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Evaluating the Threat of Environmental Change on Historic Resources: A Case Study and Assessment of Tools

Ashley Catherine Aiken
University of Pennsylvania

A thesis in Historic Preservation Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements of the Degree of Master of Science in Historic Preservation 2007.
Advisor: Michael C. Henry

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in

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Advisor	Program Chair
Michael C. Henry	Frank G. Matero
Lecturer in Historic Preservation	Professor of Architecture

Dedication

I dedicate this thesis to my family, who has always supported me in my academic studies, and to my fiancé, who has been my main source of motivation and inspiration throughout this entire process.

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I would like to express my gratitude to all those who helped in the completion of this thesis. First, I would like to thank my professor and advisor Michael C. Henry, for his suggestions and guidance during my time of research and writing and for all the lessons he has taught me over the last two years. My reader, Dr. Chad Freed, was also a great resource with his expertise in the hydrogeology field, availability and willingness to answer all of my questions, and for allowing me to expand my technical knowledge by sitting in on his classes week after week. I would like to give a special thanks to my fiancé Michael R. McDuffee for acting as my outside editor, site visit companion and source of endless support throughout the entire process.

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Overview

Climate change trends have triggered very slow-acting, large scale environmental impacts on the world. Changes in the environment threaten to have potentially serious and dangerous effects on historic properties. Historic properties that lie in coastal regions may be especially vulnerable to the effects of climate change. Historic property stewards are in need of effective methods of identifying, monitoring and assessing the progress of the potential environmental threats. Ultimately, it is essential to develop and understand the time frame in which stewards have to act, in order to make the most informed appropriate decisions and proactive interventions on a historic property.

To explore the implications of this topic in depth, a case study was undertaken on the Abel and Mary Nicholson House, located in Elsinboro Township, Salem County, New Jersey. Situated on a tidal marshland within the Delaware Estuary, two miles east of the Delaware Bay, the two-and-a-half story, brick house was built in 1722 and is a National Historic Landmark. The original structure is known for its patterned end brick architecture featuring a diapered-pattern and its construction date in vitrified brick on its east façade. The Nicholson house is a monumental example of Delaware Valley's local architecture and well-to-do Quaker residences and integrates the Quaker's emphasis on family and community.

In the eighteenth century, the tidal marshland surrounding the Nicholson House was reclaimed for agriculture by the construction of low-rise levees or banks. Today, the Delaware Estuary is currently evolving with rising sea levels and related saltwater intrusion into the coastal, unconfined aquifer. Storms and rising tides have overtopped the banks, and the retreat of agricultural activity has removed the economic impetus for the repair and maintenance of the dike system. The site location is within the Middle Atlantic Coastal Plain, which is relatively flat and facing land subsidization, making the rate of relative sea rise higher and well above the world average. This combination of rising sea levels, failed levees and land subsidence presents serious potential long term threats to the house, which lies on a plot less than 10' above sea level. Composed of a hand-made, low-fired brick foundation, the rising water table and zone of saturation in the groundwater could waterlog the basement and introduce damaging salts to the footings, cellar walls and floor, potentially compromising the historic fabric and structural integrity of the building. With such threats at hand, it is important to establish the time frame within which the property stewards must react before the building is damaged. Although the building fabric currently exhibits no visual evidence of salt presence, there are some key indicators that the water table is near the basement floor. For instance, levee failure in the area has exposed the site to the effects of tidal flooding. Dying trees and the prevalence of phragmites, an invasive plant species that grows in saltwater, around the property further indicate the progress of saltwater encroachment on the site.

The study identifies the information and factors that the steward would need to know to evaluate the rate of saltwater encroachment on the Nicolson house's historic masonry foundation, including groundwater level, groundwater saline content, direction of groundwater flow and depth to building foundations. The study recognizes available tools and methods for determining the rate of groundwater rise and saltwater encroachment in the vicinity of the Nicholson house's foundation to infer how long before the deterioration mechanism is activated and the estimated time available for response. Potential monitoring methodologies include: observing changes in vegetation and land formations over time with the comparison of aerial photographs and cross-reference to topographic maps, groundwater modeling of saltwater transport as a contaminant, and installing monitoring wells or test pits to measure groundwater levels and saline content with survey tools or data loggers and laboratory analysis. Through research and application, the methods were compared and evaluated on their cost, resolution, accuracy, precision, availability, complexity, durability, time requirements and overall effectiveness. Based on the analysis, the comparison of aerial photography was determined to be very valuable as a preliminary assessor of the level of threat. The installation of wells to monitor groundwater level and salinity content emerged as the best overall method for evaluating the variables and assessing the threat of saltwater encroachment on the property. The installation of monitoring wells is advised as one of the main recommendations for the case study and a proposed monitoring program is outlined.

Based on the case study, other historic sites with potential environmental threats may necessitate a similar methodology of identifying and investigating monitoring tools in order to determine the most effective and appropriate tools for assessing their particular threat. With the right tools, stewards may successfully monitor the threat on their historic property and be equipped with the information necessary to make the appropriate decisions regarding the historic property's future.

1.0 Effects of Environmental Change

1.1 An Environment in Flux

Over the last few decades, the extent of anthropological influence on recent climate change trends has been debated. Whether or not one is convinced of the human impact on global warming, there is documented evidence that suggest the Earth's climate is warming and sea levels are rising. There is scientific consensus that increases in greenhouse gases have led to the warming of the atmosphere and are causing glaciers to melt.[1] In turn, the melting of glaciers is causing ocean water to warm and expand thermally.[2] Both of these effects are increasing the volume of the ocean and are the root cause of the trend of rising sea levels.[3]

Geologic and archaeological record has also informed us that changes in climate over a period of time have happened in the past and are a part of an expected and natural process of the Earth's environment.[4] During previous episodes of progressive climate change, humans have successfully adapted and survived the impacts of climate change. There are a few probable reasons why this particular episode of climatic change is raising the attention of the general world population and become the focus of debate for so many environmentalists and policymakers. We now have the necessary tools and techniques capable of detecting and measuring this phenomenon that happens on a longer time scale than our personal observation. Furthermore, current and available past data indicate that

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[1] Climate Change 2007: The Physical Science Basis: Summary for Policymakers, p.2.
[2] Ibid.
[3] Ibid.
[4] http://www.helm.org.uk/.

climate change is occurring at a rate significantly higher than in the past. Finally, human activities are suspected to be responsible for this increase in rate.

1.2 The IPCC and the Upcoming Fourth Assessment Report

The Intergovernmental Panel on Climate Change (IPCC) was created with the aim "to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation."[5] The IPCC is considered the leading international network of climate scientists and the ultimate resource for current, comprehensive evaluations of the global present state of knowledge on climate change. To date, the IPCC has published three Assessment Reports since 1990 and is currently working on its Fourth Assessment Report *Climate Change 2007: The Physical Science Basis: Summary for Policymakers*, which represents the efforts of the first of three of its Working Groups that generate the reports. The second working group is in the process of creating another portion of the Fourth Assessment Report: *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers*. All authors of the assessment reports are experienced climate scientists, although the reports are shaped by government officials.[6]

Although the IPCC is still in the process of finalizing its Fourth Assessment Report, the organization recently made available a the first working group's *Climate Change 2007: The Physical Science Basis: Summary for Policymakers* on February 2nd, 2007, revealing the contributions of working group I to the IPCC's Fourth Assessment Report. The

[5] http://www.ipcc.ch/
[6] Rosenthal and Revkin, p.3.

document builds upon the IPCC's Third Assessment Report, which came out in 2001, and includes new information, data and understanding of climate change that have become available and apparent since the previous report through recent study results, advances in modeling and improvements in analysis. In early April 2007, working group II released their unedited edition of *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers*, which outlines the key policy-relevant findings and builds on the Third Assessment Report with new information. *Climate Change 2007: The Physical Science Basis: Summary for Policymakers* includes statements on the current understanding of human and natural drivers of climate change, observed climate change, climate processes and attribution, and estimates of projected future climate change. *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers* addresses the adaptability and vulnerability of natural and human systems to changes in climate.

The document represents the first time that gradual warming of the atmosphere is regarded as an unequivocal, progressive trend and that substantial evidence has supported the notion that human activities since the industrial revolution, mainly resulting from the burning of fuel and forests, are directly connected to the increases in global average temperatures. *Climate Change 2007: The Physical Science Basis: Summary for Policymakers* indicates that human activity is "very likely" the cause and main driver of global warming and could influence the earth's climate system in potentially momentous ways. According to the document, human activities since 1750 have increased the global atmospheric concentrations of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide. Data concerning atmospheric data from pre-industrial times were taken from ice cores that reveal data from thousands of years ago. Fossil fuel use and changes in land use are the primary sources of excess carbon dioxide concentrations while agriculture is primarily responsible for increasing concentrations of methane and nitrous oxide.[7]

The increases in greenhouse gases have altered climate energy balance and increased radiative forcing, leading to increases in average temperatures across the world.[8] The average increase in temperatures over the last 50 years is 0.23°F (0.13°C), which is almost more than double that for the last 100 years.[9] Since 1850, eleven of the last twelve years (1995-2006) rank among the warmest years of global surface temperature on record.[10] The atmospheric warming depresses the amount of carbon dioxide absorbed in the land and ocean, leaving more emissions in the atmosphere that lead to greater warming.[11]

According to the first summary report, the ocean has been absorbing more than 80% of the added heat in the atmosphere, and as a result, has warmed up and expanded, leading to average global sea level rise rates of 0.07 inches per year from 1961 to 2003. The rate of average global sea level rise between 1993 and 2003 is even higher at 0.12 inches per year, but it is unclear as to whether this is because of natural variability from decade to decade or if this represents a long term trend or if this is because of switching methods of

[7] Climate Change 2007: The Physical Science Basis: Summary for Policymakers, p.2.
[8] Ibid.
[9] Climate Change 2007: The Physical Science Basis: Summary for Policymakers, p.4.
[10] Ibid.
[11] Climate Change 2007: The Physical Science Basis: Summary for Policymakers, p.11.

data collection (Prior 1993 data was collected from tide gauges and 1993 and later data was collected from satellite altimetry.)[12] Despite the uncertainty, the report does mention that there is *high confidence* that there was an overarching trend toward rising sea levels from the 19th to the 20th century. The rates were determined by estimating the contributions from several different potential sources or sea level rise including thermal expansion, glaciers and ice caps, Greenland ice sheets, Antarctic ice sheets, and the sum of individual climate contributions to sea level rise. The rate of sea level rise can vary significantly in different areas of the world. The difference is created by several factors, which may include, but are not limited to, land subsidence and land surface topography. Land movement, up or down, will affect the level and rate of relative sea rise in a given area. Land surface topography may also affect the level and rate of relative sea rise intruding on a given area because a very steep coastal zone will have a much smaller shoreline shift than a low-lying, plain-like coastal zone (Figure 1).

Other long term changes in climate have been observed involving trends of increases in the recurrence of extreme weather conditions, as well as changes having to do with Artic temperatures and ice levels, precipitation amounts, ocean salinity, and wind patterns. The report included a table (Table 1), listing extreme weather phenomena which have observed late 20th century trends. The listed extreme weather phenomena include warmer and fewer cold days and nights over most land areas, warmer and more frequent hot days and nights over most land areas, warm spells/heat waves, frequency (or proportion of total rainfall from heavy falls) increase over most areas, area affected by droughts

[12] Climate Change 2007: The Physical Science Basis: Summary for Policymakers, p.5.

increased, intense tropical cyclone activity increases, and increased incidence of extreme high sea level. All extreme weather trend phenomena were evaluated on the likelihood that it is a recent trend occurring in late 20th century (and typically post 1990), the likelihood that human activities had an influence on the trend, and the likelihood that the trend will continue. All phenomena were ranked either More likely than not, Likely, Very likely, and Virtually certain. This chart implies that extreme weather as a whole has increased significantly and is very likely in most cases to continue. Amid all these documented and likely trend-following changes in climate, the first summary report mentions that there are some aspects of the climate, including the diurnal temperature range (DTR), Antarctic sea ice extent, meridional overturning circulation of the global ocean, which did not experience any significant changes upon monitoring.

An increased number of simulations have allowed for more likely projections of future changes in climate than those found in the Third Assessment Report. The first summary report predicts that there will be approximately 0.4°F (0.2°C) global average temperature increase per decade for the next two decades. An increased warming of about 0.2°F (0.1°C) per decade is predicted if the concentrations of greenhouse gases and aerosols are kept to their 2000 levels.[13] Further warming and climate changes are very likely to occur in more drastic levels if greenhouse gas emissions continue to be released at their current, or above their current, rates.[14] Even if greenhouse gas concentrations are effectively capped and stabilized, human-influenced warming and sea level rise are expected to

[13] Climate Change 2007: The Physical Science Basis: Summary for Policymakers, p.10.
[14] Ibid.

continue for centuries to come in response to the past and current significant increases.[15] Even though global average sea levels rose significantly in the range of 6-9 inches in the 20th century, the report predicts a rise of 7-23 inches by 2100.[16] According to several climate experts and biologists, if the level of warming falls into the middle of the range of predictions, it will have a significant effect on the world's ecosystems and likely alter climate patterns that the agricultural industries and water suppliers depend upon.[17] The first summary report further mentions that, since the Third Assessment Report, there has been an overall increase in the confidence level of the future climate projections described in the reports, thanks to the availability of more evidence, data, and general understanding of the climate processes.

After thousands of years of experiencing a relatively stable climate, the earth has entered a period of continual change. The most recent occurrence of climate change similar to current levels was the warming of the earth that occurred between ice ages, approximately 125,000 years ago.[18] During that time, sea levels were likely 12 to 20 feet (4 to 6 meters) higher than what they are today. Most of that extra water is trapped in the ice sheets of Antarctica and Greenland.[19] According to the United States Geological Survey, the coastline has changed significantly within the last 5 million years (Figure 2), largely due to fluctuations in the amount of water trapped in ice sheets. During the interglacial time, the earth experienced average global temperatures ranging from 5 to

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[15] Ibid.
[16] Rosenthal and Revkin, p.2.
[17] Ibid.
[18] Rosenthal and Revkin, p.4.
[19] Ibid.

9°F (3 to 5°C) higher than present day temperatures based on ice cores.[20] Such temperatures may occur again near the end of the century if greenhouse gases continue to build up in the atmosphere at the current rate.[21]

The summary stills leaves many areas unexplored, particularly on the speed and extent of predicted changes. This is left open-ended because there are so many variables that could affect said changes, including future population, pollution trends, complex relationships between greenhouse emissions and the earth's climate and absorptive properties.[22]

Even though the Fourth Assessment Report is still being finalized, it has received some criticism based on the contents of *Climate Change 2007: The Physical Science Basis: Summary for Policymakers*. The criticism centers around the fact that the panel of scientists lowered their estimate of global sea level rise significantly from the Third Assessment Report. The Third Assessment Report predicted rises of a few inches to as much as three feet, which would be catastrophic for low-lying regions of the world.[23] The estimate was lowered because the panel did not include water released from melting glaciers and ice sheets on land, which are potentially major contributors to sea level rise.[24] The panel left out this information because there was no solid scientific understanding of the rate melting of polar ice caps; their estimate was mostly based on the extent to which the warmed oceans would expand.[25] Recent evidence has been reported that indicate that the water from the polar glaciers and ice sheets of the Artic and

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[20] Climate Change 2007: The Physical Science Basis: Summary for Policymakers, p.10.
[21] Rosenthal and Revkin, p.4.
[22] Rosenthal and Revkin, p.3.
[23] Dean, p.1.
[24] Ibid.
[25] Rosenthal and Revkin, p.4.

Antarctic could flow much faster toward the seas and contribute more substantially to the global sea level than originally estimated.[26] Observation of the Columbia glacier's melting progress over 25 years is indication enough that glacier melting is not a trivial matter (Figure 3) and (Figure 4). However, this evidence was not included because it is speculative and taking this evidence into account would be against the IPCC's charter.[27] Other recent studies may provide more evidence in support of this theory, but were not included since they did not meet the December 2005 cutoff date for submission of scientific papers and other data to the IPCC.[28]

Several distinguish scholars and experts in the field had their own comments on *Climate Change 2007: The Physical Science Basis: Summary for Policymakers*. Dr. Michael C. MacCracken, former head of the Office of Climate Change during the Clinton administration, reviewed the first summary report and stated that lowering the worst-case sea level estimate would "result in a serious misimpression being conveyed to policymakers and the public."[29] He also mentioned that the majority of American experts find the estimate to be almost certainly wrong, several of which thought that the original estimate was already too optimistic.[30] Dr. Shindell, climate expert at the NASA Goddard Institute for Space Studies, stated that "The melting of Greenland has been accelerating so incredibly rapidly that the IPCC report will already be out of date in predicting sea level rise, which will probably be much worse than is predicted in the IPCC report."[31]

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[26] Ibid.
[27] Ibid.
[28] Dean, p.2.
[29] Ibid.
[30] Ibid.
[31] Ibid.

Shindell also recognized that the errors in estimations may be unavoidable given the difficulties confronting the panel, which is faced with the challenge of succinctly summarizing the findings of a field in which the research and knowledge is constantly being updated at a very fast rate.[32]

1.3 Proposing Change in Response to Climate Change

There have been various regional, national and international measures to minimize the probable human contribution to the changes in climate change. One major international attempt was the Kyoto Protocol, which was an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC) and acts as an amendment to the international treaty on climate change.[33] The ultimate aim of the Kyoto Protocol was to get the commitment of several developed nations to significantly reduce their amount of greenhouse gases and carbon dioxide emissions through their own public policy initiatives and strategic legal tools within a given period of time.[34] Several governments have since attempted to reduce the demand for energy, or moderate the rate of increase, while exploring eco-friendly, alternative fuel sources. Over 160 countries have committed to the agreement thus far.[35] The United States, currently the largest contributor to greenhouse gas emissions at about 25% of the world's emissions[36], has signed the Kyoto Protocol but the U.S. Senate has still not ratified the treaty and therefore

[32] Ibid.
[33] Environmental Literacy Council. http://www.enviroliteracy.org/article.php/278.html
[34] Ibid.
[35] Ibid.
[36] Rosenthal and Revkin, p.2.

the U.S. cannot be held to meeting the conditions of the treaty.[37] The Kyoto Protocol was deemed too costly for the U.S. economy by the Bush Administration, leading the U.S. to adopt a more voluntary incentive campaign on emission reduction.[38]

Although the United States has not ratified the treaty, it has been at the forefront of researching and combating climate change through the investment of nearly $5 billion per year on research and tax incentives for new technologies for the past six years.[39] In addition, individual states such as California have started to develop their own climate change policies.

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[37] Environmental Literacy Council. http://www.enviroliteracy.org/article.php/278.html
[38] Ibid.
[39] Rosenthal and Revkin, p.2.

2.0 Climate Change Threats on the Built and Historic Environment

2.1 Potential Effects of Climate Change on the Built Environment

Climate change policies set by different government agencies and organizations mostly define objectives to reduce the greenhouse gas emissions through the energy efficiency and the use of advanced, eco-friendly technology. However, reducing the amount and rate of greenhouse gases we put into the atmosphere now, will not get rid of the amount that currently exists in the atmosphere from hundreds of years of past greenhouse gas producing activities. Hence, significant changes in climate can be expected over the next few decades regardless of what actions are taken with respect to current emission rates. Based on the IPCC's *Climate Change 2007: The Physical Science Basis: Summary for Policymakers* publication, higher overall year-round temperatures, regional precipitation changes that will results in flooding in some areas and drought in others, and more extreme weather in general are all to be expected. These changes may affect our existing infrastructure and our future designs in our built environment. One should consider whether the built environment will be able to accommodate these changes, and if not, whether the built environment will be able to be readily adapted to meet new design requirements within reasonable cost and time.

Climate change could affect more than just the physical part of the building environment. Building and general construction relies heavily on tried and true traditions, especially for tradespersons, that are passed on through several generations. Building and general construction also relies on building codes and regulations, which inherently stem from past experience of what does and does not work. Construction traditions and building codes are based on the assumption that the world will remain more or less the same from generation to generation. However, now that there is substantial evidence indicating that this will not be the case, some of these beliefs and traditions may need to change. If the climate in a given region is altered significantly, it may be enough to require that officials modify the building codes and regulations that are enforced today. For instance, buildings in regions experiencing heavier precipitation and more severe storms than in the past may find that their current drainage systems do not have the capacity to effectively drain the extra water away from the building and may need to be enhanced and the gutters enlarged to carry more water.

Effectively modifying the building codes to reflect the requirements of the changing climate will likely take some time. The delay in adjusting and redistributing the building code could result in the construction of new infrastructure or rehabilitation of older infrastructure that is inadequate in sustaining the effects of the new environment. Furthermore, construction is built upon methods of tradition. Telling tradespersons to change their traditional methods of construction, time-verified methods that they and their parents and grandparents have performed for several decades, and enforcing the modification would likely be extremely difficult.

Climate change has already affected the built environment and threatens to bring more severe physical impacts. Some organizations have recognized this threat and have published related documents on the potential extent and implications of the threat and ways in which the public can respond, now and in the future. In the United Kingdom, new Construction Research and Innovation Strategy Panel (nCRISP) has collaborated with the UK Climate Impacts Programme and Engineering and Physical Sciences Research Council (EPSRC) to produce a research agenda for understanding the possible impacts of climate change on different aspects of the built environment. nCRISP performed a preliminary review in 2002 which identified the key research issues regarding climate change that the construction industry may face in the future. The key research issues are listed as follows: the adaptability of existing infrastructure to new climate extremes; the modification of drainage systems and transport networks to accommodate for changes in precipitation levels; and the adjustment of cooling systems, passive and active, in response to rising temperatures, while still maintaining energy efficiency.[40] The preliminary review called for further research to develop a better understanding of the potential extent of climate change impact on the built environment. Published in 2003, this agenda is intended to begin answering that call by laying out the necessary objectives for the major research areas as identified by key stakeholders, in order to gain a sufficient knowledge base that could inform decision-makers to develop effective and practical climate change strategies. The report describes current EPSRC/UKCIP research projects, pertaining to all aspects of the built environment including urban drainage, urban environments and planning, energy and telecoms, buildings, transport, built heritage and risk management, and their objectives and means to encourage the active participation and efforts of more researchers and stakeholders.

[40] Building Knowledge for a Changing Climate, p.2.

The major climate adaptation concerns for the climate change impact on buildings identified in the report included[41]:

1. Effective and efficient cooling methods to respond to increased temperatures;
2. Maintaining air quality within buildings;
3. Improving building envelope designs and flood-proofing techniques to prevent mold and infiltration to respond to increases in precipitation in some areas;
4. Re-using water in building systems response to increase in droughts in some areas;
5. Improving the robustness of roof in response to increases in wind intensity;
6. Finding better waste disposal strategies to avoid pollution by site storage and heavy precipitation;
7. Promoting flexible building designs for the eventual reuse of buildings.

For the benefits of future research, there is a greater demand for computer modeling to provide accurate simulations of new designs to test them and provide ready solutions and a much lower cost than real-life mock-ups. In addition, there is a need for better guidance on the performance and vulnerabilities of certain construction assemblies and materials to judge if they would be effective in different changing climates for the long term.

[41] Building Knowledge for a Changing Climate, p.14.

2.2 Potential Effects of Climate Change on the Historic Environment

Certain entities of the built environment are especially vulnerable to climate change. In particular, climate change could have potentially extreme and irreversible adverse effects on the historic environment, which includes everything from buried archeological sites, monuments, object collections, structures and their contents, as well as landscapes, parks, gardens, and earthworks. Protecting the historic environment from climate changes holds more challenges than looking after the built environment in general. Ultimately, the changes in climate threaten to destroy historic fabric, which may negatively affect the interpretational experience for future generations. Climate change can also have significant indirect impacts on the historic environment through the anthropological response in the form of adaptation and conservation measures.

Historic properties typically hold some type of significance to the world or region in which they reside. The historic environment not only provides a sense of character, place and identity but it also serves as a substantial economic resource, as a result of leisure and tourism. However, heritage properties are non-renewable resources. Once historic entities are damaged or destroyed, they cannot always recover or be re-created. Historic resources cannot always be adapted to changes in the environment in the same ways that the rest of the built environment can. In most cases, a more sensitive and unique approach is required. Unique challenges in protecting the historic environment from changes in climate arise from the fact that conventional adaptation strategies intended for the built environment may not be appropriate for historic properties. Some adaptation strategies used on more modern structures may be considered inappropriate and even more harmful than the actual direct climate effects. And for most historic resources, relocation and rebuilding is not an option as it might be for other structures. Many historic resources are too fragile to survive a relocation campaign and may lose significant historic fabric. In addition, relocation and rebuilding campaigns require large sources of funding that can be difficult for historic site managements to acquire. Furthermore, significant changes to historic properties could decrease their authenticity and consequently decrease its ability to attract tourists.

The impact of climate change on our cultural heritage is important for several reasons. To begin, historic structures are associated with their original or current context and the Secretary of Interior's Standards for the Treatment of Historic Properties recommend preserving the structure within that given context, as well as the site and setting itself.[42] However, if the environment surrounding the historic structure is changing, then its context may be naturally changing in response to environmental pressures as well. For instance, extreme weather may erode a landscape's natural features or a historically significant access path to the structure. A prolonged drought may eradicate the natural vegetation of a given area and perhaps promote the growth of new species. Historic landscapes and archeological sites, which are naturally representative of the site's context as well, may be directly affected by this kind of change in climate.

In addition, a given historic structure was only built to sustain the elements of the climate at the time in which it was built. The historic structure may now exist in an environment that is completely different from the one in which it was built and the location may be far

[42] The Secretary of the Interior's Standards for the Treatment of Historic Properties, p. 51

from optimal due to natural and man-made changes to the surrounding environment. This change in environment could lead to the demise of the historic property since a historic environment's stability is closely related to its interactions with the ground it lies upon and the atmosphere it lies within.[43] The structure's design and materials may not be able to withstand the burden of a modified climate and environment just as a building built to code in one region may not meet the code requirements of a different region due to the difference in climates. The age of the design and materials should also be taken into consideration because after years of natural decay, a given historic structure's original design and materials will likely be much more fragile than when it was originally built, unless major preservation, rehabilitation, or restoration work has been performed on it. In addition, the structure's systems and materials may have already exceeded their life expectancy. Therefore the age of a historic structure and its materials may naturally make it more vulnerable to accelerated deterioration when the environment changes and becomes unbalanced[44]. Finally, a change in climate in a given region may also manifest new pathologies and delay exiting ones within a given historic structure. Having not dealt with the pathologies before, the historic property stewards may have difficulty identifying, analyzing and diagnosing the evolving decay mechanisms and may not have the budget, resources, time and energy to do so and effectively stop the mechanisms. In addition, the historic site management may have to modify their maintenance plans to meet the different protection needs of the historic resource for the new climate. However, in most cases, climate change has increased the extent and severity of existing climate-related threats to historic properties as opposed to introducing many new threats.

[43] Climate Change and the Historic Environment, Poster.
[44] Ibid.

This has reinforced the concept of improving and revising long-held preservation strategies to accommodate for more severe impending threats to historic properties rather than breaking the mold and designing entirely new strategies, which puts significantly less extra stress on historic resource conservators.

The most extreme outcome that climate change could have on the historic environment is the eradication and severe damage of historic properties. The destruction of historic fabric would significantly impair future generations' ability to experience and enjoy their cultural heritage. Some of the direct impacts of climate change have already been recognized and stated by the English Heritage in the *Climate Change and the Historic Environment* booklet published in January 2006. In the absence of a similar report for the US, the UK report provides insights into the potential type and scale of impacts that might be experienced in the various climate regions of North America. The direct impacts acknowledged by the English Heritage[45] are listed and explained below:

1. Coastal erosion and rising sea levels could threaten to overcome nearby historic properties.

2. Ground subsidence, caused by changes in soil composition, could compromise the foundations of historic buildings, since historic buildings tend to be more affected by changes in the soil than modern buildings due to their more porous materials and direct contact with soil surfaces.[46]

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[45] Climate Change and the Historic Environment, English Heritage, p.4.
[46] Climate Change and the Historic Environment, Poster.

3. More frequent and severe flooding could ruin historic fabric of buildings due to prolonged immersion in floodwaters, alter the landscape of historic sites due to the natural erosion of moving water, and make the areas uninhabitable due to increased insurance rates and health reasons.

4. Changes in hydrology could alter the features of a historic property and place buried archaeological remains at risk. Archaeological preservation relies on the hydrological, chemical and biological balance of the soil, and their variation could affect the survival of archaeological artifacts.[47]

5. Fewer frosts and drier summers could change the vegetation on historic properties and put additional stress on building materials. This change in environment may also encourage the northward migration of pest and diseases and expose the vegetation and materials to new threats of deterioration that they will likely have little protection against.

6. A warming climate could impact vegetation and building materials existing on a historic property as well. Increases in humidity and temperature and UV radiation may damage building materials and object collections exposed to the outside.

7. The alteration of traditional agricultural practices, in response to climate change, may threaten archaeological landscapes and buried archaeological sites with the introduction of new crops and the way traditional crops are planted and grown.

[47] Ibid.

8. Increased frequency of extreme weather events poses a risk to historic fabric that is aged, weathered and unfit to sustain the extra environmental stress and strain.

As indicated by the list, climate change could affect the historic environment on many levels. Another recent publication, this one authored by the World Heritage Centre and members of its advisory committee, also addresses potential climate change impacts on the historic environment with a table (Table 2) that lists the climate change risk and its associated physical, social and cultural impact on cultural heritage by each climate indicator.[48] There could also be direct impacts of climate change on historic environments which have not been proposed or discovered; only time will dictate the full extent of climate change effects that the historic environment will be challenged with in the future.

Historic properties are also threatened by the impact of adaptation campaigns and policies aimed to increase alternative, renewable energy supplies and reduce the demand for energy. Well-intentioned adaptation campaigns, such as 'soft' coastal defense, can have adverse affects on the historic environment. 'Soft' coastal defense refers to strategies that attempt to harness or manipulate natural processes, like the installation of drainage systems or beach recharging, while 'hard' coastal defense refers to strategies that attempt to resist natural processes, like the construction of major flood-prevention structures.[49] 'Soft' coastal defense has become more common lately, mostly because 'Hard' coastal defense is virtually unattainable, but 'soft' coastal defense does not provide the necessary

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[48] Predicting and Managing the Effects of Climate Change on World Heritage, p.14-16.
[49] Climate Change and the Historic Environment, English Heritage, p.4.

protection for archaeology and historic buildings and landscapes.[50] The construction of major flood-prevention structures can inflict damage on archeological sites along the waterfront and disrupt the historic character and context of a historic site.[51] The installation of rainwater drainage systems on historic structures and sites can impair the architectural integrity of a building if not designed with sensitivity to the original architectural.[52]

Policies intended to increase alternative, renewable energy supplies may also have an impact on the historic environment. Examples include the construction of new renewable energy infrastructure, such as wind farms or hydro-electric facilities, and the installation of new biomass crops. New renewable energy infrastructure has to go somewhere and sites of potential archeological significance may be proposed to be sacrificed for this effort.[53] Wind farms may adversely affect the character of historic landscapes or the context of a historic property.[54] New biomass crops may affect the hydrogeology of a site and risk tainting buried archeology.[55] Designing policy to reduce automobile transportation, lessen the demand for air travel, and encourage the utilization of sustainable, mixed-use neighborhoods, can both reduce the demand for energy and also positively affect the historic environment.[56] On the other hand, some energy-saving tactics can negatively affect the historic environment with insensitive design that detracts from the character and fabric of the building, or by proposing the demolition of historic

[50] Ibid.
[51] Ibid.
[52] Ibid.
[53] Ibid.
[54] Ibid.
[55] Ibid.
[56] Climate Change and the Historic Environment, English Heritage, p.5.

buildings so that they can be replaced by a new, modern building that are supposedly more energy-efficient.[57]

There are other ways in which the historic environment can be indirectly affected by climate change. For instance, climate change could greatly endanger some historic properties that were previously unaffected, which will most likely lead the properties' insurance rates to skyrocket, leaving some private home-owners unable to pay. These private owners may be forced to sell their property, but high insurance rates may decrease the demand. The owners may therefore be more likely to abandon these properties, leaving them to demolition by neglect. The government could take responsibility and purchase the property at a low price. This solution can only go so far though, as the government will not be able to purchase every abandoned or available historic property.

It is also important to turn the tables and consider what type of impact, if any at all, the historic environment might have on climate change. The conservation and use of historic properties does not require a lot of energy and sometimes saves energy that would have been used to build a replacement structure. Additionally, most historic buildings were built during time periods where energy was not as readily available as it is today and therefore do not require much energy to function properly as a comfortable place of shelter.[58] Historic neighborhoods were mostly built in high-density fashion and in times when cars were not so heavily relied upon, so stores and services were typically located within close walking distances of the community residences, which spares the

[57] Ibid.
[58] Ibid.

environment from automobile emissions.[59] Furthermore, historic buildings are generally good at conserving energy with their thick walls and small windows, strong, long-lasting, durable materials, good proportions and high ceilings to promote natural ventilation, close proximity of one another (for retention of heat), cost-effectiveness, sustainability, and reusability.[60] Since historic properties do not require much energy to occupy, the reuse of historic properties instead of building new is a successful strategy in reducing greenhouse gas emissions and the preferred alternative in combating climate change.

Due to all of the potential direct and indirect effects of climate change on the historic environment, there is an overwhelming need for research and studies in the area. Research should consider how known impending climate trends, like increasing temperatures and overall weather severity, will affect the rate, intensity, range and overall impact of current active deterioration mechanisms in certain historic materials of a specific region. Deterioration mechanisms include all variations of biological, chemical and physical attacks on building materials. For instance, increased temperatures may increase the rate of chemical attack, and increased rainfall could result in more biological degradation in materials.[61] The research should also consider new deterioration mechanisms that could develop as a result of the effects of climate change. Understanding the properties, characteristics and vulnerabilities of the historic materials is essential for this research. Emphasis should also be placed on monitoring these impacts to develop a direct correlation between climate changes and the effects on historic materials in order to fully understand and asses the risks. From these studies,

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[59] Ibid.
[60] Climate Change and the Historic Environment, English Heritage, p.6.
[61] Building Knowledge for a Changing Climate, p.18.

predictive tools and methods may be identified for certain materials and deterioration mechanisms. As a result of the initial research and studies, preservation leaders will be able to identify areas of further research that deserve priority. The studies and research should aim to assist cultural heritage preservationists to develop new adaptation strategies for the historic environment to ultimately meet the objective of preventing future deterioration and preserving the structure and its most distinguishable characteristics. Furthermore, the strategies should address how to determine when is the appropriate time to undertake a preventative intervention.

There have already been some world-wide effects of climate change on certain cultural heritage sites. For example, northern Thailand's 600-year-old ruins of Sukhothai, which translates to "dawn of happiness", includes artifacts from ancient royal palaces, Buddhist temples and city gates.[62] The ruins, including the priceless artifacts, have recently experienced, and continue to experience, irreversible damage from floods in the area.[63] Other affected sites include the Belize barrier reef, which has faded in color as a direct result of warmer sea temperatures, and Spain's Donana National Park, whose wetlands are experiencing salt damage as a result of rising sea levels.[64] There are also several invaluable historic sites that are in grave danger of being swallowed by the adjacent oceans, like the Old City on Kenya's Lamu Island, which is a UNESCO World Heritage site and has existed since the 12th century. Lamu represents the first settlement of the Omani Arab sultans, who ruled the eastern coast of the continent before they moved to

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[62] Kennedy, *The New York Sun*.
[63] Ibid.
[64] Ibid.

Zanzibar, and is therefore a significant landmark in Africa.[65] Lamu is now a tourist destination that is known for its winding alleyways and its 8-mile long sandy beach.[66] Losing Lamu would be a terrible loss of Africa's tangible history.

Despite all these potential looming threats and real world examples of sites being affected, climate change is a relatively new topic in the preservation field. There has been extensive research and studies published and presented on our evolving world environment by environmental scientists, academics and professionals to the benefit of the world population. However, there has been comparatively little response or discussion on the topic within the preservation field. Given recent publications from the UK, press related to climate change and its effects on our cultural heritage in the New York Times and calls for members interested in discussing the topic from ICOMOS, preservationists may be beginning to recognize the need to address this issue.

2.3 Possible Climate Change Effects on the Coastal Historic Environment

Historic properties located in coastal areas are particularly vulnerable to the effects of climate change. Because of early settlement patterns, a large number of our valued historic landscapes and structures lie in coastal regions which are most threatened by environmental change. With such a large percentage of heritage sites in jeopardy, there is a dire need for recording and understanding the effects of climate change in these regions, and for promoting defense initiatives and developing disaster preparedness, prevention, management and mitigation strategies to be used in the case of an emergency.

[65] Ibid.
[66] Ibid.

Climate change endangers historic maritime landscapes, structures, buildings, and archaeology in several ways, ranging from minor disruption of historic features to complete physical obliteration. Climate change effects contribute to rising sea levels that have receded beaches and wetlands and trigger coastal erosion and more severe flooding. Severe flooding will likely occur more often because of increased rainfall and higher storm tides and river surges, rising water tables and the overstressing and eventual failing of flood defense structures.[67] Since the sea level has increased in relation to the land, the 100-year storm, a storm that results in severe floods and typically only occurs once every 100 years, will likely return more frequently than every 100 years and may become the 75-year storm or 50-year storm. On top of that, the severity of the floods created by the new 100-year storm will increase. This effect is particularly severe when rising sea levels are occurring simultaneously with land subsidence, making the rate of relative sea rise even greater and further decreasing the return period of storms. As a result of all these likely climate changes, the coastal historic environment is likely to experience more frequent and intense immersions in waters.

Rising sea levels have also led to saltwater intrusion, which involves seawater seeping into the groundwater and contaminating the freshwater resources and coastal aquifers. Saltwater intrusion can raise the height of groundwater and also the zone of dispersion, the freshwater and saltwater interface (Figure 5). Freshwater floats on top of saltwater because it has a lower density (1.0 g/cm^3) than saltwater (1.025 g/cm^3).[68] The line of transition, or zone of dispersion, represents the point where the freshwater (total

[67] Flooding and Historic Buildings, p.2.
[68] Freed, p.180.

dissolved-solids concentration of less than 1,000 mg/L) becomes saltwater (total dissolved-solids concentration of greater than 1,000 mg/L) by the definitions used by the United States Geological Survey. An increased water table and zone of dispersion can potentially affect the foundations of nearby structures at elevations close to sea level and cause moisture and salt accumulation and lead to deterioration and contribute to loss of the foundation's structural integrity. Heritage sites located in salt marshes are especially vulnerable due to their shallow topography and exposure to tidal flooding.

Of all heritage properties, coastal archaeological sites are particularly susceptible to these effects because most lie within inter-tidal and sub-tidal zones.[69] Furthermore, several coastal archaeological sites are often poorly recorded due to limitations in surveying. Some remain undiscovered because either the area has not been surveyed yet or is covered by other deposit layers.[70] Facing direct threats and without good documentation, many archaeological sites, are in danger of being lost forever, and sometimes without anyone ever knowing the true extent of its significance.

Climate change may affect the coastal historic environment indirectly as well. Coastal and flood defense programs could have unnecessary implications on the historic structures, landscapes and archeological sites. In most cases, the coastal historic environment is part of coastal towns, villages and ports, where the overall goal of the defense program often is to simply 'hold the line', which frequently has negative impacts on cultural heritage assets, and do not take into account the effects on individual

[69] Coastal Defense and the Historic Environment, p.5.
[70] Ibid.

entities.[71] Lighthouses, military defenses, and rural buildings known for their coastal character, represent exceptions that may receive individual attention and defense strategies.[72] For the most part, historic properties do not get treated any differently with respect to flood prevention and defense strategies in coastal defense management programs. Historic properties should be considered as separate entities with individual needs, which require acknowledgment and integration into shoreline management planning. The best way to embrace the coastal historic environment's needs and include them in shoreline management planning is to ensure that the information that makes the historic property in need of unique attention, is accurate and readily available.[73]

Certain coastal defense strategies, like 'holding the line', have negative impacts on the historic environment. 'Holding the line' basically refers to beach recharging, a method that can extract insulating aggregate from submerged, offshore archaeological sites or result in the burying of known archaeological sites in the region that is being recharged.[74] 'Advancing the line' can have the same negative impacts, but means to make for a greater barrier between the water and civilization instead of maintaining the original expanse.[75] 'Managed realignment' or 'limited or no interventions' may result in the further flooding or erosion of the historic sites.[76] Different strategies also have the potential to affect the hydrology and groundwater levels in a given area, which could promote new organic

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[71] Coastal Defense and the Historic Environment, p.5.
[72] Ibid.
[73] Coastal Defense and the Historic Environment, p.7.
[74] Coastal Defense and the Historic Environment, p.3.
[75] Ibid.
[76] Ibid.

growth and significantly transform buried archaeological remains.[77] Ultimately, the extent of influence of these strategies lies in their details, which accordingly warrant careful review before enactment. Their operational details should also be considered, as large shipments of additional aggregate could impact underwater archaeological resources.[78]

With respect to the indirect effects of flooding, the approach to historic properties has to be just as cautious after a flood as before it. Building and insurance agencies may put forth certain standards for recovering buildings and landscapes post-flooding.[79] However, the recommended procedures may not be in the best interest for historic properties and may do more harm than good.

[77] Ibid.
[78] Ibid.
[79] Flooding and Historic Buildings, p.7.

3.0 Response to the Climate Change Threats on the Historic Environment

3.1 England's Response

In terms of individual country's responses to this impending threat, England has been very active in researching and evaluating the threat of climate change to the future of historic structures and sites. English Heritage, acting advisory organization on the historic environment for the English Government, has been especially proactive in addressing these issues and initiating and funding studies, research and publications on the topic. English Heritage has also been at the forefront of developing governmental policies on climate change, working collaboratively with other government organizations on reducing fuel consumption and emissions that contribute to climate changes, and ensuring that the impacts on heritage sites are taken into account in the forming of climate change policy.[80]

Multiple reports and pamphlets have been published on the topic by the University College London's Centre for Sustainable Heritage (CSH), established by Director May Cassar in March 2001. May Cassar authored a report entitled *Climate Change and the historic environment*, published in 2005 by the CSH and UCL. The publication is the result of a scoping study on the implications of climate change for the historic environment funded by the English Heritage. The aim of this study was to create a methodology for recording, understanding, managing and assessing climate risk for the historic environment. In addition, the study explored the aspects of climate change that

[80] Climate Change and the Historic Environment, English Heritage, p.6.

may pose the greatest risk to the historic environment, how climate change might impact the historic environment and the mitigation strategies that are available to combat the effects of climate change on the historic environment.[81] The study began in 2002, following the publication of the UKCIP02 climate change scenarios. The original research for the report was primarily carried out by Dr. Robyn Pender and the study concerns the England's entire heritage family, composed of England's built heritage of buildings, landscapes, parks, gardens, as well as England's art compilation of objects and collections.

The report looks at documented climate change in England, such as increased rainfall and drought or higher sea levels, and considers its impact on England's historic properties, particularly archaeological and coastal sites, through various examples with already discernable effects. The report points out important areas requiring more information and research and provides recommendations for further discourse on the impact of climate change on the historic environment. The report defines the goals of the scoping study, identifies available sources information and research on climate change, approximates the susceptibility of England's heritage sites to climate change, uses demonstration maps to recognize sites that are especially vulnerable to climate change, determines how policy could change to reflect this new region of study, and identifies missing links, or areas requiring more research and information, and makes recommendations for future actions. This publication signifies the first explicit connection between climate change and the historic environment in the UK and quite possibly the world. The publication also is

[81] Climate Change and the Historic Environment, Poster.

distinguished for being one of the first written documents to address the impacts of climate change on the built environment in general. The study and report were successful due in part to the strong participation and collaboration of heritage managers, scientists, and policy makers.

The CSH was founded under the collaboration of three UCL departments: the Bartlett Faculty of the Built Environment, the Institute of Archaeology, and the School of Library, Archive and Information Studies. The CSH's definition of heritage contains buildings and landscapes, as well as objects and collections, which may be more or less moveable. The CSH offers a Master of Science Degree in Sustainable Heritage that looks at issues of sustainability in relation to climate change. As a self-acclaimed model for sustainable practice, a small, interdisciplinary team leads the research of CSH and focuses on past, present and future climate as it relates to sustainability and cultural heritage. Under CSH research, the team outreaches to external stakeholders and informs future heritage managers of climate effects.

According to Joel Taylor, one of the CSH research fellows, the CSH was created with an aim to meet a need that did not already exist. The aim was to move between the professional and academic barriers between environmental, architectural, and historic object/collection conservation to create a more unified approach to these issues through participation in collaborative technical research, education programs, publications and consulting. The CSH also aims to encourage the various professional disciplines that are responsible for protecting cultural heritage to come together on issues that threaten the sustainability of cultural heritage. The CSH is the first and only institution of its kind, bringing to light these topics concerning preserving heritage in a changing climate. Already, the CSH has begun to form and complete general plans for responding to climate change in our historic environment.

In January 2007, the CSH hosted an international workshop entitled 'Climate Change Vulnerability: Maps and Guidance for Cultural Heritage Protection' which was held at the University College London's main campus. The workshop presented the findings of the NOAH's ARK project (Global Climate Change Impact of the Built Heritage and Cultural Landscapes) (SSPI-CT-2003-501837), which is supported by the European Commission DG Research under the Sixth Framework Programme. Topics discussed in the workshop included climate change guidelines, the use of climate maps and heritage climate maps, modeling climate change with Hadley Models (HADCM3 and HADRM3), damage maps for different materials, risk and multiple risk maps for different materials, and overarching themes and conditions observed as a direct result of climate change. The workshop closed with group discussions of the guidelines on Cultural Heritage Adaptation Strategies to Climate Change and a panel discussion on the future of cultural heritage in Europe. Future publications from the CSH and outside sources are expected to stem from this workshop.

The NOAH's ARK project was created with the objective of predicting the impact of climate change on built cultural heritage in Europe and providing methods of adaptation to assist site managers and conservationists and to support policy and decision makers. Since its formation, the NOAH's ARK project has studied and predicted the effects of climate change on built cultural heritage over the next 100 years. From this research, NOAH's ARK has identified the most critical risks to Europe's built cultural heritage and has devised adaptation strategies for its cultural landscapes and materials in the form of guidelines and tools. The guidelines intend to address the following subjects: rainwater and drainage infrastructure, effects on structures, effects on materials and indoor and outdoor interactions. Some primary tools include web-based Climate Risk Maps and a Vulnerability Atlas, both of which help to determine the threats in climate change. The results of this research have become the basis for developing policy in climate change response.

With all the discussion on the challenges, climate change related or not, of managing the historic environment in England, organizations have formed to assist in increasing awareness on this topic. One such organization is Historic Environment Local Management (HELM), which was established in 2004 by English Heritage with collaboration and support by the Department for Culture, Media and Sport, the Department for Communities and Local Government and the Department for Food, Environment and Rural Affairs.[82] HELM's main aim is to become an established resource of information and training to aid decision-makers, and build their confidence and understanding in working with the unique needs of the historic environment.[83] HELM also has funding programs that help sponsor publications and training sessions on the topic.[84] HELM's website contains policy, created by English Heritage, on the issues that the historic environment is confronted with and shows case studies to help illustrate

[82] http://www.helm.org.uk/
[83] Ibid.
[84] Ibid.

the breadth and impact of these issues.[85] The website also contains guidance put forth by English Heritage, HELM partners, local authorities, regional agencies and other key organizations. The website divides up the information intended for different types of stakeholders, ranging from elected officials, planners, heritage specialists, owners, transportation engineers, historic site managements, and historic site users in general. There is a specific area of HELM's website that is dedicated to addressing climate change and associated adaptive responses, new building regulations for energy efficiency, new coastal defense policies, and alternative renewable energy sources and policies, and their implications on the historic environment.[86]

English Heritage identifies the state of its historic environment in an annual report, referred to as *Heritage Counts*.[87] *Heritage Counts 2006* represents the 5th edition of the survey. In this annual report, the major trends and challenges facing the historic environment are identified. The 2006 edition focused on the important role of users and communities of historic sites. In the 2004 report, it was acknowledged that "long-term climate change… threatens to impact upon all aspects of daily life, not least the survival of heritage assets." The 2004 report attempted to provide the necessary background information to explore and develop ways of measuring the impact of climate change on the historic environment, which was one of the key questions proposed by the Historic Environment Review in 2002.

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[85] Ibid.
[86] http://www.helm.org.uk/server/show/nav.9255
[87] www.heritagecounts.org

3.2 The International Response

Several international organizations with invested interest in the conservation of cultural heritage have started to recognize the importance of this topic and promote discussion among preservation and conservation professionals through online discourse and conferences. Current President of the ICOMOS, International Council on Monuments and Sites, Advisory Board John Hurd has sent out a call via e-mail for the participation of ICOMOS members in the ICOMOS Scientific Programme on Global Climate Change. An exploratory report, supported by the ISC's, Polar Heritage, Earthen Architectural Heritage and Risk Preparedness, was presented at the meeting of the Scientific Council in Edinburgh in September 2006. Hurd called on all ICOMOS members to register their individual interest if they wish to be involved in discussions of global climate change with the Scientific Council in the future, indicating that ICOMOS is actively planning for future dialogue on the subject matter.

The Association for Preservation Technology International, an organization dedicated to promoting appropriate technologies for the preservation of historically significant sites and structures, has also begun to confront issues of climate as it relates to sustainability in preservation. At APTI's upcoming conference in San Juan, Puerto Rico to be held in November 2007, climate is the theme of one of its conference tracks. The APTI Call for Papers brochure describes the Climate track as an exploration of traditional building technologies that make historic properties naturally green with integrated systems and resilient, renewable building materials, as well as sustainable within its given environment. In addition, APTI's Sustainable Preservation Technical Committee has begun a topic related to climate change within its self-titled forum on APT's Bulletin Board, an online forum to facilitate communication between members of APTI.

As a response to global change in general, the journal Mitigation and Adaptation Strategies for Global Change was established in 1996. The journal publishes various worked-out ideas for countering climate change, including an eight step process for assessing the level of vulnerability of particular areas to the effects of global change. The step by step process (Table 3) involves computer modeling, of which steps 1-3 are intended to take place prior to modeling while steps 4-8 are part of the modeling process and help refine the model.[88] This approach is meant to develop a methodological framework for stakeholders to the ultimate benefit of endangered properties.

There has been recent international press on climate change effects on our cultural heritage. One example is an article entitled "Global Warming Threatens Archaeological Sites, Scientists Say" in The New York Sun in November 2006. The article indicates that cultural heritage sites around the world have endured centuries of wars, vandalism, and natural disasters, they may not be able to survive the impacts of climate change. On November 7, 2006, Tom Downing, who co-wrote "The Atlas of Climate Change," with Kirstin Dow and is from the Stockholm Environment Institute, released a report at the United Nations climate conference that described threats to archaeological sites, coastal areas and other treasured cultural assets. Downing's report said that the ocean would eventually swallow up ancient coastal settlements and have other severe effects on historic entities. The article mentioned that Downing hopes the report will help people

[88] Assessing Vulnerabilities to the Effects of Global Change: An Eight Step Approach.

see that climate change means more than just environmental effects of higher temperatures and more extreme weather, quoted as saying that "All of us will feel the loss of our culture."[89] According to the article, executive director of the United Nations Environment Program, Achim Steiner, believes that "Adaptation to climate change should and must include natural and culturally important sites" and that we cannot respond by simply entrapping sites in a protective bubble or keeping the notable and transportable elements in museums.[90] At the United Nation climate conference, Steiner called upon governments around the world to curtail the extreme rate and potential severe and permanent effects of climate change.[91] The full results of the conference have yet to be seen, but at least climate change's effects on historic and cultural properties have been acknowledge and presented in front of the world's government leaders and environmental decision-makers.

3.3 The United States' Response

Unlike its European counterparts, the United States and other North American countries are still in the beginning stages of addressing long-term climate change and its potential effects on our historic resources. The comparative deficit of research and academic discourse on the subject can be partially attributed to the fact that these North American countries generally have a younger history and therefore a younger, less-extensive collection of built cultural heritage. In addition, although the United States is fairly proactive and accomplished at marketing and selling its history, it cannot compete with

[89] Kennedy, *The New York Sun.*
[90] Ibid.
[91] Ibid.

Europe in capturing the same magnitude of interest and tourist population merely because it does not have the same level of existing artifacts. Simply put, Europe has much older historic fabric and much more of it. With generally more historic fabric, the effects of climate change on its built cultural heritage would likely be more apparent as evidenced by physical effects on or within the historic fabric. In addition, the older the historic fabric, the greater the likelihood that the fabric is naturally more rare and fragile with age, therefore signifying that Europe's built cultural heritage fabric may exhibit more physical effects and at more damaging levels. Hence, a naturally larger number and more intense display of physical effects on historic fabric may have prompted European countries to more closely examine this phenomenon and explain why European countries have embraced the topic of climate change effects on our cultural heritage earlier and to a greater extent the United States.

Although there is little written on the topic of climate change as it relates to our historic environment, the United States has some experience dealing with the effects of climate change. For instance, the Cape Hatteras Lighthouse (Figure 6) in North Carolina for years had been threatened by rising sea levels that had encroached upon the structure. Given its proximity to the ocean, which has increased over time, the lighthouse's foundation, composed of a delicate balance of yellow pine timbers, freshwater, compacted sand, brick, and granite, was always at risk for coastal erosion, saltwater intrusion, and engulfment by the ocean.[92] The lighthouse ended up being the subject of several case-specific designed adaptation strategies, the first one starting as early as

[92] http://www.nps.gov/archive/caha/moving.htm

1930.[93] Many different strategies were attempted at various periods in the lighthouse's history, including the installation of sheet pile groins, walls built perpendicular to the shoreline, and re-stabilizing the beach by adding more sand material from elsewhere and building it up the beach with a sandbag barrier, but these strategies did not have much lasting effect.[94] Several long-term preservation actions were considered, such as the addition of more groins, installation of an encircling sea wall, and the moving of the tower to a safer inland location.[95] Relocation ended up being selected as the best solution and the Cape Hatteras Lighthouse was moved in 1999 about 2,900 feet from its original location, which stands approximately 1,600 feet from the shoreline (Figure 7).[96] The Cape Hatteras Lighthouse ended up being successfully moved with very little consequential damage. Ironically, the new location was the same distance from the shoreline it stood when originally built in 1870[97], leading some to believe that relocation is also only a temporary solution.

Although the level of climate change impact on historic properties is still highly debated, there is no dispute over the fact that cultural heritage assets are generally fragile and have the potential of being damaged or destroyed by much less that a catastrophic event. Historic preservation professionals will need to anticipate the potential threats of climate change to historic resources, understand which properties are at risk and are particularly vulnerable to threats, and prepare to respond if those threats are realized. Organizations in the United States need to plan how they will respond upon recognizing certain historic

[93] Ibid.
[94] Ibid.
[95] Ibid.
[96] Ibid.
[97] Ibid.

entities as high-risk, and whether or not that means saving the historic resource in question. Ultimately, it is essential to develop and understand the time frame in which one can act in order to make the most informed appropriate decisions and proactive interventions before it is too late.

4.0 Introduction to the Case Study: The Abel and Mary Nicholson House

4.1 Intent of the Case Study

To explore one implication of climate change on the historic environment in depth, a case study was undertaken. The case study follows the investigation of how one might employ methods of monitoring the climate change related threat and determine how long before the threat becomes active and starts to deteriorate the historic resource. The selected case study is the Abel and Mary Nicholson House, whose historic brick masonry foundation is suspected to be threatened by and vulnerable to regional water table rise, saltwater intrusion and tidal flooding. The threat of saltwater encroachment cannot be seen, however, that does not mean that it is any less important than a crack on a building. The regional trends could put the foundation at risk to water logging and salt deterioration. Salt deterioration involves the absorption of saltwater in the masonry pores. When the water evaporates, it leaves behind salts that crystallize. Salt crystallization results in the cracking of the masonry pores and destruction of the brick material. Salt deterioration would put the masonry foundation at risk for damage and accelerated deterioration that could result in the loss of the historic fabric and foundation's structural integrity. Knowing the current status and the pace of the impending threat, the position of the water table and salt layer with respect to the building foundations and the rate of relative rise of the water table in this case, would help determine the time frame in which the property stewards have to act before the water and salt from the groundwater reach and cause deterioration of the building foundations, assuming that conditions continue to occur at the same rate they have in the recent past.

As these changes may occur on too long a time scale to be measured in the time available for this paper, the emphasis of this proposed site investigation is on the approach of the problem, the development and assessment of different tools, and the thinking behind the process, rather than ultimately determining the level of threat and developing the time frame as the end result. Before examining the possible methods and tools that one has to work with and that will effectively monitor the progress of saltwater encroachment on the masonry foundation, the building's characteristics, context, history, significance, past and current use and existing conditions, should be familiarized and documented, as in any site investigation.

4.2 Building Context, Description, History and Significance

4.2.1 Building and Site Context

The Abel and Mary Nicholson house (Figure 8) is located in Elsinboro Township, Salem County, New Jersey, in the southwestern portion of the state (Figure 9). Situated on the edge of a tidal marshland, the site is about four miles south of downtown Salem, only two miles east of the Delaware River and located just north of Alloway Creek (Figure 10) and (Figure 11). The site is reached off a half-mile gravel access path (Figure 12) and (Figure 13) from Fort Elfsborg-Hancocks Bridge Road (County Road 624) and it's within tax parcel Block 42, Lot # 13[98]. The house is at latitude 39.52° and longitude 75.48°[99] and part of a 5-acre farmland tract and the house lies on the highest point of the tract[100]

[98] Abel and Mary Nicholson House National Register Application.
[99] http://www.state.nj.us/dep/gis/imapnj/imapnj.htm
[100] Preservation Plan for The Abel Nicholson House, p.7.

(Figure14). The entire site is less than 10 feet above sea level[101] (Figure 15) and is located in the Lower Delaware Watershed Region. The building is surrounded by grass lawn and trees (Figure 16). A particularly large tree shades a large portion of the south elevation of the building (Figure 17). The plot of grass surrounding the site and the access path are surrounded by phragmites (Figure 18), an invasive plant that grows in brackish water[102]. The building is located less than 5 miles northeast of the Salem Nuclear Plants, which lie on artificial island (Figure 19).

4.2.2 Architectural Description

The Abel and Mary Nicholson house is a registered National Historic Landmark, which it applied for in 1999. The original brick structure, built in 1722, is known for its patterned end brick architecture featuring a diaper pattern and date of construction in vitrified brick on the east end gable wall (Figure 20). The 1722 building (Figure 21) is a two-and-a-half story, three bay brick house covered with an asphalt-shingled gable roof, which was originally covered with wood shingles.[103] Two chimneys border the east and west edges of the building, although the west chimney is abutted against the 1859 addition chimney. The brick patterns along the exterior reveal that originally the building had hipped pent roofs above the first floor, which stretched across the entire length of the north and south elevations.[104] Above the basement level, the brick is laid in a Flemish bond pattern with vitrified brick on all sides of the building block except for the east wall, which has the

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[101] United States Geological Survey Quad Map: www.maptech.com
[102] http://www.invasiveplants.net/phragmites/Default.htm
[103] National Historic Landmark Nomination Form, p.5.
[104] National Historic Landmark Nomination Form, p.4.

diapered pattern and is laid in modified English bond. On the HABS drawings, the dark blue headers are labeled "salt-glazed brick". The house is built upon a high, low-fired, unsealed brick foundation and measures about 36 feet - 6 inches by 22 feet in area.[105] The primary access to the house used to be through the south entrance of the 1722 block[106] that is distinguished by its large stoop with seven granite steps and brick sidewalls, laid in common English bond (Figure 22). The old main entrance and front of the house face a branch of Alloway Creek, which was historically the primary mode of transportation to the property at the time of construction.[107] A bulkhead door, located on the south façade, leads to the basement from the outside. From the 1859 addition, one can see evidence of the original frame kitchen remaining in the original 1722 west wall (Figure 23).

Like the 1722 block, the 1859 addition (Figure 24) is also two-and-a-half stories, composed of brick, has wooden-frame, multi-sash windows, supports chimneys on the east and west ends of its gable roof and is laid on a brick foundation. The 1859 addition abuts the west end of the original building, but it does not match the exterior of the 1722 block in several ways. The 1859 addition lines up flush with the north façade and is set back 3 feet on the south façade. In addition, the 1859 roof ridge does not match the one of the original building and lies several feet below it. In fact, the entire addition almost hides behind it and lets the original structure dominate architecturally.[108] In 1859 block, the brick is laid in common bond with eighth course headers and is composed of 6-bays.

[105] National Historic Landmark Nomination Form, p.4.
[106] National Historic Landmark Nomination Form, p.4.
[107] National Historic Landmark Nomination Form, p.4.
[108] National Historic Landmark Nomination Form, p.5.

The 1859 addition has two entrance doors, also with brick stoops and stairs, amounting to a total of three entrances on the south façade. A brick path connects all the entrances on the south façade. An additional brick chimney has been added onto the west façade since the original construction of the addition (Figure 25). William Nelson, the previous owner who built the 1859 addition, also left his mark upon the building with a marble block that had his initials and the 1859 date of construction, placed in the center of the gable. There are two dormers located in the attic on the south façade, but only one on the north façade. The main entrance today is made through the 1859 addition's south door which enters to the kitchen (Figure 26). There are no means of access into the building on the west elevation besides a bulkhead in the south corner that leads into the building.

4.2.3 Building and Site History

The 5-acre tract of land was originally part of a 2,000 acre tract which had direct access to the Alloway Creek.[109] The Abel and Mary Nicholson house was built in 1722 by John Mason (builder) and William Petty (brick layer.)[110] The site's known owners are listed as follows chronological order[111]: Samuel Nicholson (1675-1694), Abel Nicholson (1694-1752), John Nicholson (1752-1820s), Davis A. Nelson (1820s-1852), W.H. Nelson (1852-1864), Davis Nelson (1864-1883), M.A. Wiley (1883-1926), W.H. Shough, H.H. Williamson (1926-1941), Salem National Bank & Co. (1941-1945), Gilbert Harbeson (1945-1964), Gilbert H. Harbeson (1964-1995), PSE&G, Public Service Electric and Gas

109 Preservation Plan for The Abel Nicholson House, p.7.
110 National Historic Landmark Nomination Form, p.10.
111 Preservation Plan for The Abel Nicholson House, Figure 35.

Company (1995-2004) and Salem Old House Foundation (2004-present.) The building is currently vacant.

The construction chronology of the building includes the dates of first construction and major campaigns of subsequent additions/alterations. The construction chronology is listed as follows[112]: In 1722, the main building was constructed with a one-story, gabled roof, and frame kitchen attached on the west elevation. Before 1828, there were three other buildings built on the property and within several feet of the Nicholson House. In 1859, building owner W.H. Nelson constructed an addition that was built onto the west façade of the original building. Before 1887, major alterations were made to the 1722 block concerning the roof, stoop, windows and front door. Between 1859 – 1887, a two-story frame shed roof was added onto the west elevation and a one-story shed was added to the south elevation of the 1859 block. Between 1887 -1940, alternations were made to both blocks and the two story frame shed on the west elevation was removed. Between the 1940s – 1980s, the 1722 block was restored, utilities were installed in the 1859 block, the one-story shed was removed and a fire on the site razed the other farm buildings adjacent to the Nicholson house. After 1995, a new roof was installed on the entire building, select windows and doors are boarded up on the south elevation, and security and fire detection systems are installed, and by 2007 gravel was added to the house's access path to make it easier for vehicles to travel on after poor weather and maintain the grade. For the most part, the Nicholson house remains fairly similar to its original design

[112] Preservation Plan for The Abel Nicholson House, p.2-3.

because there have been comparably so few major campaigns and little interference with the original fabric and design in its 285 year history.

4.2.4 Significance

The Nicolson house is historically significant because it is a monumental example of Delaware Valley's local architecture and well-to-do Quaker residences, which were considered mansions in their own day.[113] Abel Nicholson came to America when he was 3-years-old on the ship Griffin in 1675 with his family.[114] His father, Samuel Nicholson, purchased the 2,000 acre tract of land in what is now known as Elsinboro Township and also purchased a plot of 16 acres in the City of Salem that he donated the land to the Society of Friends for the construction of the first Salem Meetinghouse.[115] When Samuel died, his estate was divided between his two sons, of which Abel inherited his father's homestead and built the Nicholson house.[116] For 75 years, the Nicholson house stood as one of the tallest, largest and well-constructed dwellings in the Salem County countryside.[117] Elaborate and enduring, the Nicholson house portrays social and economic power through the way it is designed and used.[118] The monumental front entrance, flanked by bricks inscribed with the initials of many of the Nicholson's Quaker neighbors, reinforced the importance of movement in and out of the house and evoked the feeling of the area's Quaker elite symbolically observing your entrance into the

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[113] Herman, p.189.
[114] Preservation Plan for The Abel Nicholson house, p.18.
[115] Preservation Plan for The Abel Nicholson house, p.18.
[116] Preservation Plan for The Abel Nicholson house, p.18.
[117] Herman, p.199.
[118] Herman, p.194.

threshold of the house.[119] The Nicholson's house is designed in a form of linear hierarchy with the most important room of the house being the common room, which was purely meant for greeting guests, social entertaining, and as an area for displaying one's wealth and communal authority.[120] Other notable features include the writing closet, located left of the fireplace in the common room, which had a window built into it for light and shelves for holding books. The writing closest is an example of smart and practical design that had the added bonus of being shown off to the neighbors as well as a display of intellect and worldliness. The rest of the spaces were also clearly articulated for means of display and service.[121] Above all, the Nicholson house integrates the Quaker's emphasis on family and community and counters the assumptions that all Quaker architecture was designed to be plain and that the Quakers did not have a material culture.[122] Quite the contrary, the house was regarded as a distinguished display of wealth and permanence among the Quaker community.[123]

The Nicholson house is also a significant example of Quaker and early American architecture because it is one of the few surviving ones and it is also one of the few examples that have been left more or less untouched and preserved with the objective of having as little interference with original material as possible. The same cannot be said for other, more well-known historic properties that have had to be kept in pristine condition and adapt to various tourist needs and expectations over time. Because of its

[119] Herman, p.198.
[120] Herman, p.198.
[121] Herman, p.211.
[122] Herman, p.199.
[123] Herman, p.198.

preserved detail, the Nicholson house is also believed to be the most intact patterned-brick to survive in the United States.[124]

4.2.5 Past and Current Use

The Abel and Mary Nicholson house has been consistently used for domestic purposes ever since it was built in 1722.[125] The dwelling has been vacant since the last private owner and occupier, Sarah Harbeson, who passed away in 1995.[126] Since that time, her family's belongings and furniture have been removed from the house. Despite the installation of an alarm system and a locked gate (Figure 27) at the beginning of the half-mile access path, there have been several incidences of vandalism at the house, with the most recent one occurring on January 6th, 2007.[127] In this case, three juveniles carrying dangerous substances were caught running away from the house after they had broken into the Nicholson house by kicking down the 1722 south entrance door after being unable to gain access, though still damaging the lock, through 1859 south entrance door.[128] They triggered the silent alarm which sent police from Lower Alloway Creek Township.[129]

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[124] Abel & Mary Nicholson House, Salem County Historic Society.
[125] National Historic Landmark Nomination Form, p.3.
[126] Preservation Plan for The Abel Nicholson House, p.19.
[127] From Staff Reports, New Jersey Gazette.
[128] Ibid.
[129] Ibid.

4.3 Existing Conditions

4.3.1 Site Observations and Building Context

The Abel and Mary Nicholson house was not always the only structure on the site. There were three other farms buildings built near the house and more along the access path, as shown in earlier aerial photographs (Figure 28). All of the other buildings on site have since burnt down.[130] Some of the building's foundations can still be seen today according to Ronald Magill, president of the Salem Old House Foundation, the owner of the site. If the farm building held any livestock for an extended period of time, there may be possible contamination of the soil in the area surrounding the house. Contamination of the soil in the immediate vicinity of the house is also possible if there is any leakage of the existing above-ground oil storage tank on the west façade (Figure 29). The oil storage tank rests on a concrete pad that is experiencing major cracking (Figure 30). There could also potentially be unknown stores of oil underground within the area of the site. The oil storage tank supplied oil to be used as fuel to heat the house but may also lead to oil and hydrocarbon contamination of the soil nearby. In either case, soil contamination could result by heating oil leaching into and tainting the groundwater.

There is an existing drinking well on the site that was hand dug, 30 - inches in diameter, and has a built-in pump that enters the house through the cellar's south wall (Figure 31). The water is pumped into a 12-gallon storage pressure tank in the cellar (Figure 32), where water is drawn in from in the plumbing and to the various normal fixtures

[130] Preservation Plan for The Abel Nicholson House, Figure 35.

throughout the 1859 part of the house.[131] There is a waste water pipe that drains to a septic field approximately 33 feet north of the house and exits the building on the north side of the east room cellar wall.[132] The well most likely historically supplied the occupants with fresh water for drinking, bathing and other uses. This well currently is covered by a large, 1-inch thick flagstone cover and the well capping rises about 3-3/4 inches above the ground, making it appear unlikely that surface water can flow into the well. Currently, the water level in the well rises to about 4 feet – 10 inches below the ground level, according to measurements made by a weighted measuring tape. The actual well depth, measured again with the weighted measuring tape, was approximately 10 feet - 4 inches below the ground level. The Preservation Plan for the Abel Nicholson house, researched during 1998, cites the well as being 8 feet – 9 inches deep and 2 feet – 3 inches of water. According to documents included in the Updated Final Safety Analysis Report (FSAR) of the Salem Nuclear Plants, the well was cited as 15 feet deep and 42 inches in diameter. This may refer to the well characteristics at any time between the mid-1960s, when the Salem station's Preliminary Safety Analysis Report (PSAR) was being researched, to 1987, when the FSAR was updated. The Updated FSAR also depicted another drinking well on site that existed along the access path near the location of the burned down farm buildings, but this well has since been filled in with cement, probably around the time that the buildings burned down.[133]

The house receives power to operate its fire protection and security alarm systems from overhead utility electric poles, which run along the access path. The electrical service is

[131] Preservation Plan for The Abel Nicholson House, p.42.
[132] Ibid.
[133] Ronald Magill, Salem Old House Foundation.

connected to the house through the north wall of the 1859 cellar, where an electric panel is located along with the security control panel.[134] When detecting motion or heat at any point throughout the first floor, the security alarm systems notify the Lower Alloway Creek Police Department by sending a signal by telephone line.[135]

There is no drainage system for surface water, or any means of deflecting precipitation away from the building, on the roof, on the ground, or on the building itself. The rain falls from the roof directly to the ground and as a result the building exhibits drip lines along the north and south elevations (Figure 24) and (Figure 26), respectively. The entire site gradually slopes to the southwest as indicated by the topographic maps and survey performed by Gleissner Associates P.C. in 1998. Since the site has a slight slope and is relatively flat, it most likely does not effectively drain surface water away from the house.[136] Moreover, in the Nicholson house's preservation plan, Watson & Henry Associates qualified the site as in poor condition with respect to surface water drainage. The lack of drainage for rain and surface water may explain why the basement is so prone to flooding after a rainstorm.

In the eighteenth century, the tidal marshland surrounding the Nicholson House was reclaimed for agriculture by the construction of low-rise levees or banks.[137] Storms and rising tides have overtopped these levees and banks, and the retreat of agricultural activity has removed the economic impetus for the repair and maintenance of the dike

[134] Preservation Plan for The Abel Nicholson House, p.41.
[135] Ibid.
[136] Preservation Plan for the Abel Nicholson House, p.34.
[137] Sebold, Chapter 4.

system.[138] The dike system has yet to be repaired, which exposes the Nicholson house to direct regional effects and hinders the protection of the Nicholson house site against floodwaters and rising tides.

4.3.2 Description of the Cellar's Existing Conditions

As the level of the house that is closest to the subsurface, the cellar represents an important area to record observations and the existing conditions. The observations are focused on the cellar and divided into overall conditions and specific conditions found in each of the four designated spaces. Two of the rooms belong to the 1722 block and the other two belong to the 1859 block.

The 1722 and the 1859 blocks are connected through a door frame in the basement. Both blocks are composed of two rooms in the cellar and the rooms align with the natural divisions observed on the other floors. Both blocks' cellar spaces can be accessed from a staircase leading to the first floor interior in the northwest corner of the east cellar room (Figure 33), although the 1722 block used to be accessed from an interior staircase previously located in the northwest corner of the east room.[139] Both cellar blocks can be accessed from the exterior by their respective exterior bulkheads on the west façade (Figure 34) and (Figure 35). Both rooms in both of the blocks have arched chimney supports (Figure 36), (Figure 37), (Figure 38) and (Figure 39). The walls in all the rooms have been either coated with an application of mortar wash or have been whitewashed

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[138] Ibid.
[139] Ibid.

(Figure 40). This white coat has faded in some areas of both building campaigns. It is believed that the depth of the building foundations, although presently unknown, may lie relatively close to the water table, since historically builders tended to start constructing the building's foundations right above the water table level.

The cellar is in poor condition overall. Although the brickwork appears to be very durable with time, the cellar walls still have significant evidence of deterioration. On a site visit in mid-October 2006, following a heavy rainstorm, the basement was found flooded (Figure 41) and the sump pump was not working, although it has since been replaced. The cellar is apparently prone to flooding due to poor surface water drainage. On a site visit in early February 2007, following a snowfall, the basement was not flooded but instead was experiencing below-freezing temperatures that froze the exposed soil and left several small blocks of ice on the material fabric. On another site visit at the end of February 2007, a pool of water was found in the interior southeast corner of the 1722 building (Figure 42). The brick courses at the bottom of the cellar walls were typically damp to touch, laden with heavy water staining (Figure 43), and were typically more friable and deteriorated than any other parts of the walls. On the exterior wall near the ground level the mortar joints are typically eroded and cracked and the bricks are often broken and experiencing green staining (Figure 44). A typical condition that is found in the basement is the dark or white discoloration of the brick in the lower part of the wall near the ground, which is found in both building campaigns (Figure 45) and (Figure 46). In some cases a distinguished, horizontal line of white deposits that runs along the entire width at about mid-height of the interior cellar (Figure 47). The line of white deposits, approximately 3-5 brick courses in height, is located just below the halfway point of the height of the wall and is very close to the above-grade/below-grade divide. The white line is emphasized by its contrast with the dark-stained brick located below. The dark-stained brick extends the rest of the length of the wall to the ground. The top part of the white line is less distinguishable because the above layers of brick do not have such a dark stain, but instead are lighter and better described as a faded version of the original brick palette. The preservation plan described the condition of the brick foundations as poor with respect to water penetration.[140]

The 1722 block is composed of brick that is hand-made and low-fired, and unfinished with a soft surface that appears to be fairly permeable to water, although several walls have since been painted over with whitewash or a mortar wash. The brick masonry units are typically 9-½" long, 4-½" wide, and 2-¾" high, following the 1683 law that regulated the size of bricks in the area.[141] The brick was likely purchased by Richard Woodnut, an Englishman who was the only known brick artisan in Salem at the time, according to documents found in the Salem County Historical Society.[142] In the 1722 block, each room has one window on the north ((Figure 48) and (Figure 49)) and south ((Figure 50) and (Figure 51)) walls. The windows on the south façade are stepped down by about 4 courses to perhaps allow for more light to come in, since the south façade naturally receives more direct sunlight in this region.[143] The walls in the cellar of the 1722 block are 17- ¾ inch thick. The 1722 block's west room floor is laid with a single layer of

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[140] Preservation Plan for The Abel Nicholson House, p.36.
[141] Salem County Historical Society, p.25.
[142] Ibid.
[143] National Historic Landmark Nomination Form, p.7.

running bond brick, although some of the bricks are missing and exposing the soil along the east wall (Figure 52). In the east room of the 1722 block, the entire floor is composed of bare, packed soil. The first floor framing is exposed in both rooms. The joists, which are built into the cellar walls, run 21-inches on center in the west room and 30-inches on center in the east room. Several of the joists are damp to touch and are experiencing moisture-related deterioration. To combat the deflection of the floor joists, two steel I-beams that run east to west in each room have been installed since 1950, and are supported by concrete piers. All of the steel I-beams are corroded. An expired duck (Figure 53) was found on the floor during the first site visit in February 2007, indicating that wildlife is able to enter the house.

The 1859 addition is composed of brick that is also unfinished but mostly covered with a whitewash or mortar wash. The brick masonry units are typically 8 ½" long, 4-¼" wide, and 2-¼" high. The cellar floor is composed of a single layer of running bond brick and the walls are 14-inches thick in the 1859 addition block.[144] The wall thickness is different from the 1722 because it is composed of a different type of wall construction and the 1722 block has a built in water table that runs along horizontally on the façade and ends right above the cellar windows (Figure 54). The north ((Figure 55), (Figure 56) and (Figure 57)) and south ((Figure 58) and (Figure 59)) walls of both rooms are similar except that the east room contains two windows on the north and south wall, while the north and south walls of the west room only contain one window each. The west room of the 1859 cellar is filled with a 20th century mechanical equipment (Figure 60) and a water

[144] HABS Drawings.

pump (Figure 61). The west room also contains a steel I-beam to reinforce against the deflection of the floor joists. In the southeast corner of the east room, there is a red tile cylinder pipe in the floor which may be intended for drainage (Figure 62). The pipe is presently filled with miscellaneous pieces of brick and other materials. The wooden joists and first floor framing are exposed in the west half of the cellar as well. In the east room of the 1859 addition, the joists are laid 19-22 inches on center and are higher up the wall than the joists in the west room, which are laid 17-19 inches on center. All of the joists are built into the brick cellar wall and have moisture-related deterioration.

4.3.3 Regional Characteristics

4.3.3.1 Climate

The Engineering Weather Data provided by the Air Force Combat Climatology Center (AFCCC) from Dover, DE, recorded between 1976-1996, gives us insight into the typical weather experienced at the site. The city of Dover, Delaware data was used because it is the closest city to the site with this level of record data. In general, the area experiences warm, humid summers and cold winters with rain, snow and ice.

The highest mean temperatures are in the high 70's °F and are experienced during the months of July and August.[145] The highest mean dew-point also occurs during these two months and is in the high 60's °F. The coldest month is January which has an average daily temperature of approximately 32°F and experience the lowest dew-point that is just

[145] AFCCC Engineering Weather Data, p.2.

above 20°F. The precipitation ranges from about 3 to 4.5 -inches across the entire year. Precipitation is fairly even across all seasons but the most rainfall appears to occur during the summer time, although the months of March, May and December typically experience high levels of precipitation as well. The humidity levels are highest during the summer months as well and the annual average is at 70%.[146] There are annually 4,773 mean heating degree days, typically dominating from October to May, compared to 1,224 mean cooling degree days, typically dominating from June to September.[147]

Solar radiation, which is strongest during the summer months (highest at 2600 Btu/sq.ft./day for the month of June), is highest on the south façade for the un-shaded structure in this area.[148] However, the Nicholson house is shaded by a large tree on the south façade, so it may not receive as much sunlight as it could and may not dry out well after wetting on that façade.

This area of Delaware and southern New Jersey is frequented by is frequented by Polar Canadian air masses in the fall and winter and occasionally invaded by Arctic Canadian air late in winter.[149] During the spring and summer, the dominant air mass is Maritime Tropical.[150] The site's terrain is open and extremely flat with little obstructions which allows a vigorous wind flow. Prevailing winds on a monthly average during the winter (December to February) are from a northwest direction with a range of speeds from 1 to

[146] AFCCC Engineering Weather Data, p.11.
[147] AFCCC Engineering Weather Data, p.13.
[148] AFCCC Engineering Weather Data, p.15.
[149] Updated Final Safety Assessment Report for Salem Units 1 and 2, Chapter 2.
[150] Ibid.

greater than knots, though the typical range is 6 to 24 knots.[151] Average monthly winds for the spring months (May to June) typically originate from the northwest and southwest direction, although some more minor winds come from the southeast direction as well. The northwest and southwest direction experience wind speeds ranging from 1 to 34 knots, and typically range between 6 to 24 knots. The southeast winds also range from 1 to 34 knots but typically range between 6 to 14 knots. Average monthly winds for the summer months (July to August) are from the southwest direction and wind speed ranges from 1 to 24 knots and typically fall between 1 to 14 knots. Average monthly winds for the fall months (September to November) are from the northwest and southwest direction and range from 1 to 34 knots and typically fall between 1 to 14 knots.

4.3.3.2 Background for Geological Characteristics

Before going into the site's surface, sub-surface and hydrological characteristics, it may be useful to explain some of the basic concepts and terminology used in describing the geology and groundwater formations of various sites.

The characteristics of the United States' hydrologic systems are extensively documented and well-known thanks to the efforts of the United States Geologic Survey (USGS). The U.S. Geologic Survey is primarily responsible for both assessing the Nation's water resources and understanding them well enough to predict the environmental consequences of changes in development and management of those resources. In partnership with individual states and local agencies, the USGS consistently monitors the

[151] AFCCC Engineering Weather Data, p.17-18.

quantity and quality of the Nation's water supply and the impact of both natural and man-made forces on our water resources through the conduction of various studies. The data and results collected from these studies are made available to the public in published reports, presentations, interactive websites and responses to specific inquiries.

Groundwater occurs in the layers of soil and rock that make-up the Earth's crust and therefore groundwater is studied under the domain of geology. The United States' geology is extremely complex and, naturally, so is its groundwater. Since groundwater is so intricate and variable, it is very difficult to understand the mechanics and dynamics for individual locations without doing specific subsurface site investigations. Understanding the characteristics of groundwater requires an understanding of the geology it is layered within. This includes the type of rock or soil, which is the deterioration product of rock, and its water-bearing characteristics, like the volume of openings and their interconnectedness, which depend on the rock's mineral composition, geologic age and overall structure. Hydraulic conductivity, the rock's ability to transmit water, is one of the characteristics of the rock that is very important to helping identify groundwater flow properties. Hydraulic conductivity is typically expressed as the volume of water that would be transmitted through a unit cross-sectional area of rock under a unit slope over time.

Groundwater is below the earth's surface and occurs in two different zones. The shallowest zone, the unsaturated zone, contains both water and air in the voids of rock layers and can range anywhere from less than a meter below ground surface to over 100 meters. The saturated zone is located directly below the unsaturated zone and is identified by having only water in the rock's interconnected pores. Near the upper part of the saturated zone, the water in the pores is under pressure equal to the atmospheric pressure, and this water level is called the water table; hence, a given rock's porosity is very important in determining the amount of water a rock can hold and dictating the water table level in the ground. The strong surface tension of water supports the capillary fringe, which occurs in the saturated zone above the water table. Below the water table lies what is actually referred to as groundwater. Groundwater may be composed of both freshwater and saltwater. Since freshwater is less dense than saltwater, it typically lies in a separate layer above the saltwater. The elevation where the freshwater becomes saltwater is called the zone of dispersion. A diagram of the different components of groundwater is shown in Figure 63). Groundwater can be extracted from this area by wells, seeping, springs or other means. Groundwater can be recharged by precipitation that falls down on the land surface and percolates through the unconsolidated zone to the saturated zone. When water reaches the saturated zone, it follows the lateral path downward created by hydraulic gradients, or difference in elevations creating a natural slope, in the groundwater system by gravity until it reaches a discharge area. Hence, the movement of water from recharge areas to discharge areas is most often controlled by hydraulic gradients.

Some saturated zones have high enough hydraulic conductivity values that they are capable of supplying water in large quantities to sufficiently support springs or wells. These saturated zones are called aquifers and act as pipelines that transport groundwater from recharge areas to discharge areas. Other saturated zones, that have low values of hydraulic conductivity, are referred to as confining beds, or aquitards. An unconfined aquifer is an aquifer that is underlain, and not overlain, by a confining bed, so water can freely infiltrate the ground surface and collect in the aquifer. An unconfined aquifer does not fill all the rock's opening with water and instead has both a saturated and unsaturated zone, which range in thickness over time in relation to each other.

The Earth's surface is generally underlain by a layer of unconsolidated rock deposits, which are underlain by a layer of consolidated rocks, known collectively as bedrock. Although the unconsolidated rock layer is typically only a few meters thick, certain areas of the nation have significantly larger areas of surficial areas of unconsolidated deposits, like the Atlantic Coastal Plain. Groundwater in different areas is typically classified by the following: their composition and arrangement; the porosity of the dominant aquifers within respect to their origin, mineral composition of the dominant aquifer with respect to solubility; water storage and transmissivity of the dominant aquifer, and the nature and location of recharge and discharge areas.

Groundwater is one of the most widely available of all natural resources and is an important factor in economic growth. In rural areas, groundwater is often the dominant source of water, although urban districts rely on groundwater as a large source of its water as well.

4.3.3.3 Surface Characteristics

The site lies within the Middle Atlantic Coastal Plain, whose surficial layer consists of unconsolidated sediments that are composed primarily of tertiary sand, silt and clay that is transported by streams from higher regions along the plain. The Middle Atlantic Coastal Plain is a linear eco-region covering approximately 34,630 mi^2 that stretches from Delaware Bay and the Delmarva Peninsula in the north to nearly Jacksonville in the south and lies within the Delaware estuary.[152] The region contains flat and coastal swamps and marshes that lie about 3 to 7-feet above sea level.[153] According to topographic maps of the site provided by Maptech, Inc., the entire site is under 10' elevation above sea level and very flat. Many soil types in this region are poorly drained and have low levels of permeability.[154] The land cover is primarily a mosaic of forest, wetlands, and agriculture.[155]

4.3.3.4 Subsurface Characteristics

The site is underlain by an extensive surficial layer of unconsolidated deposits that is thousands of meters thick consisting of gravel, silt, sand, clay and limestone.[156] The area has experienced land subsidence as part of a natural process involving the consolidation of the loose sediments, which may partially be due to the over-pumping of area aquifers, depleting the groundwater that helps keep the unconsolidated sediments level.

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152 Updated Final Safety Assessment Report for Salem Units 1 and 2, Chapter 2.
153 Heath, p.52.
154 Ibid.
155 Ibid.
156 Heath, p.52.

According to the USDA Natural Resources Conservation Services, the building is built on OTMA Othello, Fallsington and Trussum soils with 0 to 2 percent slopes. Directly surrounding the site is soil MbuB, Mattapex silt loam with 2 to 5 percent slopes. Both types of soils are deemed very limited in supporting a building with a basement due to the shallow depth to the saturated zone, as indicated by the highlighted red area in the map from the National Soil Survey in (Figure 64).[157] Both soil types have a high risk of corrosion with concrete and uncoated steel and have a high potential for frost action.[158] Both soil types have relatively low permeability of 0.20-0.63 inches per hour.[159] MbuB has a liquid limit of 23-43% and plasticity index 7-18 for the first 9 inches of silt loam.[160] OTMA has a liquid limit of 21-33% in the first 1-13 inches of silt loam (the first inch is characterized as Mucky peat.) MbuB is composed of approximately 14.2% sand, 71.8% silt and 14.0% clay. OTMA Othello is composed of approximately 30.0% sand, 60.0% silt and 10.0% clay. OTMA Fallsington is composed of approximately 45.0% sand, 40.0% silt and 15.0% clay. OTMA Trussum is composed of approximately 43.2% sand, 38.8% silt and 18.0% clay.[161] According to the American Society of Testing Materials (ASTM) standards, sand consists of aggregate particle sizes ranging between 0.075 – 4.75 mm and silt consists of finer aggregate particle sizes that are less than 0.075 mm. Clay consists of the very fine particles found in silt and water that bonds to the particles through electrostatic forces. According to i-MapNJ GIS mapping program found online,

157 USDA Natural Resources Conservation Services, National Soil Survey.
158 Ibid.
159 Ibid.
160 Ibid.
161 Ibid.

the site is uncontaminated. Ultimately, this soil is not the ideal platform to support the Abel and Mary Nicholson House or any kind of structure.

4.3.3.5 Site Hydrology

The underlying bedrock aquifer is (Ccua Composite confining unit aquifer.)[162] The regional direction of ground water movement is toward the branches of the Alloway Creek. On the Nicholson house site, the groundwater is expected to move from north to southwest and into the adjacent marshland, based on the site topography. Movement of groundwater though the site is quite low as a result of the comparatively low coefficients of permeability and the low hydraulic gradients.[163] The hydraulic gradient of the aquifers at the site is too small to measure[164] and down-dip thickening of clay layers interrupts the governing of groundwater movement solely by hydraulic gradients.[165] Based on these facts, it is probable that the only groundwater movement at the site is a result of tidal influences.[166] Hence the tidal flow, which greatly exceeds the runoff flow, likely dominates the flow velocity at the site. In the 1980's, the normal daily range in the height of the tide at the site was up to 5.8 feet.[167] One problem that affects the groundwater in this region is the increasing prevalence of saltwater in previous freshwater regions and aquifer. This phenomenon is more explicitly explained by the

[162] I-Map NJ.
[163] Updated Final Safety Assessment Report for Salem Units 1 and 2, Chapter 2.
[164] Ibid.
[165] Heath, p.52.
[166] Updated Final Safety Assessment Report for Salem Units 1 and 2, Chapter 2.
[167] Ibid.

relatively recent environmental changes that have been occurring in and around the Delaware estuary.

4.3.3.6 Sea Level Rise and Salt-water Intrusion in the Delaware Estuary

The Delaware Bay and the estuary of the Delaware River, which extends inland as far as Trenton, have been formed by post-glacial era sea level rise.[168] The total area of the estuary is 13,000 square miles and includes regions in New York, Pennsylvania, New Jersey, and Delaware.[169] It is estimated that the sea has risen approximately 300 feet since the retreat of the glaciers.[170] Sea level rise in the area is demonstrated in a chart depicting mean sea level rise trends over the course of several decades in Philadelphia (Figure 65). Relative sea level rise is able to be measured and calculated from tide-gauge data taken from five monitoring locations that are located along the mid-Atlantic coast. These five locations are Sandy Hook, Atlantic City, Cape May, Battery Park, and Lewes.[171] The data is collected and interpreted by the National Oceanic Atmospheric Administration (NOAA).[172] Based on measurements taken in 2004, Sandy Hook experienced an average increase of 3.88 mm/year, Atlantic City had an average increased of 3.98 mm/year, Cape May had an average increase of 3.98 mm/year, Battery Park had an average increase of 2.77 mm/year and Lewes had an average increase of 3.16

[168] Hull and Titus, p.6.
[169] Hull and Titus, p.9.
[170] Hull and Titus, p.6.
[171] Cooper, Beevers, and Oppenheimer, p.5.
[172] Cooper, Beevers, and Oppenheimer, p.5.

mm/year[173]. All of the rates were average together to get a value of 3.53 mm/year as the average sea level rise for the state of New Jersey, which is twice the rate of the global average sea rise.[174] The relative sea level rise is also made significantly larger due to land subsidence and sediment compaction of the Mid-Atlantic Coastal Plain.[175] On top of that, the sea level rise has the potential to reshape the perimeter of Mid-Atlantic Coastal Plain, given its flat, low elevation. As mentioned in early chapters, higher sea levels could result in an increase in the frequency of severe storms and greater damaging impacts on the shoreline in the form of floods. The damage may also be experienced by neighboring regions, which may have previously not felt the effects of the storms and may not be sufficiently prepared against them.

The Delaware Estuary has attracted some attention over the past several decades because of the relatively recent changes it has experienced in sea and salinity levels and how the changes might be related to the greenhouse effect. In a joint report by the Environmental Protection Agency and the Delaware River Basin Commission, the implications of a global average sea level rise of 21-inches by 2050 and 7-feet by 2100, which were the accepted predictions at the time the report was published. The global average sea level rises would coordinate to Delaware River rises of 2.4-feet and 8.2-feet respectively, assuming the current relationship continues. The study does not take into account changes in precipitation. In this report, the authors form conclusions about the expected increase in estuary salinity and possible increase of the salt concentration of the Potomac-

[173] Cooper, Beevers, and Oppenheimer, p.5.
[174] Cooper, Beevers, and Oppenheimer, p.5.
[175] Hull and Titus, p.i-ii.

Raritan-Magothy aquifer system. The report discusses the implications of these changes and looks at possible means of response. The report made the following conclusions[176]:

1. Sea level rise could substantially increase the salinity of the Delaware estuary in the next century.

2. Accelerated sea level rise could cause excessive salinity concentrations at Philadelphia's Torresdale intake if no countermeasures are taken.

3. Accelerated sea level rise could threaten the New Jersey aquifers recharged by the Delaware River.

4. Planned but unscheduled reservoirs could offset salinity increases expected in the next forty years.

5. Possible shifts in precipitation resulting from the greenhouse warming could overwhelm salinity increases caused by sea level rise.

6. Uncertainties regarding future climate change do not necessarily imply that waiting for better predictions is the most prudent strategy.

7. A regional study should be initiated that examines the potential impacts of precipitation changes as well as sea level rise for the Delaware estuary and adjacent river basins.

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[176] Hull and Titus, p.i-ii.

A projection of the Delaware's and New Jersey's coastal zones geography for a sea level rise of 20 feet shows the difference between the current coastline and the future coastline and the respective areas of marshland and beach areas (Figure 66).

As defined by the USGS, saltwater has a total dissolved-solids concentration that is greater than 1,000 milligrams per liter (mg/L) or ppm (parts per million).[177] Seawater has a total dissolved-solids concentration of approximately 35,000 ppm and it is mostly composed of chloride, at approximately 19,000 ppm.[178] Freshwater is defined as having a total concentration of dissolved salts as less than 1,000 ppm.[179] Saline water can be broken up into three levels of salt concentrations: slightly saline water from 1,000 – 3,000 ppm; moderately saline water from 3,000 – 10,000 ppm; and highly saline water from 10,000 – 35,000 ppm.[180] In fresh groundwater along the Atlantic coast, the chloride values are expected to be less than about 20 ppm, which makes for a large, distinguishable difference between saltwater and freshwater when comparing their chloride concentrations.[181] The occurrence of salt water is actually controlled by the movement of freshwater.[182] Freshwater, being less dense than saltwater, floats on top of the saltwater and the line of transition represents the point where the freshwater becomes saltwater (at a total dissolved-solids concentration of greater than 1,000 mg/L) by the definitions used by the United States Geological Survey. This transition line is often referred to as the salt line or the zone of dispersion. The EPA drinking water standard

[177] Barlow, Box A.
[178] Ibid.
[179] Ibid.
[180] Ibid.
[181] Ibid.
[182] Heath, p.55.

states that the maximum allowable chloride concentration for drinking water is 250 ppm (parts per million.) The maximum allowable sodium concentration is 50 ppm, and chloride concentrations that are greater than 78 ppm generally exceed the sodium standards because the chloride elements are attached to the sodium elements (NaCl).[183] There are different standards for different uses such as water used for irrigation instead of human consumption.

Chloride concentrations in the Delaware estuary have been measured since the 1960's by the Delaware River Basin Commission (DRBC), which has set up automatic monitoring sites along the river to take readings of chloride concentrations on a daily bases.[184] This allows the DBRC to keep track of the movement of the salt line, or the interface between the freshwater and saltwater when the water has a chloride concentration of 250 ppm or higher.[185] The DBRC uses daily mean specific conductance data from the USGS, in addition to its direct chloride measurements, to help with calculating the salt line.[186] The salt line is directly impacted by the weather and time of year. During the winter and spring when the area has more rain and snow, the salt line is found further downstream. During the summer, when the area is drier, evaporation rates are faster and the water use demands are higher, the salt line progress further upstream.[187]

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[183] Hull and Titus, p.ii.
[184] Santoro, p.14.
[185] Santoro, p.14.
[186] Santoro, p.14.
[187] Santoro, p.14.

It is the flow of freshwater through streams and toward the ocean that prevents low-lying area water networks from having the same salt concentration as the ocean.[188] Increases in the salinity of the Delaware estuary and its movement upstream by saltwater intrusion could convert some of its existing coastal freshwater wetlands into salt marshes. This could render some previously-used water resources for residential, agricultural and industrial purposes obsolete. This phenomenon is quite common when a drought occurs and freshwater flow decreases and allows the saltwater line to progress further inland. When combined with sea level rise, saltwater may be able to penetrate coastal freshwater aquifers.

For example, there was a drought in the region containing the Delaware estuary in 1964, which resulted in increased chloride concentrations in the river water to 150 ppm (parts per million).[189] Since the freshwater flow was low, the salt water from the river recharged the Potomac-Raritan-Magothy aquifer and increased its levels of chloride concentrations.[190] The Potomac-Raritan-Magothy aquifer is a great supplier of freshwater to the greater Camden area and other communities in New Jersey.[191] The Potomac-Raritan-Magothy aquifer is a major freshwater resource and is normally recharged by freshwater areas of the Delaware estuary, but when the water is being pumped out faster than water is coming in, like during a drought, the aquifer is recharged by salt water instead. As a result, several drinking wells that draw from this aquifer were contaminated. Even though this contamination occurred almost 50 years ago, salt water

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[188] Cooper, Beevers, and Oppenheimer, p.13.
[189] Hull and Titus, p.i.
[190] US National Assessment of Potential Consequences of Climate Variability and Change, Rising Sea Levels.
[191] Ibid.

has still been observed in the aquifer.[192] Future droughts and episodes of low freshwater flow could trigger the contamination of this aquifer by salt water again. If this drought occurred with a 2.4-foot rise above the sea levels in 1986, then the river water may reach chloride concentrations as high as 350 ppm.[193] If this drought occurred with an 8.4-foot rise above the sea levels in 1986, then 98% of the recharge would be greater than 250 ppm and 75% of the recharge would be greater than 1000 ppm.[194]

4.4 Potential Impacts of Saltwater Encroachment on the Nicholson House

The combination of rising sea and salinity levels, failed levees and land subsidence in the vicinity of the Nicholson house presents serious potential long term threats to the structure. Given that the house lies on a plot of land that is less than 10-feet above sea level and about 2 miles from the Delaware River and within the Delaware estuary, it is suspect to have future problems with salts getting into the foundation through the groundwater and being overcome by progressing marshland.

Damage to the historic fabric of the Nicholson house due to salts that were drawn up from the groundwater can occur in the building could occur in the following manner. Due to the height of groundwater in the area rising, the zone of dispersion, or the vertical interface between freshwater and saltwater, rises as well. The salts that are in the groundwater may get into the foundations of the Abel and Mary Nicholson house if the water table or capillary fringe rises high enough to meet the level of the building's

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[192] Ibid.
[193] Ibid.
[194] Ibid.

foundations. The water table separates the zone of saturation, where the ground is completely saturated and water can move freely, from the zone of aeration, where the ground's pores are full of water and air. The capillary fringe is the zone of soil immediately above the water table that sucks up and retains water from the zone of saturation by capillary action in which the pores in the soil act like capillary tubes. The smaller the pore, the higher the water rises. The total rise depends on the soil characteristics including the average pore size and interconnectedness. If the water table or capillary fringe rise to the level of the building's brick foundations, it is possible that the brick foundations could soak up the saltwater by capillary action and surface tension of water (water's natural attraction to other surfaces as opposed to other water molecules) of into its own pores and allow the saltwater to distribute itself in the masonry walls and foundations through rising damp. Of course this all depends on how high the zone of dispersion is in the groundwater and if there is enough water to feasibly carry the dissolved salts into the brick foundation.

Once the salt is within the brick material it has the potential to cause major damage once it comes out of solution. When the wall dries, the water evaporates from the brick's surface but leaves behind the salts on the brick's surface in the form of a white powdery salt substance known as efflorescence. In this case the salts can simple be brushed off the surface of the brick and no harm will be done to the material. However, if the water evaporates and the salt crystallizes within the pores of the brick material, known as sub-efflorescence, the salt crystals can expand to beyond the pore size and destroy the brick pore structure. In turn, this leaves more room for salt in solution to be held, and potentially more damage to the brick material, in the future. The same might also happen under extremely cold conditions, where the saltwater freezes, crystallizes and expands to a point where the brick material is destroyed. This results in the spalling of the brick's surface or destruction of material inside the brick as well. Over time, this pattern could destroy significant portions of the historic fabric and weaken the brick material that composes the foundations and cellar walls, reducing their structural capacity. Without intervention, this could lead to the eventual collapse of the structure if the structural components cannot support the loads that it once could. Taking into account the effects of long-term groundwater moisture exposure on the foundation, it is safe to assume that the salt migration through the groundwater into the Nicholson house masonry foundations by capillary action and rising damp could eventually lead to the deterioration and eventual loss of the house if left untreated.

There is also the possibility that salt in the groundwater may not be the Nicholson house's greatest threat. The encroachment of the marshlands on the property is another threat that has to be considered. If the water table rises significantly so that it surpasses the level of the building foundation and cellar floor, the Nicholson house may be more threatened by water-logging and upward heaving as opposed to deterioration by salts in the water because water-logging would trigger a faster decay mechanism. This could also mean different consequences for different parts of the basement because the cellar floor is composed of two different materials in different rooms of the building. For instance, the east room of the 1722 building has an exposed earthen floor while the majority of the other rooms are covered with brick floor. If the water table rises above the cellar floor in the 1722 east room, the water will most likely leach freely into the cellar. This may result in more moisture problems for the Nicholson house, but should have very little effect on its structural integrity. As for the rest of the cellar, the water will likely accumulate under the basement floor and could possibly make the brick floor buckle under the pressure and lead to subsequent flooding. Another possible problem could arise, if the groundwater below the building is moving and not static, the unconsolidated particles below the foundation and footings may be transported away by the moving water and the building could be left unsupported. In this instance, the building foundations may settle unevenly or collapse based on the location and size of the voids that have formed. Furthermore, brick foundations are generally more porous and subject to material degradation. A prolonged moisture exposure to brick has the potential of gradually turning the brick back into the clay from which the brick was first made.[195] Therefore, the encroachment of marshlands and the water table level in general is also a perceived threat to the Nicholson house. At this time, it cannot be determined which threat is more imminent and which threat could result in the most severe consequences.

4.5 Indicators of Saltwater Encroachment

Although the building fabric currently exhibits no visual evidence of salt presence, there are several key indicators of saltwater encroachment in the area around the Nicholson house. For instance, the site's proximity to the Delaware River put it in a position of where it can be easily affected by events and trends occurring in the river. In addition, levee and dike failure in the area has re-exposed the site to the direct effects of tidal

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[195] Friedman, p. 52.

flooding and saltwater encroachment from the Delaware River. Furthermore, changes in the vegetation in the area may also indicate a change in groundwater composition which could likely be caused by an increase in salt concentration. For example, there are dying trees around the house and the trees may be dying because the tree is unable to survive a change in the groundwater composition. The dying trees can be differentiated by their lack of leaves and minor branches when compared to other trees in the surrounding area during the late spring, summer, and early fall. Dying trees represent that there could have been a change in the groundwater composition, although it is also possible that disease, lack of water or some other mechanism could be killing them. The prevalence of phragmites (common reed), which is an invasive wetland plant species that is typically found along the eastern United States, around the property is also indicative of the groundwater composition. Phragmites typically grow and thrive in saltwater-infiltrated regions. Recently, there has been an outbreak of phragmites in the area surrounding the Nicholson house and this may indicate the extent of saltwater encroachment on the site and the salt concentrations levels of the groundwater.

4.6 Case Study Justification

The Abel and Mary Nicholson house was chosen as a case-study for several reasons. For instance, with several observed indicators of saltwater intrusion on the area, combined with actual data from reports on the Delaware Estuary verifying that this phenomenon is occurring, it seems that is not a matter of "if" but rather a matter of "when." Hence, there is visual and documented evidence that this threat of saltwater encroachment is real and active. Since there has been such good geological documentation and associated analysis of this area by governmental organizations, through various reports and investigations, the data is readily available, trusted and accepted as verifiable fact. Furthermore, the Nicholson house is particularly susceptible on many levels, given its foundation's position relative to the groundwater level and the age and vulnerability of the unprotected, hand-made, low-fired brick foundation. Finally, the Nicholson house's history and significance make it an irreplaceable, exceptional example of historic architecture that is worthy of attention and concern about its future and its preservation for future generations.

5.0 Proposal and Analysis of Methods for the Case-Study

5.1 Introduction to Proposed Methods and Methodology

To assess the level of threat of saltwater encroachment on the Abel and Mary Nicholson house site, a methodology needs to be developed and explored. It is essential to identify the information that present and future stewards of the Nicholson house need to know to protect the house from the possible threat of saltwater encroachment from rising tidal levels, or breached levees, in the Delaware Bay. Once the type of information is identified, applicable tools and methods can be developed to measure and monitor those variables over a specified period of time. The following variables need to be measured and/or monitored in order to properly evaluate the threat of saltwater encroachment on the Nicolson house's historic masonry foundation:

1. Groundwater level.
2. Groundwater salinity content.
3. Direction of groundwater flow.

A fourth variable, the depth to building foundations, is associated with the groundwater level variable since it is not a variable that changes over time and more effectively serves as a benchmark that is compared to the groundwater level. The tools and methods should be developed with aims to measure and monitor these variables. Other background information about the materials and soil characteristics, as well as environmental conditions, may also need to be included in the analysis of the threat.

All tools and methodologies involve preliminary acquisition and analysis of existing site information. The following tools and methodologies for monitoring the variables of the saltwater encroachment threat were researched and applied to this case study: comparison of aerial photography over time with cross-reference to a topographic map, installation of test pits and laboratory salt ion testing of well water, installation of monitoring wells and laboratory salt ion testing of well water, and modeling saltwater transport and groundwater flow using Groundwater Modeling System (GMS) applications. Methods for determining the depth of the building foundations were not evaluated on their effectiveness for measuring the variable since the variable is associated with fully evaluating the groundwater level variable.

All tools and methodologies were assumed to take place over the course of one year, whether through constant monitoring, periodic measurements or single measurements. In some cases, the tools were unable to be applied due to time constraints, complexity, and uncontrollable circumstances. The cost, resolution, accuracy, precision, availability, complexity, durability, and time requirements of the methods will all be important evaluation criteria to consider for determining the effectiveness of tool and method in obtaining the value of each variable. Ultimately, it is pertinent to find out if any of these methods are effective in measuring the presence and rate of saltwater encroachment for this specific case and if the methods could be applied and effective in other similar cases by historic site stewards.

Prior to employing any tools in this methodology, the building history should be documented and a building survey of the existing conditions and the surrounding site should be performed. This will help determine whether or not the historic property is indeed at risk for saltwater encroachment and exactly what aspects of the threat or the historic entity make the property particularly vulnerable to that risk. Historic property stewards will have to decide for themselves or consult with practicing professionals to determine if any of these proposed methodologies are applicable to their particular site.

5.2 Acquiring and Analyzing Existing Information

Examination of the historical and existing terrain and sub-terrain surrounding the property will assist in the analysis of the historic site for saltwater encroachment. Information about the historical terrain and sub-terrain of the property can be found in old construction documents which are often accessed through archival research or historic city records. Information about the present terrain and sub-terrain of the property is made available through a variety of sources including geologic and hydrologic reports and journals, topographic surveys, soil surveys and maps. Comparisons between the historic and present terrain and subterranean conditions can provide valuable information about long term trends in the evolution of the landscape surrounding the historic property.

5.2.1 Understanding the Historic Terrain and Sub-terrain

Depending on the age of the building and the preservation of its building documents in archives or municipality records, one may have access to existing documents like construction or rehabilitation documents, as-built plans, older site maps, sanborn maps or old aerial photographs that may reveal the characteristics and nature of the historical terrain on the site.

Original building plans or as-built plans that are intended for original building construction or a rehabilitation campaign, usually show the locations and material characteristics of supply lines, sanitary sewers, perimeter drains, roof drainage, land surface drainage and other aspects of the overall site drainage system.[196] Original building plans or as-built plans can usually be found in local archives, historic societies or building department records of the historic site's municipality. Older site maps can usually be accessed through a neighboring county historical society. Older site maps often reveal the site's previous hydrology including the locations of stream beds, abandoned reservoirs, drinking wells, marshland, and alterative water courses and man-made access points. Older site maps are also usually found in local archival institutions, historic societies or municipality records. If available, sanborn maps can be helpful in showing any previous construction that occurred on the site prior to when the historic property was built. They can also disclose the locations of old privies and cisterns on site. Sanborn maps can usually be found in the map departments of county or city libraries.

Old aerial photographs can show former patterns of vegetation, stream orientations, water body locations, and any visible anthropogenic influences.[197] Such photographs are often kept by county clerk's offices or a given state's Department of Environmental Protection

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[196] Harris, p.170.
[197] Freed, p.104.

(DEP). Old aerial photography was typically taken from military aircrafts for federal agencies and defense purposes. Now the aerial photography is mostly made available to the public through the Cartographic and Architectural Branch (CAB) of the National Archives, as well as individual state departments. With aerial photographs one can perform a fracture trace analysis on the site. A fracture trace analysis involves interpreting lines of fracture in bedrock through observation of the tonal variation in soil, alignment of vegetative patterns, straight stream segments or stream valleys, aligned surface depressions or gaps in ridges.[198] The fractures could indicate a surface expression of joints, zones of joint concentrations or faults.[199] A fracture trace analysis must always be double-checked for misleading features that could be fences, roads, and planted tree-lines.[200] A fracture trace analysis can only be performed in areas which have a small surficial layer of unconsolidated deposits. Tonal variation of the soil should be observed for any aerial photograph of a given site, because it is a great indicator of the moisture content of the soil. On aerial photographs, the lighter the soil, the drier it is, and the darker the soil the wetter it is.

Any of these old and archival documents may hold valuable information that could save the owner funds that would have been spent on geologic investigations to find out that information otherwise. In most cases, the historic property is too old to have some of these documents to begin with, or the documents have since been lost over time. This should not discourage the site owner or management, as much can be inferred from current documents that are often more easily accessible.

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198 Freed, p.104.
199 Freed, p.104.
200 Freed, p.104.

In the case of the Abel and Mary Nicholson house, there were no early construction or rehabilitation documents or sanborn maps since the house was built back in 1722 and such documentation is very rare or non-existent given the age of the building. The archives did have an older site map depicting ownership of different tracts of land in the area and another older site map (Figure 67) from 1876 found in the preservation plan. The 1876 map is useful because it depicts major and minor water courses, roads, other structures and the name of their owners, and marshland areas in relation to the Nicholson house. Unfortunately the scale of the map is not shown, but a relative scale can be inferred based on the distance of the Nicholson house to the nearby roads, at least the ones that have not changed significantly since 1876.

There was a scale on a 1932 aerial photograph (Figure 68) and (Figure 69) of the area surrounding the Nicholson house, which was found in the Aerial Photography Library of the Bureau of Tidelands Management, a sector of the New Jersey state Department of Environmental Protection. There were also stereoscopic aerial photographs of the region taken on January 1, 1940 in the Aerial Photography Library. The stereoscopic aerial photographs were in the form of transparent frames and are intended to be used with a stereoscope, in order to view the three-dimensional qualities of the site's terrain and structures. This state department typically charges a $100 viewing fee for pulling the aerial footage, which may be waived for the property owner or representative of the property owner who is only looking at the owner's property. The fee may also be waived if this information is intended for a non-profit organization, but both of these special conditions have to be brought to the attention of the department during the application process. The County Clerk's office, which can often be a good source for aerial photographs, only had early photographs dating back to 1977, which is not early enough for a proper comparison. Since the Nicholson house lies on the Mid-Atlantic Coastal Plain, which has a large surficial layer of unconsolidated deposits, the fracture trace analysis is irrelevant. However, there are several tree-lines and moisture content variations in the soil around the site observed in both the 1932 and 1940 photographs. Both periods of aerial photography revealed that there were multiple structures existing on the same plot of the land that the Nicholson house lies upon. From one of the 1940 stereoscopic aerial photograph frames (Figure 70), it appears that there was one structure, perhaps the barn, which sat directly to the east of the Nicolson house and two more structures that sat northeast of the house. Also, there appear to be three other structures located north of the Nicholson house and along its access path, as shown in the close up view of the same photograph (Figure 71). In addition, from the 1940 photograph, it appears as if a flood has recently occurred in the area since all the marshland is very dark and seems to be covered with water since there are no land or vegetation details as seen in the 1932 photograph. Unfortunately, flood records for the region were unable to be obtained for 1939; however, the record 24-hour maximum precipitation amount for New Jersey (14.81-inches) did occur on August 19, 1939, albeit for the city of Tuckerton[201], which lies directly east of the Nicolson house, on the opposite coast of New Jersey. It is quite possible that Salem County also experienced heavy precipitation during that year and was still seeing the effects at the beginning on 1940.

[201] http://www.ncdc.noaa.gov/oa/climate/extremes/2000/august/extremes0800.html#extremes

Other invaluable documents, although slightly rarer to come by, are the safety assessment reports for nearby nuclear plants. When a given site gets considered as a future site for a nuclear facility, a preliminary safety assessment report (PSAR) is carried out to judge the suitability of the site. Once the site is decided upon a final safety assessment report (FSAR) is completed and that safety report is occasionally updated several years later. Preliminary and final assessment reports contain a large amount of information about a site, including geologic investigation results, hydrologic data, climate records, population projections, and species statistics, among several other areas of information and visual display of that information. Nearby historic sites can take advantage of the information found in these reports and the high level of testing and comprehensive results that the average historic site management budget cannot accommodate. The date that the extensive site information was gathered depends on when the nuclear plant was being considered for a given site, and therefore reflects the site at the time the site investigation was performed. Depending on the type of information, some of the site data can still apply for the site today. For instance, geologic formations will likely remain relatively the same, whereas climate, species and population data recorded may drastically differ from the records today. The Nuclear Regulatory Commission (NRC) keeps the hardcopies of these reports in their Public Document Room located in Rockville, Maryland, and their staff is in the process of scanning the reports and making them available online. Most of the reports completed in the 1980s and later have been already put online, but many of their earlier reports remain in hard-copy form in their library. The NRC does contract out a copy service through which the public can order hard copies to be mailed to them. Occasionally the NRC omits certain parts of chapters in the report from public access but for the most part, the reports remain more or less fully intact. Only a few historic sites can readily take advantage of this wealth of information because they are not always located nearby a nuclear facility.

The Abel and Mary Nicholson house is located within five miles of two nuclear test facilities that are situated on the nearby artificial island, referred to as Salem units 1 and 2. These units are operated by PSEG Nuclear, LLC. The PSAR for these units was completed during the 1960's and the FSAR was completed in 1976 and updated in 1987. A copy of the updated final safety assessment report revision 20 was available at the Public Document Room and a CD of the report containing chapters 1-3, 9 and 10 was ordered and received for approximately $15. Chapter 2: Site Characteristics, held the most valuable information. Within this chapter, the Updated FSAR had a map and data sheet giving the locations and characteristics and owners of all wells in the vicinity of the nuclear plants. On that list, are two dug wells #6 and #7, (Figure 72) on the Nicolson house property. One of the wells is the drinking well that still exists today. The other well is located along the access path to the Nicholson house and on the former site of another group of farm buildings all owned at the time by past-owner G. Harbeson. The other well was filled in when the old farm buildings burned down.[202] According to the Updated FSAR, both the wells were recorded as 15-feet deep and 42-inches in diameter, which may be describing the existing well anywhere between the mid-1960's to 1987 since either one of the Gilbert Harbesons, junior or senior, could have owned at the time. These measurements differ significantly from today's measurements which are 10-feet

[202] Ron Magill.

and 4-inches deep and 30-inches in diameter which is interesting. Another figure depicts the geologic cross-section of the surrounding site (Figure 73) which reveals the intricate stratigraphy of the area, including main layers of Cohansey sand, Kirkwood formation, Vincentown sand, non-marine sediments and undifferentiated consolidated rocks, or the bedrock layer. Overall, there is good information about the past and present existing terrain conditions on the Nicolson house site in this report.

5.2.2 Understanding the Existing Terrain and Sub-terrain

A greater understanding of the existing terrain and sub-terrain of a historic site can be developed through looking at current, publicly available documents. Examples of these documents include water department maps, geological maps, soil survey maps, USGS quad maps, topographic surveys, and aerial photographs will help one understand the existing terrain on the site.

Water department maps can show the location of existing catch basins, storm sewers, sanitary sewers and other utilities under the site or under neighboring sites.[203] Water department maps are found in the historic site's municipality's water department and are able to be accessed with permission from the owner of the property. Geologic maps can be helpful in showing the type of bedrock formations, the consolidated rock, and other geologic maps can be helpful in showing the type of surficial deposits, the unconsolidated soil, which exist under the site.[204] Geologic maps can be accessed on the USDA website

[203] Harris, p.171.
[204] Freed, p.103.

through their Soil Extent Mapping (SEM) Tool or their Web Soil Survey, which provides additional information on the characteristics of the soil from soil survey reports.[205] The soil survey maps, like (Figure 64), indicate what soil types are found on the site. Knowing the soil types allows one to look up the characteristics by the scientific classification system and learn more about the soil chemistry, stratigraphy and chemical and mechanical properties.[206] United States Geologic Survey (USGS) provides quad maps for any area within the United States. The quad maps show the site's topography and reveal the natural dips, peaks and the slope of the land surface within and around the site. The contour lines are typically spaced at 1-foot intervals. The quad maps also depict roadways and existing water courses and bodies, including marshland. USGS quad maps are easily accessed and ordered online through several websites like maptech.com.

The historic property steward may consider getting a topographic survey of the site performed by a licensed surveyor if they need more detailed information than is found in the quad map. Although topographic surveys can be expensive, they are particularly useful. Like the USGS quad maps, they show the existing topography of the site, but usually to a finer scale with contour lines spaced at 0.1-foot intervals, which is especially valuable when one has a relatively flat site. From this, one can get a good idea of the surface water drainage path of a site and a rough idea of the slope and direction of groundwater and aquifer flow underneath the site based on the locations of existing water bodies and natural slope patterns of the site's terrain. The survey should always have at

[205] http://soils.usda.gov/
[206] Freed, p.103.

least one benchmark marked clearly on it. The benchmark represents the point that marks the true vertical reference point, which is tied back to some known elevation like a nearby road. Current aerial photographs can be obtained online through several online programs like Google Earth and Microsoft Virtual Earth, as well as Geographic Information Systems (GIS) maps for which the shape-files can usually be easily downloaded from state's websites. Some states have interactive GIS mapping programs online which do not require owning the actual GIS program, like the state of New Jersey who has created the I-map NJ user interface to graphically display an array of geologic and environmental data.

As for the Abel and Mary Nicholson house, the water department maps were not accessed but several underground utilities were identified in the Preservation Plan and the approximate location of the septic system top of lid was identified in the topographic survey performed by Gleissner Associates, P.C. in 1998. A geologic survey map was obtained from the interactive I-Map NJ website and reveals that the bedrock geology is composed of tertiary sand, silt and clay and the bedrock aquifer is composed of coastal plain surficial sediment (Figure 74). A soil survey map was obtained through the Web Soil Survey on the USDA National Resources Conservation Service website and revealed that the site lies on topsoil composed primarily of OTMA and MbuB soils. OTMA indicates that there are Othello, Fallsington and Trussum soils present and MbuB indicates that Mattapex silt loam is present directly around the site.[207] Both types of soils are deemed very limited in supporting a building with a basement due to the shallow

[207] USDA Natural Resources Conservation Services, National Soil Survey.

depth to the saturated zone, as indicated by the highlighted red area in the map from the National Soil Survey in (Figure 64).[208] The USGS quad map was obtained using maptech.com (Figure 14). As shown in the close up view of the quad map (Figure 15), the entire site is relatively flat and lies less than 10 feet above sea level. The Nicholson house site is represented by the two dots located at the end of the dashed line, which represents the access path. The major county roads are represented in red and white, while other alternative access-ways are outlined in solid lines most likely indicating a more developed road that provides access to more than just a single residence. The USGS quad map also shows the neighboring marshland and vegetation in the area and where the water bodies and courses lie in relation to the site. Based on the quad map, it appears that the marshland and water bodies lie very close to the house, which is especially disconcerting given its relatively flat terrain.

In 1998, a topographic survey was performed on the Abel and Mary Nicholson house by Gleissner Associates, P.C., and a digital photograph of the survey is included (Figure 75). The survey has two iron pin benchmarks located on the east and west sides of the Nicholson house; the east one at 10.00-feet above sea level and the west one at 11.71-feet above sea level. The contour lines are spaced at 1-foot intervals but multiple elevations are labeled on the plan to a 0.1 foot resolution which is appropriate for the site. The peak elevation of the survey area is 12.6-feet above sea level just north of the Nicholson house and the lowest dip lies to the southeast of the Nicolson house at 8.3-feet above sea level. The site generally slopes downward from northwest to southeast. The approximate septic

[208] USDA Natural Resources Conservation Services, National Soil Survey.

system location is north of the house and has a top of lid of 11.29-feet above sea level. All the types of trees are labeled, as well as different materials, which are generally marked by different hatch patterns on the survey. The finished floor elevations for the first floor and for the cellar for each building block were also labeled on the survey. The finished floor of the 1722 building is labeled as 16.62-feet and the cellar is labeled as 9.75-feet. The finished floor of the 1859 addition is labeled as 15.84-feet on the east side and 15.09-feet on the west side and the cellar is labeled as 9.10-feet. The elevation of the well water was also labeled as 6.1-feet, along with the varying elevations of the ground level around the building pad, which ranged from as low as 10.9-feet in the southeast corner of the building to as high as 12.6-feet in the northwest corner of the building. Although the exact elevations on this survey may not be accurate, the relative differences between ground level, cellar floor, and water level of the well should be accurate. Therefore, in 1998, the difference between the 1859 cellar floor and the ground level ranged from 3.15 to 3.5-feet across the pad. The difference between the 1722 cellar floor and the ground level ranged from 1.15 to 2.35-feet across the pad. The difference between the cellar floor and the water level in the well is 3-feet.

Three main issues arose from observing the survey. First, it was necessary to find out in the benchmarks were still in place. A metal detector was used to find the iron benchmark pin on the west side of the building. The presence of the iron benchmark pin on the east side is inconclusive since the metal detector did recognize something metallic in the area of its survey location, but a metal pin was later found on the porch. The pins could have easily been pulled out by some unknown entity like a lawnmower for instance. Once it was confirmed that one of the benchmarks was still in place, it was necessary to find out if the benchmarks were tied back to a vertical reference point, like a nearby road, at the time of surveying or if the first pin was just set at an arbitrary height that all other site elevations could be made relative to. To answer this query, it was necessary to consult the surveyor. Due to the dissolution of the surveying company, attempts to access the original survey yielded minimal success. However, the surveyor did recall making the assumption that he likely took the base elevation for the benchmarks from a nearby intersection off the USGS Quad sheet and projects that the values are accurate to within +/- 1-foot. He said that he probably did this because he was unable to find any good elevation markers in the area. It is yet to be determined if there exists an economical way to tie back the remaining benchmark to a vertical reference. Although the survey elevations may not be entirely accurate, the survey is still valuable in providing relative elevations between two different locations on the survey area. Therefore, if wells were installed, their locations on the survey area could be taken with a total station and tied back to the benchmarks so that one could know what the well elevation height and position is in relation to the rest of the site.

Access to recent aerial photography for the Nicholson house was readily available from several online resources that provide the views. Aerial photograph from 2002 was obtained from the I-Map NJ website (Figure 76). In the aerial photograph, one can observe that the Nicholson house is the only structure that remains on site. The surrounding marshland and vegetation is observed in the photograph and the areas of drier soil, the lighter area of red and beige, clearly stand out in this photograph. The road names are also identified digitally within the picture.

5.2.3 Aerial Photograph Comparison

Another potential tool is the comparison of two aerial photographs of different time periods and drawing conclusions from their similarities and differences. The 1932 aerial photograph was selected to be compared with the 2002 aerial photograph because it is older and represents a slightly greater time difference between the photographs. In addition, the 1940 photograph, although in higher resolution than the 1932 photograph, is suspect to having been taken during a flooding period, given the composition of its marshland, which could distort the results. The original objective of comparing the 1932 and the 2002 aerial photographs was to compare changes in vegetation types, locations and overall characteristics because vegetation may be significantly affected by saltwater encroachment over a period of 70 years. It was assumed that both the past and present aerial photographs represented the average level of tidewaters and that no recent major flooding or droughts had occurred in the area at the time each photograph was taken. Each aerial photograph was brought into AutoCAD and adjusted to equal scales and areas which totaled to approximately 1-square mile for each of them. Both aerial photographs were broken up into different groups exhibiting the same tonal qualities in the soil by drawing poly-lines to outline their respective areas. The lines were kept visible so that one can easily see how the different areas were divided. Then the areas were added up into the following categories for the 1932 graph: total light area, total marshland area and total other (darker) area. The areas were added up in the following categories for the 2002 graph: total light area, total pink-toned soil area, total marshland area and total other (darker) area. Because of the intensity of the pink tones, their area was tabulated separately from the total light area category. The photographs and the total areas are shown side by side for comparison purposes in (Illustration 1).

The most important area comparison is the amount of total marshland area compared to the remaining area within the square mile boundary. In the 1932 photograph, the total marshland area is 0.37 square miles and the remaining area is 0.63 square miles. In the 2002 photograph, the total marshland area is 0.47 square miles and the remaining area is 0.53 square miles. As shown in the photograph and through the calculations of the marshland areas, the marshland surrounding the Nicholson house site appears to be increasing in a very visible manner and enclosing in around the other area and the site itself. Based on the area calculations, an approximate 0.1 square miles increase in marshland occurred over a period of 70 years. This translates to about a 310,000 square yard increase or a 3,000,000 square foot increase. The average rate of this encroachment is 0.001 square miles (4000 square yard, 40,000 square feet) per year, obtained by dividing 0.1 square miles by 70 years. If the marshland encroachment continues at this rate, the property will be consumed by marshland within the next 100 years, and perhaps even earlier depending on the level of the building foundations. Although the original purpose of comparing the aerial photography was to observe changes in vegetation, a much more impending threat, encroachment of marshland, became apparent and required attention over the encroachment of saltwater. After all, it does not matter if saltwater-contaminated groundwater is approaching the site if marshland encroachment approaches at a much faster, more visible rate and directly threatens to swallow the historic site. Since the site's topography is so flat, the relative marshland encroachment rate is even faster. By comparing these two aerial photographs, another threat to the historic property was revealed and able to be assessed, so the importance of performing this relatively simple process cannot be stressed enough.

5.2.4 Other Photographic Comparisons

Other types of photographs may be compared to develop an understanding of what kind of changes have occurred in and around the site over the course of several years. For example, in the case of the Abel and Mary Nicholson house, it is important to be aware of any changes grade that might have occurred. To find out if there has been a change in grade, one can examine old site analysis and building record drawings to get, for instance, the distance between a basement window sill and the ground level. If such a measurement was recorded, it can easily be compared to the value of an identical measurement taken today. However, if that measurement was not taken on an earlier survey or included in the building plans, there are other ways to determine that measurement. Historic American Building Survey (HABS) drawings and photographs, early historic building records completed typically during the depression era as a means to provide work for unemployed architects and engineers, can be extremely valuable as a earlier comparison of building measurements to those recorded today. Often photographs were taken with a survey stick that allow for easy dimensional scaling of the building.

Brick buildings have a particular advantage in measurement because if one knows the height of a single brick course, one can determine the entire height of the wall above ground level, allowing for the interpretation of a change in grade. This particular method was carried out on the Abel and Mary Nicholson house. HABS drawings and photographs were used to determine if there had been any noticeable change in grade on the Nicholson house site. Upon reading the courses of brick on the east facade in the HABS drawings/photographs and comparing them to photographs from the site, evidence of a grade change is inconclusive. The reason that a grade change was not able to be recognized was because the Nicholson house's early HABS photographs have various degrees of vegetation blocking the facade. In one photograph there appears to be only 19 courses below the water table and in another photograph there appears to be 21 on the right and 22 on the left. In the 1941 HABS elevation there were 20 courses drawn below the water table on the right and 21 courses drawn on the left, which is actually the same number that was counted on recent site visits in October 2006 and February 2007. The later HABS drawing depicts 21 courses below the water table on the right and 22 on the left. Hence, a grade change cannot be confirmed and if there has been a change in grade since the HABS drawings, it seems to be relatively small.

5.2.5 Site Flow-net Construction

The graphical construction of the site's flow-net, is another tool that uses aerial photography, surveys and topographic maps, and can help lead to a better understanding of the site's groundwater flow. A flow-net is a network of equipotential lines and associated streamlines which exhibit steady groundwater flow conditions in both two and three dimensions.[209] The streamlines resemble the flow path of individual particles as they travel through an aquifer flow system and they all remain parallel to each other and never cross because groundwater flow is assumed to be laminar.[210] Flow-nets can be constructed manually, with computer contouring or with groundwater flow models.[211] The manual flow-net construction method makes the assumptions that the aquifer is homogeneous, fully saturated, isotropic, stable over time, has incompressible soil and water, has laminar flow, follows Darcy's Law, and has known boundary conditions.[212] If groundwater flow properties like thickness, bottom slope, and hydraulic conductivity for an aquifer vary significantly, then the flow-net method is not recommended. In a map view, the equipotential lines are vertical and the streamlines create vertical plane and the groundwater flows through the streamlines.[213]

An example of how a flow-net is constructed, found in the book Applied Hydrogeology by C.W. Fetter, (Figure 77). Constructing a flow-net involves taking existing geologic and hydrologic conditions into account.[214] Geologic conditions include aquifer properties, stratigraphy, and aquitards or impermeable boundaries which groundwater cannot flow through like consolidated rocks, dikes or clay layers.[215] Hydrologic conditions take into account constant head boundaries which represent bodies of water

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209 Fetter, p.133.
210 Freed, p.90.
211 Ibid.
212 Fetter, p.133.
213 Freed, p.94.
214 Freed, p.97.
215 Ibid.

exposed on the land surface like lakes, swamps and rivers.[216] Hydrologic conditions also take into account constant flux boundaries involve seepage and infiltration, and no flow boundaries like aquitards, streamlines and divisions within the groundwater.[217] The following steps should be taken when constructing a flow-net[218]:

1. Identify the equipotential boundaries.

2. Draw equally spaced and parallel streamlines that lie perpendicular to one of the equipotential boundaries.

3. Include the no-flow boundaries as streamlines in the flow-net system, remembering that they too must be drawn in parallel.

4. Draw the equipotential lines orthogonal to the streamlines to finish the system of curvilinear squares.

If the flow-net is constructed properly, the change in head between equipotential lines should be equal and a circle that touches all four sides will fit into each curvilinear square.[219]

A possible flow-net configuration was carried out manually and with the aid of computer generated contours in AutoCAD for the Abel and Mary Nicholson house and is shown in (Illustration 2) The flow-net is drawn over the 2002 aerial photograph and is supposed to extend vertically into the subsurface to represent of the flow of the unconfined aquifer

[216] Ibid.
[217] Ibid.
[218] Ibid.
[219] Freed, p.92, 98.

below. The triangle represents the slope in head or the hydraulic gradient of the vertical cross-section of the aquifer. The height above sea level of the marshland that lies to the north of the property was assumed to be 9-feet based on the USGS quad map. The groundwater level in the marshland is known because it is exposed, as shown in the aerial photograph. This point was taken as a constant head boundary and the maximum equipotential. Another equipotential indicator is the depth to the groundwater that was measured for the existing well. At this point the groundwater was 4-feet and 10-inches below ground level, and assuming that the Nicholson house plot also is 9-feet above sea level, based on the USGS quad map, the depth to groundwater can be subtracted from the ground level to get the groundwater's relative elevation of 4-feet and 2-inches. Assuming a linear slope, the minimum equipotential constant head boundary was located at the marshland south of house and calculated as 2-feet and 1-inch. The equipotential lines were placed every ¼ -foot and four streamlines were created in all. The sides of the flow-net are not necessarily no-flow boundaries but treated like streamlines nonetheless. The way the site drains naturally made it difficult to complete the flow-net and keep the streamlines parallel at the south end of the site and bottom of the flow-net. From the flow-net a probable path of groundwater was inferred, as well as its source and sink points, for the Nicholson house site.

In addition to collecting and analyzing different documents for information about the site's existing terrain, it is also important to remember to have an outside, experienced professional perform a survey of the existing conditions of the site. The site visit should include a field investigation and result in a report that characterizes the terrain and sub-terrain of the site based on the observations. A survey of the site's existing conditions should be performed to develop a better understanding of the site's characteristics and conditions and supplement the background information found from documental research.

5.3 Installation of Monitoring Wells

Another potential method is installing wells (Figure 78) on the site to monitor groundwater levels and salinity of the groundwater. Monitoring wells require casing, solid-wall pipe, which shapes the well, and a screen, pipe with holes, slots, gauze or a continuous wire wrapped around it, which allows water to enter but keeps unconsolidated sand, which composes most aquifers, out.[220] When the sand is fine-grained and well-sorted, like in the case of the Nicholson house, the screens should be surrounded by a coarse sand or gravel encasement.

Monitoring wells can provide the owner with a wealth of information including how the water table varies over different seasons and due to tidal influences. From this data, an average water table height can be calculated and the overall maximum and minimum extents of the water table position can be discovered. Monitoring wells also assist the owner in characterizing the substrate that the historic property lies upon because soil samples can be obtained at different depths from the drill spoils and sent in for laboratory testing which will identify the type of soil, its composition and general properties. In addition, installing wells allows for samples of the groundwater to be taken and sent in for laboratory analysis. The groundwater can be regularly tested and examined for

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[220] Heath, p.52.

contaminants such as salt ions and one can monitor the concentration of these contaminants over time. Much information can be gathered from only a few strategically placed wells, and that information can be used in creating a computer model of the phenomenon. Given the variety of useful data they provide, monitoring wells are considered an important, and almost essential, tool for assessing a threat of saltwater encroachment on a property.

5.3.1 Determining the Extent of the Subsurface Investigation

The first step in the process of installing well is to determine the purpose of the wells. In the case of the Nicholson house, the purpose is to determine the extent of groundwater contamination (salt) from a known source (saltwater intrusion in the groundwater from the Delaware River) as well as the variation in the level of the groundwater itself. The water table could be affected by more than just tidal influences, as soil type, rainfall, topography, land use and irrigation can influence the water table level as well.[221] Since the Nicholson house case study calls for the examination the characteristics of the groundwater over a period of time, the installation of monitoring wells is appropriate. There are other types of geologic investigations that could be considered for different sites with different information objectives.

For instance, instead of monitoring wells, test pits could be dug on the site instead. Digging test pits is considered non-destructive testing because it involves only removing earth that is not directly adjacent to the building and is therefore not being stressed. Test

[221] Norman and Turnour, p.1.

pits should be considered as a valuable tool for discovering information about the type of bearing materials, and the levels of load they can bear, and the location of groundwater beneath the historic property. Test pits can only be dug if the property is surrounded by open land, like the Abel and Mary Nicholson, and therefore would not risk disturbing the soils and peace of any neighboring properties. Approximately 8 to 10 strategically placed test pits can typically be installed during one day when one rents a backhoe and hires a geotechnical engineer.[222] Test pits usually reach about 15 to 20-feet in depth.[223] If the test pits fill with water, they have intercepted groundwater and that depth can be measured. Soil samples are often collected from test pits and are characterized in the laboratory by sieve analysis and plastic and liquid limits testing. After the geologic information has been recorded and the soil samples have been taken, the test pits are usually filled in with gravel in order not to cause future harm to the building or its occupants. Since test pits can be limited in depth by shallow consolidated rock material and other obstructions, bore drilling is often subcontracted out because the drills can go through material that the backhoes cannot. Borings are similar to wells but they are not cased, where piping is installed to shape the well. Borings and monitoring wells are usually created with hollow-stem auger drills (Figure 79), which rotate into the ground and simultaneously bring up the soil to create the hole in the ground. Other drilling devices commonly used for well installation and hydrogeologic investigations are mud-rotary and air percussion.[224] The soil that is brought up is referred to as drill spoils. A certified geologist or geotechnical engineer should be in charge of examining the drill

[222] Harris, p.182.
[223] Ibid.
[224] Freed, p.109.

spoils and creating a well log showing the depth and thickness of the stratum.[225] A preliminary check of boring logs to see if any previous borings have been made on the site can save the owner time and money spent on drilling new boreholes.[226]

The installation of temporary wells may be considered if one does not wish to monitor groundwater levels and groundwater chemistry. Depending on state regulations, temporary wells have a very limited, specified time frame before they have to be filled in. In the state of New Jersey, where the Nicholson house is located, temporary wells have to be filled in within 48 hours of drilling. Temporary wells do not have to be installed with drills and can be installed with a Geoprobe™ unit instead (Figure 80). A Geoprobe is a hydraulically-powered percussion/probing machine that is directly pushed into the ground and removes soil cores to create a hole in the ground.[227] A Geoprobe is typically used to create temporary wells that go to depths of up to 100-feet.[228] A Geoprobe unit is often operated out of and attached to a regular size vehicle and therefore transported easily from site to site. Other Geoprobe models have rubber tracks that put minimal stress on the bearing soil. A Geoprobe is a lot faster and cheaper than a drill rig and you generally hire a contractor to operate the Geoprobe for an 8-hour day, which allows you to install several wells during one day for the same price. An example of all the components found in a Geoprobe contract include the daily rate to rent the Geoprobe, including the type of unit specified, Geoprobe-related equipment, 8 hours, or one day, on-site and an OSHA trained operator, and 9 soil samples collected while drilling three 10-

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[225] Friedman, p.160.
[226] Ibid.
[227] http://www.enviroequip.com/sales/geoprobewhatisit.htm
[228] http://www.enviroequip.com/sales/geoprobewhatisit.htm

foot deep micro wells. The micro wells would each require the following materials: a 1"x5' PVC screen, 1"x5' PVC riser, and 1" PVC slip cap. In some cases the contractor will also supply bailers to be used for water sampling. A typical Geoprobe job will cost approximately $1200. It is not considered good practice to use Geoprobe to install monitoring wells and therefore a Geoprobe could not be used on the Nicholson house site.

Possible archeological implications should be considered whenever an intrusive subsurface investigation is performed. This is particularly pertinent for a historic site, which may hold valuable artifacts and sources of information in its substrate. It may be necessary for an archeologist to be present at the time of invasive drilling if there is reason to believe that archeological entities may be found.[229] At the very least, the leftover drill spoils should be left essentially untouched on site, with appropriate measures taken to prevent attrition like covering the soils with tarps and sealing it with concrete blocks. This will allow for an archeologist to inspect the soil for artifacts at some point during the monitoring process if additional funds are found to sponsor the investigation or an archeologist volunteers their services.

5.3.2 Placement of Monitoring Wells

Once a historic property steward decides on investing in installing monitoring wells, one of the first things that the historic site owner has to think about is how many wells they will need and where they should place those wells. If a contractor bills the client per

[229] Friedman, p.161.

well, the steward will have to figure out the fewest number of wells required to provide the necessary information in order to save on costs. If the contractor bills the client per day, the client will likely be able to install as many monitoring wells as they need in the exact locations that they need them. However, the client may not opt to install as many monitoring wells as he can within one day because the site is a historic site and drilling has the potential to disrupt the natural and landscape of the site and cause accidental damage. Furthermore, the more wells drilled, the greater the possibility that archeological artifacts could be disturbed and lost. There is a balance between obtaining more information to help protect the site in the future and preserving the site in the present that the steward has to maintain.

The owner-selected locations for well installations will rarely become the actual installation locations of the wells. This is because there are often unforeseen conditions, such as the presence of underground utilities, which end up revoking the proposed locations. Contractors, upon observing the site, may also have better ideas of where to place the wells based on their experience. The fact that the wells are often built in a location other than the one they were originally planned to be built on should not devalue the strategic placement of the wells.

There is some strategy that goes into placing monitoring wells on the site. For instance, with just three wells, one can map the contours of the potentiometric surface, or the water table level, and determine the flow path, assuming that the aquifer is isotropic. This is done with the contour method, which results in a representation of the contoured potentiometric surface (Figure 81). The contour method is implemented by carrying out the following steps[230]:

1. Draw a line that connects each well in a three or four well array.

2. Note the total head as an elevation in each well.

3. Measure the map distance between each well along the connection line.

4. Find the difference in total head between each well in the direction of the connection lines.

5. Calculate the directional hydraulic gradient between each well by dividing the distance into the differential head.

6. Select convenient equal head increments between each well pair and calculate the position of the head value with linear interpolation.

7. Connect the map points of equal total head. These are equipotential lines, lines with equivalent head.

8. The true hydraulic gradient is the change in head along the flow path and the flow path will be perpendicular to the equipotential lines in a direction of decreasing total head.

Since no monitoring wells have been installed on the Nicholson house as of yet, the contour method could not be applied.

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[230] Freed, p.58.

There are certain restrictions on the placement of monitoring wells. For instance, all monitoring wells should be located greater than 100-feet away from permanent or semi-permanent water bodies like dams and water channels, other buildings, large and mature trees, and existing water pumps.[231] According to the New Jersey Safe Drinking Water Act NJAC 7:10, drinking wells need to be installed at least 50-feet away from any kind of septic system and the same would likely be applied to monitoring wells. Proposed well locations should also be able to be reached by the drilling equipment with minimum disturbance of the site. As for the Nicholson house, the proposed well locations in relation to the house are shown on a site map located in (Illustration 3). The well locations were selected based on the previously mentioned restrictions and strategies for mapping the potentiometric surface.

If there is an existing well, as in the case of the Abel and Mary Nicholson house, the well should be included in the overall hydrogeologic investigation but should not be included as one of the main wells needed to monitor the groundwater. This is for testing uniformity reasons since time and method of construction could have an effect on the readings and data collected. The existing well should be considered as superfluous information in the investigation and not as one of the wells used in the construction of the potentiometric surface. This is also reinforced by the fact that the existing well is rarely set in a strategically appropriate place to construct a potentiometric surface. However, the existing well is useful for predicting the monitoring wells' groundwater levels and saltwater characteristics and concentrations.

[231] Norman and Turnour, p.1.

5.3.3 Selecting a Contractor to Install the Monitoring Wells

The first step in hiring a contractor to install monitoring wells is to send out a Request for Proposal (RFP) to at least three well-drilling contractors. The RFP should clearly define the expectations of the well-drilling process. Upon receiving and reviewing the proposals, a contractor can be selected. Proposals can be compared by cost, the nature and type of the materials and services provided and company's insurance coverage. The size of the drill rig should also be inquired about because the client should not accept any equipment that will likely tear up the historic site. The client should be wary of proposals with lump sum bids that do not list material and services provided.

For the Abel and Mary Nicholson house, the typical proposal described the following materials and services. The proposal included three 2" wells drilled to 15'-20' in depth, where each well includes one 2"x10' screen / PVC / gravel pack, one 2" locking cap / (with padlock), one stick up well protector/lock or flush protectors, and one NJDEP monitoring well permit. For each well, a soil sample would be taken at every 2' interval for the first 10' and taken every 5' for the remainder of the well depth and all soil samples would be placed in an individual drillers jar (approximately 1 pint in size) provided by the company. Any special containers for the soil samples would have to be obtained by the client. The client would also have to provide their own special containers and sampling devices for any well water samples they want to take at the time of well-drilling and thereafter. The wells should be installed flush with ground surface to avoid damage by lawnmowers and other landscaping devices, as well as to avoid lawsuits from the occasional visitor. The well-drilling contractor may use Global Positioning System

(GPS) to locate the exact location of the wells once they are installed. The whole drilling process may take less than one day, depending on the number of wells to be installed. The contractor provided the unit cost and number of units for each budget line item required. The total cost per well came to a total of $1250 and the total cost of three wells was $3750.

Consulting the well-drilling contractor about other jobs that he or she has done in the area around the historic site can incur additional knowledge about the site since well-drilling contractors often hold a wealth of information about the hydrogeology of the local area that they work in. For instance, in the case of the Nicholson house, the well-drilling contractor said that he previously had a job in Rosenhayn, New Jersey, which is located southeast and further inland of the Nicholson house, in which the client wanted to find out if the site had the appropriate subsurface salt concentration to support a shrimp farm. The site had wells drilled about 2700 to 3000-feet below the ground level about 25 years ago with the intention of storing gas and pumping it out when needed. Upon testing the salt concentration of the well water, the contractor was surprised to learn that the water could indeed be used to support a shrimp farm because it was equivalent in salt concentration to seawater. This related case suggests that saltwater has encroached on the New Jersey coastal subsurface more than originally thought.

5.3.4 Obtaining a Permit for the Monitoring Wells

State well permits are usually required for each well that is to be drilled. The well drilling contractor is the one who has access to the permit application and applies for the state permit to drill wells and not the owner. The selected contractor will ask the owner for information required in the well permit application including the property name, address, municipality, county, block, lot, property owner, property owner address, and property owner contact person. The well permit application also requires the submission of a site map or plot plan depicting the location of the site in relation to the nearest road or intersection, which should also be provided by the client. The well permit application process can take anywhere from one week to one month or longer depending on the state. Once an approved state well permit is received by the contractor, the contractor can apply for county and township well permits if applicable. Usually individual states provide a phone number for the owner to call a few days before the wells are drilled so that the state has time to research and go out to the site to mark any underground utilities. This process is intended to protect the site and drillers from the negative consequences of drilling into existing and unknown underground utilities.

5.3.5 Installation of the Monitoring Wells

The client should be present when the monitoring wells are installed to make sure that they are installed in the manner that the client wants and to answer any questions from the contractor. The wells should be installed in the order of lowest to highest elevation.[232] Once the wells are installed, the exact position and elevation of the wells should be determined with the aid of a Total Station or GPS device. As the wells are being drilled, the color of the soil should be observed and recorded. If the water table is shallow enough, a mottling line along the circumference of the well cavity may be

[232] Norman and Turnour, p.1.

observed upon removal of the soil. The mottling line is distinguished by a dark rust color that contrasts with the rest of the soil. The dark line is created by deposits of minerals like iron oxide and represents the highest level that the water table has reached.[233]

In New Jersey, where the Nicholson house is located, the well permit application process has been recently modified as of May 2006. The well permit application process now takes about 3 weeks in the state of New Jersey. The site map of the Nicholson house that is to be submitted in the permit application is shown in (Illustration 3). Three to ten days before the well drilling is scheduled to begin, the owner should contact the Underground Utilities Department at 1-800-272-1000 when drilling within the state of New Jersey. Monitoring wells have yet to be installed at the Abel and Mary Nicholson house.

5.3.6 Data Collection and Sampling from Monitoring Wells

Once the monitoring wells are installed, data collection can begin. The three main forms of data collection are as follows: taking soil samples from the drill spoils and performing laboratory testing on the samples to determine the characteristics of the bearing soil; monitoring salt ion presence in the groundwater through the regular collection of samples and laboratory testing; and monitoring ground water levels with a data logger over a year.

It is recommended to take the soil samples from the well drill spoils and that samples be taken every few feet until the water table is reached to see if any of the soil characteristics change with depth. The samples should be collected in drillers jars and should contain at

[233] Freed.

least a pint of soil. The soil samples should be sent to a lab and a sieve analysis test should be performed to record the grain size distribution. Knowing the grain size distribution of the different soil layers helps to characterize the soil and understand its properties. The liquid and plastic limit laboratory testing can also be carried out in order to determine the plasticity index, which quantifies the range of moisture contents through which the soil behaves plastically, or easily moldable. The plasticity index for the Abel and Mary Nicholson house soil is expected to be very high because it consists of large percentages of clay.

Before the well water samples can be obtained, the well should be developed, or energy should be introduced into the aquifer material to disturb it.[234] The purpose of developing the well is to flush away the unrepresentative fluids or compressed fine material that drilling creates.[235] This way the aquifer material will collapse against the gravel pack and allow for a smooth transition of pressure from the aquifer to the well in order to obtain representative samples.[236] A well can be developed by over-pumping, raw-hiding (moving the pump up and down the well screen), surging with a concrete block which behaves in the way that a plunger does, air-lifting/pumping, air surging by introducing bubbles into the system, or high velocity jetting which involves jet washing the screen and is generally thought of as the best method available.[237] The well should be developed each time before a sample is taken in order to obtain accurate readings.

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[234] Freed, p.118.
[235] Ibid.
[236] Ibid.
[237] Freed, p.119.

The well water samples can be obtained in a variety of ways. Most of the methods involve using a low-flow pump of some nature that pumps between 100 and 500 mL/min. Using a peristaltic pump is one of the pumping options. A peristaltic pump will suck up water very slowly and deposit the water directly into the containers. The peristaltic pump operates electronically and you can typically rent it for about $25/hour. A whaler pump is another pumping device that conveniently hooks up to a car battery. A bladder pump is another good option. Grundfos Redi-Flo is another type of pump that has a control box that lets you adjust the rate at which you are pumping or purging from the well. The following considerations should be made when selecting a pumping device[238]:

1. Does it collect a representative sample?
2. Can it be easily cleaned and decontaminated if it is to be used in more than one well?
3. Will it work in the application that is at hand?
4. Can it lift the water from the water level in the well to the surface?
5. Can it pump the well at a rate sufficient to purge it prior to sampling?
6. Will the method of pumping or the materials from which the pump is made change the water chemistry of the sample?
7. How easy is it to use the device?

[238] Fetter, p.396.

8. How reliable is the device?

9. How much does it cost to buy, maintain, and operate?

In the case of all pumps, five gallons of water should be pumped from the well before a sample is taken. A low-flow sampling data sheet should also be filled out by the operators for quality assurance. An example of a Department of Environmental Protection (DEP) low-flow sampling data sheet is found in (Table 4). When pumping directly into containers, it is recommended to make sure that the containers are sterile and properly sealed so as not to produce any misleading results.

The well-drilling contractors may provide a pump when the wells are initially dug, but the steward will need to purchase or rent a pump or hire an outside professional to perform both the regular sample collection and the laboratory analysis. Hiring professionals has its advantages because they are experience and have tried and true methods of sample collection to collect pure and representative samples.

Because sampling is intended to detect salt ion contamination only, a pump is not required for sampling and other cost-effective methods can be used. The New Jersey Department of Environmental Protection does not put forth any standards of sample collection and does not require any report of well sampling results concerning saltwater contamination. A pump may be required for testing for other forms of water contamination, particularly for hazardous chemicals. One alternative method of well water collection involves installing a multilevel groundwater sampling device (Figure 82) into a single borehole. The device will sample a small amount of water from different elevations and the samples will be representative of that portion of the aquifer.[239] Hence, a vertical distribution of saltwater contamination may be developed and monitored over time to detect the rate of saltwater encroachment on a site on a vertical scale.[240] This device is fairly expensive to install and perhaps should not be considered for installation until the presence of saltwater is confirmed in a test pit.

Another method of well water sample collection is through the use of bailers. Bailers are containers used to remove water out of a well. They are dropped into a well and into the well water and hung from a stainless steel wire. The bailers are then bobbed up and down to ensure a representative sample and removed. A ball is located at the bottom of the bailer and floats up when surround by water to let the water into the container. The ball falls back into place, sealing the container, when it is removed from the well water. Once the bailer is filled with water, it is removed from the well and positioned over the containers. A small pipe is inserted into the bottom of the bailer, moving the ball, and releasing the well water sample into the container. When pouring, the water should be allowed to overflow the containers to maximize the mixing of the sample.[241] Photographs from the bailer well water sampling of the existing well on the Abel and Mary Nicholson house site are shown in (Figure 83) and (Figure 84). In general, bailers are fairly inexpensive. Reusable bailers typically are sold for $80/each and disposable bailers, used on the Nicolson house existing well, are sold for under $5/each. Bailer rope typically costs $0.05/foot. Bailers are typically less than 2-inches in diameter in order to fit in standard monitoring wells.

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[239] Fetter, p.394.
[240] Fetter, p.395.
[241] Norman and Turnour, p.3.

Well water sampling protocols have been developed by the EPA.[242] The protocols specify the type of sample that is needed the type of container and the method by which the sample container is cleaned and prepared, whether sample is filtered, type of preservative that is to be added to the sample in the field, and the maximum time the sample can be held prior to analysis in the laboratory.[243] Methods of well water sample collection and preservation are specified in Title 40, Code of Federal Regulations, Part 136 by the US Environmental Protection Agency.[244] They are also contained in ASTM – Guide D 3694-96 Standard Practices for Preparation of Sample Containers and for Preservation of Organic Constituents.[245]

The final parameter to be measured is the water table level in the wells to get an idea of how the potentiometric surface fluctuates over the course of a normal day and throughout different seasons of the year. The water table is expected to be at its highest during the winter and early spring and at its lowest during the summer and early fall. A data logger is recommended for recording water levels because it can remain in the well and record the water level for a long period of time. A good example of the type of water level logger required is the HOBO U20 Water Level Logger (Part # U20-001-01). The more expensive titanium version is also available and generally recommended in water with high salt concentration, however, the levels of salt concentration that are expected at the Nicholson property should not affect the operation of the logger. The water level logger should be calibrated, programmed and deposited in the well to record the level of the

[242] Fetter, p.390.
[243] Ibid.
[244] Fetter, p.391.
[245] Fetter, p.391.

potentiometric surface over the period of at least a year to see if there is a general trend of rising groundwater. The logger has to be held by a stainless steel wire and the wire needs to be attached somehow to hang the water loggers so that we would be able to retrieve them on a later date. Since the wall caps are typically made of plastic, hooks would likely be able to be drilled into them to attach the wire. Once a year has passed, the data logger can be recollected and its data can be downloaded and analyzed. It would be recommended to check on the logging process of the data logger at various times in the year to make sure that it is still operating properly.

5.3.7 Laboratory Testing of Well Water Samples

There are companies that will provide both well drilling and laboratory analysis of water and soil samples. Laboratory analysis can get more complex if testing for other contaminants such as sewer water. Although, the practicing hydrogeologist will likely be involved with the collection of well water samples, he or she will rarely perform the chemical analysis of water samples.[246] This task is usually undertaken by trained laboratory professionals and is typically performed in a specialized analytical laboratory.[247]

In the case of the Abel and Mary Nicholson house, the well water samples that were collected with bailers from the existing well were brought back in containers to the Architectural Conservation Laboratory at the University of Pennsylvania. Three samples

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[246] Fetter, p.389.
[247] Ibid.

were taken from the same well water to ensure the quality of the results. All of the samples were subjected to salt ion spot tests and pH testing. Salt ion strip testing for the concentration of a particular salt ion was only performed once the salt ion spot tests were completed and the presence of various salt ions was confirmed or not. The salt ion spot tests were completed according to the laboratory procedure found in Appendix D. The three well water samples were tested for the following salt ions: sulfates (Figure 85), chlorides (Figure 86), carbonates (Figure 87), nitrites (Figure 88) and nitrates (Figure 89).

The results of the tests can be found in (Table 5). The three well water samples only tested positive for chlorides by emitting a whitish/blue precipitate when exposed to the chemical compound indicators. The laboratory procedures for the pH and chloride strips were carried out as specified on the packaging. Two different pH tests were performed; one that specified a range of pH values from 1 to 14 and another that was more precise and ranged from 6.0 – 8.1. Based on the first test, the pH of the samples appeared to agree at a value of 7 (Figure 90). In the second test, the pH of the samples appeared to agree at a value of either 6.6 or 7.2 (Figure 91). Since the samples only tested positive for chlorides, the chloride salt ion strips were the only salt ion strips used. According to the chloride strip results and key, all the samples have no salt concentration (Figure 92) and (Figure 93). Since the samples tested positive for chloride under the spot tests, it is likely that the samples do contain chlorides, but perhaps not at levels recognized by the salt strips. Such a low salt concentration necessitates a re-evaluation of the sampling and testing method and the predicted environmental phenomenon. It would be recommended to try another more standard sampling method and to check the effectiveness of the salt strips by testing them on known salt concentrations in solution. It would also be recommended to look into testing the salt ions of solid materials like the brick found in the cellar walls to see if it matches the salt ions found in the well water.

5.4 Determination of Depth to Building Foundations

In order to fully assess the threat of saltwater encroachment on a historic property, one needs to know the building foundations or footings depth and the characteristics of the foundation including the material type and supporting profile. Once one knows the foundation depth, one can compare it to the depth to the water table, which is measured by the water level loggers in the wells. If the water table fluctuates either between seasons or on a daily basis due to tidal effects, the foundation depth should be compared to the average annual depth to the water table and the minimum annual depth to the water table to judge whether or not the water table is in a position to affect the building foundations.

As part of this investigation, one would need to determine whether there have been any significant grade changes on site since its construction if possible. One would also need to measure the distance between the cellar's finished floor and the ground level. To find this distance, measurements of the interior of the Nicholson cellar were taken from the ground level to each interior cellar window sill because all windows are above grade level. Then, the distance between the ground level and each window sill was measured on the exterior. By subtracting the exterior distance from the interior distance, one can obtain the cellar depth below grade distance at each window location.

This method was performed on the Nicholson house and the resulting depth differences are shown in (Illustration 4). The depth of the existing well water below ground level was also recorded as 58-inches because it may represent groundwater level in that location. When compared with the nearest cellar finished floor depth, there is only a difference of 15.5-inches, or 1.3-feet, between the top of the cellar floor and the groundwater level found in the existing well. In the 1998 topographic survey map, the distance between the groundwater level found in the well and the top of the cellar floor is 3-feet. Assuming the basement level has remained the same, this represents a large change in the groundwater level (1.7-feet) over a short time-span of 8.5 years. If these numbers are representative of the phenomenon, this marks a 2.4-inch increase in groundwater level every year. If the groundwater continues to rise at this rate, the groundwater will reach the foundations in about 6.5 years. Of course, the true groundwater level would have to be confirmed over time because the measurement taken on one of the site visits in February may not be representative of the actual groundwater level. Although this method is a rough estimation and relies on accurate measurements, it may be worthwhile to go through and can give the steward an approximation of the threat's progression.

One would also need to determine the depth to the foundations. There were three methods that were considered in the Nicholson house case study and they were Ground Penetrating Radar, Rod-on-Foundation Method, and archeological test pits. Occasionally, the depth to foundations information is available in archival documents or original building plans, but not in the case of the Nicholson house.

5.4.1 Ground Penetrating Radar

Ground Penetrating Radar (GPR) can provide information about the layers and soils in the substrate, as well as locate building foundations and water table levels. GPR (Figure 94) involves the reflection of shortwave radio waves to identify voids, discontinuities, and changes in density in through different structural materials like heavy masonry or concrete walls or foundations.[248] The radio waves can pick up small differences in temperature through a material and those thermal differences are attributed to internal discontinuities, previous alterations, voids full of water or other damage within that material.[249] The depth that the GPR electromagnetic waves penetrate depends on both the material and characteristics of the substrate and building foundation as well as the level of frequency.[250] In order to detect the water table, the GPR device's central frequency of the antennae needs to be set to about 100 MHz.[251] The GPR results are depicted in a graphical output that typically depicts the different voltage levels of each received radio wave with different shades of grey.[252] The main flaws with this device is that the radio waves may not always be able to pass through certain materials and sometimes the readings can be misrepresented by metallic elements embedded in the structure or substrate.[253] The GPR device is operated by pulling it along the ground in order to create a continuous line profile, which is its greatest advantage over other similar

[248] Friedman, p.159.
[249] Ibid.
[250] Ibid.
[251] Ibid.
[252] Ibid.
[253] Ibid.

devices.[254] GPR surveys usually only require one person to operate and can be performed at a relatively fast pace.[255]

5.4.2 Rod-on-Foundation Method

In the Rod-on-Foundation method, the foundation and footings profile and depth is determined using a guess and check process. This method involves taking a stake, rod or garden hoe, and measuring tape and sticking the sharp end of the rod into the basement soil floor diagonally toward the direction of the foundations. If the stake hits the foundation wall or base, then the distance is measured and the depth is calculated based on Pythagorean's theorem. Then the procedure is carried out again, but this time from a further distance away. The procedure is carried out until the stake does not hit the foundation and one is left with an approximate depth of foundations. The rod-on-foundation method is much less expensive than hiring a contractor to perform a GPR survey, although one finds out less information at a lower resolution than the results of a GPR survey. The rod-on-foundation method may be recommended as a precursor to the GPR survey because the method may or may not provide all the information necessary regarding the foundations. It is wise to invest in the less expensive method and get back those results first before taking on the more expensive tool, in order to see if the level of information GPR provides is necessary to inform the site investigation and evaluate the threat.

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[254] Ibid.
[255] Ibid.

5.4.3 Archeological Test Pits

Alternatively, installing archeological test pits is another method of determining the depth to the foundations. The test pits are strategically installed above the proposed locations of the building foundations and are dug until they expose the footings and the relative depth from the ground is measured.

None of the methods were employed on the Abel Nicholson house due to cost and time constraints.

5.5 Modeling Saltwater Transport with Computer Modeling Applications

Recent advances in mathematical and computer modeling application have allowed for successful predictions of future flow behavior in hydrogeologic formations. Several computer programs have been made to model the effects of saltwater intrusion and other groundwater contamination phenomenon. Given the high quality of results and predicting capacity of the programs, they are worth considering as a method for evaluating hydrogeologic threats on historic properties. In the case of the Abel and Mary Nicholson house, it would be helpful to model the levels of the water table and zone of dispersion in relation to the building's foundation.

In order to build a model, one needs certain data from the site which can usually be obtained by drilling wells and testing boring samples and referring to professional journals, reports or surveys of the area being modeled. To begin creating a model, it is necessary to know the physical configuration of the all the site's aquifer and confining layers, including their location, area, and thickness.[256] The modeler also needs to know the locations of the surface water bodies and streams, as well as the boundary conditions for all aquifers. The following hydraulic properties are also needed for all aquifers and confining layers on site: transmissivity or permeability, storage coefficient, specific storage, potentiometric gradients and recharge amounts.[257] Specific types of models have other additional data requirements. It is also important to remember that the model will need to be calibrated upon creation and a sensitivity analysis needs to be performed.[258] It is also highly desirable to confirm the appropriateness of a model with field verification.[259] All models should follow set American Society for Testing and Materials (ASTM) standards for groundwater modeling.[260]

There are several types of models available to choose from but only four general types of problems: groundwater flow, solute transport, heat flow and aquifer deformation.[261] Two most commonly used models include groundwater flow models and solute-transport models. Groundwater flow models typically apply to[262]:

1. The study of regional steady-state flow in aquifer systems.

2. Regional changes in hydraulic head cause by changes in aquifer discharge or recharge.

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[256] Fetter, p.517.
[257] Ibid.
[258] Ibid.
[259] Ibid.
[260] Ibid.
[261] Fetter, p.516.
[262] Fetter, p.517.

3. Changes in head near a well field, dewatering well system, injection well, or infiltration basin.

4. Interactions between surface-water and groundwater.

Solute-transport models have been used in studies of salt-water intrusion and several types of groundwater pollution distribution paths.[263]

Several models are classified as either finite-difference or finite-element, which reflects the nature of their underlying grid pattern. Finite-difference models (Figure 95) use a rectangular network of nodes, which contain points of known information and equations for solving unknown variables. Finite-element models (Figure 96) instead divide a given aquifer into polygonal cells that are intersected at node points, which represent unknown values that require interpolation between nodal points to solve.

Groundwater Modeling Systems (GMS) has created several groundwater modeling programs, all of which are intended to model particular groundwater phenomena. Fem-water and MODFLOW are both programs that have been created by GMS. Fem-water is a finite element analysis program that is suited for modeling saltwater intrusion. MODFLOW is a block-centered finite difference analysis program, which is able to simulate confined, leaky confined, and unconfined aquifers. MODFLOW is limited in the fact that it can only model saturated flow in porous mediums under uniform temperature and density conditions. MODFLOW would likely be the more appropriate for the model for evaluating the Nicholson house's particular threat.

[263] Ibid.

There are some limitations to groundwater flow models that are inherent across several applications and interfaces. For instance, models do not always have the capacity to account for outside influences such as projected sea level rise.[264] In most cases, the models cannot represent future shorelines and do not consider land subsidence or erosion.[265] Models also rely on the assumption that the area will remain the same with respect to development.[266] In addition, digital elevation modeling is somewhat limited and can result in the overestimation of land elevations and the subsequent underestimation of the susceptibility of coastal areas due to poor vertical resolution.[267]

Since these computer applications are very expensive and require training, it is not recommended that a historic site invest in such a modeling program. If the historic property steward has already collected all the information that is required to build the model, then the management may consider contracting a geologist with experience working the modeling programs, to create a model of the historic site's conditions and to accurately predict future levels of groundwater and saltwater in the area. No modeling options were explored for the Nicholson house except that it might be preferable to use a finite-difference model as opposed to a finite-element model because of the different meshing capabilities.

[264] Cooper, Beevers and Oppenheimer, p.6.
[265] Ibid.
[266] Ibid.
[267] Ibid.

6.0 Evaluation of Tools and Recommendations for Further Study

6.1 Assessment of Available Tools

The methods and tools that were described, investigated and sometimes applied in the previous chapter were judged and rated for their effectiveness and appropriateness in evaluating the variables necessary in signifying saltwater encroachment on a historic site. The methods and tools include: comparison of aerial photography over time with cross-reference to a topographic map, installation of test pits and laboratory salt ion testing of well water, installation of monitoring wells and laboratory salt ion testing of well water, and groundwater modeling. Each method and tool is evaluated on its effectiveness of measuring and/or monitoring the following variables: groundwater level, groundwater salinity content, and the direction of groundwater flow. The methods and tools were analyzed for their effectiveness of measuring different variables under the following evaluation criteria: cost, resolution, accuracy, precision, availability, complexity, durability, and time requirements.

Cost refers to the monetary expense that is required to carry out the method. Resolution refers to the level of detail and sharpness in the product of the method. Accuracy refers to how close the results of the method are to the true value. Precision refers to the reproducibility of the results of the method and the degree that individual results agree with one another. Availability refers to the accessibility of these methods to the general public. Complexity refers to the level of difficulty of the method and the number of steps necessary for carrying out the method. Durability refers to the likelihood of the method to be applicable, available and usable in the future. Time requirements refer to the amount of time commitment necessary to carry out the method.

Each tool was ranked either “good”, “acceptable” or “poor” in the above categories and the ratings are displayed in (Table 6), (Table 7), and (Table 8) in Appendix B. Collectively, the ratings should indicate the method’s performance and suitability for evaluating the variable. The rankings are explained as follows. A “Good” ranking generally implies that the method is favorable with respect to a specific criterion. An “Acceptable” ranking implies that the method, although not favorable, is reasonable with respect to a specific criterion. A “Poor” ranking implies that the method is unfavorable with respect to a specific criterion.

Under the cost criterion, a method that ranks “good” can be completed for little or no expense. A method with a ranking of “poor” requires a significant amount of monetary support to carry out. A method that ranks “acceptable” in the cost category lies somewhere in the middle on the cost scale, requiring some nontrivial financial support but deemed to be worth the extra expense.

Under the resolution criterion, the method that ranks “good” produces a product with a very high resolution and fine degree of detail. The method that ranks “acceptable” produces a product with a mediocre resolution that is still adequate for the criterion. The method that ranks “poor” produces a product with low resolution that is unrefined and generally unacceptable for this case.

Under the accuracy criterion, the method that ranks "good" produces a product that is generally representative of the true value with a high level of confidence. The method that ranks "acceptable" produces a product that is close to the true value with a reasonable level of confidence. The method that ranks "poor" produces a product that does not represent the true value and is inapplicable.

Under the precision criterion, the method that ranks "good" is able to reproduce the same results upon multiple trials. The method that ranks "acceptable" is able to reproduce roughly the same results on multiple trials, with a small and tolerable degree of difference between the results. The method that ranks "poor" is unable to reproduce the same result on multiple trials and has a large and unacceptable variation between the values of its results.

Under the availability criterion, the method that ranks "good" is widely available and accessible to the public. The method that ranks "acceptable" is slightly more difficult to access and employ, but the method is worth the trouble of accession. The method that ranks "poor" is very difficult to come by and carry out to a point which makes the method undesirable to use.

Under the complexity criterion, the method that ranks "good" involves very few steps, is user-friendly, and is fairly easy to implement by operators with ranging levels of experience. The method that ranks "acceptable" is more difficult to comprehend and carry out and involves a few intricate steps. The method that ranks "poor" is very difficult to understand, has lots of complex steps and requires additional knowledge and training to implement.

Under the durability criterion, the method that ranks "good" is likely to be a dependable method that is expected to be available, applicable and usable in the future. The method that ranks "acceptable" is not as reliable of a method because its availability, applicability and usability may vary over time, though it is generally still expected to be a valid method in the future. The method that ranks "poor" is not expected to be a viable method in the future.

Under the time requirements criterion, the method that ranks "good" has minimal time requirements and does not take very long to prepare, implement and gather and interpret the results. The method that ranks "acceptable" requires a greater time commitment to carry out but is deemed to be worth the extra time obligations. The method that ranks "poor" takes a long time to implement and process the results and may not be worth the extreme time commitment.

Each of the tools were evaluated individually with respect to the evaluation criteria for each variable. As an example of the logic that went into ranking the methods, the comparison of aerial photography over time, with cross-reference to a topographic map, method rankings are explained as follows. The aerial photography and topographic method is a fairly inexpensive method for all variables and ranks "good" under costs. Minimal to no costs are associated with obtaining past and present aerial photographs and topographic maps. The resolution of this method is "poor" with respect to evaluating the groundwater level because, depending on the topographic survey, the elevations may only be known to the nearest foot, which is typical of a USGS Quad map. The method also has “poor” resolution with respect to measuring the groundwater salinity content, because the only possible numerical approximation relates to the area of phragmites. The method has “acceptable” resolution with respect to the direction of groundwater flow since the general directional slope can often be inferred from the topographic map. The accuracy of this method is ranked as “poor” with respect to evaluating the groundwater level because the user only knows the groundwater level at bodies of water, rivers and marshlands, where the topographic elevation above sea level is equivalent to the groundwater level. The accuracy is also “poor” with respect to measuring groundwater salinity because the only possible indicator is the presence, given areas of phragmites and not the salinity content. The accuracy is “acceptable” with respect to the direction of groundwater flow variable because the topographic maps indicate surface slope which is often mimicked in the groundwater and can be assessed by knowing the elevations. The precision is “acceptable” with respect to groundwater level because one would expect to get similar results using this method, despite inaccuracy in the results. The precision is “poor” with respect to groundwater salinity content due to the fact that areas of the phragmites may be easily miscalculated. The precision is “good” with respect to the direction of groundwater flow because the results will likely coincide in the same direction since it is based on only a few points of sea level elevation in the topographic map. The availability is “poor” with respect to all variables because early aerial photographs of a site do not always exist, are often hard to find and are not always made available to the general public. The method’s complexity is ranked “acceptable” for the groundwater level and direction of groundwater flow variables because it involves the creation of a flow-net, which might require some background knowledge of hydrogeology. The method's complexity is ranked "good" for groundwater salinity content since it only involves the sum of areas. The durability of the method ranked "good" with respect to both the groundwater level and direction of flow variables because the method of evaluating the variables can likely be used in the future. The durability of the method ranked "acceptable" for measuring groundwater salinity content because the vegetation patterns may changed by a fire or other species so that the vegetation can no longer act as an indicator of saltwater presence. The time requirements were ranked as "good" with respect to all three variables because comparing the areas and constructing the flow net takes a reasonable amount of time to obtain the information about the variables.

According to (Table 6), (Table 7), and (Table 8), the overall best method was determined. The overall best method was determined based on the total number of "good" ratings that appear in all three tables in relations to the number of "poor" ratings. The installation of wells to monitor groundwater level and salinity content emerged as the best overall method for evaluating the variables and assessing the threat of saltwater encroachment on the property. The installation of monitoring wells ranked higher than test pits mainly because of the increased accuracy and precision that comes with monitoring the variables over time and the better data resolution provided by the data loggers.

Although not as highly rated as the test pit and monitoring well methods, the comparison of aerial photography over time with a topographic map, was determined to be a very valuable tool as a preliminary assessor to an alternative threat. The method was extremely useful in recognizing the progress of another variable and possible greater threat on the Nicholson house: marshland encroachment. Based on the table results, the worst overall method was groundwater modeling, which is largely due to the high cost of the computer modeling applications, the difficultly of learning and operating the modeling programs, the amount of necessary information for creating the model, the inability of model to account for certain factors inherent in the phenomenon, and the amount of time required to build a model.

6.2 Case Study Recommendations

Based on the analysis of (Table 6), (Table 7), and (Table 8), the installation of monitoring wells to measure groundwater level and salinity content is advised for the Abel and Mary Nicholson house case study in order to monitor the threat of saltwater encroachment on the property. The following outlines the recommended program for monitoring at the Nicholson house, which was created for the stewards of the property. It is recommended that the steward secures funds from the grant institutions to financially support the monitoring program. Once the program is well-funded, a well-drilling contractor can be hired to install the monitoring wells. The wells are recommended to be installed with the appropriate auger rig that will cause minimal disturbance to the site. There should be at least three monitoring wells installed in the vicinity of the property. The wells should be strategically placed so that the wells represent the corners of a polygon, which the Nicholson house lies within, as shown in the site plan (Illustration 3). The polygon shape allows one to map out the potentiometric surface using the contour method, once the groundwater levels are determined at each well, to ultimately map out the groundwater flow and levels underneath the Nicholson house.

Within each well, the groundwater level and salinity content should be monitored over the course of at least one year. The groundwater level can be monitored with a water level data logger that is hung from the stainless steel wire attached to the well caps. After one year, the water level data logger can be removed and the water level data can be downloaded and analyzed.

It is recommended that water samples be taken from each of the wells at the same time every month over the course of a year. At least three 1-pint samples should be taken from each well during each sample period for good practice in maintaining the quality of the results. The steward may consider hiring a company to perform the water sample collection from the wells and laboratory analysis to test the water for the types and concentrations of salt ions. If the steward decides to collect the samples, it is recommended that the steward use a low-flow sampling pump, instead of bailers, and develop the well before sampling to ensure a more representative sample. If the steward decides to test the samples for salt ions, it is recommended that the steward rent out a properly equipped laboratory, if they do not already have access to one, and order the materials, such as the salt strips and chemical solutions, in advance. The salt ion spot test and chloride strip test procedures, found in Appendix D, should be followed for all water sample testing.

After one year of monitoring, the water level data and laboratory results should be graphed and analyzed for apparent trends. If saltwater encroachment is occurring, one would expect the water levels to progressively rise over time through the natural fluctuates of tidal and seasonal patterns, and the chloride and salt concentrations to rise over time as well.

6.3 Justification and Importance

This study merits exploration because the world is changing at a relatively brisk pace and significantly altering the environments upon which valued resources were originally built. It is important to recognize the probable threat to historic resources because historic structures and landscapes may not be able to withstand this impending change. Based on the case study, other historic sites with potential environmental threats may necessitate a similar methodology of identifying and investigating monitoring tools in order to determine the most effective tools for assessing their particular threat. Working to understand and measure the effects of climate change may grant historic property stewards the time and the information necessary to make the appropriate decisions regarding the historic property's future.

There are pitfalls inherent in this case study. For instance, the tools and methods may not be able to measure the long-time progression of saltwater intrusion. In addition, some of the developed tools may only apply to this site and this particular diagnostic problem and not to other heritage sites and investigations. Even if some of these tools could be effectively used on other cultural heritage sites and investigations, the heritage site may be in such a fragile condition that it would not be recommended to apply the investigative tools. After all, it is important to remember that these historic resources are facing change and potential threats that may not have existed before and certainly were not considered at the time the resource was established.

The case study also approaches preservation from a practical perspective. Instead of reacting to the deterioration of the Nicholson House, it takes a proactive approach by evaluating the threat of a likely deterioration mechanism before it becomes active. By assessing the stage and level of threat upon a resource, a time frame may be developed within which the owners will have time to design appropriate solutions and apply them. The project involves taking an active role in the preservation of the Nicholson house and a preventative approach to its deterioration. Finally, if any of these methods of evaluating the threat of saltwater deterioration are deemed effective, they could be applied to similar projects in the future.

It is worth noting that this is a multi-disciplinary problem that concerns not only historic preservationists, but engineers, geologists, policymakers and other academics, practitioners and professionals. Affects of climate change and responses to climate change have not traditionally been presented in the preservation field and it is important to recognize their potential impacts. Other professional fields have done extensive research in regards to climate change and it is recommended that preservationists borrow from these other fields and build on this knowledge with their own research objectives that consider the preservation perspectives and needs. These studies will assist the preservation field in developing a better understanding of the impacts of climate change on historic resources. The involvement of preservationists in other professional field's studies will allow professionals from historic preservation and outside historic preservation to gain and raise awareness of each other's professional work and collaborate on common objectives in regards to climate change. Furthermore, preservation involvement in climate change studies will help bring preservationists, as stakeholders, and preservation concerns to the table and help engage preservation professionals in the decision-making process regarding governmental responses to climate change. Overall, climate change is something preservationists should be concerned with and involved in creating the policies that react to these changes in order to more effectively preserve cultural heritage resources for future generations.

Afterword: Solution Recommendations

The tried-and-true remediation methods for preserving historic buildings may not be the best methods for every historic building or site. In fact, some of these traditional methods may be quite damaging to the property.

For instance, when building owners or management personnel find discoloration on the building's walls, whether it be the presence of white deposits like salts or lime run or green staining like biological growth, the natural instinct is to immediately coat the walls with a white wash or paint so that one cannot see the discoloration. However, this method does not solve the problem, and in some cases, makes the problem even worse.

In the case of the Abel and Mary Nicholson house, this method would be particularly harmful. If the white deposits on the interior cellar walls are salts and the salt line represents the level of water evaporation from the wall and consequent height that the salts have been transported in the building wall through rising damp, then it is apparent what areas are being affected by this phenomenon. Covering this up would also cover up the evidence of this phenomenon. In addition, the appearance of salts on the surface of the interior cellar wall is generally a good thing because it means that the salts are no longer inside the brick and causing damage to the brick material. This also means that the water in the salt solution is evaporating and the wall is effectively bringing the salts to the surface. If the wall is white-washed or painted over, the salt solution would not be able to evaporate in the same location because the new coat would block the passage of water molecules into the atmosphere, which would increase the moisture content of the brick wall at that level. The salt solution would be forced to move higher in elevation, by the accumulation of more salt solution, up the brick wall until it could find a place where it could evaporate. Hence, the paint or white-wash application appears to solve the problem by covering the condition, but instead traps the salt solution in the brick and pushes the salt solution farther up the wall to inevitably affect more brick material and to a greater degree.

Another problem that the Abel and Mary Nicholson house faces is the lack of drainage on and around the entire building, which may be responsible for the flooding of the cellar basement after heavy rainstorms. Since flooding in a building can be very detrimental to a building's materials, systems, structure, foundations and occupants, it may seem that designing and installing flashing and other water re-direction mechanisms on the building, although disingenuous to the building's architectural character, would be essential to preventing its cyclic flooding and promoting its preservation and overall structural health. However, if the hypothesized phenomenon of saltwater encroachment on the building is active, then salt in the groundwater may already be at such a level where it is contaminating the brick foundations and cellar walls. If this is so, the freshwater runoff that accumulates in the building cellar and around the immediate exterior and percolates into the soil and groundwater levels below, may actually be diluting the saltwater and reducing the salt concentrations in the groundwater. In this case, the lack of drainage may be helping to placate the effects of saltwater intrusion on the Nicholson's house masonry foundation. If proper drainage systems were installed, the house would be subjected to the full effects of a saltwater encroachment. Since this occurrence and the potential benefits of a lack of drainage system cannot be confirmed or denied this occurrence, affixing drainage systems would not be recommended at this time.

Even though it sometimes seems necessary to take some form of immediate action or maintenance plan to solve the problem, sometimes the best response for the building is to do nothing until one fully understands the phenomenon and can design an appropriate method to treat it. Applying a remediation method in which one is not sure about the outcome and simply waiting to see what happens is considered an inappropriate method for historic properties. And as exhibited in the Abel and Mary Nicholson house, what may be initially observed as a problem may actually be a solution to a greater problem.

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Appendix A: Figures

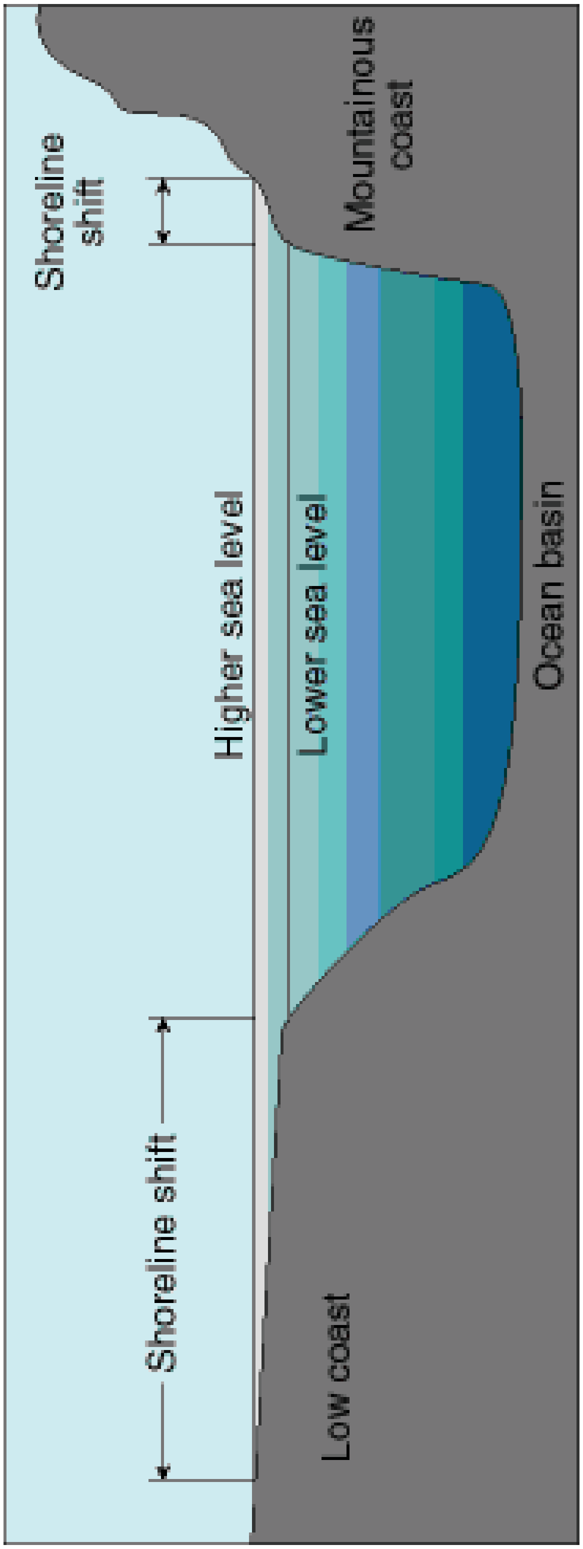


Figure 1. Diagram explaining the difference in the extent of shoreline shifts in mountainous and low-lying coasts. (Source: United States Geological Survey website: www.usgs.gov)

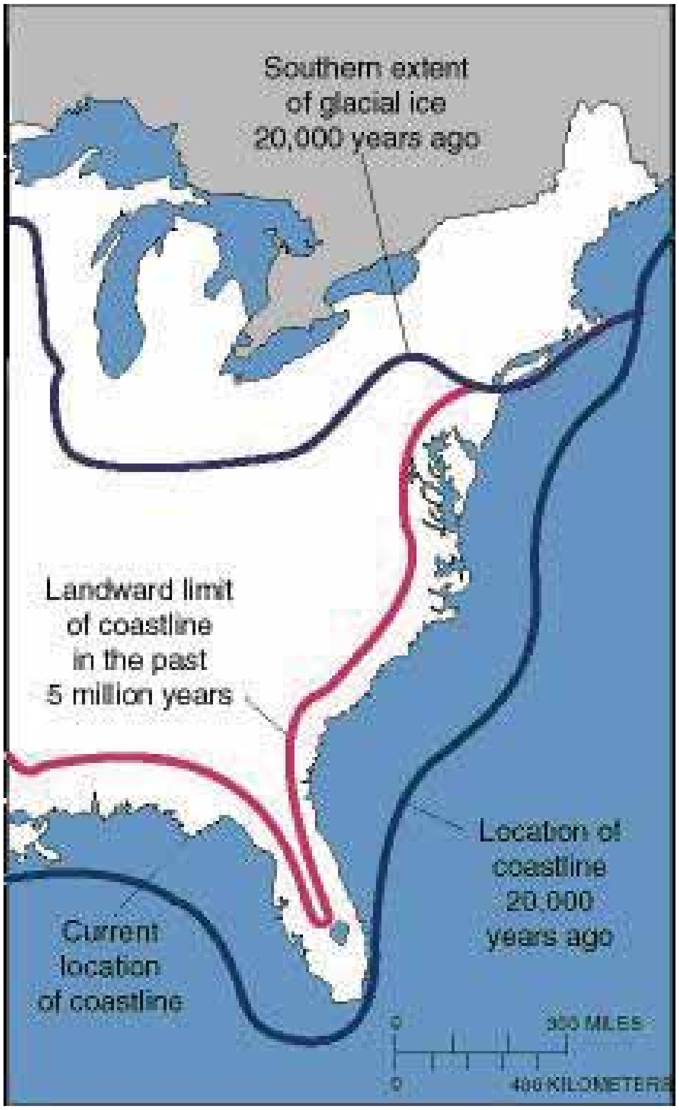


Figure 2. Depiction of the current coastline location, the coastline location from 20,000 years ago, the landward limit of the coastline in the past 5 million years, and the southern extent of glacial ice 20,000 years ago (Source: United States Geological Survey website: www.usgs.gov)

Figure 3. Photograph taken of the Columbia Glacier in 1980. Note the arrow that marks the same location found in the following photograph. (Source: National Aeronautics and Space Administration website: www.nasa.gov)

Figure 4. Photograph taken of the Columbia Glacier in 2005. Note the arrow that marks the same location found in the previous photograph. (Source: National Aeronautics and Space Administration website: www.nasa.gov)

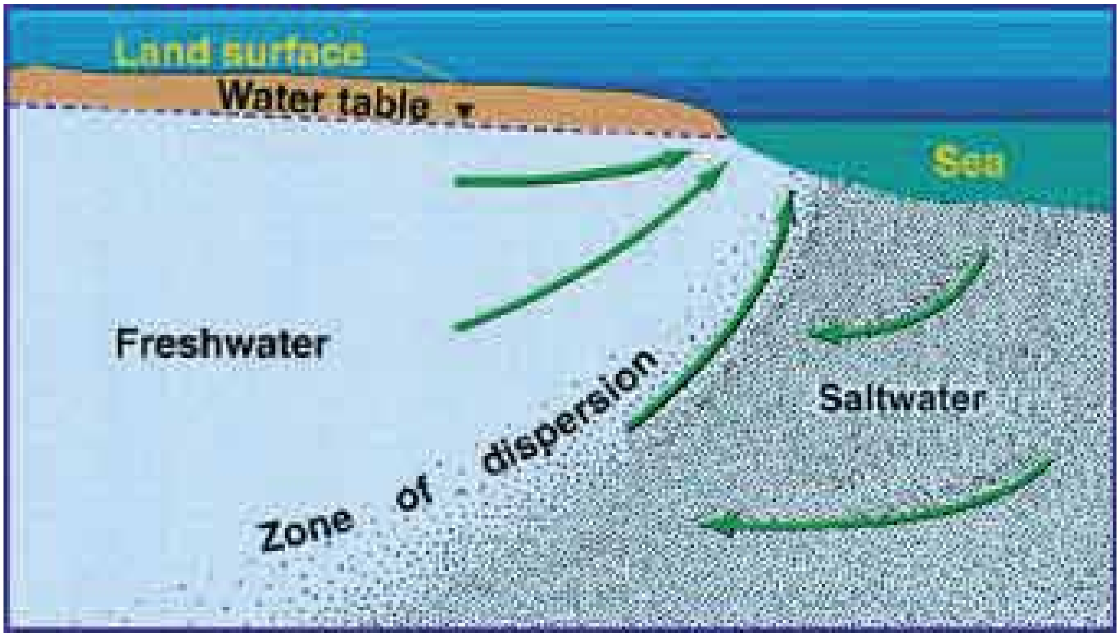


Figure 5. Diagram of the zone of dispersion, or the interface between freshwater and saltwater zones in groundwater, and its relation to the water table and the sea. (Source: United States Geological Survey website: www.usgs.gov)

Figure 6. Photograph of the Cape Hatteras Lighthouse and the nearby beach. The sandbags are there to prevent further beach erosion. (Source: United States Geological Survey: pubs.usgs.gov/circ/c1075/images/lighthouse.gif)

Figure 7. Photograph of the Cape Hatteras Lighthouse and the moving apparatus. (Source: National Park Service Photo: http://www.nps.gov/archive/caha/views.htm)

Figure 8. Photograph of the Abel and Mary Nicholson House, north and east façades. (Source: A. Aiken; taken 10/12/2006.)

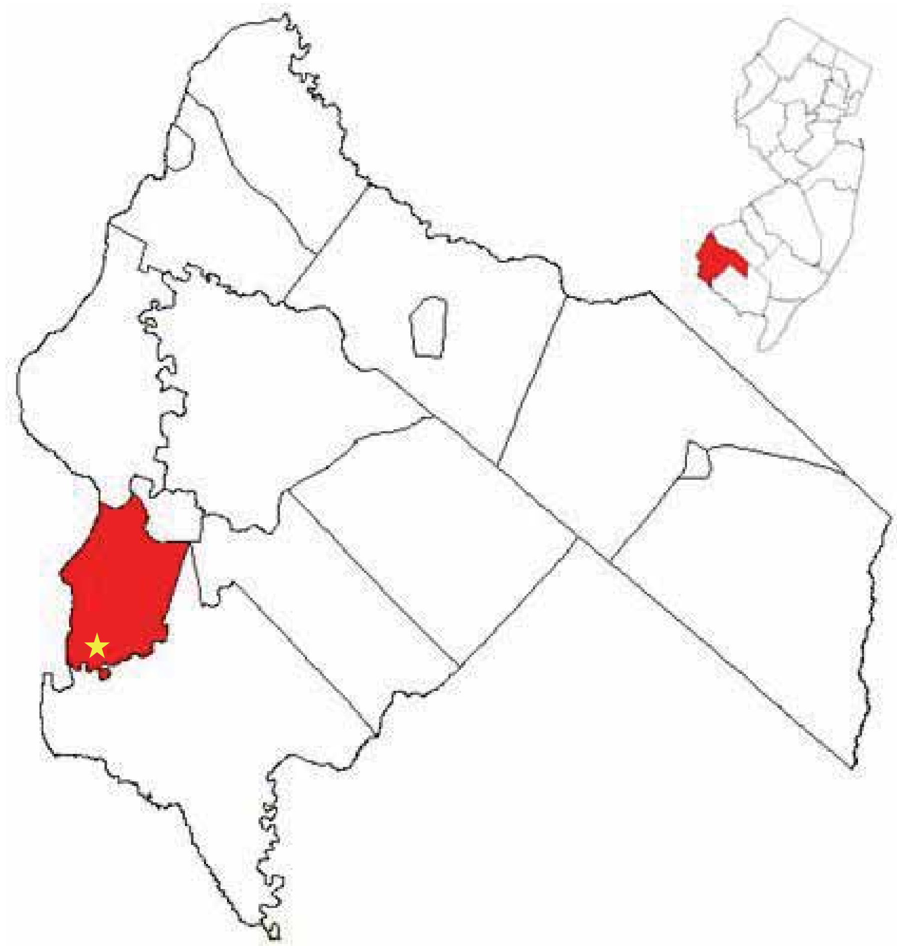


Figure 9. Elsinboro Township as it lies within Salem County, in relation to the state of New Jersey. The star indicates the location of the Abel and Mary Nicholson House. (Source: The State of New Jersey website: http://www.state.nj.us/)

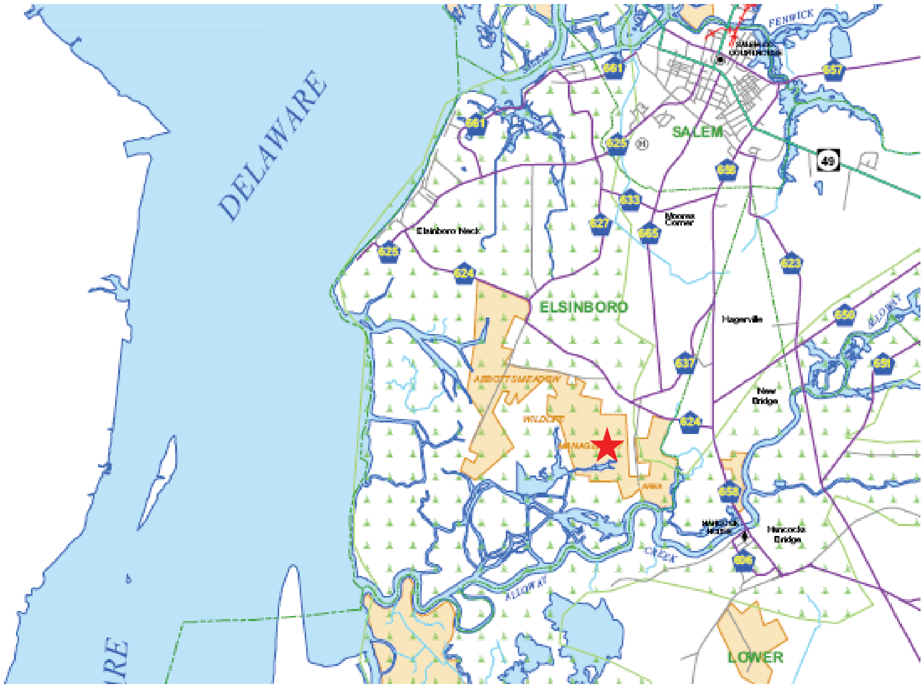


Figure 10. Area location map showing the City of Salem and the Delaware River in relation to Elsinboro Township and the Abel and Mary Nicholson House (red star.) (Source: New Jersey Department of Transportation website: http://www.state.nj.us/transportation/)

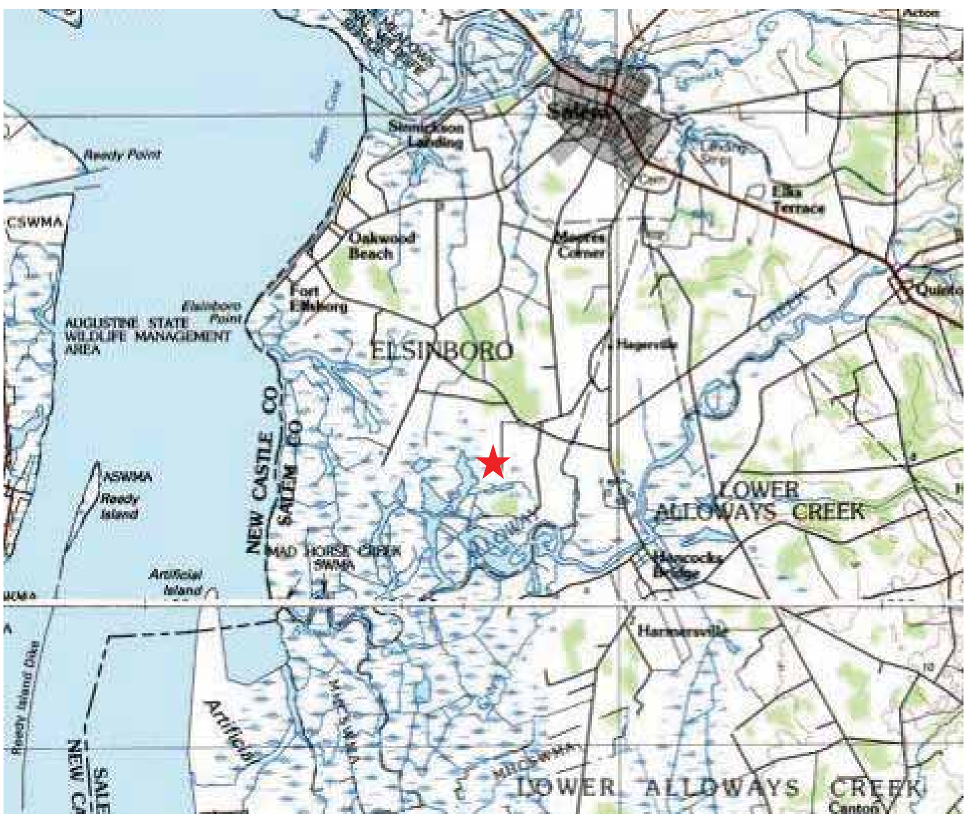


Figure 11. Area location map showing the location of the Abel and Mary Nicholson House (red star) in relation to Elsinboro Township. (Source: USGS quad map from www.maptech.com)

Figure 12. Photograph of the gravel access path leading to the Abel and Mary Nicholson House (view looking south toward the Nicholson House.) (Source: A. Aiken; taken 3/8/2007.)

Figure 13. Photograph further along the access path, approaching the Abel and Mary Nicholson House (view looking south toward the Nicholson House.) (Source: A. Aiken; taken 10/12/2006.)

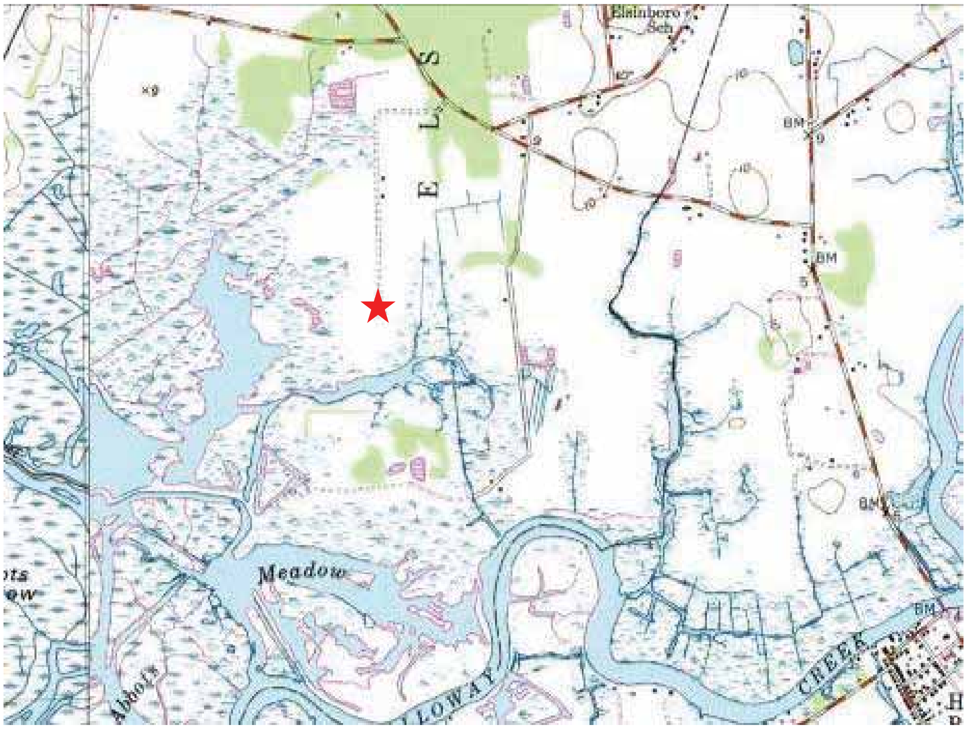


Figure 14. Area topographic map showing the location of the Abel and Mary Nicholson House (red star.) (Source: USGS quad map from www.maptech.com)

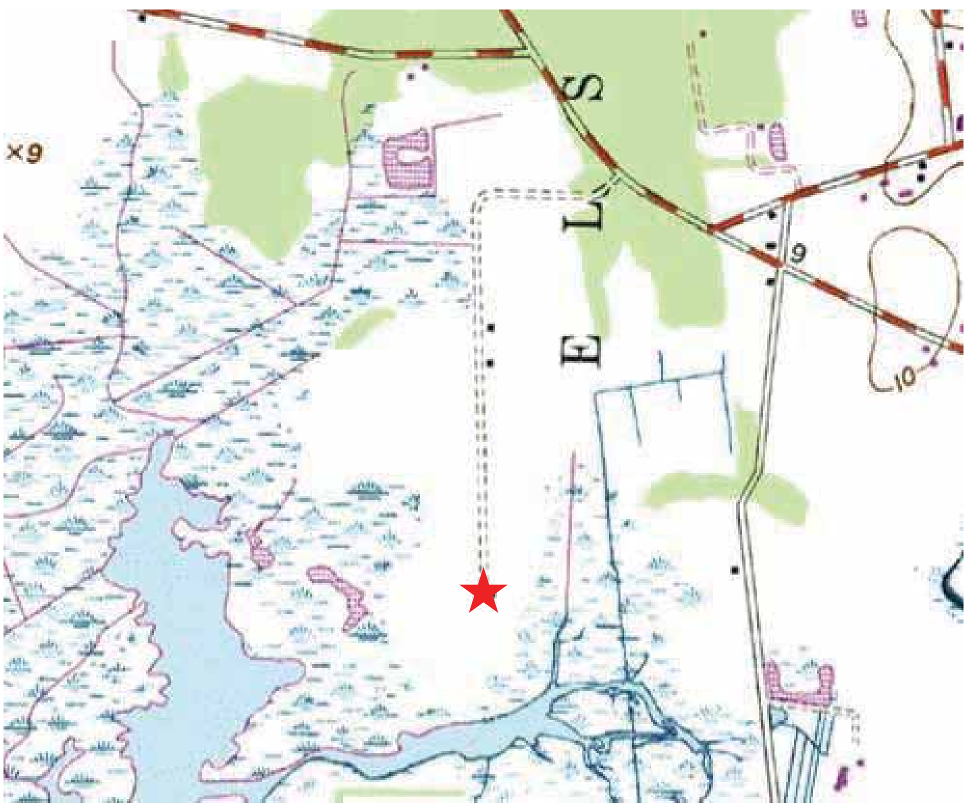


Figure 15. Zoomed-in area topographic map showing the location of the Abel and Mary Nicholson House (red star.) (Source: USGS quad map from www.maptech.com)

Figure 16. Aerial photograph of the Abel and Mary Nicholson House and the surrounding area. (Source: Salem County Historical Society)

Figure 17. Photograph of the large tree shading the south façade of the Abel and Mary Nicholson House. (Source: A. Aiken; taken 10/12/2006.)

Figure 18. Photograph of the fields of phragmites and dead trees surrounding the site of the Abel and Mary Nicholson House (view looking west.) (Source: A. Aiken; taken 10/12/2006.)


Figure 19. Photograph of the Salem Nuclear Plants taken from the Abel and Mary Nicholson house access path (view looking southwest.) (Source: A. Aiken; taken 3/8/2007.)

Figure 20. Photograph of the notable diapered-pattern brick end on the east façade of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 10/12/2006.)

Figure 21. Photograph of the north façade of the 1722 original block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 10/12/2006.)

Figure 22. Photograph of the historical main entrance on the south façade of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 10/12/2006.)

Figure 23. Photographic evidence of earlier attached kitchen addition on the west façade of the original building. (Source: A. Aiken; taken 10/12/2006.)

Figure 24. Photograph of the north façade of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 10/12/2006.)

Figure 25. Photograph of the west façade of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 26. Photograph of today's main entrance on the south façade of the 1859 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 27. Photograph of the locked gate blocking vehicles from driving on the access path to the Abel and Mary Nicholson house. (Source: A. Aiken; taken 10/12/2006.)

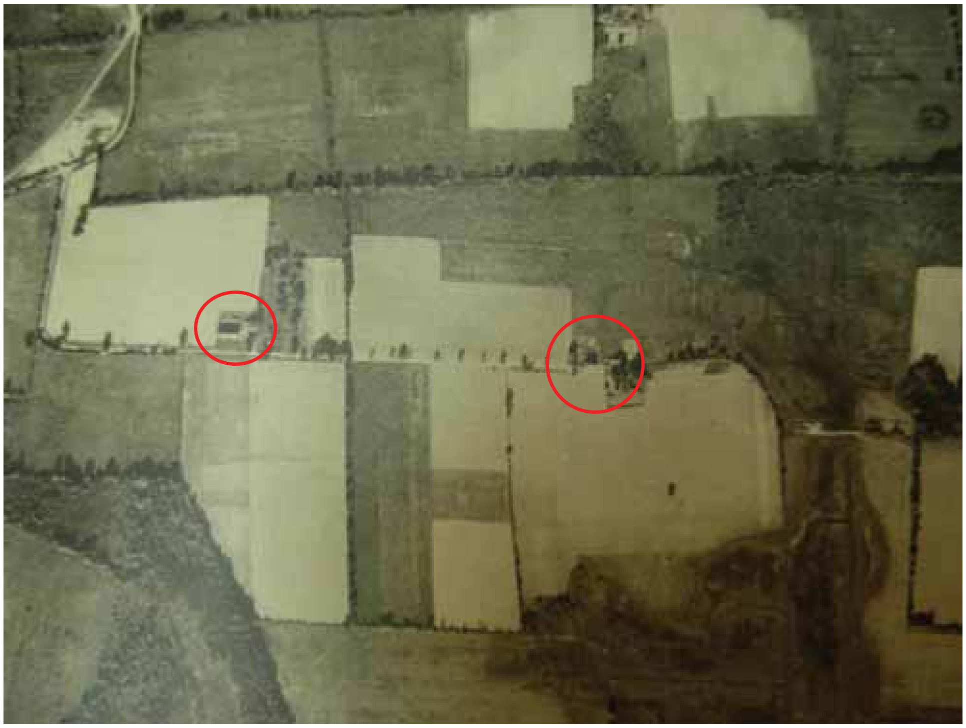


Figure 28. Photograph of 1932 aerial photograph of the site showing the other farm buildings, which no longer exist, located near the Nicholson house. The larger circle contains the Nicholson house while the smaller circle contains farm buildings along its access path (Source: New Jersey Department of Environmental Protection; taken 3/14/2007.)

Figure 29. Photograph of the oil storage tank on the west façade of the Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 30. Photograph of the major crack in the concrete pad supporting the oil storage tank on the west façade of the Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 31. Photograph of the existing drinking well and pump located a few feet from the south façade of the Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 32. Photograph of the 12-gallon storage pressure water tank located on the south wall of the west cellar room in the 1859 block of the Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 33. Photograph of the interior staircase that provides access to the entire cellar. The staircase is located on the west wall of the east room in the 1859 block of the Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 34. Photograph of the bulkhead door, on the south façade, that leads to the basement of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 35. Photograph of the bulkhead door, on the west façade, that leads to the basement of the 1859 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 36. Photograph of the east room wooden reinforced arched brick chimney support on the east wall of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 37. Photograph of the west room wooden reinforced arched brick chimney support on the west wall of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 38. Photograph of the east room arched brick chimney support on the east wall of the 1859 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)


Figure 39. Photograph of the west room arched brick chimney support on the west wall of the 1859 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 40. Photograph of the fading whitewash coating on the north wall of the 1859 block east room of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 41. Photograph of the flooded cellar from the cellar staircase, looking into the1859 block east room of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 10/12/2006.)

Figure 42. Photograph of the pool of water found at the southeast corner of the 1722 block east room of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 43. Photograph of the damp water staining at the bottom of the south wall of the east room in the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 44. Photograph of the green staining and poor brick and mortar conditions at the bottom, east corner of the north facade of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 45. Photograph of the dark discoloration of the north brick cellar wall near the ground of the 1722 block west room of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)


Figure 46. Photograph of the discoloration of the south brick cellar wall next to the water staining, near the ground of the 1859 block west room of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)


Figure 47. Photograph of the white discoloration of the south brick cellar wall near the ground and under the window of the 1722 block west room of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 48. Photograph of the north cellar wall in the east room of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 49. Photograph of the north cellar wall in the west room of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 50. Photograph of the south cellar wall in the east room of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 51. Photograph of the south cellar wall in the west room of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 52. Photograph of the floor in the east corner of the west room of the 1722 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 53. Photograph of the expired duck on the floor near the west wall of the west room of the 1722 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 54. Photograph showing the water table and change in brick coursing on the east end of the south façade of the 1722 block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 55. Photograph of the north wall of the east room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 56. Photograph of the north wall of the west room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 57. Photograph of the north wall of the west room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 58. Photograph of the south wall and ductwork in the east room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

Figure 59. Photograph of the south wall and west room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)


Figure 60. Photograph of the mechanical equipment in the west room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)


Figure 61. Photograph of the water pump in the west room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/23/2007.)

Figure 62. Photograph of a red cylindrical pipe possibly intended for drainage in the east room of the 1859 addition block of the Abel and Mary Nicholson house. (Source: A. Aiken; taken 2/7/2007.)

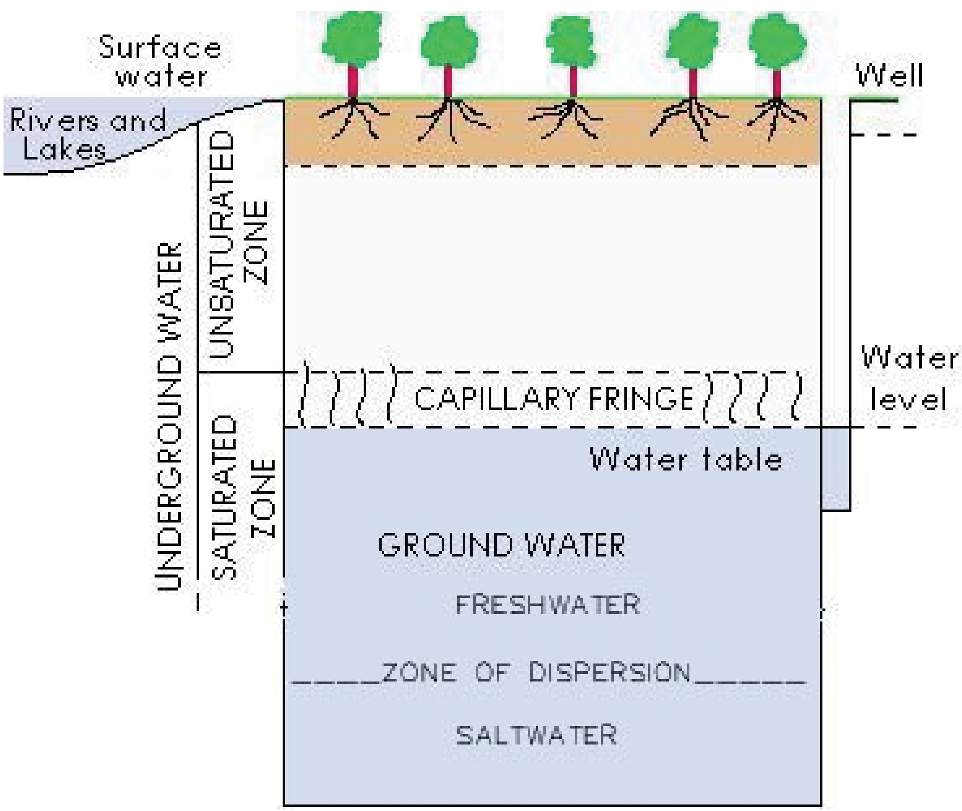


Figure 63. Diagram of the different components of groundwater. (Source: Purdue University: Agricultural & Biological Engineering Department and the United States Environmental Protection Agency)

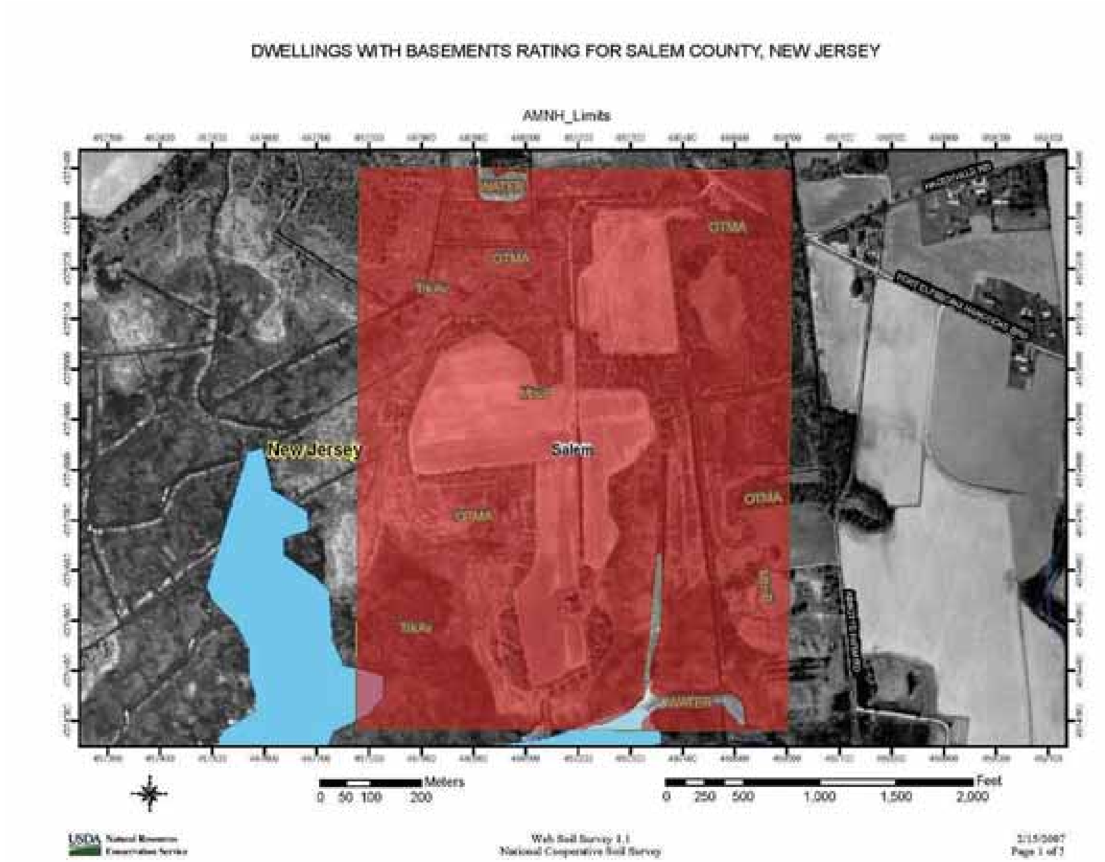


Figure 64. Aerial photograph depicting the area of interest. The red highlights represent soils that are very limited in supporting a building with a basement due to the shallow depth to the saturated zone. (Source: USDA Natural Resources Conservation Service: National Web Soil Survey)

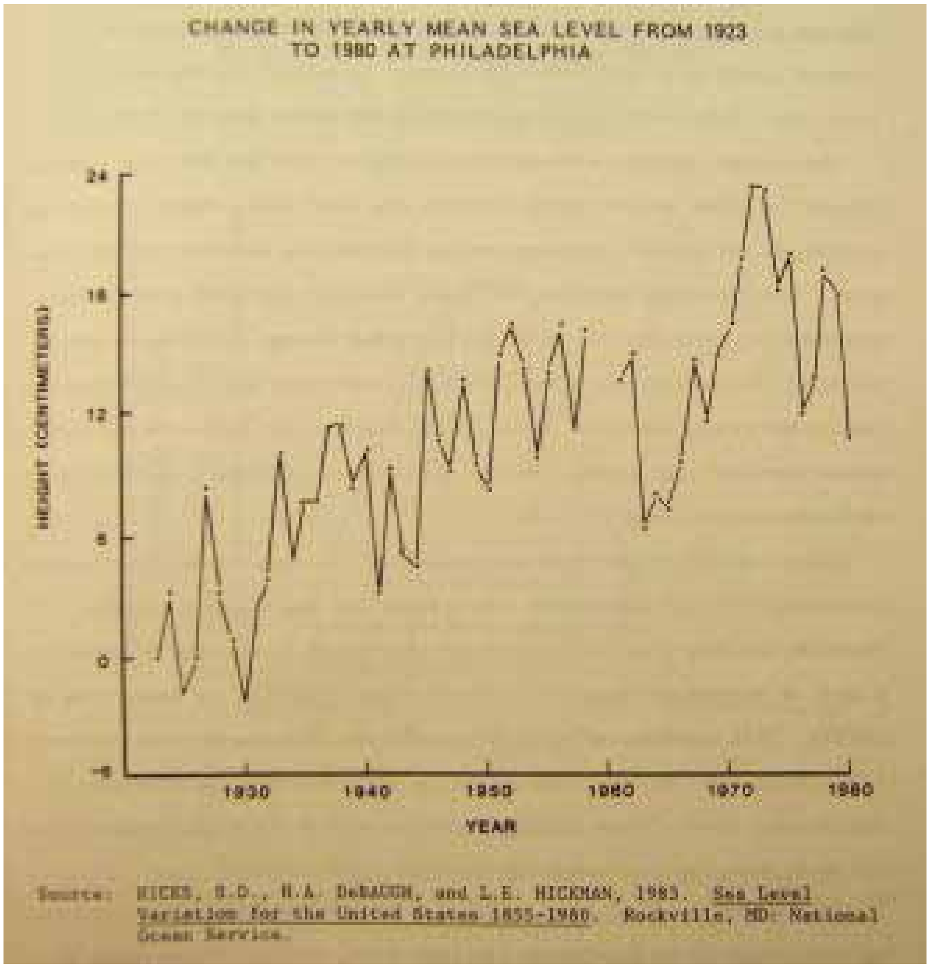


Figure 65. Graph of mean sea level change in Philadelphia over several decades. (Source: *Greenhouse Effect, Sea Level Rise, and Salinity in the Delaware Estuary*.)

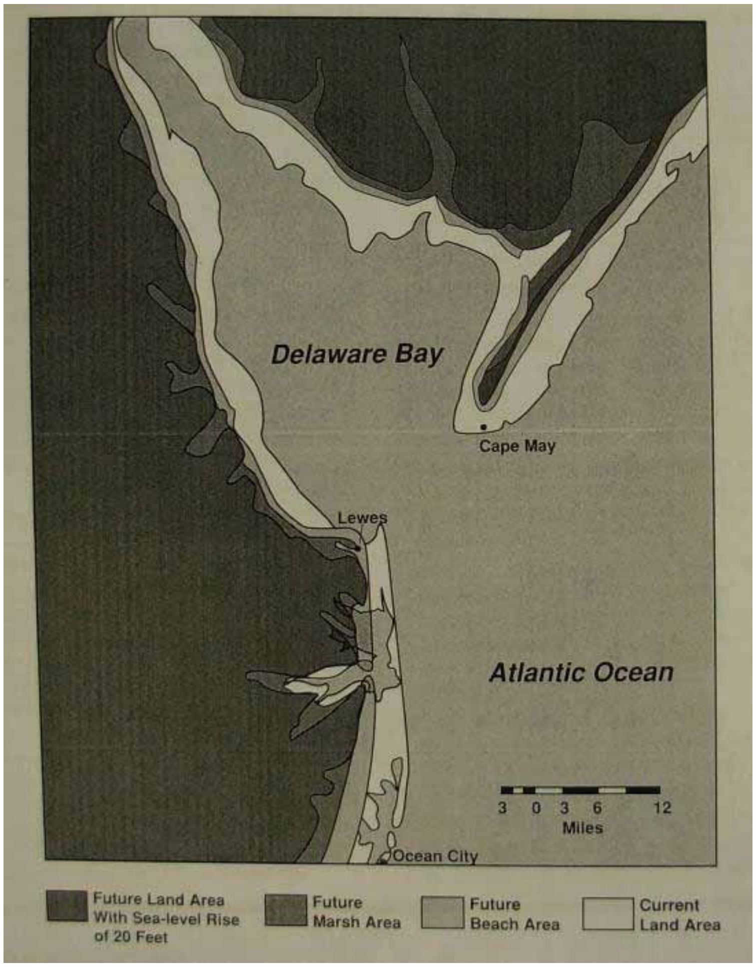


Figure 66. A projection of Delaware's and New Jersey's coastal zones geography for a sea level rise of 20 feet. (Source: Delaware Estuary Situation Report: *Sea Level Rise: How Could a Potential Rise in Sea Level Due to Global Warming Affect Delaware*? p.7.)

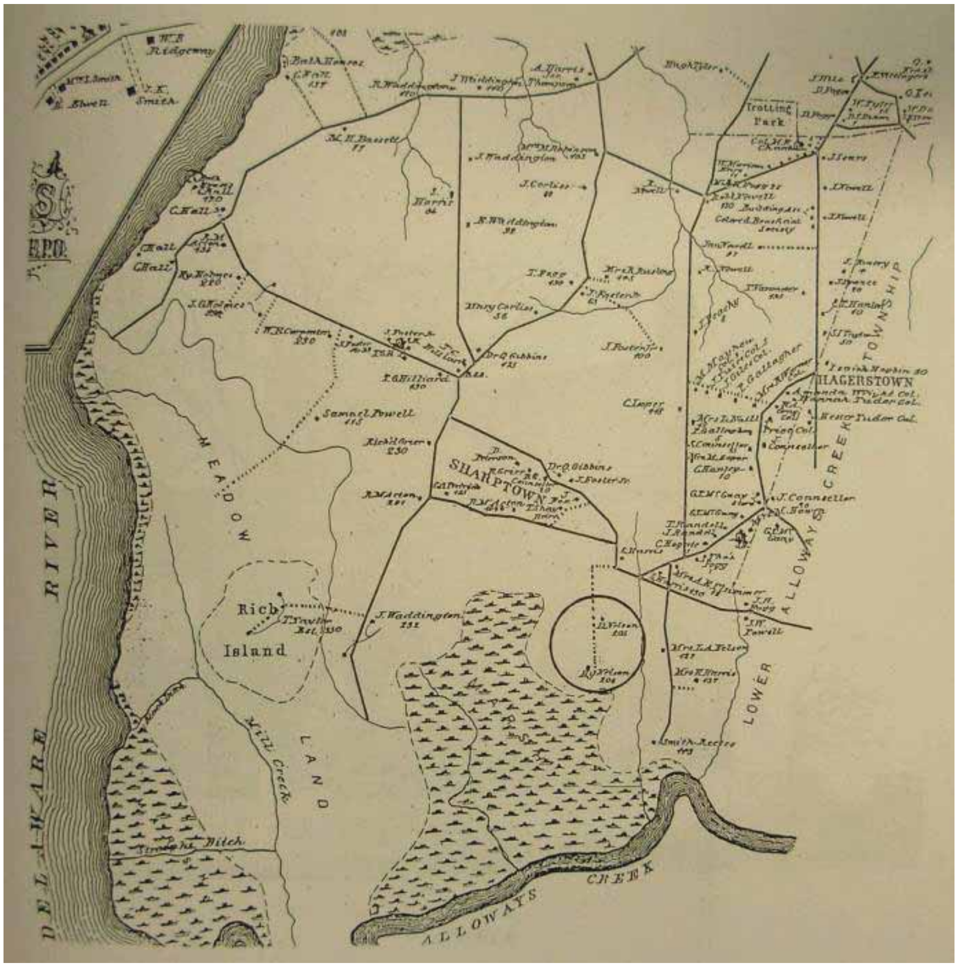


Figure 67. Map of Elsinboro Township found in the 1876 Atlas of Gloucester and Salem Counties. (Source: Preservation Plan for The Abel Nicholson house.)

Figure 68. 1932 Aerial photograph of the region surrounding the Abel and Mary Nicholson House (circled). (Source: New Jersey State Department of Environmental Protection: Bureau of Tidelands Management, Trenton, NJ.)

Figure 69. Close-up of 1932 Aerial photograph of the region surrounding the Abel and Mary Nicholson House (circled). (Source: New Jersey State Department of Environmental Protection: Bureau of Tidelands Management, Trenton, NJ.)

Figure 70. Zoomed view of 1940 Stereoscopic aerial photograph (Frame 8-62) of the region surrounding the Abel and Mary Nicholson House (circled). (Source: New Jersey State Department of Environmental Protection: Bureau of Tidelands Management, Trenton, NJ.)

Figure 71. Close-up of zoomed view of 1940 Stereoscopic aerial photograph (Frame 8-62) of the region surrounding the Abel and Mary Nicholson House (circled). (Source: New Jersey State Department of Environmental Protection: Bureau of Tidelands Management, Trenton, NJ.)

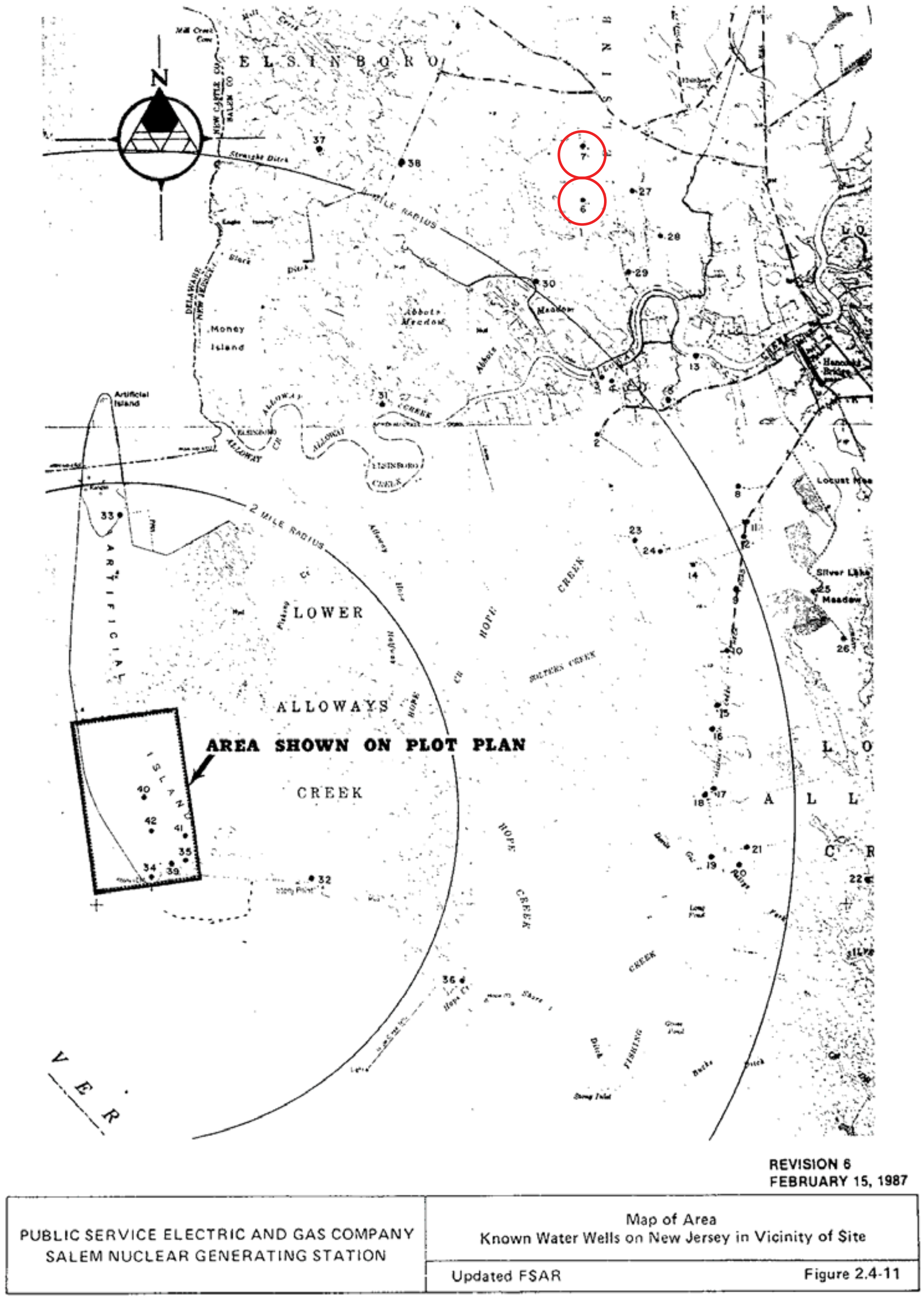


Figure 72. Map of area and existing wells near the PSEG Salem Nuclear Generating Station. Wells #6 and #7 lie on the Nicholson property and are circled. (Source: Nuclear Regulatory Commission: Updated Final Safety Assessment Report for Salem Units 1 and 2.)

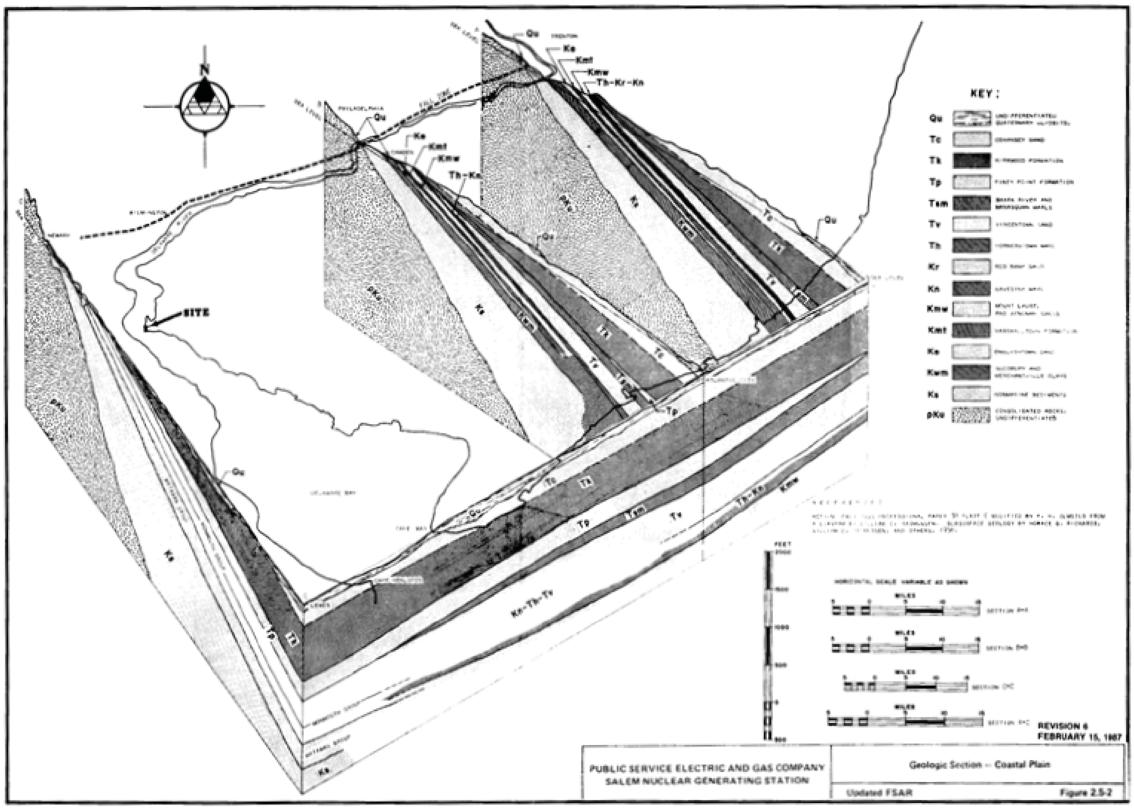


Figure 73. Geologic Cross-Section of the Coastal Plain underlying the Abel and Mary Nicholson House (circled). (Source: Nuclear Regulatory Commission: Updated Final Safety Assessment Report for Salem Units 1 and 2.)

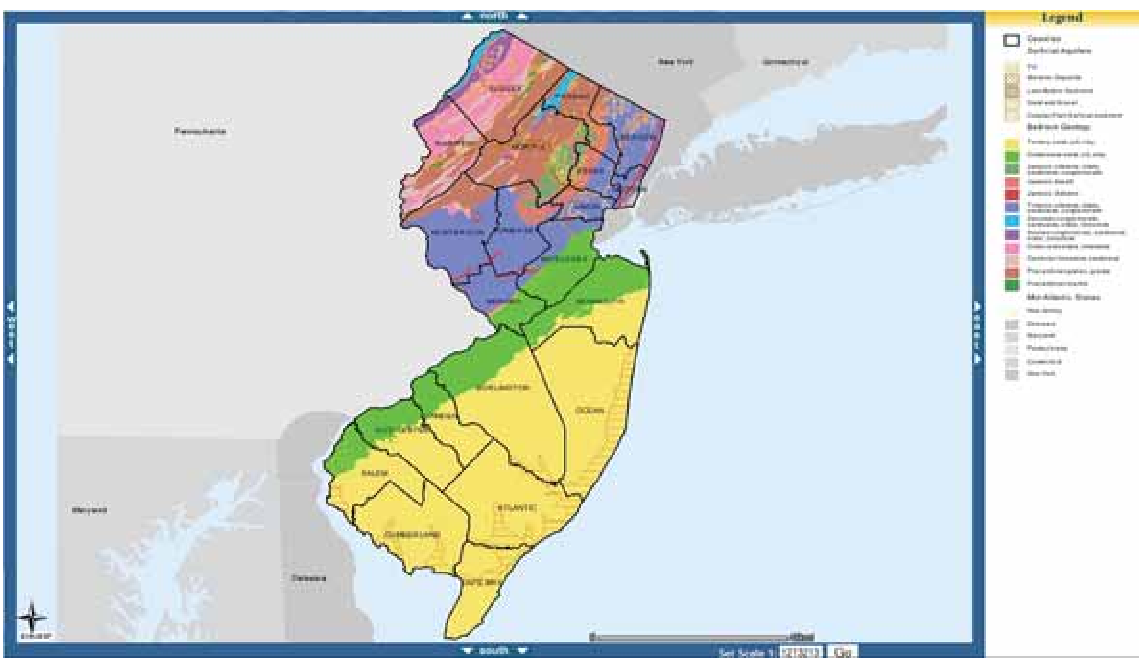


Figure 74. Geologic Survey Map revealing the bedrock geology composing different counties in New Jersey. (Source: I-Map NJ website; New Jersey Department of Environmental Protection.)

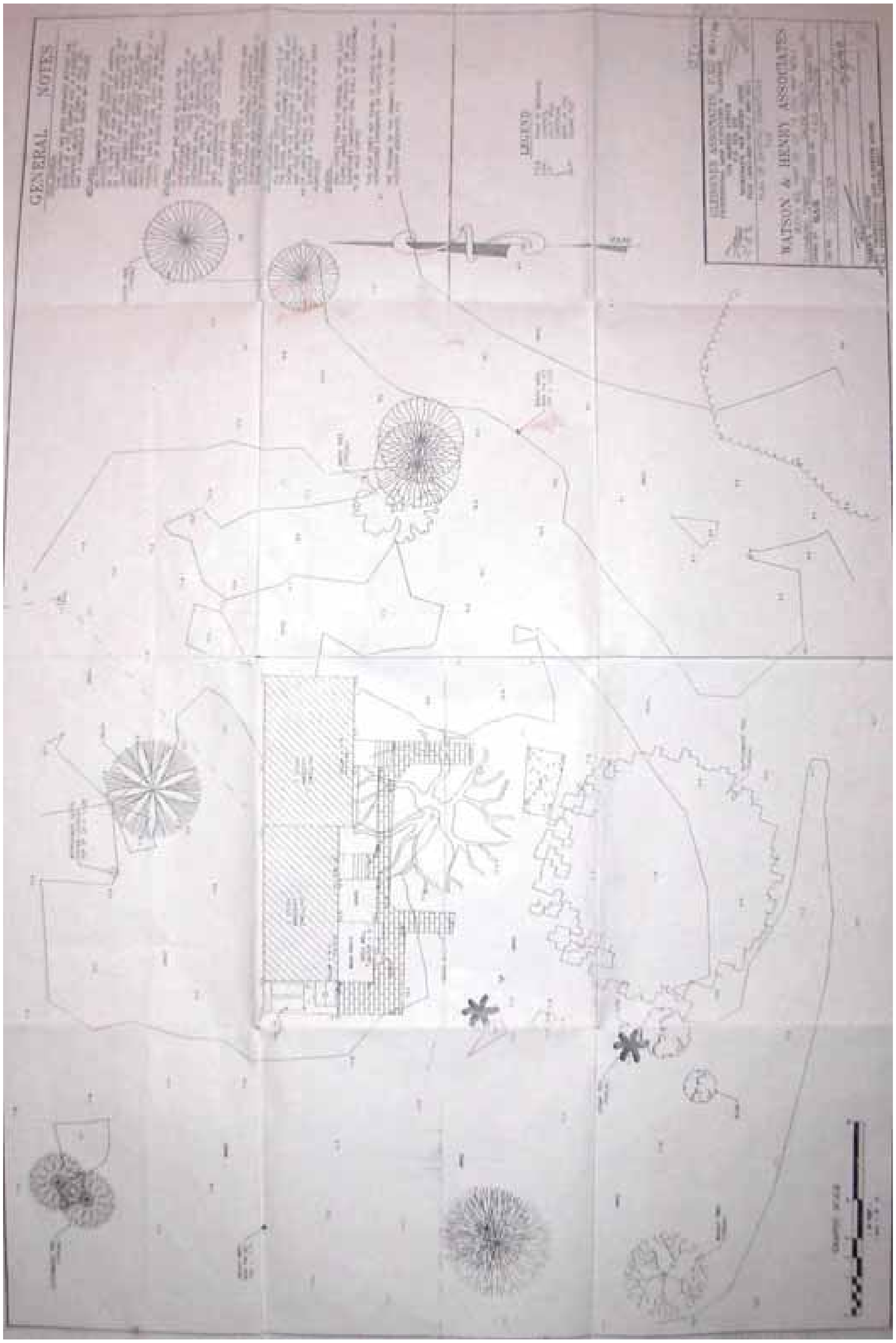


Figure 75. Plan of Existing Conditions for Watson & Henry Associates. 1998 Topographic Survey. (Source: Gleissner Associates, P.C.)

Figure 76. 2002 Aerial photograph of the region surrounding the Abel and Mary Nicholson House (circled). (Source: I-Map NJ website; New Jersey Department of Environmental Protection.)

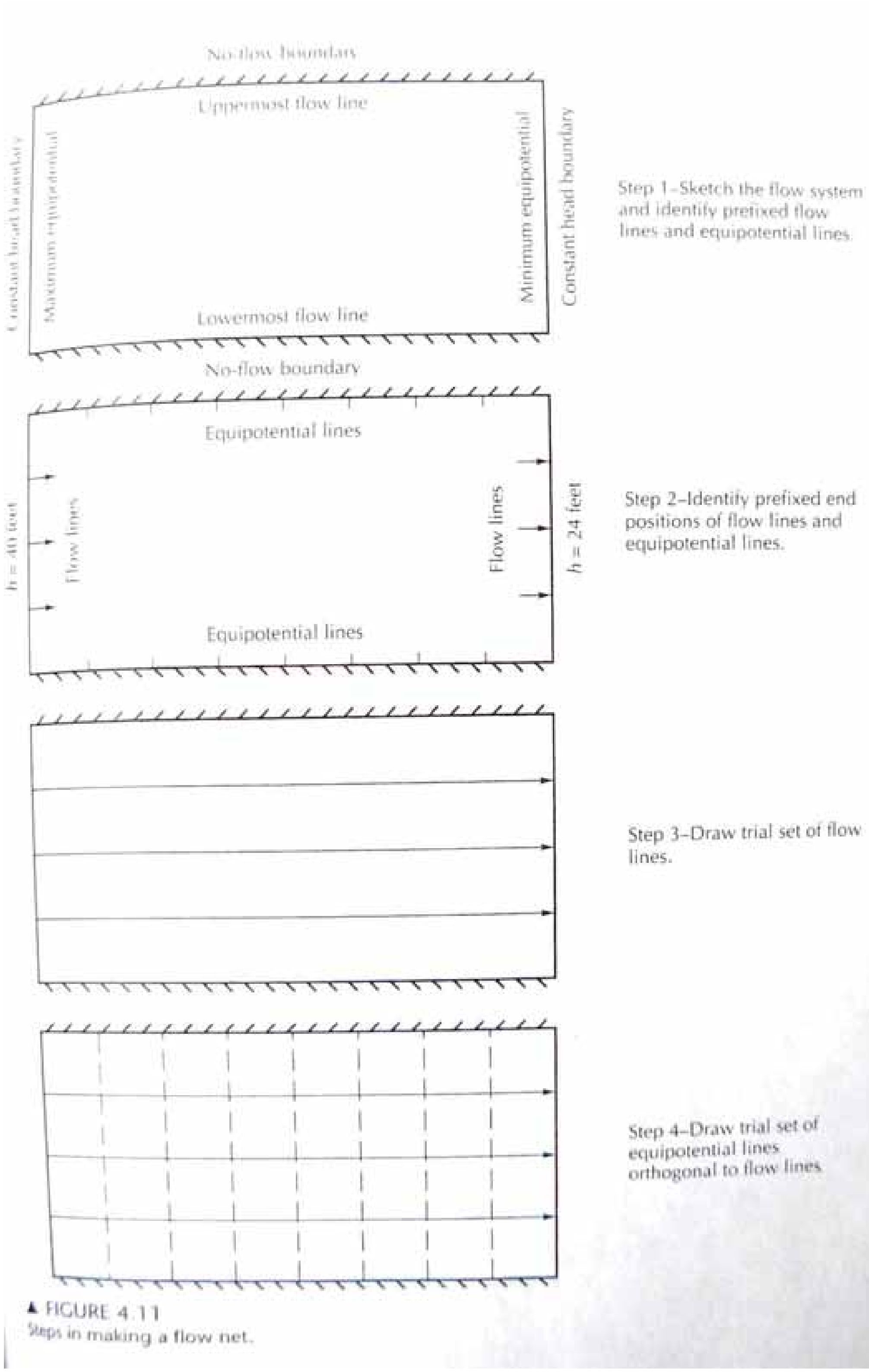


Figure 77. Example of how a flow-net is constructed. (Source: C.W. Fetter, Applied Hydrogeology Fourth Edition.)

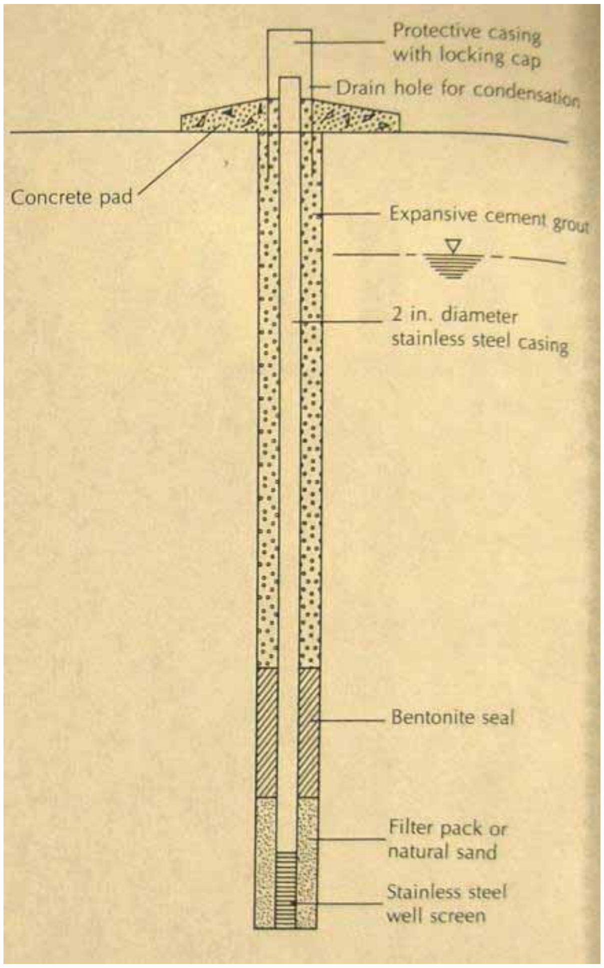


Figure 78. Diagram of typical groundwater monitoring well. (Source: Applied Hydrogeology, Fourth Edition, p.392.)

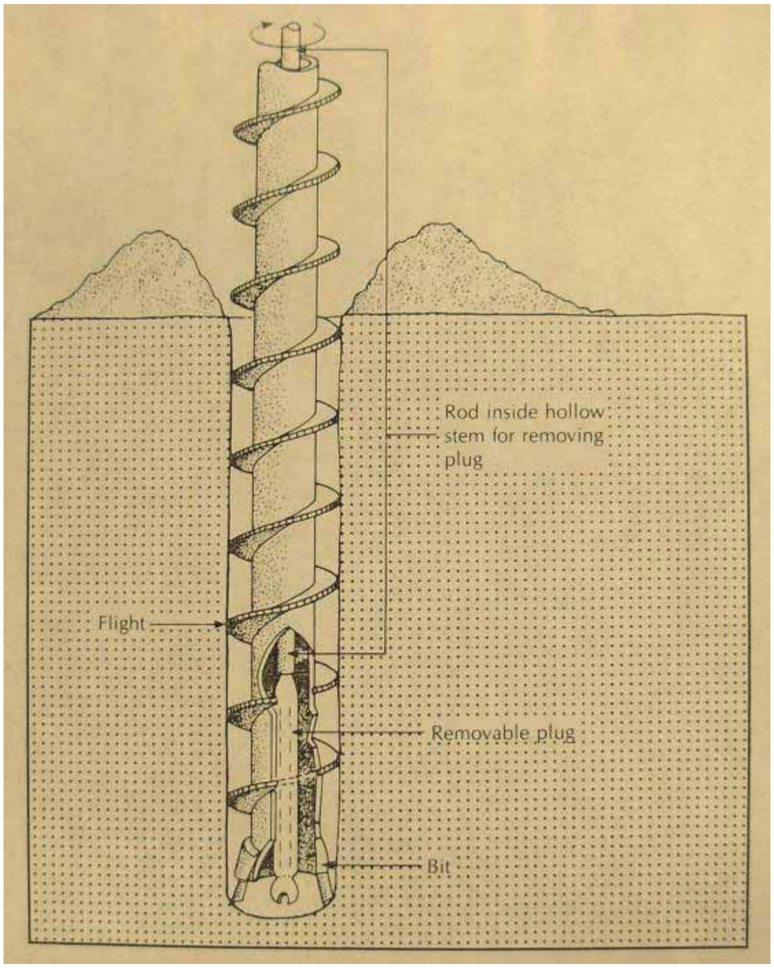


Figure 79. Diagram of hollow-stem auger drilling. (Source: Applied Hydrogeology, Fourth Edition, p.393.)

Figure 80. Photograph of Geoprobe Van. (Source: www.epa.gov).

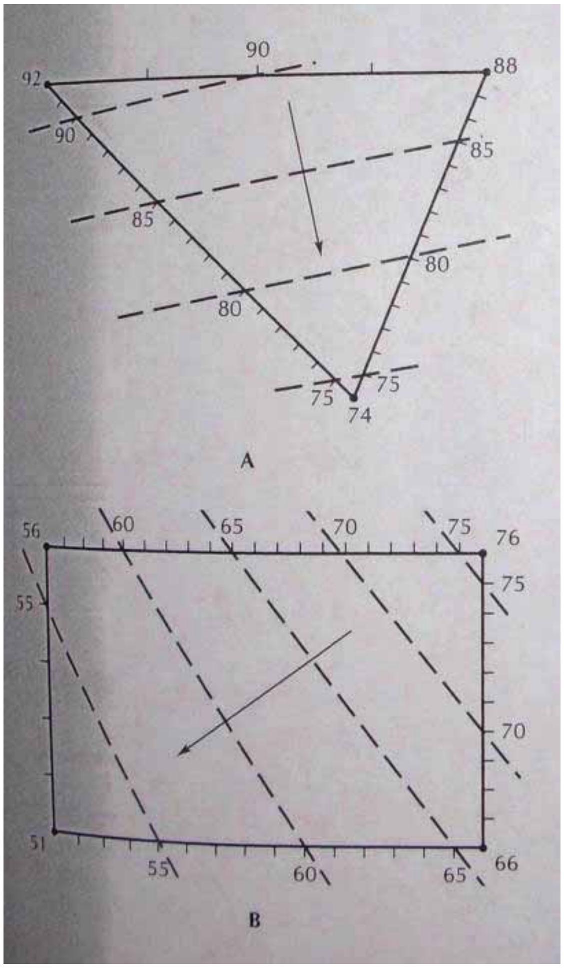


Figure 81. Graphical method for determining the slope and direction of a potentiometric surface with A) Three wells and B) Four wells. (Source: Applied Hydrogeology, Fourth Edition, p. 107.)

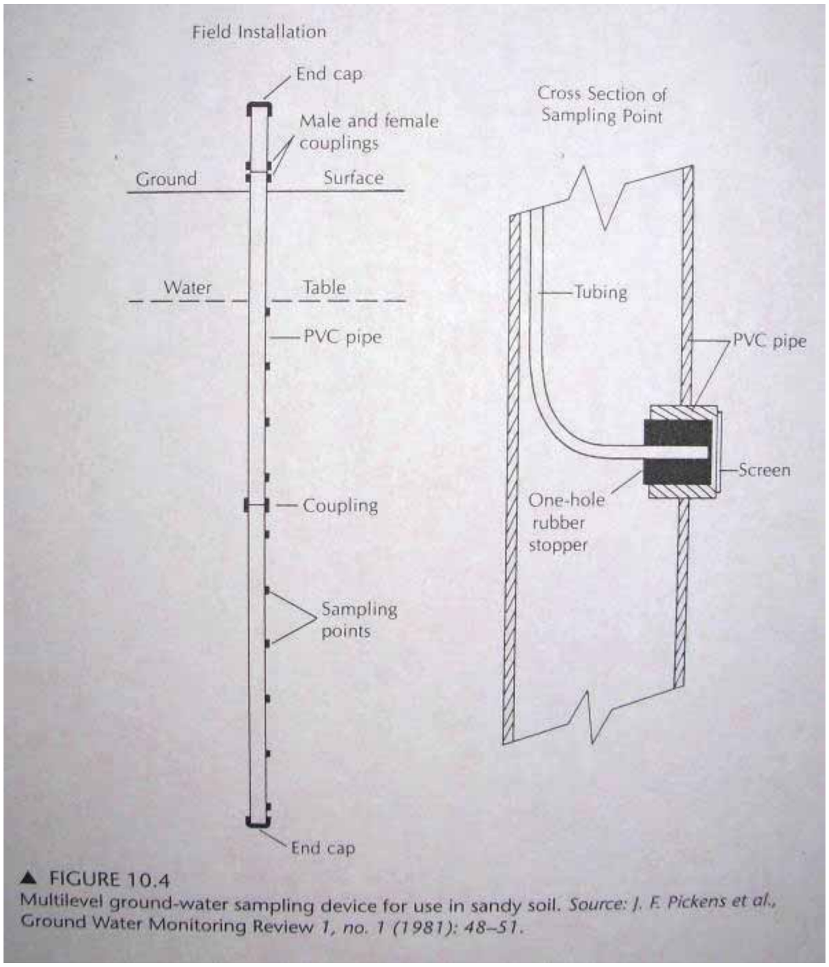


Figure 82. Depiction of a multi-level groundwater sampling device intended for sandy soil. (Source: Applied Hydrogeology, Fourth Edition, p. 394.)

Figure 83. Photograph of bailer sampling of the existing well near the south elevation of the Abel and Mary Nicholson house. (Source: A. Aiken; Taken 3/8/2007.)

Figure 84. Photograph of transferring the well water sample from the bailer to the containers nearby the source well on the south elevation of the Abel and Mary Nicholson house. (Source: A. Aiken; Taken 3/8/2007.)

Figure 85. Photograph of the sulfate salt ion laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. (Source: A. Aiken; Taken 3/22/2007.)

Figure 86. Photograph of the chloride salt ion laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. Notice the difference in clarity between the well water and the control. (Source: A. Aiken; Taken 3/22/2007.)

Figure 87. Photograph of the carbonate salt ion laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. (Source: A. Aiken; Taken 3/22/2007.)

Figure 88. Photograph of the nitrite salt ion laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. (Source: A. Aiken; Taken 4/8/2007.)

Figure 89. Photograph of the nitrate ion laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. (Source: A. Aiken; Taken 4/8/2007.)

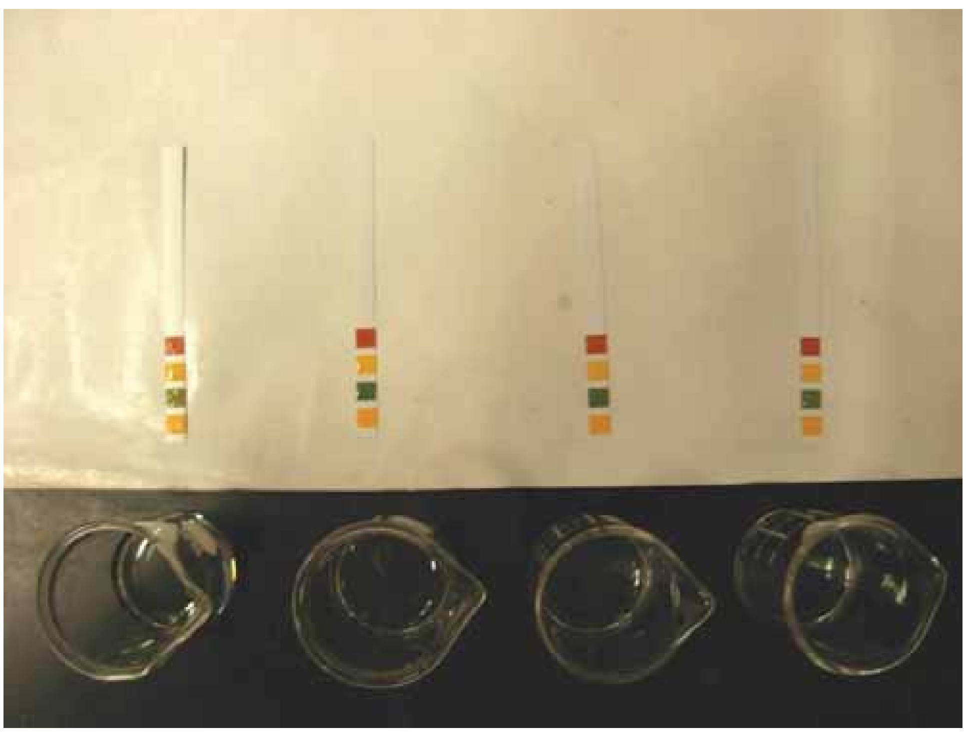


Figure 90. Photograph of the pH laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. Note the slight difference in green color of all three well water sample strips from the control strip on the far left. (Source: A. Aiken; Taken 4/8/2007.)

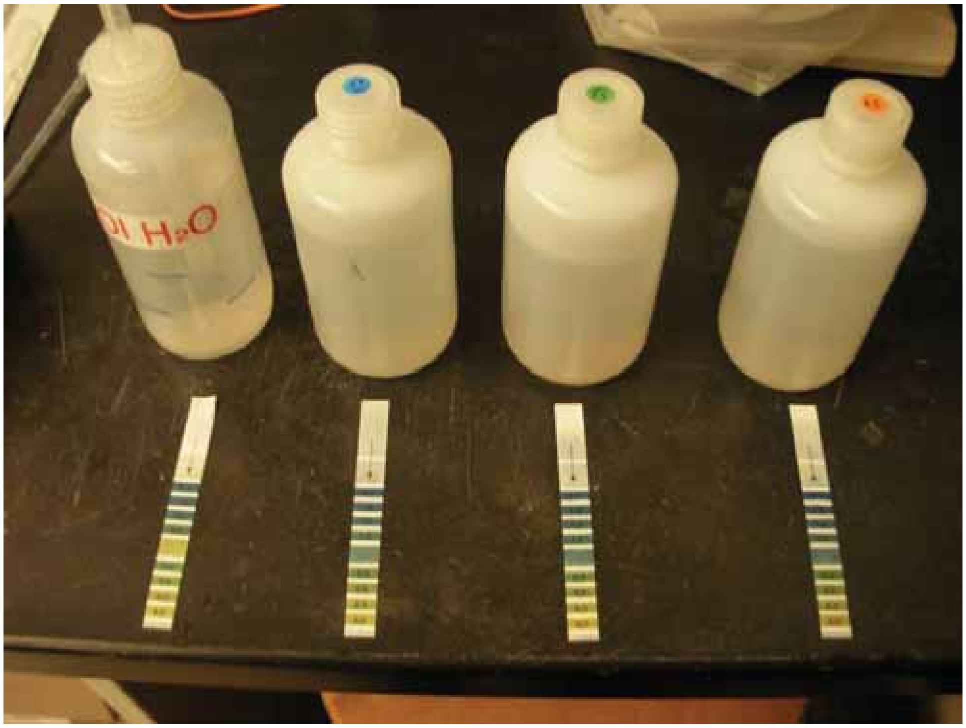


Figure 91. Photograph of a second pH laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. Note the difference in color of the well water strips from the control strip on the far left. (Source: A. Aiken; Taken 4/8/2007.)

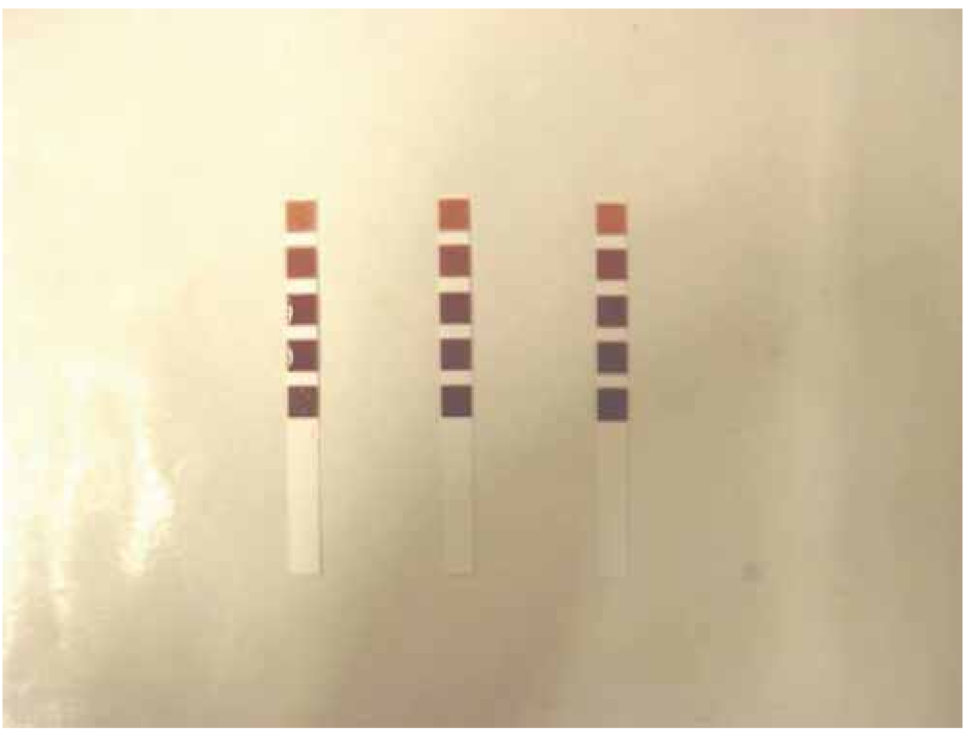


Figure 92. Photograph of the chloride strip laboratory test results of the water taken from the existing well on the Abel and Mary Nicholson house property. (Source: A. Aiken; Taken 4/8/2007.)

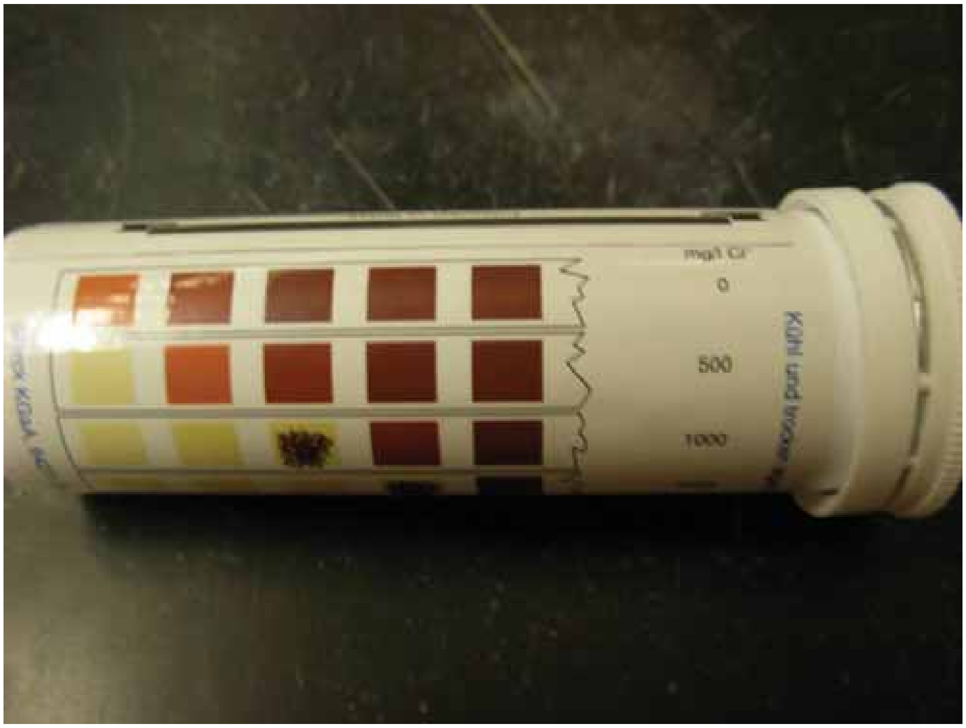


Figure 93. Photograph of the chloride strip laboratory test key. (Source: A. Aiken; Taken 4/8/2007.)

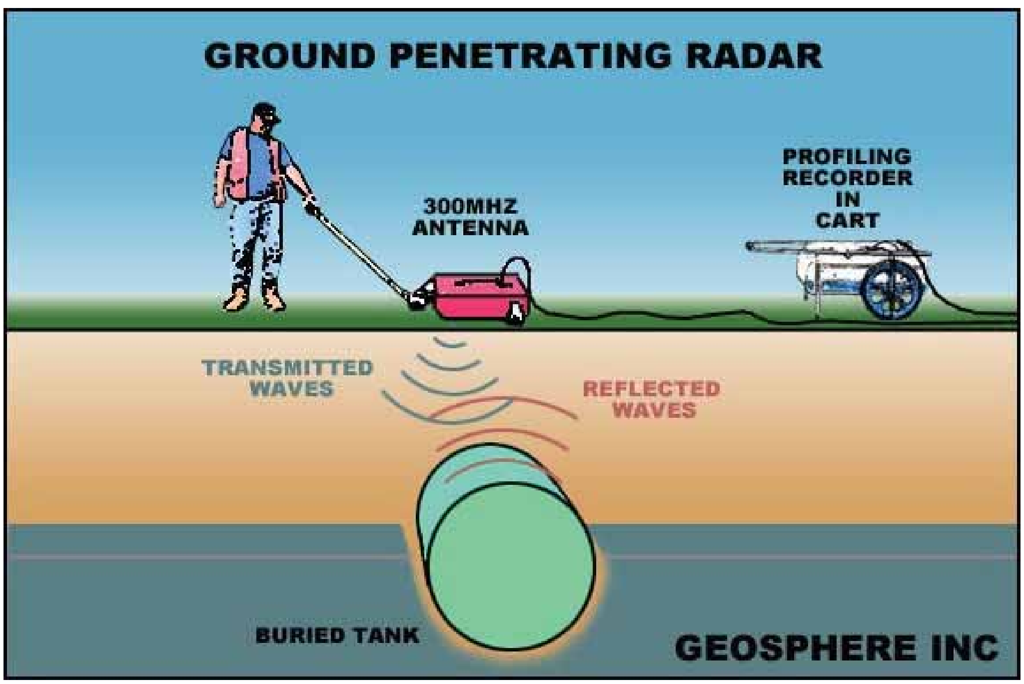


Figure 94. Diagram of Ground Penetrating Radar. (Source: Geosphere Inc. website).

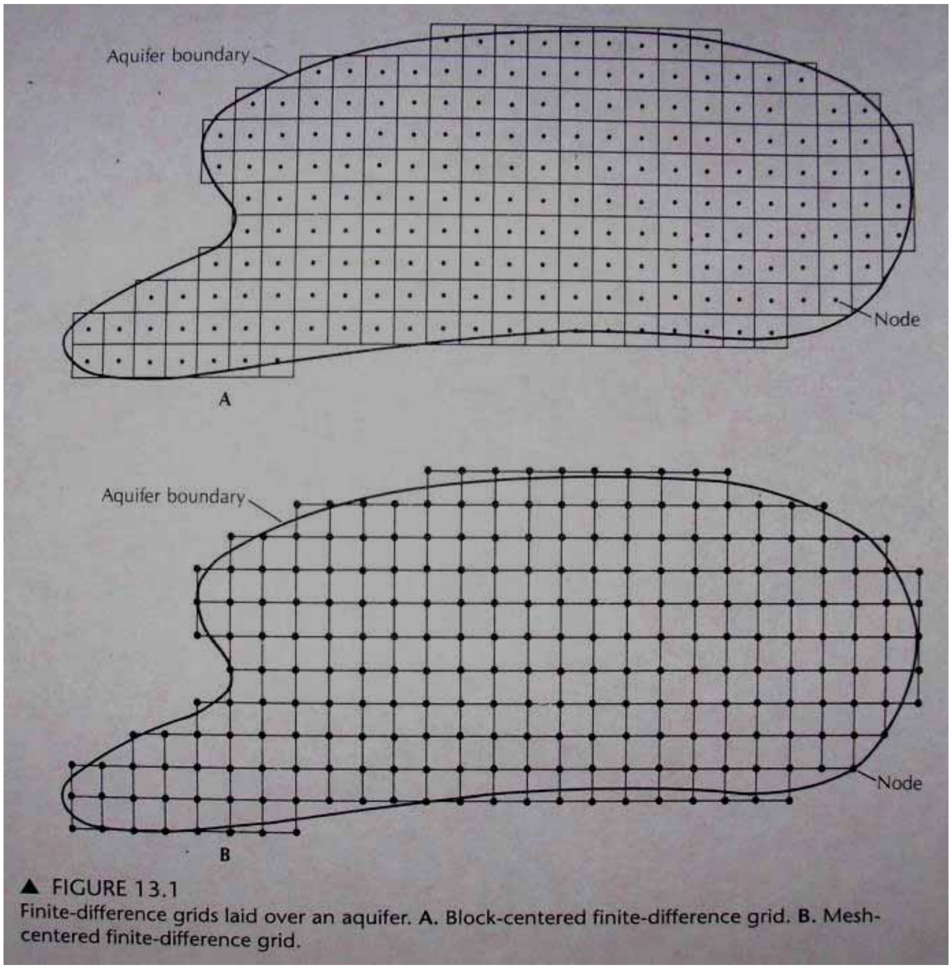


Figure 95. Example of two different finite-difference grids for a given aquifer; block-centered or mesh-centered. (Source: Applied Hydrogeology, Fourth Edition, p. 520.)

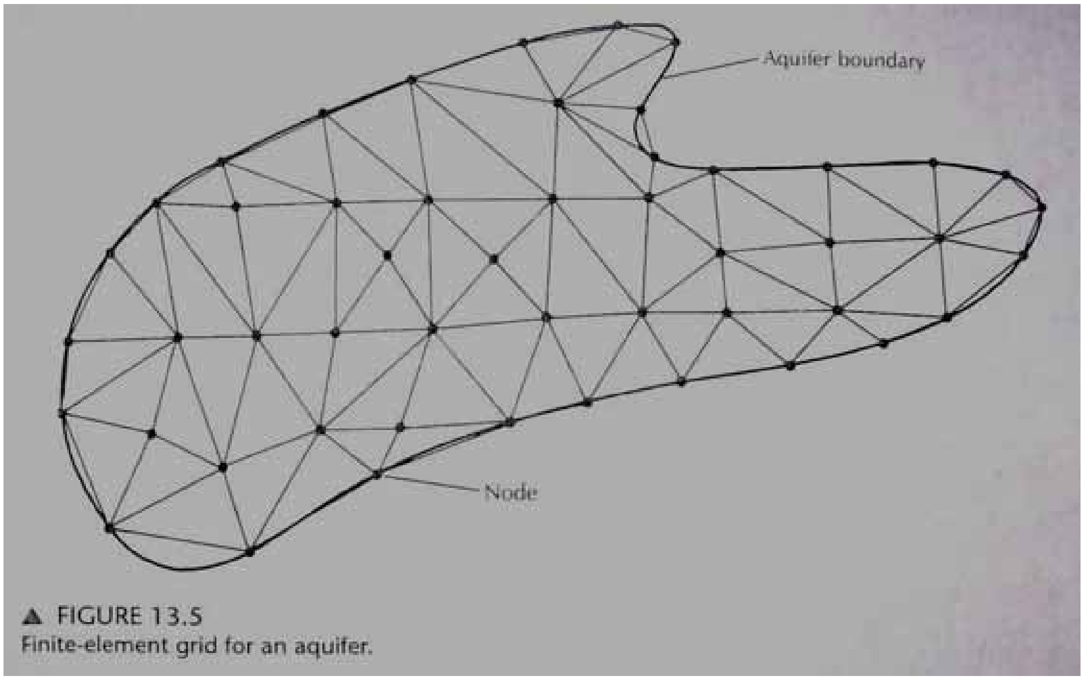


Figure 96. Example of a finite-element grid for a given aquifer. (Source: Applied Hydrogeology, Fourth Edition, p. 525.)

Appendix B: Tables

Table 1. Recent Trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20th century trend. (Source: Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Scientific Basis: Summary for Policymakers.)

Table SPM-1. Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[e]	*Virtually certain*[e]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[d]	*Likely (nights)*[e]	*Virtually certain*[e]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f, h]	*Likely*[i]

Notes:
(a) See Table 3.7 for further details regarding definitions
(b) See Table TS-4, Box TS-3.4 and Table 9.4.
(c) Decreased frequency of cold days and nights (coldest 10%)
(d) Increased frequency of hot days and nights (hottest 10%)
(e) Warming of the most extreme days and nights each year
(f) Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgement rather than formal attribution studies.
(g) Extreme high sea level depends on mean sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.
(h) Changes in observed extreme high sea level closely follow the changes in mean sea level {5.5.2.6}. It is *very likely* that anthropogenic activity contributed to a rise in mean sea level. {9.5.2}
(i) In all scenarios, the projected global mean sea level at 2100 is higher than in the reference period. {10.6}. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Table 2.: Principal Climate Change risks and impacts on cultural heritage (Source: Predicting and managing the effects of Climate Change on World Heritage by the World Heritage Centre p. 14-16.)

Climate indicator	Climate change risk	Physical, social and cultural impacts on cultural heritage
Atmospheric moisture change	– Flooding (sea, river) – Intense rainfall – Changes in water table levels – Changes in soil chemistry – Ground water changes – Changes in humidity cycles – Increase in time of wetness – Sea salt chlorides	– pH changes to buried archaeological evidence – Loss of stratigraphic integrity due to cracking and heaving from changes in sediment moisture – Data loss preserved in waterlogged / anaerobic / anoxic conditions – Eutrophication accelerating microbial decomposition of organics – Physical changes to porous building materials and finishes due to rising damp – Damage due to faulty or inadequate water disposal systems; historic rainwater goods not capable of handling heavy rain and often difficult to access, maintain, and adjust – Crystallisation and dissolution of salts caused by wetting and drying affecting standing structures, archaeology, wall paintings, frescos and other decorated surfaces – Erosion of inorganic and organic materials due to flood waters – Biological attack of organic materials by insects, moulds, fungi, invasive species such as termites – Subsoil instability, ground heave and subsidence – Relative humidity cycles/shock causing splitting, cracking, flaking and dusting of materials and surfaces – Corrosion of metals – Other combined effects eg. increase in moisture combined with fertilisers and pesticides
Temperature change	– Diurnal, seasonal, extreme events (heat waves, snow loading) – Changes in freeze-thaw and ice storms, and increase in wet frost	– Deterioration of facades due to thermal stress – Freeze-thaw/frost damage – Damage inside brick, stone, ceramics that has got wet and frozen within material before drying – Biochemical deterioration – Changes in 'fitness for purpose' of some structures. For example overheating of the interior of buildings can lead to inappropriate alterations to the historic fabric due to the introduction of engineered solutions – Inappropriate adaptation to allow structures to remain in use
Sea level rises	– Coastal flooding – Sea water incursion	– Coastal erosion/loss – Intermittent introduction of large masses of 'strange' water to the site, which may disturb the metastable equilibrium between artefacts and soil – Permanent submersion of low lying areas – Population migration – Disruption of communities – Loss of rituals and breakdown of social

		interactions
Wind	– Wind-driven rain – Wind-transported salt – Wind-driven sand – Winds, gusts and changes in direction	– Penetrative moisture into porous cultural heritage materials – Static and dynamic loading of historic or archaeological structures – Structural damage and collapse – Deterioration of surfaces due to erosion
Desertification	– Drought – Heat waves – Fall in water table	– Erosion – Salt weathering – Impact on health of population – Abandonment and collapse – Loss of cultural memory
Climate and pollution acting together	– pH precipitation – Changes in deposition of pollutants	– Stone recession by dissolution of carbonates – Blackening of materials – Corrosion of metals – Influence of bio-colonialisation
Climate and biological effects	– Proliferation of invasive species – Spread of existing and new species of insects (eg. termites) – Increase in mould growth – Changes to lichen colonies on buildings – Decline of original plant materials	– Collapse of structural timber and timber finishes – Reduction in availability of native species for repair and maintenance of buildings – Changes in the natural heritage values of cultural heritage sites – Changes in appearance of landscapes – Transformation of communities – Changes the livelihood of traditional settlements – Changes in family structures as sources of livelihoods become more dispersed and distant

Table 3.: An eight step approach to guide vulnerability assessments (Source: Assessing Vulnerabilities to the Effects of Global Change: An Eight Step Approach, by Dagmar Schröter and Colin Polsky and Anthony G. Patt, from journal *Mitigation and Adaptation Strategies for Global Change* p. 573-596.)

1. Define study area together with stakeholders and choose spatial and temporal scale. 2. Get to know place over time by reviewing literature, contacting and collaborating with researchers, spending time in the field with stakeholders and assessing nearby areas. 3. Hypothesize who is vulnerable to what: refine focus on stakeholder subgroups and identify driving stresses and interactions of stresses. 4. Develop a causal model of vulnerability: – Examine exposure, sensitivity and adaptive capacity – Formalize into model(s) 5. Find indicators for the elements of vulnerability – Exposure indicators – Sensitivity indicators – Adaptive capacity indicators 6. Operationalize model(s) of present vulnerability – Apply model(s) to weigh and combine indicators – Apply model(s) to produce a measure of present vulnerability – Validate results with stakeholders etc. 7. Project future vulnerability – Choose scenarios with stakeholders – Scenarios should demonstrate full range of likely trends – Apply model(s) to produce a measure of future vulnerability 8. Communicate vulnerability creatively – Use multiple interactive media – Be clear about uncertainty – Trust stakeholders

Table 4.: Example of Low-flow sampling data sheet (Source: The Department of Environmental Protection.)

LOW FLOW SAMPLING
DATA SHEET

SHEET ____ OF ____

SITE: ______________________ CONSULTING FIRM: ______________________
DATE: ______________________ FIELD PERSONNEL: ______________________
WEATHER: ______________________

MONITOR WELL #: __________ WELL DEPTH: __________ SCREENED/OPEN INTERVAL: __________
WELL PERMIT #: __________ WELL DIAMETER: ________ inches

PID/FID READINGS (ppm): BACKGROUND: __________ PUMP INTAKE DEPTH: ________ ft below TOC
BENEATH OUTER CAP: __________
BENEATH INNER CAP: __________ DEPTH TO WATER BEFORE PUMP INSTALLATION: ________ ft below TOC

TIME	PURGING	SAMPLING	pH (pH units)		SPECIFIC CONDUCTIVITY (mS/cm)		REDOX POTENTIAL (mv)		DISSOLVED OXYGEN (mg/l)		TURBIDITY (NTU)		TEMPERATURE (degrees C)		PUMPING RATE (ml/min)	DEPTH TO WATER (ft below TOC)
			READING	CHANGE*	READING	CHANGE*	READING	CHANGE*	READING	CHANGE*	READING	CHANGE*	READING	CHANGE*		
				NA		NA		NA		NA		NA		NA		

COMMENTS:

*INDICATOR PARAMETERS HAVE STABILIZED WHEN 3 CONSECUTIVE READINGS ARE WITHIN: ±0.1 for pH; ±3% for Specific Conductivity and Temperature; ±10 mv for Redox Potential; and ±10% for Dissolved Oxygen and Turbidity.

Table 5: Salt Ion Spot Test Results						
	A	B	C	Control A	Control B	Control C
Sulfates	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction
Chloride	White/Blue Precipitate	White/Blue Precipitate	White/Blue Precipitate	No Reaction	No Reaction	No Reaction
Nitrites	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction
Nitrates	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction
Carbonates	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction	No Reaction

Table 6: Assessment of Methods for Measuring/Monitoring Groundwater Level Based on Evaluation Criteria

	Tools	Evaluation Criteria							
		Cost	Resolution	Accuracy	Precision	Availability	Complexity	Durability	Time Requirements
1	Comparison of Aerial Photography Over Time and Cross-Reference with Topographic Map	Good	Poor	Poor	Acceptable	Poor	Acceptable	Good	Good
2	Installation of Test Pits and Provisional Laboratory Salt Ion Testing	Acceptable	Acceptable	Acceptable	Poor	Good	Good	Good	Good
3	Installation of Monitoring Wells and Regular Laboratory Salt Ion Testing	Acceptable	Good	Good	Good	Good	Acceptable	Good	Acceptable
4	Groundwater Modeling	Poor	Good	Acceptable	Good	Acceptable	Poor	Poor	Poor

Table 7: Assessment of Methods for Measuring/Monitoring Groundwater Salinity Content Based on Evaluation Criteria

	Tools	Evaluation Criteria							
		Cost	Resolution	Accuracy	Precision	Availability	Complexity	Durability	Time Requirements
1	Comparison of Aerial Photography Over Time and Cross-Reference with Topographic Map	Good	Poor	Poor	Poor	Poor	Good	Acceptable	Good
2	Installation of Test Pits and Provisional Laboratory Salt Ion Testing	Good	Good	Acceptable	Poor	Acceptable	Good	Good	Good
3	Installation of Monitoring Wells and Regular Laboratory Salt Ion Testing	Good	Good	Good	Good	Acceptable	Good	Good	Acceptable
4	Groundwater Modeling	Poor	Good	Good	Good	Acceptable	Poor	Poor	Poor

Table 8: Assessment of Methods for Measuring/Monitoring the Direction of Groundwater Flow Based on Evaluation Criteria

	Tools	Evaluation Criteria							
		Cost	Resolution	Accuracy	Precision	Availability	Complexity	Durability	Time Requirements
1	Comparison of Aerial Photography Over Time and Cross-Reference with Topographic Map	Good	Acceptable	Acceptable	Good	Poor	Acceptable	Good	Good
2	Installation of Test Pits and Provisional Laboratory Salt Ion Testing	Acceptable	Good	Acceptable	Acceptable	Good	Good	Good	Good
3	Installation of Monitoring Wells and Regular Laboratory Salt Ion Testing	Acceptable	Good	Good	Good	Good	Good	Good	Good
4	Groundwater Modeling	Poor	Good	Acceptable	Good	Acceptable	Poor	Poor	Poor

Appendix C: Illustrations

Illustration 1. Aerial Photography Comparison: The Abel and Mary Nicholson House Landscape: Observing Geographic Changes Over a Period of 70 years Using Aerial Photography.

1932 Aerial Photograph
Bureau of Tidelands Management,
New Jersey Department of Environmental Protection

Total Area:	1.00 mi^2
Total Light Area:	0.26 mi^2
Total Marshland Area:	0.37 mi^2
Total Other (Darker) Area:	0.37 mi^2

2002 Aerial Photograph
i-Map NJ
http://www.state.nj.us/dep/gis/imapnj_geolsplash.htm
New Jersey Department of Environmental Protection

Total Area:	1.00 mi^2
Total Light Soil Area:	0.13 mi^2
Total Pink-toned Soil Area:	0.18 mi^2
Total Marshland Area:	0.47 mi^2
Total Other (Darker) Area:	0.22 mi^2

Illustration 2. Possible Flow-net Configuration for the Nicholson site.

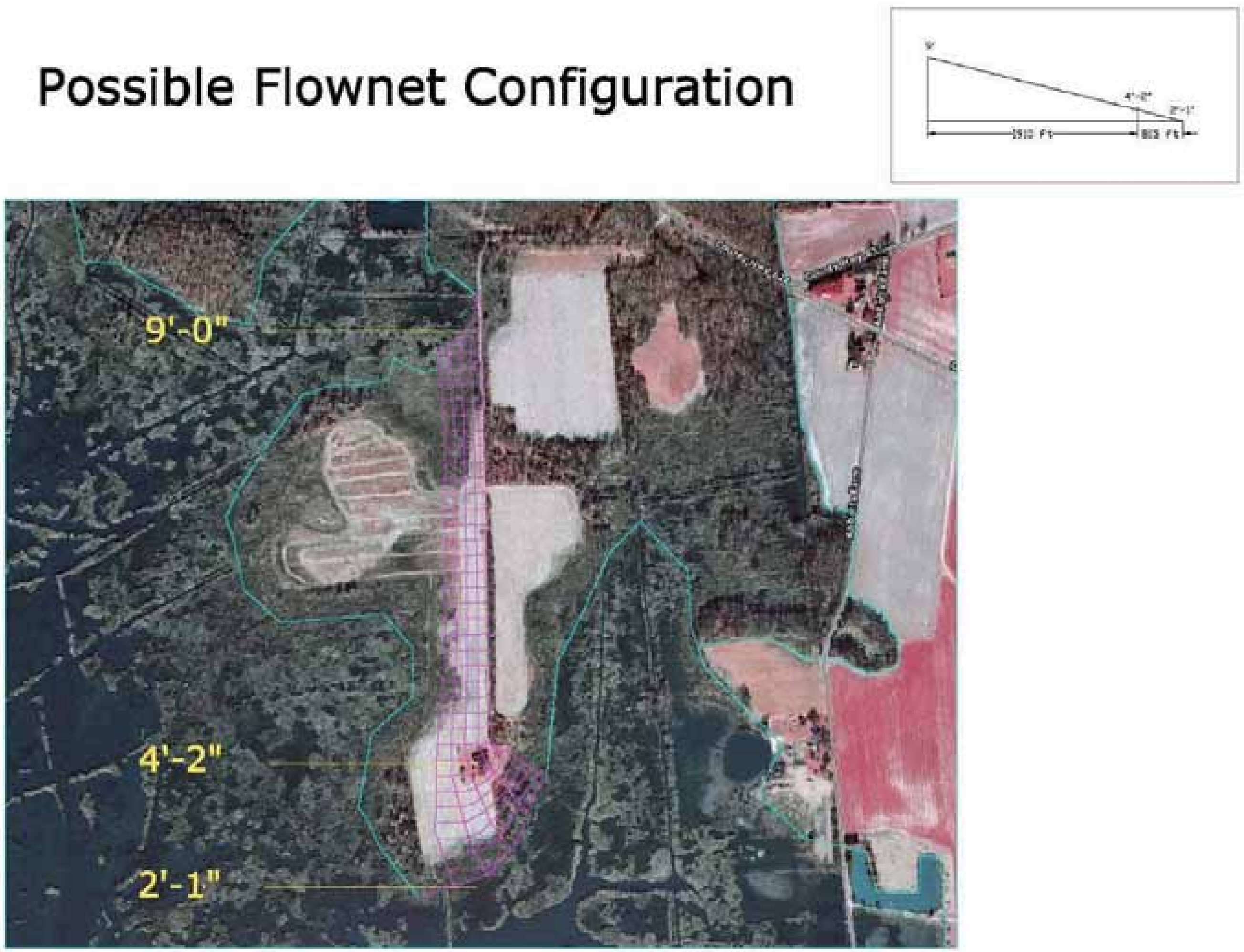


Illustration 3. The Abel and Mary Nicholson House Site Map with Proposed Well Locations.

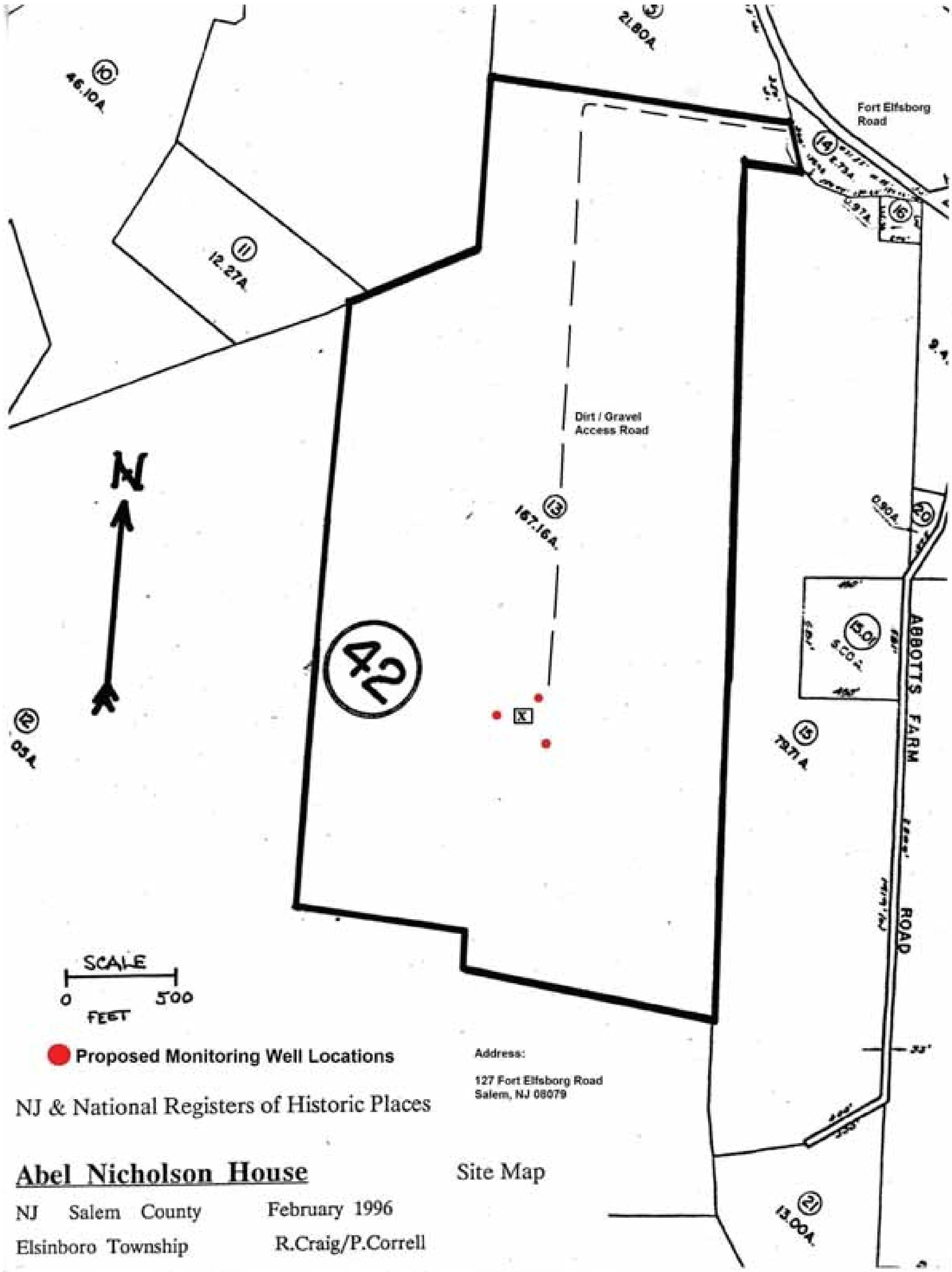
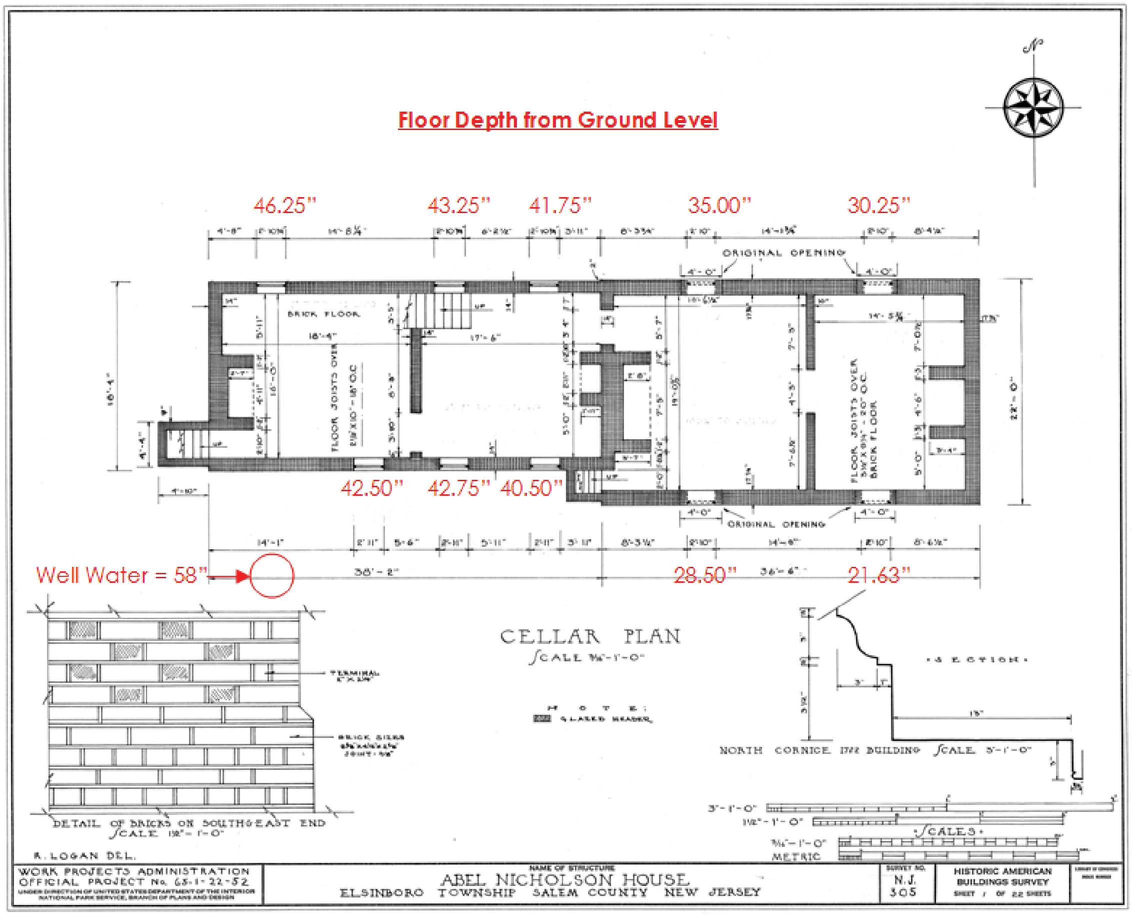


Illustration 4. Cellar Floor Depth From Ground Level in the Nicholson House.



Appendix D: Laboratory Procedures

UNIVERSITY OF PENNSYLVANIA
GRADUATE PROGRAM IN HISTORIC PRESERVATION
HSPV 555/ Introduction to Conservation Science
Spring 2006 Prof. F.G. Matero

ARCHITECTURAL CERAMICS

Experiment 13: ***Salts and Salt Resistance of Architectural Ceramics***

1.0 Purpose

To observe the deterioration effects of salt crystallization/re-hydration cycling on porous materials and to identify the most commonly occurring salt types through chemical spot tests.

The first set of procedures of this lab is useful in assessing the success of a preservation treatment and it can also be used as an artificial weathering test. The second set of procedures provides a qualitative analysis of soluble salts (from a stone, ceramic, or mortar sample), which furnishes information about the types of ions (sulfates, chlorides, etc.) present in the sample and gives an indication of the maximum quantity of single ions present. Such information provides some clues as to the source and type of deterioration responsible.

2.0 Principles

The presence of white efflorescence on the surface of masonry is always an indication of chemical deterioration processes resulting from the reaction of four components: the materials themselves, water and polluting compounds present in the water or atmosphere, and environmental conditions.

The deterioration products resulting from the reaction between these components are water-soluble salts, principally sulfates, chlorides, nitrates, and nitrates. Under certain conditions, calcium carbonate (a normal component of mortars and calcareous stones) – practically insoluble in water – can also be a deterioration product, usually appearing in the form of surface incrustations.

Water-soluble salts can originate from the soil, the air, or from the materials themselves. They are transported inside the materials by capillary action or by other means. When water evaporates, the salts crystallize (change from liquid state to solid state) on the surface or close to it. When they absorb water, they hydrate. These cause cyclic deterioration of porous material through the processes of crystallization and re-hydration.

2.1 Sulfates

The sulfates most commonly found in masonry are hydrated calcium sulfate (gypsum $CaSO_4 \cdot 2H_2O$) and more rarely, magnesium sulfate ($MgSO_4$). There are many possible origins of sulfates. Sulfates are present in agricultural land and can enter a wall through capillary action. Sea water, in addition to chlorides, contains small amounts of sulfates, especially magnesium sulfate. Sea spray can deposit these sulfates on a surface. Portland cements and related additives used in the preparation of mortars and plasters can contain small quantities of sulfates. These can be dissolved in water present in the masonry wall and be brought to the surface as efflorescence. Erroneous use of substances like gypsum for restoration can also lead to the presence of sulfates.

Another possible origin of sulfates is microbiological. In brief, there are certain types of microorganisms capable of metabolizing reduced forms of sulfur and oxidizing it to sulfates, as well as others that produce sulfides instead. These "sulfur bacteria" are often present on exposed stone, especially calcareous types. Since there is a strict analogy between calcareous stones and mortars based on calcium carbonate, it is logical to assume that these bacteria could also develop in plasters and mortars.

The most important source of sulfates, however, is atmospheric pollution. The burning of hydrocarbons leads to the transformation of the sulfur they contain into sulfur dioxide, emitted into the atmosphere as a gas. Reacting with oxygen, sulfur dioxide becomes sulfur trioxide. This last product reacts with water to form sulfuric acid that attacks the calcium carbonate and transforms it into calcium sulfate, which is unstable and destructive.

All these processes can happen in the wall. Alternatively, the sulfuric acid can form in the air and then react with the calcium carbonate of the wall. A third possibility is that the sulfuric acid formed in the air is neutralized by basic substances such as ammonia, forming ammonium sulfate, or by calcium carbonate present as atmospheric dust, forming calcium sulfate (gypsum). In a polluted environment, these sulfate solids can constitute 20 to 30% of the dust in the atmosphere.

As a final possibility, studies have shown that sulfur dioxide can be absorbed directly as sulfurous acid. This leads to the formation of calcium sulfite which oxides to sulfate. (See chart, Teutonico, p. 60).

2.2 Chlorides

These salts (especially sodium chloride) and calcium chloride are principally deposited on a wall by sea spray or as salt-laden aerosol. Chlorides can also be the result of impurities in the materials (particularly the sand or fly-ash) used to prepare mortars and plasters. Finally, some kinds of industrial activity, like the combustion of certain kinds of pit-coal, can result in the presence of gaseous hydrochloric acid (hydrogen chloride anhydrous) in the atmosphere.

2.3 Nitrites and Nitrates

Nitrites are not often found in walls because they oxide rapidly into nitrates. The decomposition of nitrogenous organic material produces nitrites. Thus, nitrites might be present where there is infiltration of sewage water or in the vicinity of old burial sites. In general, however, nitrates are much more frequent. They can have the same origin as nitrites, but can also come from the soil or as ground water runoff in agricultural regions.

Atmospheric pollution can also produce nitrates. The combustion of hydrocarbons, in addition to creating sulfur dioxide, also produces various organic molecules and nitrogen oxides. These nitrogen oxides are extremely dangerous to animal and vegetable life because, in the presence of ultraviolet light, they react with oxygen and the organic molecules present in the polluted atmosphere, forming ozone and organic radicals. The ozone, in turn, oxidizes these radicals to aldehydes and the sulfur dioxide to sulfur trioxide. This particular mix of substances produces a dangerous fog called "photochemical smog" which can be found in areas having severe pollution and long periods of strong sunlight (eg. Los Angeles or Naples). The nitrogen oxides, through a series of complex reactions, form nitric acid which reacting with calcium carbonate, leads to the formation of calcium nitrate.

2.4 Carbonates

Calcium carbonate is a normal constituent of both calcareous stones and mortars (where it is formed by the carbonization of lime). Unlike the other salts of efflorescence, calcium carbonate is practically insoluble in water. It can, however, be dissolved as bicarbonate when the water contains a high enough quantity of carbon dioxide forming carbonic acid. Carbon dioxide is a gas that is normally present in the atmosphere. Its concentration can increase, however, under particular conditions – such as in the case of certain industrial activity or when a large number of people occupy a closed room. If dissolved in water present in a humid wall, carbon dioxide forms carbonic acid which reacts with calcium carbonate, forming the more soluble bicarbonate.

There is thus the equilibrium between these various substances which leads to the production of soluble bicarbonates when there is a high concentration of carbon dioxide. When a wall begins to dry, bicarbonate salts in solution come to the surface. As evaporation takes place, the previously established equilibrium shifts in favor of the formulation of calcium carbonate which, being practically insoluble, is rapidly deposited on the surface.

2.5 Note on Cement

It should be remembered that cement can contain several soluble alkaline salts besides sulfates, nitrites and nitrates that are added to give the final product specifically desired characteristics. Thus, if cement has been used in a building where there is some humidity in the walls, the soluble salts present in the cement can migrate toward the original plasters or mortars, causing destructive efflorescence or crystallization upon evaporation.

3.0 Methodology

3.1 Equipment

- Oven
- Trays and covers
- Dessicator
- Mortar and pestle
- Test tubes

3.2 Reagents/Samples

- Deionized water
- Sodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$)
- Bricks
- 2N hydrochloric acid
- 2N nitric acid
- 2N acetic acid
- 2N sulfuric acid
- 0.1N silver nitrate solution
- Sulfamic acid
- Barium chloride solution (10% w/v in water)
- Zinc powder
- *Griess-Ilosvay's* reagent
- Diphenylamine solution

3.3 Preparation

Dry samples in the oven for 24 hours at 60° C.

3.4 Procedure

Salt Crystallization

1. Weigh the sample M_0.

2. Totally immerse the sample in a 14% solution of sodium sulfate decahydrate. A saturated solution can be used for materials of greater durability or to simulate harsher weathering conditions.

3. Immerse the sample for 24 hours.

4. Pat dry the sample with a moist paper towel.

5. Dry the sample on a Pyrex dish in the **Treated Oven** for 24 hours at 60° C.

6. Cool the sample in a dessicator and weigh each sample (M_n).

7. Continue the drying – immersion cycle (weighing the samples each time) until there is evidence of macroscopic deterioration or until the samples are completely destroyed.

Qualitative Analysis of Water-Soluble Salts and Carbonates

1. Grind the sample to a fine homogenous powder in a small mortar and pestle; a few milligrams of sample are sufficient for qualitative analysis.

2. Put half of the sample so obtained in a 10 cc test tube for the following analyses and conserve the rest for an eventual control.

3. Add about 2 cc of distilled or deionized water to the test tube and shake gently to dissolve the material.

4. Wait a few minutes until the insoluble part of the sample is deposited at the bottom of the test tube. The solution must be clear; otherwise, it is necessary to filter it using fine filter paper and a small funnel.

5. Conserve the test tube containing the insoluble part of the sample for the analysis of carbonates. Split the clear solution into 4 equal parts putting each part in a small test tube.

   For the best possible control of experimental results, it is necessary to execute, simultaneously, so-called "white" reactions. That is, for each of the following tests, the analysis of the actual solution should be followed by an analysis using only the water (the same water used for the preparation of the solutions). The results of the "white" reactions can then be compared with this obtained using the sample solution.

6. Analysis of Sulfates SO_4^{--}

   a. In the first test tubes add 1 or 2 drops of 2N Hydrochloric Acid (HCl) and 1 or 2 drops of a 10% solution of Barium Chloride ($BaCl_2$).

   b. A white precipitate of barium sulfate ($BaSO_4$), insoluble in dilute nitric acid, indicates the presence of sulfates.

   c. The reaction can be summarized as follows:

$$SO_4^{--} + BaCl_2 \rightarrow BaSO_4 + 2Cl^-$$

d. Repeat the procedue with a test tube of de-ionized water.

7. Analysis of Chlorides (Cl^-)

   a. In the second test tube add 1 or 2 drops of 2N nitric acid (HNO_3) and 1 or 2 drops of a solution (0.1N) of silver nitrate ($AgNO_3$).
   b. A whitish-blue, gelatinous precipitate of silver chloride (AgCl) indicates the presence of chlorides.
   c. The reaction can be summarized as:

$$Cl^- + AgNO_3 \rightarrow AgCl + NO_3^-$$

   d. Repeat the procedure with a test tube of de-ionized water.

8. Analysis of Nitrites NO_2^-

   a. In the third test tube add 1 or 2 drops of 2N acetic acid (CH_3COOH) and 1 or 2 drops of *Greiss-Ilosvay's* reagent.

   b. A more or less intense pink color indicates the presence of nitrites.

   c. Repeat the procedure with a test tube of de-ionized water.

9. Analysis of Nitrates NO_3^-

   a. In the absence of nitrites, add a small quantity of zinc powder to the same test tube used in procedure 8 above. The zinc in the presence of acetic acid, will reduce the nitrates (if present) to nitrites. These will then react with the *Greiss-Ilosvay's* reagent. In this case, therefore, a more or less intense pink color indicates the presence of nitrates.

   b. If nitrites were present in procedure 8, use the fourth test tube for this analysis. Add a small quantity (one or two crystals) of sulfamic acid (HSO_3NH_2) in order to destroy the nitrites. Repeat the procedure to ensure all the nitrites are destroyed. If not, continue until they no longer are present. Avoid adding an excessive amount of sulfamic acid to the solution. Having eliminated the nitrites, add to the solution 1 or 2 drops of 2N acetic acid (CH_3COOH) and 1 or 2 drops of *Greiss-Ilosvay's* reagent. Now the solution will not turn pink because the nitrites have been completely destroyed. Add a small amount of zinc powder. A more or less intense pink color indicates the presence of nitrates.

c. An alternative method is to add 1 drop of sulfuric acid to the test tube followed by a drop of diphenylamine solution. A deep blue color indicates the presence of nitrates.

d. Repeat the procedure with a test tube of de-ionized water.

10. Analysis of Carbonates CO_3^{--}

a. Use the insoluble part of the original sample remaining at the bottom of the large test tubes.

b. Add 1 or 2 drops of concentrated hydrochloric acid (HCl).

c. Bubbles of gas (CO_2) in the solution indicate the presence of carbonates (CO_3^{--}).

d. The reaction can be summarized as follows:

$CaCO_3 + 2HCl \rightarrow CaCl_2$ (soluble) + H_2O + CO_2 (gas)

e. Repeat the procedure with a test tube of de-ionized water.

HSPV-656 Advanced Architectural Conservation
Laboratory Notes Prof. A. Elena Charola
Ion Test Strips for Semiquantitative Concentration Determination
Objective:

Correct use of commercial ion test strips.

Calculation of the approximate concentration of the ion in a given sample.

Commercially available test strips for different ions operate similarly to the pH strips. They are very practical since apart from identifying the presence of the ion in question they can also provide a semiquantitative value of the concentration of the ion in the particular solution.

Experimental:

Commercial strips are available for various ions, such as Cl^-, $SO4^=$, $NO3^-$, $NO2^-$, $PO4^{-3}$ and $NH4^+$. Note that the concentration range within which an ion can be measured depends on the ion and the particular brand of the strip. One of the draw-backs of these test strips is their cost. Therefore, their use for ion identification purposes should be limited for in-situ testing, while in the laboratory, they should ONLY be used for the semiquantitative determination of a given ion in a given sample. Samples in architectural preservation are usually solids: either an efflorescence or a porous material that is contaminated with salt.

1. Identification of the ion(s) present

Once a sample is obtained, the first step is to determine the presence of the contamination ions via micro spot tests. For this purpose, a little amount of sample is only necessary (if it is an efflorescence or in a powder form). If the salt is within a porous material, it needs to be extracted (*see Lab Notes for Determination of Moisture and Soluble Salt Content*).

2. Semiquantitative determination of the ion(s)

Enough sample must be available for weighing, this means that at least 0.5 g of the sample is necessary for a nearly pure efflorescence, or 1 g if it also contains powder of the deteriorating material.

The weighed sample—remember to subtract the weight of the container—is put into a small beaker and dissolved in water *(if you have a powdered sample taken from the surface of a deteriorating stone/render/brick, only the salt will go into solution and there will be a residue. In this case, the powdered sample should be left in water for at least an hour with occasional stirring)*.

This solution is then taken to a given volume, e.g., 10 ml, 50 ml, etc., either in a graduated cylinder or in a volumetric flask, depending on the precision required. Record this volume which contains all the ions of your sample.

An aliquot of this solution is taken in a little beaker and the test strip immersed, or drops of the solution are put onto the strip (*read the instructions for each type of test strip*). Once the color has developed, the concentration of the ion in question is given by the test strip. Please note that some test strips give the concentration in the ion itself, i.e., $NO3^-$, while others give it as a compound, i.e., NaCl. Also note that some may give the concentration in mg/l (ppm) or in g/l.

The concentration of the ion in the sample is then calculated as follows:

Ion (g/g) % = Strip Reading (mg/l) x Vsoln (l) x 100 / wsample (g) x 1000 mg/g

If the concentration of the ion in question is too high, a dilution must be prepared from the solution and this has to be taken into account in the calculation. Note that in this case the volume of the aliquot has to be measured exactly as well as the volume of the dilute solution. And then an unmeasured aliquot of this dilution is taken to make the measurement.

Ion (g/g) = Strip Reading (mg/l) x Vsoln (l) x Vdil (ml)/ Valiquot (ml) x wsample(g) x 1000 mg/g

Note:

Technically, an aliquot means a part of a number or quantity that will divide it without a remainder; thus, 5 is an aliquot part of 15. In general, it means a measured smaller volume of a larger volume. For use with the strip, it does not have to be a measured aliquot, but if a dilution has to be prepared, then the volume of the aliquot needs to be known exactly as well as the volume of the original solution and of the dilution.

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