selected wells before, during and after the fall/winter 2012-2013 Army Corps dredging activity
• Statistical comparison and analysis of wells in relation to location and time frame – the purpose is to more accurately determine which wells are of ‘poor’ quality and why
• Comparison of rainfall input to water table height, especially in regards to the drought of 2011 and plentiful rainfall in 2012 – this will allow determination of effects of drought on the aquifer as well as a better understanding of rainfall recharge rates
• Comparison of human water usage (records provided by The Village of BHI Utilities Department and the BHI Club) to water table height

Literature Cited

