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Flooding Issues at Cape Point Campground
Cape Hatteras National Seashore

Introduction: One of the NPS management issues in the Cape Point area is dealing with the frequent flooding of the campground and interdunal roads. The flooding is a natural process resulting from ponding of surface water and high water table conditions following large rainfall events or wet periods. In the past, the water would be drained from the area through a network of ditches to discharge to the ocean, thereby reducing the duration of flooding. That is no longer an acceptable practice. Drainage of water would cause adverse impacts to wetlands and would be contrary to North Carolina state law and NPS management policies.

In a previous memo to the park (December 23, 2005), I provided a summary of the issue and the hydrology of the Cape Point area. I also presented alternatives to alleviate the impact of flooding on beach access via interdunal roads. Those same alternatives apply to reducing the impact of flooding at the Cape Point campground. Briefly, those alternatives are;

1. Reactivate the system of drainage ditches and discharge flood water to the ocean.
2. Raise the elevation of the campground.
3. Relocate the campground to higher ground.

None of these alternatives seem very reasonable. The only remaining alternative is "no action". Simply accept the fact that the campground will sometimes be flooded and unusable.

In this report, I will demonstrate that the flooding is primarily a result of high water table conditions following wet periods. I will also show that the frequency and duration of flooding will continue to increase as sea level rises.

Hydrogeology and conceptual model of groundwater flow

Dr. William Anderson conducted a detailed investigation of the hydrology of Hatteras Island for his Ph.D. dissertation (Anderson, 1999). Anderson's conceptual model of the hydrogeologic framework of the area underlying the Cape Point area is an upper and lower surficial aquifer each composed primarily of medium-to-coarse sand, separated by a semi-confining layer composed of fine sand and silt. The surficial aquifers are underlain by a low-permeability confining unit that is 40 feet thick and effectively isolates the surficial aquifers from deeper aquifers. The hydrogeologic framework is illustrated in Figure 1.

Dr. Anderson continued investigating the hydrology of Hatteras Island after obtaining his Ph.D. He monitored water levels from July 2001 to March 2004 at a series of wells across the island. These data were used to calibrate the computer model described in this report.

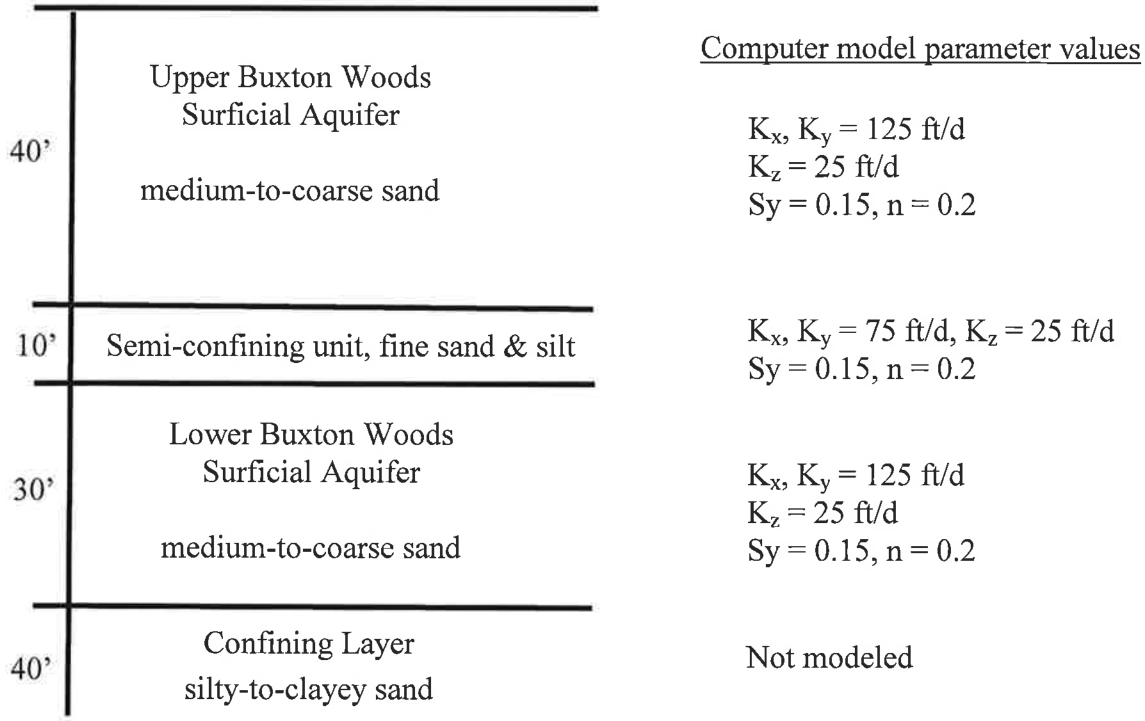

Figure 1. Hydrogeologic framework of the Cape Point area (from Anderson, 1999).
K_x, K_y, K_z is the permeability (hydraulic conductivity) in the x, y, and z directions, Sy is the specific yield, n is the porosity.

The conceptual model of the groundwater flow system has recharge over the entire island from infiltration of precipitation. The water table rises during wet periods and lowers during dry periods. Infiltration of rainfall creates a mound of fresh groundwater under the island with the high part of the mound in the middle of the island. Groundwater flows from the interior parts of the island toward the margins where it discharges to the ocean or sound. Water table elevations at the shoreline are controlled by the elevation of mean sea level.

There is some outflow of water from the interior parts of the island as surface water. This outflow occurs primarily via a system of drainage ditches in the northern part of the island that discharge to Pamlico Sound. There is very little natural surface-water flow. Most of the water that accumulates in the interior part of the island infiltrates and leaves as groundwater flow with discharge at the shoreline and near-shore environment. This process of discharge via groundwater flow is a slow process and causes the water table to remain elevated for several months following wet periods. High water table conditions cause some of the low-lying areas to remain flooded for extended periods.

A simplified computer model of the groundwater flow system was developed to illustrate the relationship between precipitation (and recharge to the aquifer) and water table elevation. The model represents a north-south cross-section across the island (Figure 2). The model has three layers corresponding to the hydrogeologic framework as shown in Figure 1. Each layer has the same properties of permeability and porosity throughout the layer.

The first and last columns of the model are constant head cells; with the head equal to zero feet mean sea level. That is, the water table is forced to be 0.0 feet at the shoreline of the ocean and sound. The model computes the water table elevation at all other cells within the model.

Recharge to the model area was varied as a function of monthly rainfall. The recharge rate was assumed to be 50% of the total precipitation. The recharge rate was entered as a variable, with a different value for each month from January 2000 to February 2010. Precipitation data were retrieved from the National Weather Service database; http://www.nc-climate.ncsu.edu/cronos/.

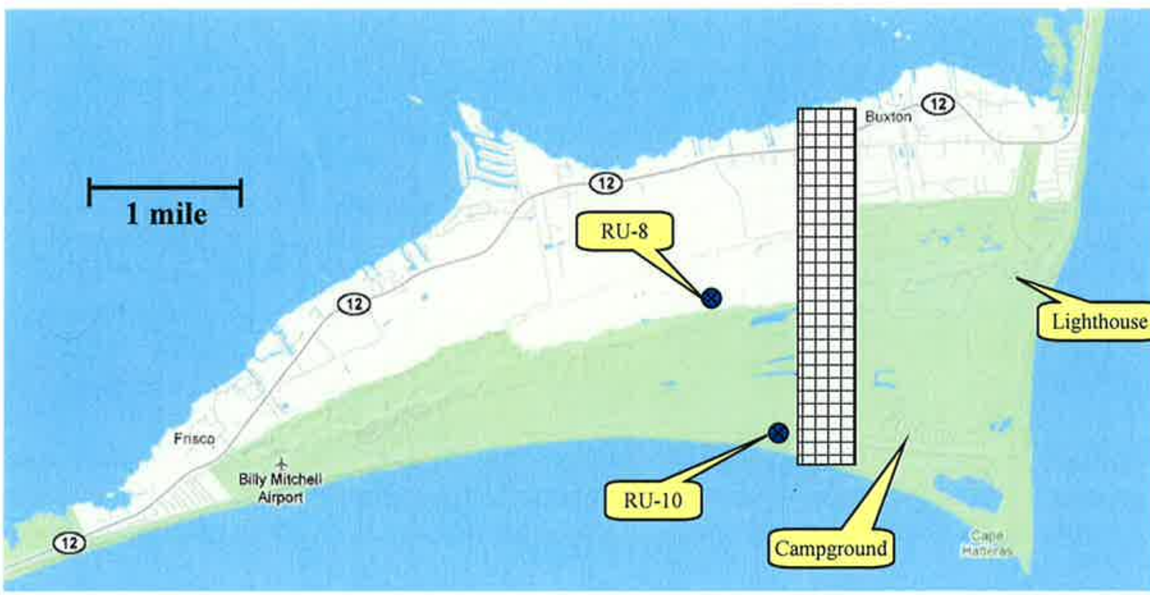

Figure 2. Representation of the grid for a computer model of a strip across Hatteras Island and location of two monitoring wells.

Model Calibration

Model calibration was evaluated by comparing predicted water levels with measured water levels at observation wells in 2001-04. Values for hydraulic conductivity (K) (aka permeability) of the aquifer were adjusted in the computer model until the predicted water levels approximated the measured water levels. If the model permeability was too low, there would be too much resistance to flow and the water table would build up too high. If the model permeability was too high, groundwater would flow toward the shore too easily and the predicted water table would be too low. The "calibrated" values of hydraulic conductivity for the model fall within the range of expected values for these types of sediments (Fetter, 2001).

Comparison of water levels calculated by the computer model with measured water levels is shown in Figure 3. Water level measurements at the monitoring wells were recorded twice daily. The computer model calculates water levels at a monthly time step. Thus, the measured water levels show much more detail and variability than the water levels calculated by the computer model. Also, the computer model is a very simple representation of the hydrogeologic system. It is used to show only the general patterns and relationship of water table elevation to recharge from infiltration of precipitation and the recession of the water table during dry or normal periods. A more detailed computer model would require several years of detailed water table monitoring and documentation of depth and duration of flooding at areas of interest. Additional geologic and hydrogeologic data would also be needed to identify the thickness and extent of various model layers and type of sediments associated with each layer of the model.

The calculated water levels show general agreement with the measured water levels and the computer model is therefore assumed to be capable of providing a general representation of the water table elevation throughout the model period (2000-2010). Monitoring well RU-8 is near the middle of the island and is compared to the calculated water level at a hypothetical observation well at approximately the same distance from the shoreline in the model grid. Monitoring well RU-10 is about 2500 feet west of the campground and is in a similar hydrologic setting as the Cape Point campground.

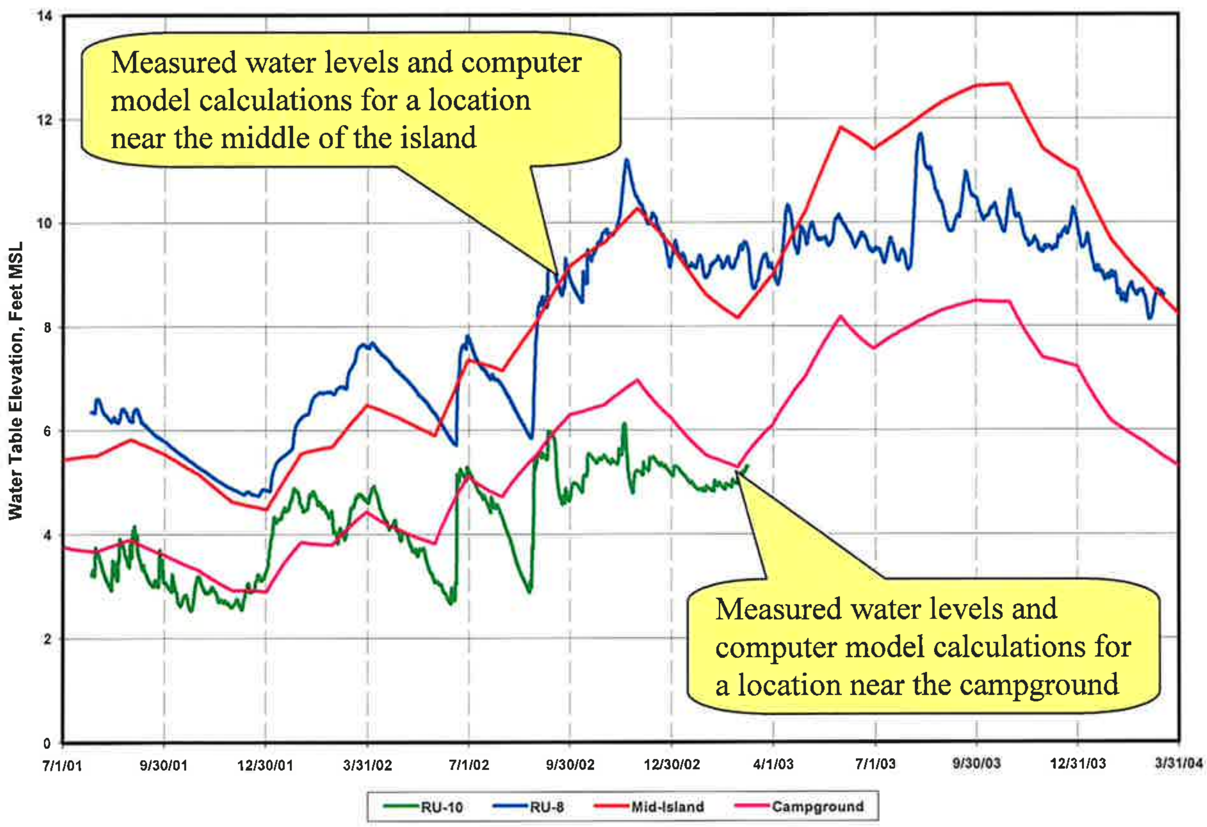

Figure 3. Comparison of computed and measured water levels.

Model Results

Figure 4 shows a graph of the computer model calculated water table elevations at the Cape Point campground for the period from 2000 to early-2010. The water table elevation closely mimics the rainfall pattern, as it should because that's how the model was set up; precipitation is the only variable input to the model. Rainfall is plotted on Figure 4 as the 3-month moving average to smooth the curve and because water table elevations change slowly compared to the flashy nature of rainfall events.

If the land surface elevation at the campground is 6 feet above sea level, we could look at the graph in Figure 4 and identify periods of time when the water table was predicted to be above land surface. Those would be periods when the campground was flooded.

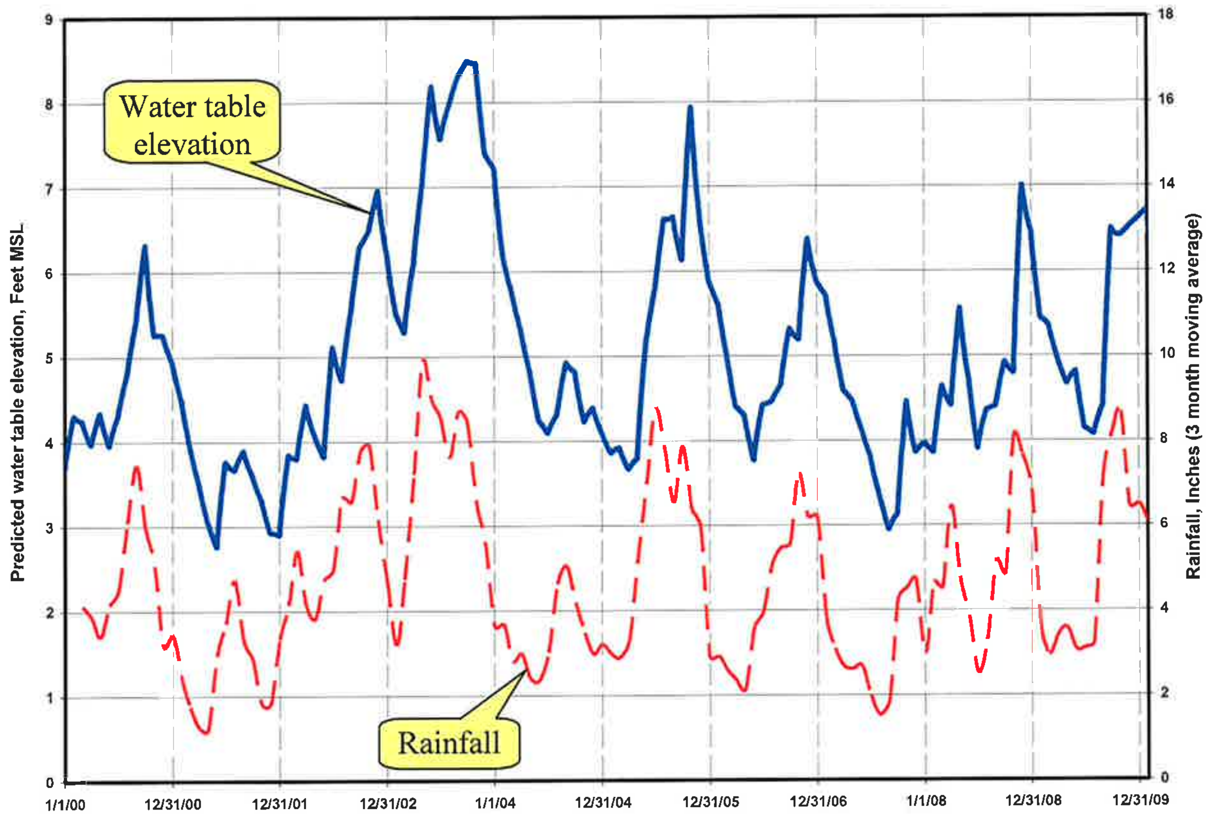

Figure 4. Calculated water table elevations at the Cape Point campground and rainfall.

We could develop a better model if we had more site-specific data regarding: the geologic material underlying the campground and surrounding area, historical record of water table elevations, and documentation of dates and periods when the campground was flooded. However, a better model is hardly necessary. We can monitor rainfall and know that during wet periods it is more likely that the campground will be flooded. Flooding might occur after several months with above average rainfall, or it might occur after one big rainfall event such as might occur with a hurricane. Likewise, the length of time required for a flood to recede will be dependent on the nature of the precipitation pattern that caused the flooding to occur and rainfall during the recession period.

Effects of Sea Level Rise

Mean sea level has been rising for several decades. It is expected to continue rising for the near future. Riggs and Ames (2003) present data showing that mean sea level has risen about a foot from the 1920s to 2000 (Figure 5). As sea level rises, the base level for fresh groundwater discharge from the surficial aquifer also rises, with the resultant effect that the water table elevation across the island rises.

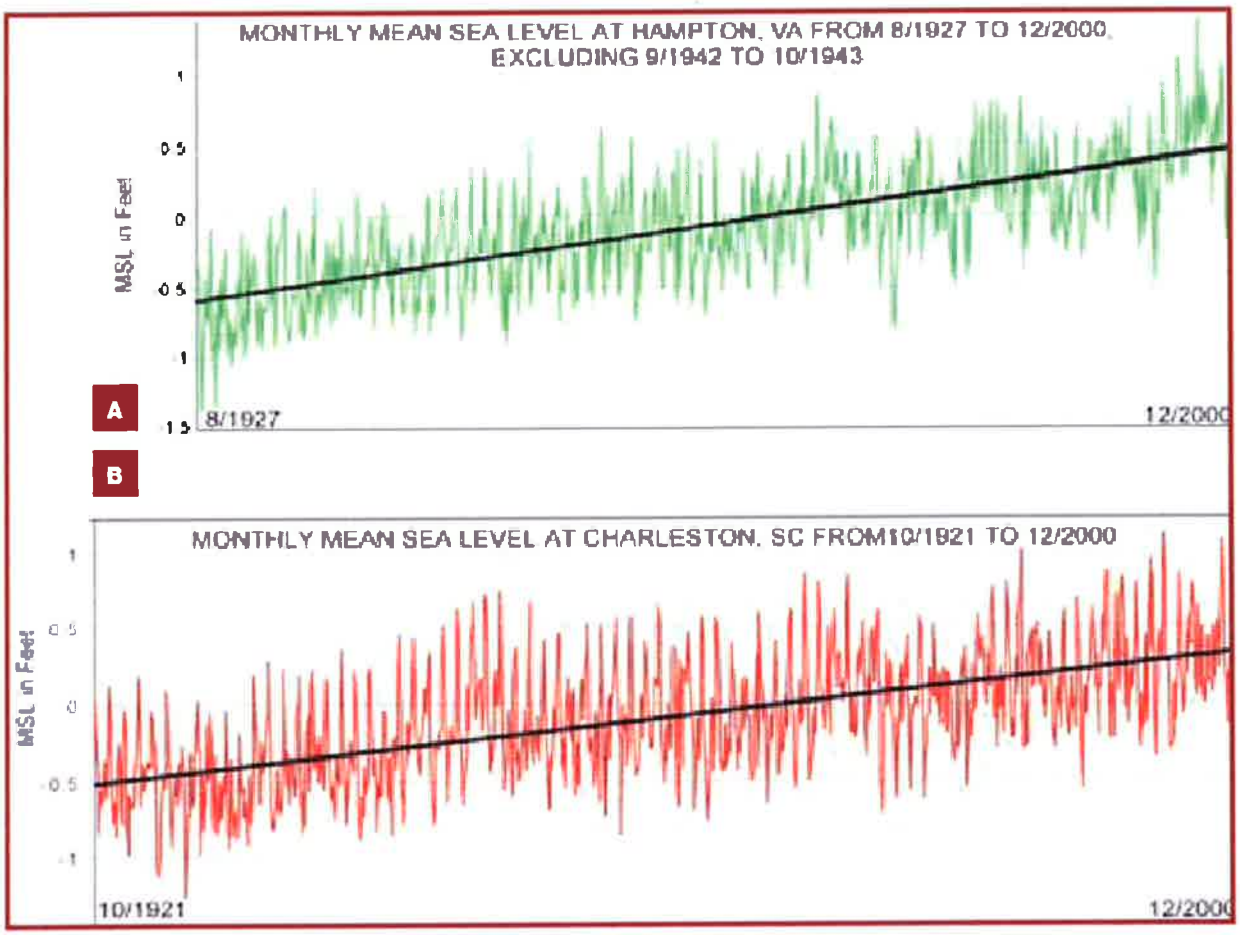

Figure 5. Tide gauge data from Hampton, VA and Charleston SC showing sea level from the 1920s to 2000 (Figure 6-3-2 from Riggs and Ames, 2003).

Figure 6 shows a cross-section of a barrier island at the ocean shoreline. It shows a lens of freshwater floating on the underlying saltwater. Fresh groundwater is recharged by infiltration in the interior of the island and flows toward the shoreline where it discharges to the ocean. As sea level rises (or falls), the elevation of the discharge zone for the fresh groundwater will also rise (or fall), causing water table elevation back from the shoreline to rise (or fall).

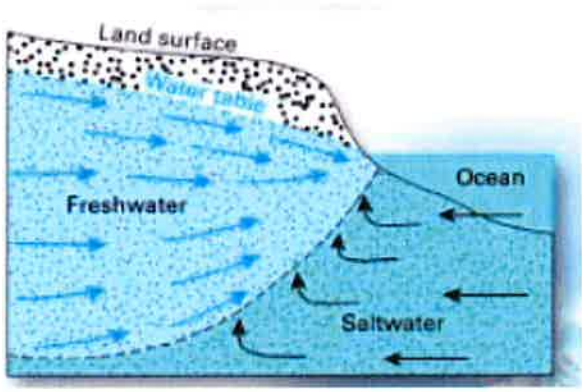

Figure 6. Relationship of freshwater and saltwater at the ocean shoreline.

Figure 7 shows model results for a scenario with one foot of sea level rise. In this case the constant head boundary of the model corresponding to the ocean shoreline is specified to be 1.0 feet. Under this scenario, the frequency and duration of flooding is expected to increase. We can't say how much because we don't have a calibrated model, only a very general, conceptual model.

Sea level has risen over the past several decades. So if it seems that the campground is flooded more frequently and for longer duration than it was 50 years ago, it probably is.

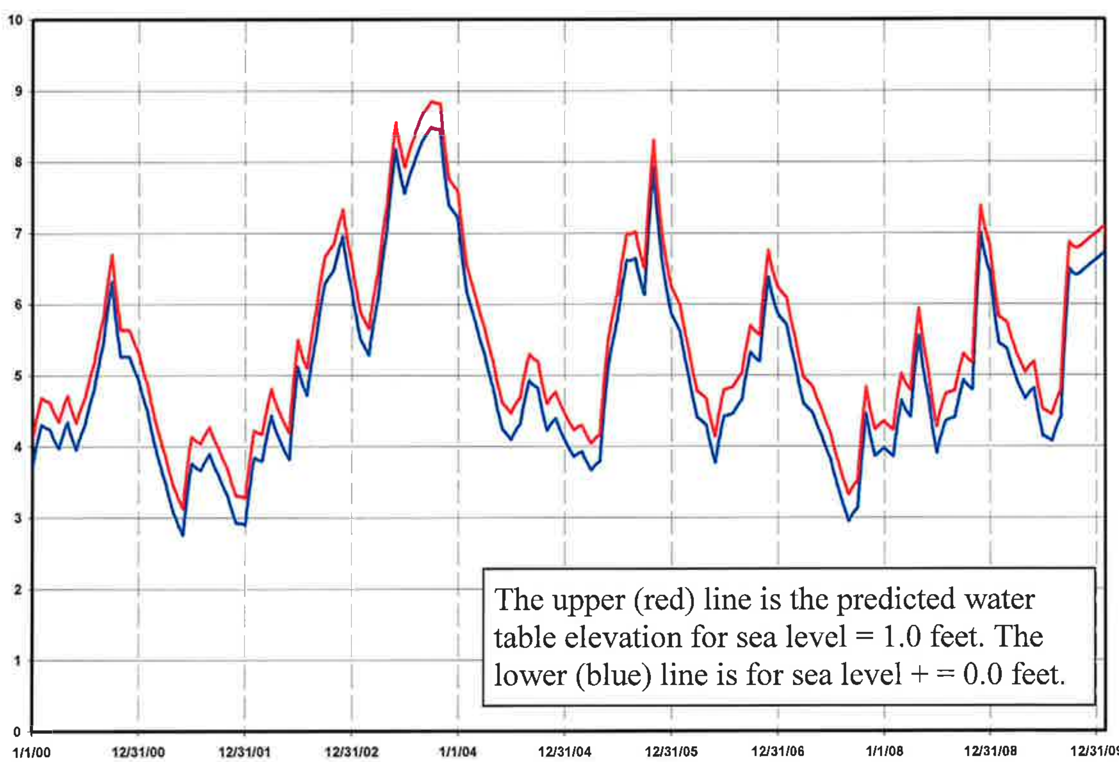

Figure 7. Comparison of predicted water table elevation change at the Cape Point campground for one foot of sea level rise.

<u>Hydrograph for Monitoring Well RU-10</u>

The hydrograph of Anderson's Monitoring Well RU-10 (Figure 8) provides some insights into the relationship between precipitation and water table elevation and the effects of the drainage ditches in the vicinity of the campground.

The water level in the early part of the graph is lower than normal. Rainfall was far below average from October 2000 through 2001. Total rainfall in 2001 was about half of normal; 29 inches instead of the normal 58 inches.

Rainfall and water table elevation in 2002 are more representative of average conditions. Total rainfall in 2002 was 69 inches, 11 inches greater than average. Large water table rises are associated with large rainstorms; 6½ inches on June 20-22, 4 inches on September 10, and 4 inches on November 16-17. The natural rate of water table decline is observed in April-June and July-August.

A large amount of rain associated with Hurricane Gustav in mid-September 2002 caused flooding in the area. NPS opened the headgate west of the campground to drain water flooding the campground. The graph shows a corresponding steep rate of water table decline in late September. The headgate was closed on September 30. The water level recovered to a stable elevation in equilibrium with hydrologic conditions. Another storm on November 16-17 produced 4 inches of rainfall, causing more flooding and causing NPS to reopen the headgate and drain floodwaters for a week. The headgate was closed on November 25.

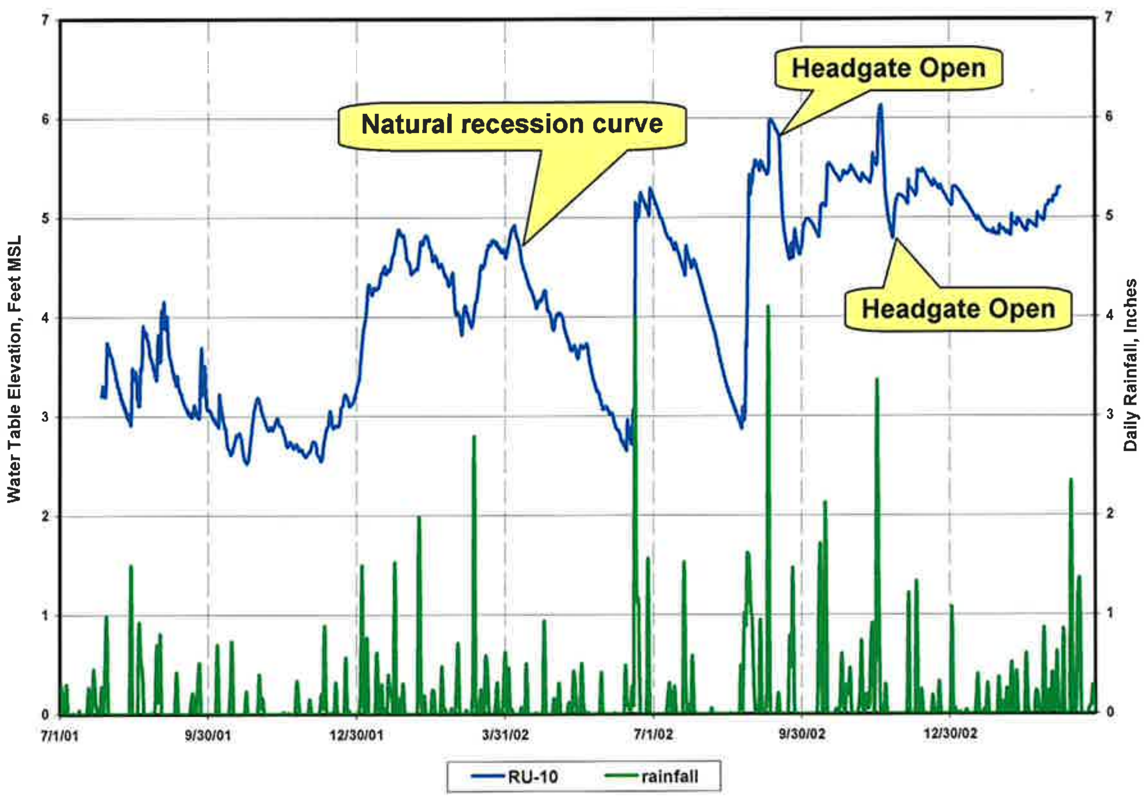

Figure 8. Water table elevation in a well west of the campground and rainfall at Cape Hatteras.

We might surmise that flooding at the Cape Point campground occurs when the water table in the area rises to higher than about 5½ feet MSL from the data on Figure 8 and NPS response of opening and closing the headgate on the drainage ditch system.

The End of Draining Floodwaters to the Ocean

Rainfall in 2003 was far above normal. Total rainfall for the year was 84 inches; average is 58 inches. The headgate was opened on March 3, 2003 to drain floodwaters from the campground. Hurricane Isabel passed through the area in September 2003, dropping an additional 4 inches of rain. The drainage ditch west of the campground continued discharging to the ocean on the south-facing beach. In April of 2004, officials from the North Carolina Division of Water Quality and the U.S. Army Corps of Engineers visited the area and reviewed the drainage ditch system with park staff. The park was subsequently issued a Notice of Violation for draining of wetlands. Park staff closed the headgate on April 28, 2004 and placed sandbags against the headgate to limit the flow of water from the drainage ditches to the interdunal area and the ocean. The headgate has remained closed since that time.

Summary

Flooding at the Cape Point campground is the result of natural hydrologic processes. The water table rises during wet periods. When the water table is higher than land surface, the area will be flooded. The frequency and duration of flooding can be expected to increase as sea level rises. There are no practical mitigation processes to reduce flooding of the campground area.

References

Anderson, Jr., William P., 1999,*The Hydrology of Hatteras Island, North Carolina*, Ph.D. dissertation, unpublished, North Carolina State University, Raleigh, NC, 293 pp.

Fetter, C.W., 2001, *Applied Hydrogeology*, 4th ed., Prentice-Hall publisher, 598 pp.

Riggs, Stanley R., and Dorthea V. Ames, 2003, *Drowning the North Carolina Coast: Sea Level Rise and Estuarine Dynamics*, NC Sea Grant Program, Raleigh, NC, Pub. No. UNC-SG-03-04, 152 p.