Conceptual Model: Connectivity of Hydrogeology at the Haberman Hampton Site to the Musconetcong River[1]

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Abstract

Much of the Musconetcong River Valley, below Lake Musconetcong at Stanhope and Netcong, is underlain by carbonate rock (Drake, 1997)   Carbonate rock is defined as "[r]ocks consisting mainly of carbonate minerals, which contain the carbonate radical ($(CaMg(CO_3)_2)$) combined with other elements. Examples are limestone and dolomite (Carter, 2005). The carbonate minerals within the rock are soluble when subject to acidic water, such as rainfall, which subsequently create conduits, enlarged fissures, cavities, and caverns that readily store and transport water through the bedrock regime. As with typical rivers within carbonate formations, the Musconetcong River relies upon the underlying and surrounding geology for its abundant, high-quality, and cold waters via direct connection. In fact, the 2004 Musconetcong River National Wild and Scenic Rivers Study states that there is a close (hydraulic) connection between the base carbonate bedrock and the river (Musconetcong Advisory Committee, 2004). The subject 77-acre property known as the "Haberman Hampton," as will be conceptually modeled, is prototypical of the karst terrain in the central Musconetcong River Valley. It contains numerous karst features, such as sinkholes, disappearing streams, and year-round springs along the Musconetcong River, which are surface manifestations of underground "streams" that connect via unfiltering conduits to the Musconetcong River. As with any surface water tributary to the Musconetcong River, these underground streams receive surface water runoff, much of which is directly discharged to the subsurface without the benefit of being filtered through a soil matrix, and thus, is more sensitive to water quality impacts such as particulate and dissolved chemicals and increased temperature. If the Haberman Hampton Tract is developed as proposed with high-density residential and commercial development, it will have a direct and irreversible impact to the Musconetcong River, and will jeopardize its respective New Jersey Department of Environmental Protection Category One Waters[2] (NJAC 7:9B) and U.S. National Park Service Wild and Scenic River[3] (16 USC, Sections 1271-1287) designations.

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[1] This concept exercise was completed as the land owner/applicant has denied access to affected stakeholders and other members of the public for onsite inspections and inclusion in the process of any intrusive field investigations.

[2] Quoted from NJAC 7:9B, Definitions *"Category one waters" means those waters designated in the tables in N.J.A.C. 7:9B-1.15(c)through (i), for purposes of* ***implementing the antidegradation policies*** *set forth at N.J.A.C. 7:9B1.5(d),* ***for protection from measurable changes in water quality based on exceptional ecological significance, exceptional recreational significance, exceptional water supply significance or exceptional fisheries resource(s) to protect their aesthetic value (color, clarity, scenic setting) and ecological integrity (habitat, water quality and biological functions)****.* (**underline and bold** added for emphasis)

[3] Quoted from Congressional Declaration of Policy of the Act - *It is hereby declared to be the policy of the United States that certain* ***selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations****. The Congress declares that the established national policy of dam and other construction at appropriate sections of the rivers of the United States needs to be complemented by a policy that would preserve other selected rivers or*

Introduction

The Haberman Hampton Tract (hereinafter identified as the "Haberman Hampton") is a 77.5 acre property, located within the Borough of Hampton, Hunterdon County, New Jersey, and is bounded by the Musconetcong River, a high-quality, trout maintained river. The Musconetcong River is the largest tributary to the Delaware River in New Jersey. As we understand, the property is proposed to be converted from a majority of row-crop agriculture to a residential and commercial development, composed of 142 single-family homes, 191 multi-family units (plus a manager's office), and 6,000 square feet of commercial space. The homes and commercial uses will be accessed by interior circulation roads. Utilities for the site will consist of a series of wet-detention basins and groundwater disposal fields for wastewater. It is assumed that potable water will also be provided on site. A 300-foot riparian zone is being provided along the banks of the Musconetcong Rivers. The future use of the riparian zone is unknown to the authors at the time of the writing of this document.

While there have been a number of documents prepared by professionals regarding the regulated features and some preliminary site investigatory work, there appears to be a significant lack of detailed understanding as to the underlying geologic framework of the site. Specifically, as will be described below, Haberman Hampton is underlain by carbonate bedrock, which contains significant underground drainage features, such as conduits, cavities, and conduits that directly connect and provide the Musconetcong River with clean, cold, and plentiful water. The importance of aquifers in carbonate formations cannot be understated or considered hyperbole. Witte and Monteverde (2006) conclude that "[k]arst is a valuable natural resource in New Jersey. In the Valley and Ridge and part of the New Jersey Highlands physiographic provinces, about 40 percent of potable water comes from karst terrain" and Nicholson (2006) states that "[c]arbonate fractured-rock aquifers in New Jersey...are the most productive bedrock aquifers in the state... (Nicholson, 2006)." Development in these environmentally sensitive areas, especially those in close proximity and hydraulically connected to high quality surface waters, such as the Musconetcong River, must be approached with caution and an understanding of the limitations of the site.

The Standards for Soil Erosion and Sediment Control in New Jersey states that "[a]n awareness of the limitations to site development posed by karst features can prevent problems, including damage to property, structures and life, and contamination of groundwater. Appropriate site testing, planning, design, and remediation help to prevent sinkhole formation during site development. Conventional methods of design and engineering may be inappropriate for karst areas. Often minor modifications in the approach to site testing and design can prevent persistent and costly post-development problems."

As will be described, it is highly probable that a high-density development, such as that proposed, will have a permanent and negative effect on this source of base-flow, and have a calculable, measurable, and permanent effect on the Musconetcong River, and its water quality

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sections thereof in their free-flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes. (**underline and bold** added for emphasis) and value to the region as a scenic and recreational amenity to residents of the State of New Jersey.

This document does not address the details of the proposed development and the impacts it will cause, but is intended to provide an understanding of the local hydrology, geology, and hydrogeology and provide the basis for planning of the ultimate use of this site in the context of issues such as Watershed Management Planning and the extending of a Sewer Service Area. What will be discussed is the fact that the approval for the extension of a Sewer Service Area to this site is premature at best, and irresponsible at worst.

The concepts of geology and the site are based on the best information that was made available to the authors through document received via the New Jersey Open Public Records Act (OPRA), their significant experience in carbonate geology, and the peer-reviewed and documented research that is available via open source journals, and government and educational institutions.

Site Background

Haberman Hampton is a 77.5 acre property, located in the Borough of Hampton, Hunterdon County, New Jersey. The tract consists of one property, identified as Block 23, Lot 1. The property is bounded to the north and on the inside meander of the Musconetcong River, to the south by Valley Road and a cemetery, and to the east by residential development. According to the U.S. Geological Society (USGS) mapping, the site's elevations range from 380 feet on the southeastern extent of the property to about 320 along the Musconetcong River (NJDEP, 1987).

The Musconetcong River is designated as a Category One trout-maintenance water. New Jersey Administrative Code, 7:7B, Surface Water Quality Standards define Category One waters as "those waters designated in the tables in N.J.A.C. 7:9B-1.15(c) through (i), for purposes of implementing the antidegradation policies set forth at N.J.A.C. 7:9B1.5(d), for protection from measurable changes in water quality based on exceptional ecological significance, exceptional recreational significance, exceptional water supply significance or exceptional fisheries resource(s) to protect their aesthetic value (color, clarity, scenic setting) and ecological integrity (habitat, water quality and biological functions)." Category One waters are of the highest quality in the state. The trout maintenance designation is defined under NJAC 7:7B as waters that can support trout throughout the year, and contain clean and cold water that this fish requires.

Under the Wild & Scenic Rivers Act [16 USC, Sections 1271-1287], 24.2 miles of the Musconetcong River were designated by U.S. Congress as a "Wild & Scenic River" by the Department of Interior on December 22, 2006. This includes a "scenic" 3.5-mile segment from Saxton Falls to the Route 46 Bridge, and "recreational" 20.7-mile segment from the King's Highway Bridge to the railroad tunnels at Musconetcong Gorge (National Wild & Scenic Rivers System, 2019). In order to be eligible for this designation, a river must be "free-flowing and possess one or more outstandingly remarkable values," according to the the National Park Service (NPS) (2018). NPS describes outstandingly remarkable values as "river-dependent natural, cultural, or recreational resources that are unique, rare, or exemplary at a regional or national scale." The reach of the Musconetcong River bounding Haberman Hampton is designated as "Wild and Scenic".

A review of historical aerial imagery via New Jersey Department of Environmental Protection's (NJDEP) NJ-GeoWeb[4] shows that the site has been in agriculture from at least as early as 1930 to 2015. According to the USGS StreamStats online hydrologic program, there is a mapped stream that crosses the site from Valley Road, flowing northwest to the Musconetcong River, with a contributing watershed of 61 to 77 acres where the stream intersects the Musconetcong River (Ries, K.G, III *et al*, 2017). Figure 1 (right) illustrates the mapped onsite stream and its contributing watershed.

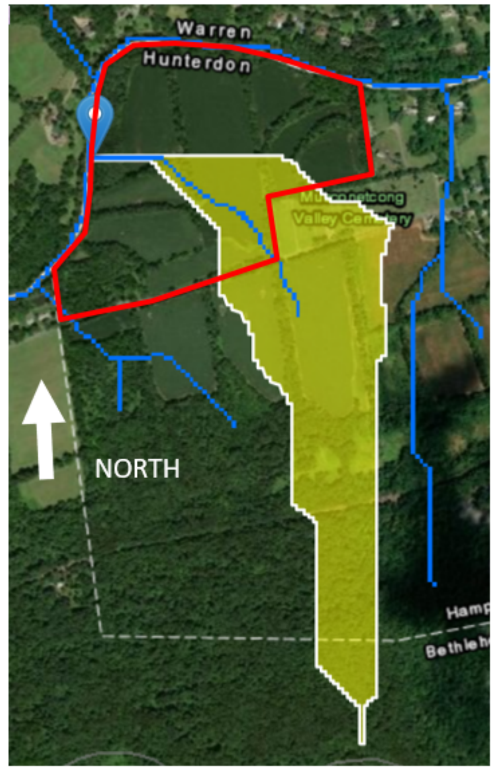

Figure 1: Watershed boundary to on-site "disappearing stream" to the Musconetcong River. Red outline is approximate property boundary and yellow shaded area is the 61- to 77-acre watershed to the confluence of the tributary to the Musconetcong River.

According to NJ-GeoWeb, Haberman Hampton is underlain by Allentown Dolomite (OCa) (NJDEP, 2011). This formation was formed in the Late Cambrian Period. The Allentown Dolomite consists of light-medium gray or light-olive gray to dark-medium gray, fine to medium grained rock. The rock consists of alternating beds of poorly laminated to massive beds in thickness of three (3) feet. There are interbedded platy/shaly beds under an inch in thickness. The formation has been identified to be as thick as 1,700 feet, with 1,610 feet thick measure in Carpentersville, NJ, about 14 miles southwest of the subject site (Drake, 1965).

Due to the carbonate composition of dolomite ($(CaMg(CO_3)_2)$), there are unique landscape features that form due to dissolution of the rock, enlarging fractures and faults that often become expressed at the surface as fracture traces, sinkholes, and disappearing streams. Sinkholes in the Allentown formation are evenly distributed, which is evidence of the homogeneous tendency of subsurface conduits and caverns to form. As a result, such karst features increase the permeability of bedrock and act as conduits for groundwater recharge (Sloto, 1991).

Karst describes the unique topographic features that are surface manifestations and subsurface features formed over soluble or carbonate (rock that dissolves when exposed to acidic water, such as rainwater, snowmelt, and runoff) and is characterized by sinkholes, disappearing streams, caves, and underground drainage (Carter *et. al.*, 2005). Figure 2 provides a generic illustration of karst terrain, above and below ground.

[4] NJDEP NJ-GeoWeb 3.0 interactive web mapping application; Imagery Layer, 1930-2015: https://njwebmap.state.nj.us/NJGeoWeb/WebPages/Map/FundyViewer.aspx

Such sedimentary carbonate, as well as shale bedrock of the Cambrian and Ordovician age, are the base of the Musconetcong River Valley from Hackettstown, New Jersey to Riegelsville, Pennsylvania at its confluence with the Delaware River. Characteristic of carbonate formations of the region, the bedrock in this section of the river is highly soluble, resulting in sinkholes, close depressions, caves, and irregular bedrock topography (Musconetcong Advisory Committee, 2004).

In general, groundwater is in a water-table condition (unconfined) and water moves through the fractures and other solution features, creating a complex and significant variation of yield and specific capacity, depending on the size and concentration of fractures. Well yields in the Allentown Dolomite have been measured on the order of five (5) to 1,500 gallons per minute (gpm), with a median of 55 gpm (Sloto, 1991). Groundwater and surface water systems have been found to be readily connected.

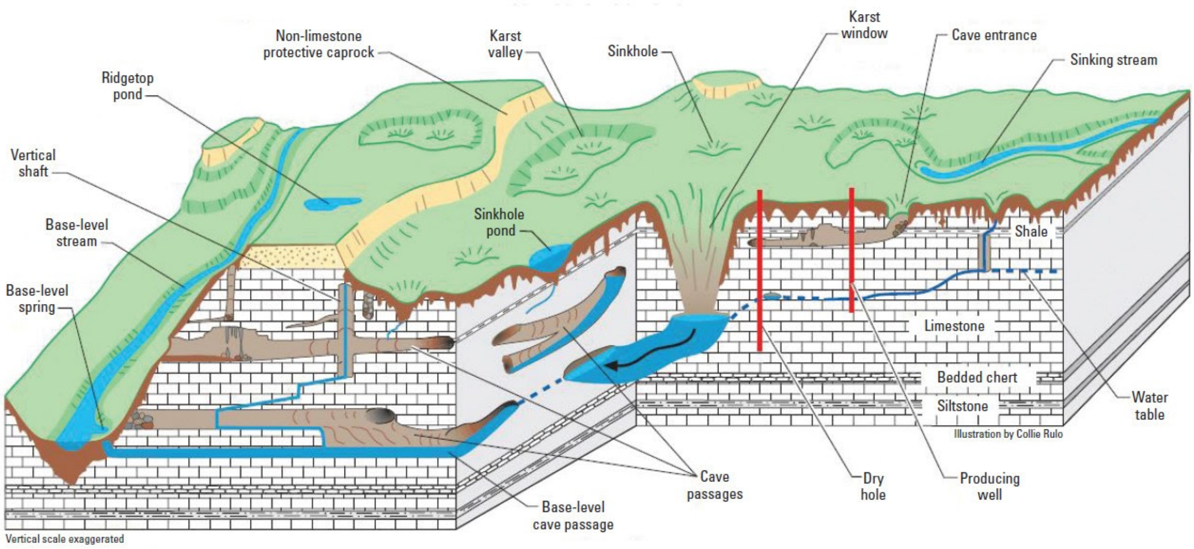

Figure 2 - Conceptual generic graphic of karst topography and drainage in carbonate geology (Taylor, 2008).

For example, in the Little Lehigh Creek basin near Allentown, PA, within the same regional dolomitic bedrock, the percent of baseflow (groundwater contribution during dry, non-flood periods) was found to range from 66 percent (%) to 92% of the annual base flow contribution. Additionally, groundwater and surface water divides do not necessarily coincide, and thus, contributions of groundwater to stream flow can also vary significantly (Sloto, 1991). Thus, while the Musconetcong River Valley is somewhat narrow (Musconetcong Advisory Committee, 2004) compared to other non-carbonate based systems, baseflow on the river is generally well maintained throughout the year. As a result of the solution features and highly permeable groundwater regime, there is a direct connection between land surfaces and groundwater, which leaves groundwater vulnerable to contamination from anthropogenic activities. There are tributary streams along the Musconetcong River that start on the valley walls and disappear into underground caverns that directly provide base flow to the Musconetcong River. The groundwater resources within the river valley are abundant, with a close connection between the base carbonate bedrock and the river (Musconetcong Advisory Committee, 2004). Haberman Hampton is typical and characteristic of the interaction between groundwater and the surface water hydrology, as will be described below.

Of particular interest in the confirmation of a direct connection of surface waters to the Musconetcong River is a letter prepared by Anthony DiLodovico of Bowman Consulting, dated August 12, 2016[5]. In his letter he specifically states that, "[t]here is an S-shaped, approximately 350 foot long, man-made vegetated drainage feature that exists in the southwest corner of the property emanating near the Valley Road culvert and extending to a point approximately 200 feet from the north-to-south tree line located between the cemetery property boundary and the Musconetcong River [see Figure 3, below]. This S-shaped, man-made vegetated feature has no direct surface connection to the Musconetcong River…" (underlined for emphasis)[6]. NJDEP, in a subsequent letter prepared by Mr. Dennis Contois, Engineering Supervisor, Bureau of Inland Regulation and dated February 23, 2017, in response to DiLodovico, agrees that there is no surface connection, but goes further and states a more absolute description that, "[t]he feature...is not connected to a regulated water[7]." DiLodovico does not state that there is, "no connection to the Musconetcong River," but "no surface connection" (underlined for emphasis).

By his own description, DiLodovico confirms the existence of karst terrain via the identification of an ephemeral and disappearing stream. He confirms that, at least, some of runoff is readily conveyed to subterranean conveyance, such as cavities and conduits.

A review of a certification of David Krueger, the wetland consultant for the proposed development, dated October 10, 2017[8] attempts to dismiss the "S-shaped" channel is man-made, as the flow as, "...if the pipe [under Valley Road] was not installed there would be no flow path"; yet he provides no explanation of the geomorphic origin of the S-shaped channel upstream of the Valley Road, which would not be impacted by the installation of the pipe. He additionally certifies that runoff conveyed via the S-shaped feature "merely [dissipates] in the agricultural field[9]." This is a classic example of a karst terrain feature identified as a disappearing stream.

By his own description, Krueger confirms the existence of karst terrain via the identification of an ephemeral and disappearing team[10]. This is corroboration of DiLodovico's conclusion.

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[5] This letter was submitted to purport that as the on-site meandering stream feature disappears before it reaches the Musconetcong River, and it claims that the watershed is less than the 50-acre minimum to provide protection of the stream, including the provision of a riparian zone that would afford water quality protection.

[6] Mr. DiLodovico describes an S-shaped, vegetated channel in the middle of a row-crop field as man-made. The S-shape of a channel is a result of natural stream geomorphology (how a stream naturally forms), and while it can be replicated by experienced fluvial geomorphologists, would be inefficient for a farmer, who in standard practice would excavate a channelized, linear drainage channel to maximize area for crops and reduce maneuvering of farm machinery.

[7] It is our professional opinion that Mr. Contois erroneously states that there is no connection to the Musconetcong River. All drainage in the watershed eventually reaches the Musconetcong River. In the case of karst geology, it is a direct connection, albeit through subsurface conduits.

[8] This certification is titled "Certification of David C. Krueger, PWS, CWD, in Support of the Application Hampton Farm, LLC for Letter of Interpretation Extension for Block 23, Lot 1, Hampton Borough, Hunterdon County".

[9] It is interesting that Krueger describes the water in the channel simply dissipating, and even goes further to state that there is no connection to groundwater or surface water as if it magically disappears from the hydrology of the system.

[10] Although using Krueger as a credible source of confirmation of site observations is questioned, as in his certification he specifically states that there are no sinkholes or surficial depressions. This is contrary to the findings of Melick-Tully and Associates (MTA), the geotechnical and geological experts for the developer. MTA's findings are described in the following section of this white paper.

Below, Melick Tully & Associates (MTA) will provide further descriptions of the karst features, and describing the connection of the disappearing stream to the river via springs on the river bank.

Site Specific Soils and Geology

A 2010 report prepared by MTA completed a site specific investigation of the subject Haberman Hampton tract, describing the geology and site specific karst features found. The investigation was completed on behalf of the land use attorney for the property owner/developer. The report

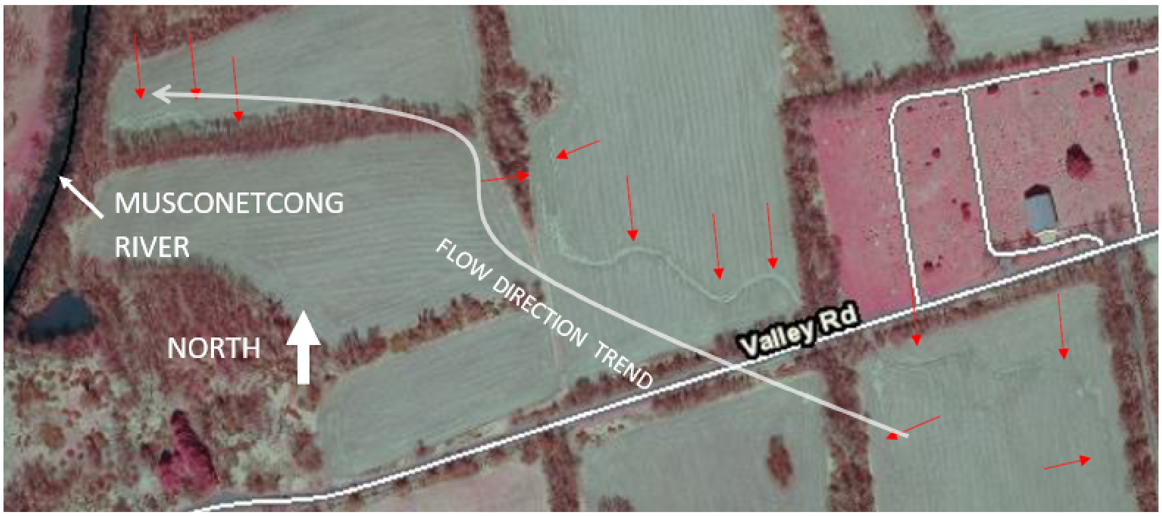

Figure 3: 2007 Infra-red aerial photograph showing the southwestern area of the Haberman Hampton site and the "S-shaped" channels that run in a southwest to northeast direction. The photograph reveals that this feature extends off site, across Valley Road to the south. This photograph was taken during the winter months, following crop harvesting and illustrates that the dry stream returns annually on its own after the area is plowed, and not man-made as purported by Mr. DiLodovico. Photographic source: NJDEP Geoweb.

included (1) a review of the published geologic formation of the area; (2) the conducting of stereoscopic aerial photograph review to identify karst landscape features; (3) a review of water production wells; (4) discussion on previous investigations completed by MTA in the area; and (5) a visit the site to confirm the desktop findings and assess the landscape for karst features and hazards (Sedwick and Tully, 2010).

MTA identifies the site as located in the Highlands Geomorphic Province, a region characterized by broad, flat-topped hills underlain by Pre-Cambrian granite and gneiss, running in a northeast-southwest direction. In between the hills, the associated narrow valleys are underlain by Paleozoic sedimentary rock. In the subject area of Haberman Hampton, the sedimentary rock consists of dolomite, and more specifically Allentown Dolomite. And, as stated as fact in the report and consistent with geological mapping, Allentown Dolomite is susceptible to solutioning and the formation of sinkholes.

Overlying the Allentown Dolomite are residual soils formed by the weathering of the bedrock, as well as glacial deposits of the Lake Wisconsin Glacial Fluvial Terrace. The residual soils consist of fine-grained soils (silts and clays) with varying quantities of sand and rock fragments that were not completely weathered. The glacial deposits consist of sands with varying proportions of gravel. Immediately along the Musconetcong River, more recent alluvial deposits exist from the rise and fall of the river as a result of floods and variable flows. The soils mapped by USDA corroborate the surficial soils (less than 60 inches from the natural land surface) consisting of silt loams and glacial deposits. Soil types identified by MTA as mapped on-site consist of Washington loam, Birdsboro silt loam, and fluvaquents and udifluvents (although further review of updated mapped soils by the author reveal this nomenclature has been updated to be Hatboro-Cordus complex).

A description of the USDA, NRCS Web Soil Survey mapped soils are as follows[11]:

> Washington loam - This series consists of deep, well-drained soils formed in glacial drift of pre-Wisconsin Age), as well as colluvium derived from the weathering and transport of limestone ($CaCO_3$) and granitic gneiss, and comprises of about 42 percent of the site, located in middle to upper elevations of the site (away from the river). These soils occur on shallow to steeply sloped glacial till deposits in limestone valleys. The solum (soils that have gone under physical, chemical, or biological modification due at or near the ground surface) ranges in thickness from 40 to 60 inches; with depth to bedrock from five (5) to 20 feet below the natural ground surface. Clay content ranges from 20 to 35 percent and sand is less than 40 percent, based on prototypical sampling locations. These soils are well-drained and saturated conductivity is relatively high; meaning water readily drains through the soil strata. In fact, this soil is identified as hydrologic soil group (HSG) B; a saturated infiltration rate of 0.15 to 0.30 inches per hour (USDA, 1986). Depth to groundwater is generally greater than 80 inches.
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> Birdsboro silt loam - Birdsboro soils were formed in stream terraces, and thus are alluvium in origin from sources materials consisting of sandstone and siltstone. This soil is located on about 17 percent of the site, and is concentrated at the southern area of the site, adjacent to Valley road and at the location of the incoming intermittent stream channel, as well as at the northeastern end of the site, along the Musconetcong River. The typical profile consists of silt loam with the lower 60 to 80 inches consisting of stratified sand to fine sand. The solum thickness ranges from 30 to 50 inches, and depth to bedrock 6 to 20 feet from the natural ground surface. The soil is well-drained to moderately well-drained, with a moderately high to high saturated hydraulic conductivity. Similar to Washington loam, Birdsboro silt loam has a HSG of B, with saturated infiltration rates of 0.15 to 0.30 inches per hour. Depth to seasonal high groundwater is generally greater than 80 inches.
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> Hatboro-Codorus complex - This soil consists of silt loams and is frequently flooded with slopes from 0 to 3 percent. These nearly level, very deep floodplain

[11] USDA Natural Resources Conservation Service's (NRCS) Web Soil Survey provides soil data and information produced by the National Cooperative Soil Survey. It is operated by the USDA NRCS and provides access to the largest natural resource information system in the world: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

soils form in alluvium derived from mica and/or schist. The two main components of the complex differ most with respect to their drainage characteristics, Hatboro soils being poorly drained, while Codorus soils are classified as moderately well drained.

Hatboro series - This soil consists of very deep and poorly drained soils formed in alluvium derived from metamorphic and crystalline rock. They are found on floodplains with shallow slopes up to three percent. Along with Codorus soils, this soil consists of about 14 percent of the site, located along the edge of the Musconetcong River. The solum ranges from 20 to 60 inches in thickness, as measured from the natural land surface, and depth to bedrock is five (5) to 10 feet or more. The typical profile is highly variable in terms of its consistency and ranges from a fine-grained silt loam to stratified gravelly sands. The depth to the seasonally high water table is from the surface to six (6) inches in depth, and is identified to be frequently flooded. The saturated hydraulic conductivity is moderately high to high, although, a shallow groundwater table will reduce the overall infiltration rates. The HSG for this soil is qualified as a B/D, meaning in a drained condition, the soil will readily infiltrate water as in a HSG B soil, but undrained it acts as a HSG D, which has the lowest saturated infiltration rates of 0 to 0.05 inches per hour. As the topography of land meets groundwater, there is a transition from a HSG B to D.

Codorus series - Similar to the Hatboro series, this soil consists of deep soils. It is somewhat poorly drained and is on slopes of three percent or less. This soil is associated and intermixed with the Hatboro series and, combined with Hatboro soil, covers about 14 percent of the site. The solum is 30 to 60 inches in depth, with bedrock more than six (6) feet. The soils are comprised of loam, silt loam, or silty clay loam, with the depth to sand and stratified materials more than 40 inches. The depth to seasonal high groundwater is between 18 and 30 inches below the natural ground surface, and is occasionally flooded. Based on the description of this soil, Codorus soils are likely higher up in the floodplain than its associated Hatboro series. Codorus series is identified as being HSG C or having a saturated infiltration rate of 0.05 to 0.15 inches per hour. This HSG is likely due to a combination of relatively high percentages of fine-grained soils and somewhat shallow seasonal high groundwater. Historically, floodplain areas associated with Codorus soils were cleared and used as pasturage (Morrison, 1917).

A geologist employed by MTA completed a site visit and walked the entirety of Haberman Hampton (Sedwick and Tully, 2010). According to the MTA report, the geologist was experienced in the evaluation of land underlain by carbonate rock (Sedwick and Tully, 2010). According to the report, it was found during the site visit that there was eight (8) foot high corn on the land, and thus, the majority of the site could not be directly evaluated (Sedwick and Tully, 2010). While much of the site could not be inspected, the geologist found two primary features that illustrate the underlying geological and hydrogeologic conditions: sinkholes and obvious springs discharging along the river edge.

MTA identified about 20 sinkholes within the wooded areas of the site, not covered by corn. Additionally, due to the existence of dolomite cobbles and boulders observed, MTA concludes that the site is underlain by shallow bedrock. The report states that sinkholes ranged in diameter from five (5) to 20 feet, with the majority in the five (5) to eight (8) foot range, and depths of two (2) feet. Of particular note was MTA's conclusion that due to the pattern of woodland avoidance, crop farming likely avoided those areas with the most karst activity (i.e. sinkholes). They concluded that enhanced solutioning patterns were trending northeast-southwest, matching mapped bedding plane trends, as well as the flow direction of the Musconetcong River .

While MTA concluded that the actively farmed areas likely do not have active sinkhole activities, there was no on-site evidence that could be observed due to the high crop. In fact, the MTA report recommends, "...an additional site reconnaissance be performed at the site once the crops are harvested to further outline any areas which would require additional study, followed by a phase of physical exporations at proposed building, basin, and other structure locations to evaluate the subsurface conditions and provide site specific design and construction criteria." As of the date of this report, to the authors' knowledge, no such further investigation has been conducted by the applicant or its experts.

A review of "Aerial Plan", located as an attachment to the MTA report and illustrated below as Figure 4, provides the location of identified sinkholes, which in conjunction with the wooded areas, does appear to follow a northeast-southwest trend (Sedwick and Tully, 2010). MTA identified that, "*[a natural] pond is present on the southwest side of the site…and springs appear to flow into the pond and into the Musconetcong River which bounds the property along the northern boundary* (Sedwick and Tully, 2010)."

The MTA report reveals several clues as to the composition of a conceptual model of groundwater/surface water connection on the site: shallow bedrock, evidence of enhanced solutioning (i.e. enlarged fissures and caverns in bedrock) in a pattern lining up with the mapped bedding, and the observed springs along the Musconetcong River (Sedwick and Tully, 2010). In order to complete a Conceptual Model of the site, an understanding of karst features and connectivity to rivers must be completed. Figure 4 illustrates the findings and conclusions by MTA. The dashed lines are probable locations of drainage conduits through the bedrock (Sedwick and Tully, 2010).

Karst and Connection of Groundwater to River

Stream geomorphology and function is controlled by bedrock geology and generally follow the areas of highest weathering or solutioning areas (i.e. bedding planes, fractures, and faults). In the case of carbonate geology, due to the high secondary porosity through fissures and caverns, groundwater rapidly drains to the underlying aquifer, and is stored or immediately discharged to downstream receiving waters.

Groundwater and surface water are "highly interconnected and often constitute a single, dynamic flow system (White, 1993)." Generally, surface drainage can be short-circuited due to

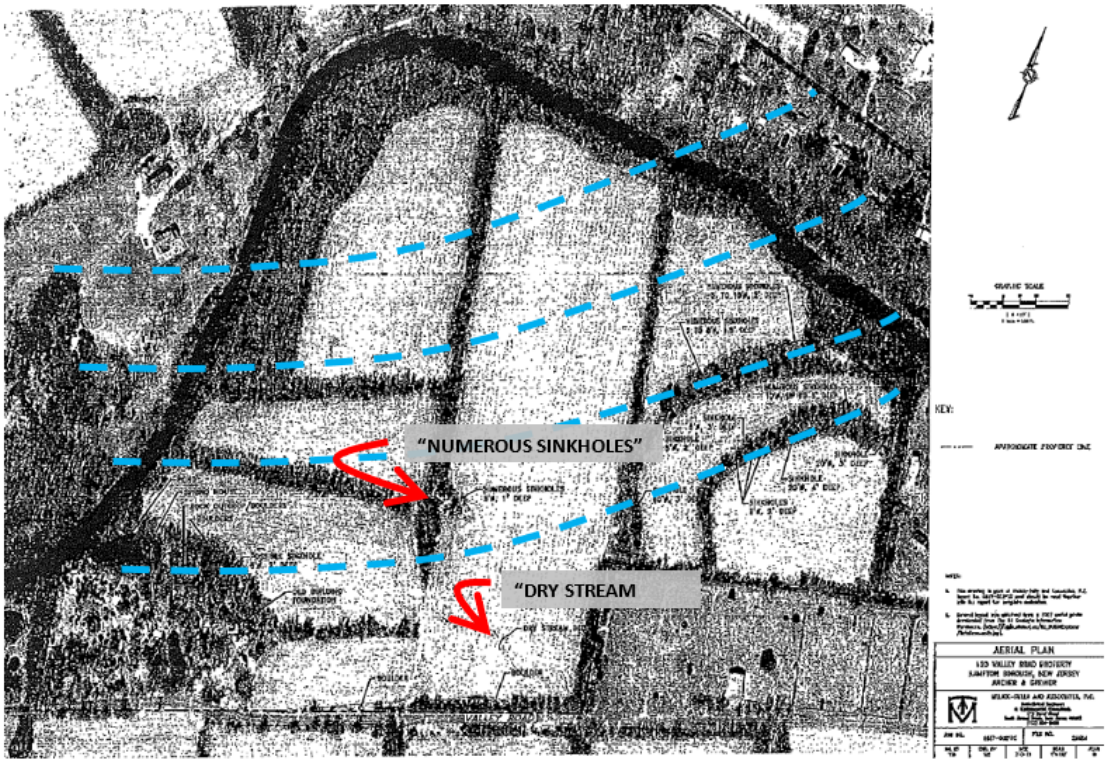

Figure 4: Melick Tully and Associates (MTA) Report figure showing the location of various karst features identified on the site, including sinkholes, boulders, rock outcrops, and the dry steam. Added to this figure by the author are highlighted labels of "numerous sinkholes" and "dry stream bed" that were labeled by MTA but not clearly read on this copy of the figure. The blue-dashed lines are the bedding planes verbally described by MTA, which match mapped bedding planes by the NJ Geological Survey and locations of enhanced solutioning and probable subsurface drainage conduits.

subsurface systems and the increased permeability through conduits within the bedrock regime (White, 1999). As a result, on lower order streams (higher in the landscape), surface runoff tends to run to the channel, then the runoff infiltrates, or more likely flows, unfiltered to the subsurface in the areas of sinkholes in the stream bed to the underlying aquifer. This appears to be the case regarding the on-site dry stream identified on the southwestern area of the Haberman Hampton that drains to the Musconetcong River.

Additionally, "[g]roundwater flow directions may not be apparent and can change direction during storm conditions. Conduits fill with water which flows to areas that are normally dry during precipitation events. These dry conduits may connect to springs and seeps that do not flow during low flow conditions (these types of springs are called overflow springs). Water can also fill up a conduit system enough to cross drainage basin boundaries. Therefore when evaluating karst, both base and storm flow conditions need to be studied (Indiana DEP, 2019)." Due to direct conduit connections to surface rivers and streams, flooding events can also backflood into the subsurface conduits and provide flood storage, and conversely the conduits provide water supply from stored runoff during dry periods (i.e. springs).

This means that water movement in karst terrain is especially unpredictable because of the many paths groundwater takes through the maze of fractures and solution openings in the rock (Winter, 1999). The groundwater in karst terrain does not move the same as groundwater in a porous medium because the flow is based on conduit or fracture flow in the bedrock. Because the karst rock is constantly changing and is heterogeneous, these fractures may suddenly or gradually open or close, and the flow velocity cannot be predicted (Indiana DEP, 2019). However, most of the rain that falls in a karst area drains into the ground rather than flowing to a surface stream (Veni, 2001). Direct drainage to the subsurface rather than flowing overland is reflected on the Haberman Hampton site, as observed from the disappearing/dry stream bed on the southwestern area of the property.

A site visit conducted to the far side of the Musconetcong River from the Haberman Hampton Tract, and on an immediate, adjacent property immediately to the west of the subject tract on January 17, 2020 revealed several features that further corroborate historic surface, and highly probable current subsurface stream flow to the Musconetcong River from wooded channels connecting the S-shaped dry stream bed closer to Valley Road. Walking along the riverbank on the south/east bank of the Musconetcong River, immediately to the west of the site, reveals streambanks that contain numerous seeps, springs, and channelized flow that emanate from the floodplain of the river. In Figure 5, about 200 feet west of Haberman Hampton, shows a typical seep along the river bank, while Figure 6, another 100 feet to the west, shows a prominent spring that, due to its subsurface source, maintains consistent temperatures that allows vegetative growth even into January.

Figure 5: Seep on south bank of the Musconetcong River, 200 feet west of the Haberman Hampton Tract. The seep was emanating about 12 inches above the river water surface at the time of inspection. Date: January 17, 2020.

Figure 6: Active spring sustaining vegetation throughout the winter, on the southern bank of the Musconetcong River, about 300 feet west of the Haberman Hampton Tract.
Date: January 17, 2020.

Walking along the northern/western bank of the Musconetcong River, viewing Haberman Hampton banks to the south/east reveal that the riverbanks are lined with rock that, apparently, are man-made (Figure 7) and support a filled floodplain. In viewing the 1931 aerial photograph (Figure 8), it shows that the Haberman Hampton property was farmed all the way up to the edge of the river, and the 1953 photograph (Figure 9) that shows an erosion/deposition fan that backed up and spread across the filled floodplain. It is highly probable that farming became difficult along the river due to karst activity and, subsequently, was abandoned and became wooded. This type of abandonment in areas of active karst areas is corroborated by the observations in the MTA report. Water still runs into the Musconetcong River via the subsurface conduits that remain below the filled surface, as evidenced via seeps observed by MTA and evidence of erosion from these seeps viewed from across the river by the primary author of this white paper.

Figure 7: View of south/east bank of the Musconetcong River toward the western area of the Haberman Hampton Tract. Note regular stone placement and filled floodplain and note exposed limestone boulders in river in the foreground. Date: January 17, 2020.

Figure 8: 1931 aerial photograph of Haberman Hampton Tract showing location where farming was practiced to the river edge. Photo source is USDA aerial imagery obtained from historicaerials.com

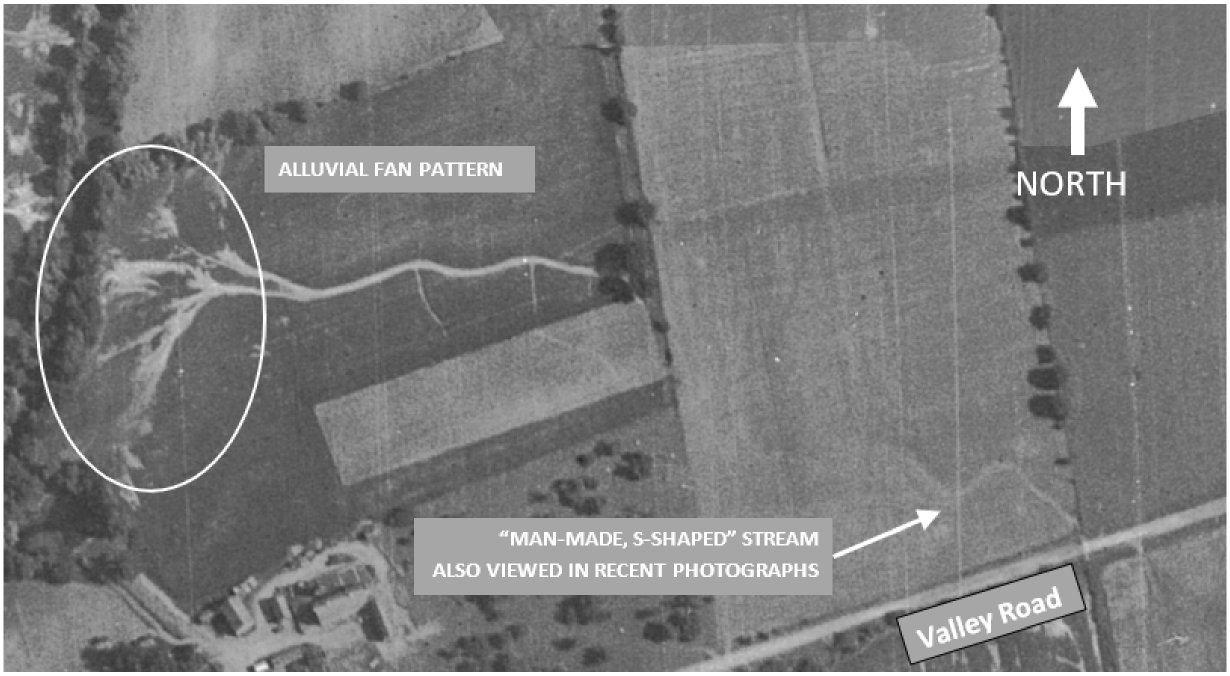

Figure 9: 1940 aerial photograph of western area of the Haberman Hampton showing effects of filling floodplain. Runoff spreads out, creating an alluvial fan pattern due to filling of floodplain. The edge of the river is already reforesting, likely due to difficulty in farming. It is noted that the dry stream bed near Valley Road has been a consistent, ***natural*** feature over the decades. Photo source: USDA aerial imagery obtained from historicaerials.com

Karst and Sinkholes

As noted in the Standards for Soil Erosion and Sediment Control in New Jersey, sinkhole formation is often accelerated by construction activities that modify a site's hydrology or disturb existing soil and bedrock conditions (New Jersey, 2014). Ground failure in karst areas is most often caused by the alteration of drainage patterns, emplacement of impervious coverage, excessive grading, and increased loads from site improvements.

According to an article published by New Jersey Geological Survey and the Department of Environmental Protection, "In addition to its value as a natural resource, karst areas are prone to ground subsidence due to the formation of sinkholes (Witte and Monteverde, 2006)."

"Karst by nature is unstable, because the carbonate rock is in a constant state of dissolution. Risk calculations cannot assume that karst will remain stable (Indiana DEP, 2019)." In fact, based on the primary author's direct experience in the development of karst landscapes, disturbance by construction activities and even the most subtle changes in drainage volume and patterns will induce sinkhole formation in areas of bedrock that contain open cavities in rock, but were filled and clogged with soil. The changes in drainage and vibrations from construction activities can dislodge the soil within such cavities. Even long after construction activities have ended, new sinkholes and sources of direct drainage to the underlying aquifers can occur. The duration of time to when new sinkholes form is dependent on the depth to bedrock, frequency, volume and concentration of flow, and extent to which existing open rock cavities are clogged.

An excerpt from the State of New Jersey 2019 Hazard Mitigation Plan:

> *Land subsidence can be defined as the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion, owing to the subsurface movement of earth materials (USGS, 2000). Subsidence often occurs through the loss of subsurface support in karst terrain, which may result from a number of natural and human-caused occurrences. Karst describes a distinctive topography that indicates dissolution of underlying carbonate rocks (limestone and dolomite) by surface water or groundwater over time. The dissolution process causes surface depressions and the development of sinkholes, sinking stream, enlarged bedrock fractures, caves, and underground streams.*
>
> *Sinkholes, the type of subsidence most frequently seen in New Jersey, are a natural and common geologic feature in areas with underlying limestone, carbonate rock, salt beds, or other rocks that are soluble in water. Over periods of time, measured in thousands of years, the carbonate bedrock can be dissolved through acidic rain water moving in fractures or cracks in the bedrock. This creates larger openings in the rock through which water and overlying soil materials will travel. Over time the voids will enlarge until the roof over the void is unable to support the land above will collapse forming a sinkhole. In this example the sinkhole occurs naturally, but in other cases the root causes of a sinkhole are anthropogenic. These anthropogenic causes can include those that involve changes to the water balance of an area such as: over-withdrawal of groundwater; diverting surface water from a large area and concentrating it in a single point; artificially creating ponds of surface water; and drilling new water wells. These actions can serve to accelerate the natural processes of creation of soil voids, which can have a direct impact on sinkhole creation.*
>
> *Both natural and man-made sinkholes can occur without warning. Slumping or falling fence posts, trees, or foundations, sudden formation of small ponds, wilting vegetation, discolored well water, and/or structural cracks in walls and floors, are all specific signs that a sinkhole is forming. Sinkholes can range in form from steep-walled holes, to bowl, or cone-shaped depressions. When sinkholes occur in developed areas they can cause severe property damage, disruption of utilities, damage to roadways, injury, and loss of life (page 5.7 - 2-3).*

Karst and Contamination

Because the groundwater and surface waters are directly connected, where the river runs through the carbonate formation through fissures, dolines (sinkholes), or disappearing streams, and the flow is rapid, there is a greater chance of spreading pollutants across long distances in a short period of time (Veni, 2001). This includes the infiltration or transfer of surface water runoff and sediment, which could include nitrogen, phosphorus, metals, pesticides, etc. from the impervious surfaces; septic tank effluent; solid trash and wastes; and accidental or intentional dumping of chemical wastes. According to the American Geological Institute, "[a]lthough these contaminants are common in any developed area, it is the ease with which they can enter karst aquifers and the rapid rates at which they can be spread that makes karst groundwater especially vulnerable (Veni, 2001)."

A study by the New Jersey Geological Society published in 2006 found that in northern New Jersey, the downward movement of groundwater contaminants has compromised countless bedrock supply wells. It explained that carbonate-rock aquifers are especially vulnerable to contamination because pollutants can travel quickly through enlarged fractures and openings that formed by the natural process of chemical weathering when rock dissolves in a manner similar to the formation of caves and caverns (Nicholson, 2006).

In a porous environment, the surface water runoff moves through the soil and the contaminants are filtered out before it enters the groundwater supply. However, the karst aquifer is extremely susceptible to contamination as there is little to no filtration of the subsurface water and any contamination can spread rapidly in the aquifer (Dalton, 2014). Because the contaminants can move so quickly without filtration through karst aquifers, research has shown that water quality problems that might be localized in other aquifer systems can actually become regional problems in karst systems (Winter, 1999).

Thermal impacts are another form of pollution that can negatively impact rivers via karst hydrogeologic systems. For the Musconetcong River, the enhanced below grade storage capacity in carbonate bedrock provides a year-round cold water supply to the river, even during drought conditions. Currently, as a NJDEP Category One, Trout Maintenance waters[12], the Musconetcong River is annually stocked with trout, which are important to ecotourism, and trout are an indicator of exceptional water quality due to their sensitivity to changes in temperature and pollutants. As recommended in the MTA report, sinkholes and cavities encountered within the developed area of the site will require remediation which can include the placement of concrete (i.e. grouting) into bedrock. Such activities will reduce subsurface flow and available storage of water for the Musconetcong River. Additionally, any large-scale treated sewage disposal to the subsurface will introduce wastewater and its corresponding higher temperatures, which will have a negative impact on the baseline water temperatures conveyed via springs to the Musconetcong River.

Conceptual Model

"We can no longer conscientiously drill three or four test borings to characterize a 500-acre site for construction or use one boring per mile to address the engineering concerns along a roadway or transmission line in karst and assume that we have all the information necessary for evaluation and design of structures (Fischer & Fischer, 2015)."

For Haberman Hampton, there has been very little site investigation work to confirm the state of the underlying geology and its probable network of conduits and connection to the

[12] Category One water is defined in NJAC 7:7B, Surface Water Quality Standards by NJDEP, are those waters with exceptional water quality and ecological significance, including for supporting important fisheries. The trout maintenance designation is provided to those waters that contain high enough water quality and low enough temperatures to support trout throughout the year, even if not self-producing.

Musconetcong River, according to the records obtained via the OPRA of New Jersey[13]. As has been described above, there is significant evidence via documents prepared by the applicant, albeit not necessarily based on intensive investigation, that the underlying carbonate geology is prototypical of karst topography, and more specifically of karst within the Allentown formation dolomite. The following are the observations and conclusions that have been reached to develop this Conceptual Model (See Figure 10) of the on site geologic and hydrogeologic conditions.

1. The Haberman Hampton Tract is located within the Highlands Physiographic Province within the Piedmont region of the Appalachian Mountain range, an area identified with long ridgelines separated by narrow river valleys. In New Jersey, the Highlands Region runs in a northeast-southwest direction through the northwestern part of the state.

2. Due to susceptibility to solutioning, karst in the Piedmont generally is located in valleys as the ridges are comprised of igneous and metamorphic rock more resistant to erosion and not subject to extensive solutioning. This site is located in this type of valley, and immediately adjacent to the river.

3. The Haberman Hampton Tract is underlain by carbonate bedrock, and more specifically, the Allentown formation, a dolostone or dolomite that is subject to solutioning on the surface of the bedrock and in bedding planes, fractures, contacts, and fault lines; with the solutioning creating caverns, fissures, and conduits. Secondary impacts of bedrock solutioning is the creation of sinkholes, closed depressions, and disappearing streams. Such surface manifestations of solutioning activity creates topography called karst such as sinkholes, closed depressions, and disappearing streams.

4. The property has been used for agriculture at least back to 1931, the earliest available aerial photograph, but likely for more than 100 years. The aerial photographic history of the site shows a primary use as row crops. Over the years the site's extent of row crops has changed. The maximum use of the site was observed in the 1931 aerial photograph, and in subsequent photographs wooded areas expanded from those areas less conducive to row crops, and likely a trend away from areas of active sinkhole formation. As a result of annual plowing, planting and harvesting, the drainage on the site has been modified, but there is a tendency for the drainage to reorganize with areas forming streams, then disappearing, and then reforming again, albeit in slightly different configurations. Changing drainage patterns of streams in karst can be rapid, especially as a result of land disturbance, such as acting farming. Such activities will trigger the opening and closing of sinkhole features on a site.

5. The Haberman Hampton Tract, being wholly underlain by carbonate rock, contains characteristic and typical karst features, as confirmed by investigations conducted by the

[13] Open Public Records Act, P.L. 2001, CHAPTER 404, N.J.S. 47:1A-1 et seq. Is a law requiring that "government records shall be readily accessible for inspection, copying, or examination by the citizens of this State, with certain exceptions, for the protection of the public interest, and any limitations on the right of access accorded by P.L.1963, c.73 (C.47:1A-1 et seq.) as amended and supplemented, shall be construed in favor of the public's right of access". Such public records also include those documents prepared by private entities and submitted to the government in the process of application for permits, for example.

property owner's consultants, MTA, for example. The investigations completed by MTA found that the site contains many sinkholes that align with the bedding planes and general trend of the Musconetcong River's direction in a northeast-southwest direction. These sinkholes were found in areas that were wooded, and very likely avoided by the farmers of the property over the generations. Sinkholes are avoided in farming due to the hazards they present to farm equipment and difficulty in growing crops due to the unevenness of the ground surface.

6. The environmental consultants, DiLodovico and Krueger, albeit non-experts in karst and carbonate geology, by virtue of their descriptions of the on site drainage, reveal that there is an ephemeral and disappearing stream, a classic karst feature. Both describe overland flow of water that “dissipates”. Based on the review of the MTA Phase I report, and aerial photographs, the subject stream discharges to the subsurface and into the underlying Allentown formation. During higher flows that overwhelm the conveyance capacity of the sinkhole throat, excessive flow is carried via surface channel flow to the Musconetcong River.

7. This ephemeral and disappearing stream, especially in its wooded section between the Musconetcong River and where it meets the farmed section of the watercourse, contains a number of sinkholes, likely due to the shallowness of bedrock and the preference for water to flow to the underlying exposed solution cavities in the top or rock and connection to conduits and caverns that exist below the site. As a result of this vertical preference of flow to bedrock, a typical surface stream that would be viewed in a stream channel in a non-carbonate formation, similarly flows, but below the ground surface where it cannot be viewed without excavation or the installation of wells.

8. The MTA report also mentions the on site observation of springs that emanate from the ground surface all along the banks for the Musconetcong River that bounds the northern perimeter of the property. These springs are a surface manifestation of underground streams that likely flow along the bedding planes of the Allentown Dolomite.

9. As corroborated with peer-reviewed research, USGS states that "[k]arst is a unique hydrogeologic terrane in which the surface water and ground water (sic) regimes are highly interconnected and often constitute a single, dynamic flow system (Taylor and Greene, 2008)." Additionally, the Musconetcong River National Wild and Scenic Rivers Study (2004), which formed the basis for the Congressionally authorized Wild and Scenic Rivers designations of many portions of the Musconetcong River, included the reach bounding the subject property. This study mentions specifically that "...groundwater flows into the river through springs in the riverbed." It also states that "...fractures and solution channels in karst areas provide a direct connection between land surfaces and groundwater, greatly increasing the potential for groundwater contamination."

As a result of a review of the available permit application documents by the land owner/developer; historic aerial photography; review of peer reviewed karst geologic and hydrogeologic publications; visits to the site’s perimeter, including along the Musconetcong

River; and the experience of the authors of this white paper, we offer the following Conceptual Model of the site.

The property is underlain by a series of folds and fracturing that has produced preferential patterns of sinkhole formation and surface/subsurface drainage. The sinkholes are located above areas, wherein, there are significant cavities and vertical throats in the bedrock. Surface water runoff drains through the soils in these areas, and gradually through erosion and gravity, carry and cause soil, respectively, to fall into the bedrock and groundwater regime. As a result, along these linear solutioning patterns on the site, surface water runoff tends to concentrate in channels, then drain to cavities and conduits in the bedrock, and finally, drain to seeps and springs that discharge to the Musconetcong River's banks and channel bed. While the western edge of the site, immediately adjacent to the Musconetcong River, was historically filled for farming, water still manages to travel relatively unimpeded in the subsurface to the Musconetcong River.

The "dry stream bed" as identified by the authors, Melick Tully & Associates, DiLodovico, and Krueger[14] is "dry" as a result of the fact that all surface water runoff either infiltrates to the subsurface along the stream channel routes or drops to the bedrock groundwater regime. This condition, again, a characteristic of karst terrain, does not allow for the establishment of a shallow groundwater table, and many lower order streams, higher in the landscape in this geologic setting are considered losing streams.

Figure 10 (below) was prepared to provide an illustration of what can be expected from the subsurface at the Haberman Hampton Tract. What the reader should take away from this Conceptual Model and the below illustration, is that there is a direct and intimate connectivity between the Musconetcong River and the waters that underlie Haberman Hampton.

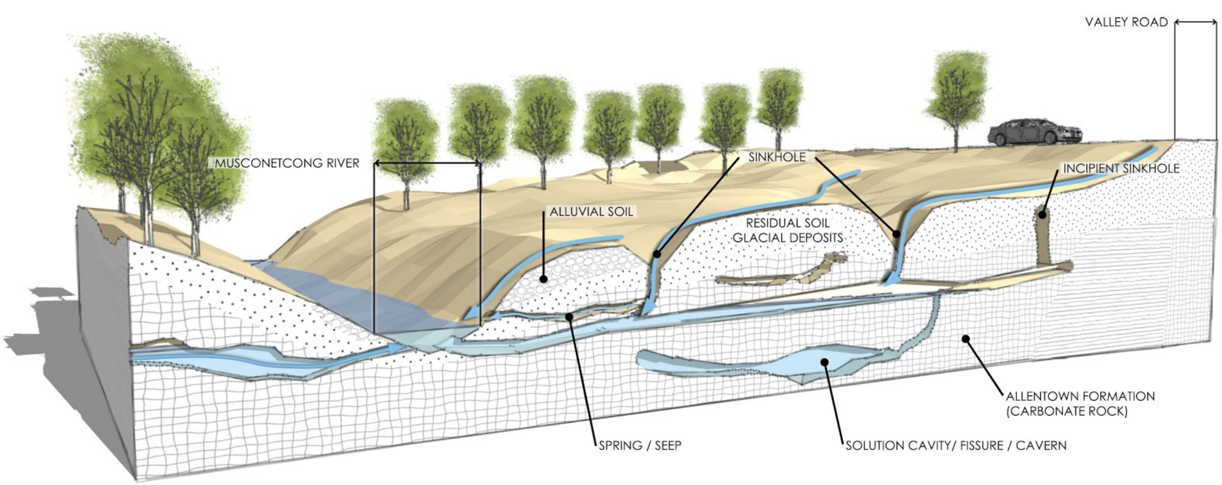

FIGURE 10: Conceptual Hydrogeology at Haberman Hampton developed by Princeton Hydro.
Conceptual Model Image: © 2020 - Princeton Hydro. ALL RIGHTS RESERVED.

[14] As discussed previously in the report, in the text in other footnotes is that DiLodovico and Krueger, while erroneously identifying the on site dry stream bed as "man-made" do, likely without intention, provide an accurate description of the characteristic "disappearing stream" of karst terrain.

For example, if the river rises during a flood, the conduits, cavities, and caverns below Haberman Hampton rise simultaneously, providing flood storage. Water that runs into sinkholes and below disappearing streams reach the Musconetcong River in a relatively short period of time. These two regimes, groundwater and the river, actually are one system.

Implications of Development on the Quality of Water in Karst Hydrogeologic Systems in NJ

There currently exists a contradiction of regulatory protection of water quality in carbonate-based water resources systems in New Jersey. As has been argued on this specific tract, the applicant's consultants have argued against and have certified that the onsite hydrologic/hydrogeologic systems do not require protection under the Flood Hazard Area Control Act (NJAC 7:13) and the Freshwater Wetlands Protection Act (NJAC 7:7A). The irony is that due to direct and unfiltered connection of surface drainage to the large, complex, and rapid conveyance of groundwater aquifers receiving surface waters that depend on these systems as their source water, a karst aquifer is more vulnerable to negative water quality effects than non-karst stream and river systems. The many cavities, caverns, and conduits through carbonate bedrock, such as the Allentown formation that underlies the site, are difficult to model for development and remediate of contamination. And, when bedrock is stabilized via methods such as grouting, the hydrogeologic impacts are *irreversible*.

While the Haberman Hampton Tract provides a significant contribution of clean, cold, and abundant water to the New Jersey classified Category One, Trout Maintenance, and Congressionally designated Wild and Scenic Musconetcong River, the applicant now has the ability, outside of the only currently designated riparian zone along the Musconetcong River, to do whatever is necessary to develop the site. Based on the hydrologic function of this site, this *300-foot riparian zone will do almost nothing to protect the primary source of clean, cold, and abundant water to the Musconetcong River*. In fact, due to the direct, continuous connection between the surface water of the Musconetcong River and the groundwater regime below the Haberman Hampton Tract, waters of the Musconetcong River, within a degree of engineering certainty, extend well into the site.

For the lack of protection provided by the existing Land Use Regulation Program rules of the unique characteristics of karst groundwater regimes, the Haberman Hampton Tract is, paradoxically, extremely environmentally sensitive due to the fact that it has almost no regulatory protection of the upland and subterranean streams on the site.

Conclusion and Recommended Next Steps

The Haberman Hampton Tract is prototypical of such karst terrain, and the proposed high density development, as proposed, will have permanent, negative impacts on the quality of the Musconetcong River based on the development of this Conceptual Model. As recommended by the 2010 MTA report, intensive and extensive subsurface investigations must progress to accurately assess the development capacity of the Haberman Hampton property. Development should be planned that avoids much, if not all, of the areas of active subsidence, sinkhole formation, and disappearing streams to protect the aquifer capacity, and maintain subterranean drainage patterns. Unfortunately, NJDEP, without understanding karst hydrogeologic connections to the Musconetcong River, approved not providing a regulated Flood Hazard Area and riparian zone for the disappearing stream in the southwestern area of the property. At a minimum, a riparian zone would have afforded protection of the clean and cold water supply to the Musconetcong River via a 300-foot riparian zone. It is important that this decision be reversed, is possible, and riparian zone be designated around a reasonably estimated centerline of the dry stream bed and subterranean stream from Valley Road to the Musconetcong River. Additionally, based on more in-depth site investigative work, buffers must be provided around other areas of known sinkholes, as well as those areas that have a high propensity for sinkhole formation.

The NJDEP Land Use Regulation Program erred in their decision to not require riparian zones around the natural stream channel from Valley Road to the Musconetcong River. This decision has actually opened up the category one, trout maintenance Musconetcong River to a calculable and measurable degradation in water quality. However, there is a second and defensible opportunity to correct NJDEP's err in judgement at the Land Use Regulation Program during the Watershed Plan Amendment process (NJAC 7:15). This rule, while having certain specifications for designating "environmentally sensitive areas", the policy statement under subsection 1.2 Policy goals, gives *broad latitude* to protect water quality via subparagraphs 1 and 2, quoted as follows:

1. *Establish and support policies, procedures, and standards which, wherever attainable, help to restore, enhance, and maintain the chemical, physical, and biological integrity of the waters of the State, including ground waters, and the public trust therein, to protect public health, to safeguard fish and aquatic life and scenic and ecological values, and to enhance the domestic, municipal, recreational, industrial, and other uses of water;*

2. *Conserve the natural resources of the State, promote environmental protection, and prevent the pollution of the environment of the State;*

Via this rule, the NJDEP has the obligation to assess watershed planning in the context of ensuring that Haberman Hampton is developed in a manner that ensures that there is a balance of the rightful use of this property with the protection of downstream high-quality waters, which provides a higher standard to protect, not just the developer of the subject land, but the residents of the State of New Jersey.

It is the authors' hope that the Conceptual Model developed herein will generate discussion that will lead to informed decisions regarding this site, and in a larger context, the need to upgrade the regulations to ensure the protection of all water resources in karst terrain. It is a missed opportunity if NJDEP knowing or, at best, was unsure, of the impacts to a category one, trout maintenance water, went ahead and approved a sewer extension within the purview of the Watershed Planning Rules based on a blatant gap in protective regulations, and not on sound science and engineering. This is the challenge the authors' put forth to reviewers of this paper.

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