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Dewatering Induced Settlement of a Historic Landmark

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ABSTRACT: Construction related dewatering in urban areas often induces damage of existing structures. The following forensic investigation highlights the complexities of such a phenomenon. Somerset plantation, a national historic landmark located in northeastern North Carolina is currently exhibiting distress. At many locations, these wooden structures on brick piers are experiencing sufficient differential settlement to impact building functionality. Heavy visitor traffic was proposed by the site staff as the cause of the building displacements. Given a perched aquifer located within a fatty clay, dewatering based settlement was suspected. Two potential sources of ground water change were investigated – (1) general drought conditions or (2) a nearby mining operation.

1. INTRODUCTION

By 2001 the main structure (the Collin's House) at Somerset Place, the largest extent plantation in North Carolina, was exhibiting sufficient deformation of the doors and windows to interfere with the functionality of the building, resulting in safety and maintenance concerns (Figures 1 and 2).



Figure 1. Collins House from Lake Phelps (adapted from NCOAH, 2003b)

Further investigation revealed shearing of porch rails and cracks in brick piers (Figure 3).

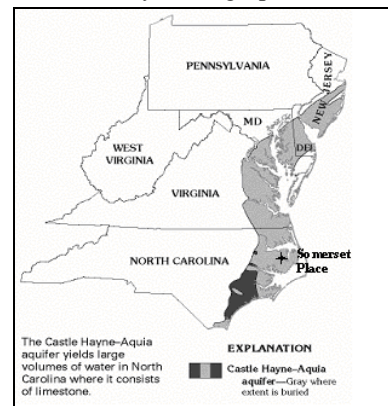


Figure 2. Castle Hayne aquifer in relation to Eastern United States (adapted from USGS, 2002)

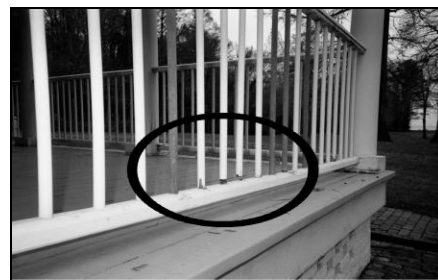


Figure 3. Porch Rails (November 2001)

Also, the house had moved sufficiently to cause a cistern lid that had been open atop the basin to become wedged between the house and the cistern in the basement. In 1989, at the hiring of the current director, all doors were reported to be fully functional. By 2001 this was no longer true. The site staffs' initial thoughts regarding the cause of distress were increased visitor traffic (more than 10,000 visitors per year) in one structure and the presence of heavy filing cabinets in another. The cause of the distress needed to be identified so that additional damage could be halted and effective repair could be initiated.

2. SITE

The present plantation site consists of a main dwelling, a kitchen, a smokehouse, a dairy, and a smaller house that originally served as the residence, until the main dwelling was built around 1830. These buildings are clustered relatively close to one another, approximately 600 feet north of the shore of Lake Phelps (Figure 4).

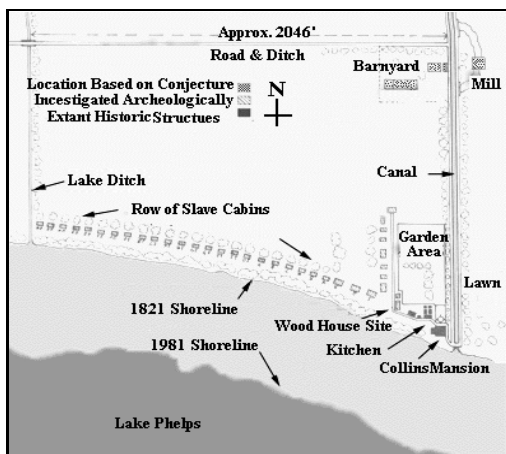


Figure 4. Somerset Plan (adapted from NCOAH, 2002a)

Through the middle of the 20th century, the water line came within 50 feet of the buildings at high water line, but now the lake lies 560 feet beyond the main house (Figures 4 and 5). The direction of settlement was clearly in the southern direction, towards Lake Phelps. The preliminary analysis implied a drought related

subsidence. As such, the rain level was compared to the lake levels (Figure 6).



Figure 5. Collins house from current lake level (November 2001)

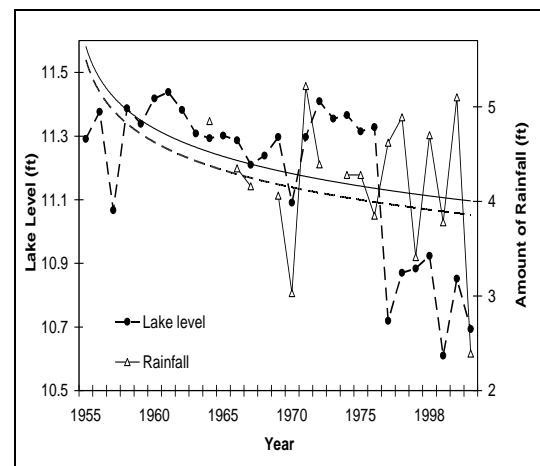


Figure 6. Yearly average of rainfall and lake levels 1955-2001 (adapted from DPR, 1993-2001 and DOA, 1977a,b)

Beginning around 1975, a disparity began to be evident. The lake began to drop faster than the rain levels. If the dewatering was strictly drought related, a more symmetric behavior would be anticipated. Thus, an additional cause of water loss was sought. To this end the soil configuration was investigated.

3. SOIL PROFILE

In a 1980 soils investigation consisting of 6 soil borings drilled to a maximum depth of 41 feet (Figure 7), samples were obtained by means of the Split-barrel sampling procedure.

Project Collins Mansion, Somerset Place State Historic Site Creswell, North Carolina		Total Depth 41.0 Ft Datum Benchmark	Surface Elevation 13+	Boring No. B-2	
Size and Type 8" Cutter Head		Job No. 80-103-AA	Water Table Data: Depth Below Surface 7.4' @ 0 Hours 3.9' @19 Hours		
Drilling Method Hollow Stem Auger		Date Started: 2/19/80	Date Completed: 2/19/80		
Depth (feet)	Classification	Sample #	From To	SPT	Remarks
5	Grey, very soft, VERY FINE SANDY SILT (ML-CL)	1	2.5' 3.5'	1	Topsoil (Diller's Classification) W=26%
	Grey, loose FINE SAND (sp)	2	5.0' 6.0'	8	W=35%
10		Dark brownish-black, soft, ORGANIC VERY FINE to MEDIUM SANDY SILT with trace to some clay. (OL)	3	7.5' 8.5'	10
	4		10.0' 11.0'	14	W= 23%
15		5	12.5' 13.5'	5	W=73%
		6	15.0' 16.0'	4	W= 60%
20	Greenish-grey, loose to medium dense, FINE SAND with trace roots and silt from 20.0' to 21.0' (SP)	7	20.0' 21.0'	14	
		8	25.0' 26.0'	4	
25					
30	Dark greenish-grey, loose, SILTY FINE SAND with some shell fragments (SM)	9	30.0' 31.0'	5	W= 33%

Figure 7. Soil boring (adapted from Fischetti, 1980)

The boring logs indicate a gradual transition between soil types. The generalized soil profile consists of 6 to 12 inches of organic topsoil overlaying very fine sandy silt. The silt increases in thickness towards the canal from 3 to 6.5 feet. The next layer is a sandy silt with a moisture content of 32% that lies 2.5 to 5 feet above a uniform fine sand layer about 9 feet thick. Under the fine sand is a layer of organic sandy silt, ranging from 6 to 11.5 feet in thickness. Two samples of the organic sandy silt showed organic contents of 15% and 19% and a moisture content of 67%. The next layer is a loose to medium dense fine sand about 10

feet thick. Beneath this deposit is a layer of silty fine sand with an increasing shell content that extends about 10 feet to a depth of approximately 27 feet. Below this fine sand is a layer of sand and shell fragments that extends beyond the boring. Dry densities of the soils ranged from 41 to 91 pcf and liquid limits varied from 30% to 47%. The borings also indicated that the groundwater levels sloped toward the canal from 3 feet at the farthest boring to 5.5 feet nearest to the canal. There was a clear differential in the water table from one side of the house to the other, towards the canal.

4. INVESTIGATION

The above exploration was undertaken to assess differential settlement that occurred in the Collin's House prior to 1980. That investigation concluded that full clay consolidation should have occurred in the 150 years since the house was built, and that substantial additional settlement was not expected. Yet, substantial differential settlements have occurred since 1980. In 2001, doors and windows were inoperable, architectural features were splintering, and there was pavement collapse, where a sidewalk north of the house experienced a localized failure due to piping. Upon removing the brick pavers, much of the sand around the buried pipe appeared to be missing.

As part of an investigation into the new deformation, measurements were taken in the doorways and windowsills on all three floors of the main dwelling. Distortions and displacements in doors, doorframes, and windows were measured with a tape measure, a plumb bob, and a level. Localized displacement was considered over the width of each specific frame. On the first floor, the doorways exhibited a racking (or localized deformation) of up to 1 to 3 inches across a 2 foot width along the top of the doorways (Figures 8 and 9), with generally more deformation in east-west diagonals. The windows showed less deformation but still sloped in the same direction as the doorways (towards the lake). Doors and windows measured on the second floor showed similar results. These deformations were opposite to the differential heights in the groundwater table previously recorded, which would indicate a change in the direction of the groundwater table draw down.

The building's framing is of bald-cypress, a strong, stiff wood, which showed no signs of sagging, indicating that the measured deformations were not caused by floor deflections.



Figure 8. Second floor doorway in November 2001

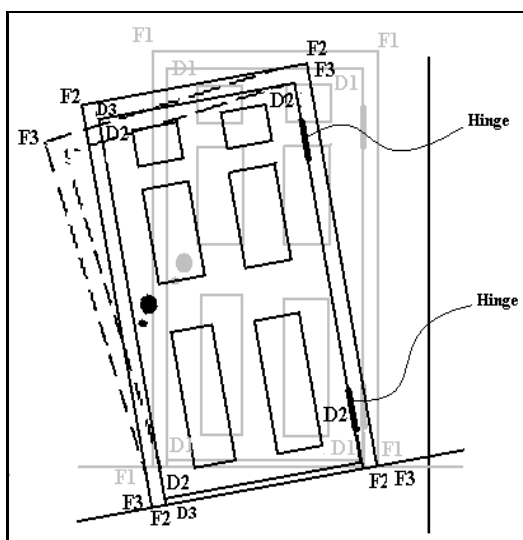


Figure 9. Displacement measurements, F3 shows racking in door causing D3 to stick (November 2001)

5. ANALYSIS

Since the rainfall and lake levels were not consistent, larger influences had to be considered. Calculation of additional stresses that

would be generated by dewatering the remainder of the top silt layer resulted in insubstantial settlements, as compared to the movements measured within the house. Based on the fact that all doors and windows were operable in 1989, the majority of the measured deformations are assumed to be new. Using the measured deformations, it was hypothesized that dewatering must have occurred in the second silt layer located at a depth of 7 feet and extending to a depth of 20 feet. Thus, the thickness of the dewatered portion of the second silt layer was back calculated, through which a change in the groundwater table was determined. The 1980 readings were used as a starting point. Selecting an average value of 2 inches for the measured deformation, it was determined that the groundwater table would have decreased approximately 6.25 feet to sufficiently dewater 1.25 feet of the second silt layer to induce such settlement. As a result the geology of the region was examined.

5. GEOLOGY

The subsurface conditions at Somerset Place are typical of the Coastal Planes physiographic province in the vicinity of the Dismal Swamp surrounding Lake Phelps, where the subsurface materials consist of alluvial deposits of sheet and lenticular sands interbedded with clays of Pleistocene to Recent geologic age (Figures 2 and 10). Somerset Place is located in Beaufort

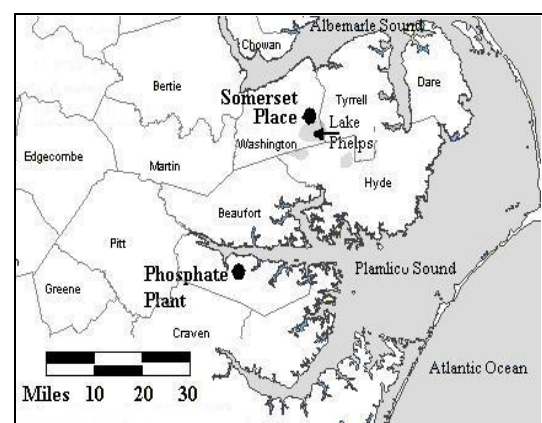


Figure 10. Regional map (adapted from DOI, 2002)

County atop the Northern Atlantic Coastal Plain aquifer system, a system composed of six regional aquifers, the most prominent of which is the Castle Hayne-Aquia Aquifer that ranges in location from New Jersey to the bottom of North Carolina and ranges in age from the Eocene to the Paleocene (Figure 11).

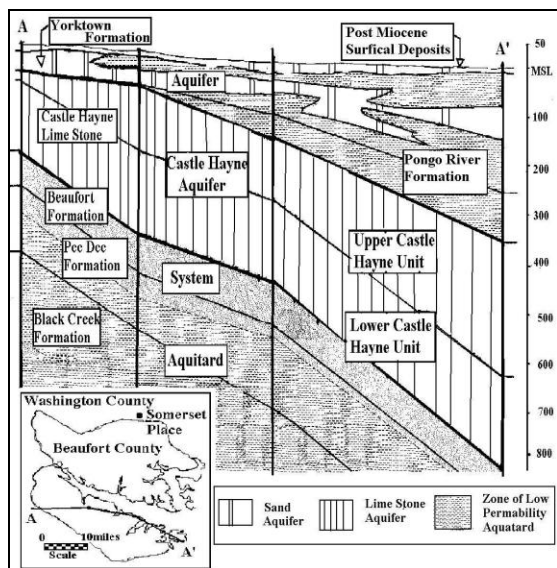


Figure 11. Castle Hayne aquifer in Beaufort County (adapted from Peek, 1975a)

The Castle Hayne Aquifer is the primary coastal aqueous aquifer, due to its limestone makeup. In North Carolina, the Castle Hayne-Aquia has two subdivisions: the larger Castle Hayne Aquifer, made of limestone, sandy marl, and coarse limey sand; and the lesser Beaufort Aquifer, containing thin beds of shell and limestone. In the Washington and Beaufort county areas of North Carolina, the aquifer is located close to sea level, at a depth of 185 feet.

Historically, water in the Castle Hayne-Aquia Aquifer runs from recharge areas of higher to lower altitude towards rivers, estuaries, and the Atlantic Ocean. The highest transmissivity of the aquifer is located in southeastern North Carolina. The aquifer does not recharge directly from precipitation and does not discharge by evaporation, due to its location. In the past, water moved eastward from recharge areas that are positioned only 50 feet above sea

level towards the North Carolina sounds, which are tributaries to the Atlantic Ocean.

6. SOMERSET AND THE PHOSPATE PLANT

In 1965 a mining operation opened near Aurora, North Carolina, south of Somerset Place (Figures 10 and 11). Initial permitting information projected a cone of depression causing measurable draw downs over a large area (Figure 12), and preliminary data collection showed an increasing zone over which the draw down occurred (Peek, 1975a-f).

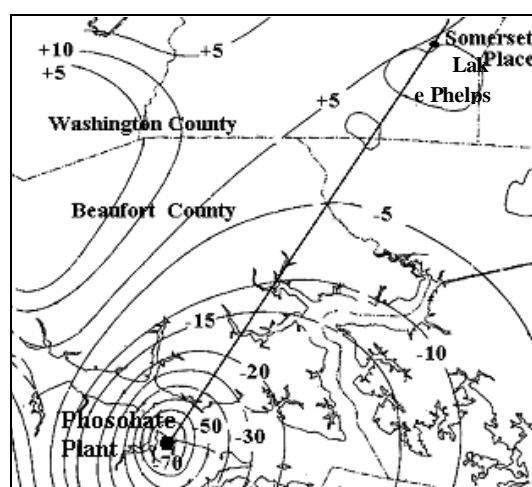


Figure 12. Castle Hayne aquifer Surface in Jan. 1975 approximately 35 miles (adapted from Peek, 1975c)

After industrial pumping began at the mine, the hydraulic head of the aquifer was lowered, which caused the formation of cones of depression in the potentiometric surface, resulting in a change of water flow toward the inland pumping centers. This could account for the reversal of the direction of water flow at Somerset Place towards the south, as evidenced by the direction of settlement. From the time the mine opened in 1965 until 1973, the predicted draw down of groundwater at Somerset, located approximately 35 miles from the plant, was in the range of 8.5 inches (Figure 13). To discover if the mining operation was indeed the cause of the troubles at Somerset, the rate of draw down was back calculated to determine the level of changes in the groundwater table needed to induce sufficient primary consolidation in the silt to gene-

rate significant structural movement. The new rate of groundwater change at the plantation was calculated at 0.31 ft/yr, compared with previous rates of 0.87 ft/yr from 1965 to 1975 and 1.9 ft/yr from 1973 to 1975, (Peek, 1975a-f). This amount far exceeds drought related forces, signifying that the mining operation is most likely the cause of dewatering. Confirmation of the analysis will be made through well installation and monitoring over the next few years.

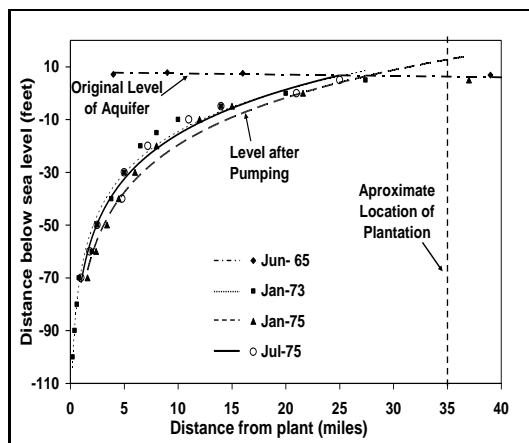


Figure 13. Potentiometric surface of the Castle Hayne Aquifer (adapted from Peek, 1975b-e)

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