



April 15, 2014  
Revised April 28, 2014

ARLC 1202

Mr. Steve Burgo  
Tredyffrin Township  
1100 Duportail Road  
Berwyn, PA 19312-1079

**Re: Carbonate Geology Study  
Wayne Glen  
Tredyffrin Township, Chester County, Pennsylvania**

Mr. Burgo:

As you are aware, Arcadia Tredyffrin, LLC proposes the development of an approximate 36 to 37-acre tract of land located at the southwest quadrant of the intersection of Walker Road and Old Eagle School Road in Tredyffrin Township, Chester County, PA. This tract of land is known as the Richter Property.

Currently the Richter Property consists of undeveloped land with scrub vegetation, non-deciduous and deciduous trees. The proposed new development will include both residential dwellings and professional office buildings. The residential development will provide 104 new units, including 45 Carriage Homes and 59 Townhomes. On the Professional Parcel, two new office buildings totaling 60,000 sf footprint (240,000 sf gross area), surface parking and a five story parking garage with a 44,000 sf footprint are proposed. The proposed development plan includes a regional stormwater management basin, two infiltration basins and a system of smaller stormwater management facilities such as: bio-retention areas, vegetated swales, permeable paving areas, subsurface infiltration basins, and a green roof system. The regional detention basin will be constructed to provide approximately 37 ac-ft of storage over approximately 5 acres of the residential parcel.

Pennoni Associates Inc. (Pennoni) has prepared a Carbonate Geology Study report with the objective of documenting the surface and subsurface conditions related to karst conditions in general accordance with Tredyffrin Township Code 174 Attachment, Appendix B, Section A-5 "Karst/Carbonate Geology". The report was prepared by Michael Morykin, Jr., a professional geologist and Edward J. Sander, a professional engineer. Both Mr. Morykin and Mr. Sander are licensed in the Commonwealth of Pennsylvania. Mr. Morykin has a specialty in Engineering Geology with extensive experience in karst areas. Mr. Sander also has extensive experience in karst areas particularly along the Route 202 corridor in Tredyffrin, East Whiteland, and West Whiteland Townships. In preparing the referenced report the following tasks were performed between January 2013 and September 2013:

- conducted a thorough site reconnaissance
- reviewed readily available geological data including, but not limited to, maps, open file reports, PADEP records related to reported sinkholes, etc.
- reviewed readily available historical aerial photographs

- performed subsurface borings and test pits to explore suspected karst features identified by the site reconnaissance
- conducted geophysical surveys at or nearby proposed BMP locations to identify locations and extent of existing subsurface karst features
- evaluated field data to provide an approximate effective soil thickness, gradation, anisotropy, and permeability to determine the capacity and rate of infiltration of the soil and relative depth of soil necessary to protect against sinkhole formation
- determined the feasibility of constructing the proposed development in this geologic condition

As a result of the various tasks listed, Pennoni prepared the report - *Carbonate Geology Study for Wayne Glen* dated April 21, 2014. As stated in the report, our observations and results of the borings, test pits, and trench excavations are consistent with the general observations that the karst features are not presently active; the features appear to be historical in nature meaning that they are confirmed surface collapses, but the conditions of these features are such that they are overgrown with vegetation and recent movements are not evident. Fourteen (14) potential karst features were identified during an initial site reconnaissance and they were further explored with a boring, test pit, or test trench. This additional exploration was conducted, in part, to assess whether the potential features identified had subsurface conditions that indicated solution activity. Of the fourteen features identified, ten (10) were confirmed to be existing karst features having apparent solution activity through our subsurface explorations and will be remediated as part of this development. Where the subsurface explorations indicated no solution activity, no remedial action is recommended.

A subsequent site reconnaissance revealed 4 additional features that were not previously identified. Of these 4 features two of them have the same characteristics as the ten discussed above and will be handled in a similar manner. The other 2 recently identified locations are the result of settlement of test pits previously excavated either as part of the aforementioned exploration, or infiltration testing. These locations will be further explored at the beginning of construction and remediated accordingly if confirmed to be karst features.

The subsurface conditions disclosed at the project site are consistent with other sites that we have experience with in the region. A grading plan has been developed for the project that provides for positive drainage to minimize the potential for sinkhole development. Further, the site layout has been designed to keep some of the stormwater management facilities at the perimeter of the development. Based on the results of our explorations completed thus far, our observations throughout the property, and our extensive experience with development in karst regions, the current design sites the surface infiltration facilities away from concentrations of identified solution activity to the greatest extent feasible and with engineering justification. Moreover, the BMPs have been designed in a manner to avoid future subsidence that could damage buildings, roadways or other structures and create an unsafe condition. The permeable pavement provides a permeable surface with storage and infiltration below the pavement surface. In the proposed design, existing karst features will be remediated at the on-set of construction with engineering best management practices prior to construction of the permeable pavement and related BMPs. It is our professional opinion, that the proposed remediation and the proposed roadway and BMP construction will provide adequate soil stability. The site design and construction being proposed for Wayne Glen will take appropriate measures to accommodate the underlying geology and minimize the potential for future solution activity. The proposed stormwater management system, with its series of facilities spread throughout the site, is designed to minimize stormwater concentration. All infiltration facilities have been designed with an impervious loading ratio of 3:1, when considered in series, as recommended by the Pennsylvania Department of Environmental Protection. It is the intent of the

developer to remediate the karst features in an appropriate manner at the beginning of construction. Remediation efforts associated with karst features within 50 ft of stormwater facilities, but not within the influence of proposed dwellings, will focus on promoting infiltration. We proposed to achieve this by using an inverted filter design that restores stable conditions in the immediate vicinity of the feature, but also allows filtered water to pass through the overburden as desired by the Township. Presented below are our intended remediation schemes for each of the karst features that are within 100 ft of either bio-retention basins or permeable pavement.

1. Karst feature #1 was identified as a possible sinkhole and is located beneath a proposed dwelling. A section of permeable pavement traverses a portion of the 100 ft buffer. At this location the depth to rock is approximately 18.5 ft below existing grade, 5 ft below the proposed basement floor elevation and approximately 10 to 13 ft below the roadway elevation. In this particular instance because of the existing and proposed conditions the intent would be to excavate the basement area and at that time further explore the karst feature conditions. The stabilization would be focused on providing conditions beneath the dwelling that would restore structural support to its foundations; remediation methodologies promoting infiltration directly beneath the dwelling is not recommended in this instance. The lateral limits of the stabilization would be minimized so that the drainage capacity of the subsoils beneath the pervious pavement is not compromised.
2. Karst feature #2 was identified as a possible sinkhole and is located in the driveway/grass area between the dwelling and the roadway. A section of permeable pavement traverses a portion of the 100 ft buffer. At this location the depth to rock is approximately 18 ft below existing grade, 13 ft below the proposed basement floor elevation and approximately 20 to 21 ft below the roadway elevation. In this particular instance because of the existing and proposed conditions the intent would be to use a combination of compaction grouting and a soil exchange using a reverse filter. We propose to perform compaction grouting at depths from approximately 18 to 12 ft below existing grade, and then further explore the karst feature conditions. Details on compaction grouting are presented below. The stabilization would be focused on providing conditions at depth that would restore the density of the natural subsoils plus address the shallow conditions with standard excavating equipment. The lateral limits of the stabilization would be minimized so that the drainage capacity of the subsoils beneath the pervious pavement is not compromised.
3. Karst feature #3 was identified as a closed depression and is located within an area of the permeable pavement. A closed depression can be the result of, or the precursor to, a sinkhole. However, our vast experience has shown that a very small percentage (< 5%) of closed depressions is associated with solution activity. In this particular case the results of Boring B-2 indicate very dense rock fragments immediately above the rock surface with medium dense saturated granular soils immediately above those soils. The lower "N" values are typically associated with the disturbance of the soils resulting from the sampling procedure (ASTM D 1556) rather than soil raveling. At this location the top of rock is approximately 9 ft below existing and proposed top of roadway. The soils will be excavated and the anticipated remedial stabilization would be one that provides appropriate roadway support and promotes drainage as required by the PA BMP Manual.

4. Karst feature #4 was identified as a possible sinkhole and is located in within an area of the permeable pavement and adjacent bio-retention basin #6. The top of rock is approximately 9 ft below existing grade and 16 ft below proposed grades. The stabilization methodology is anticipated to include further exploration of the conditions and construction of a reverse filter to promote drainage as appropriate. Design grades will be established using on-site soils compacted as appropriate.
5. Karst feature #5 was identified as a possible sinkhole and is located in an open area adjacent to (within the buffer) bio-retention basin #8. The top of rock is approximately 6.6 to 7 ft below existing grade and 11 to 12 ft below proposed grades. The stabilization methodology is anticipated to include further exploration of the conditions and construction of a reverse filter to promote drainage as appropriate. Design grades will be established using on-site soils compacted as appropriate.
6. Karst feature #6 was identified as a possible sinkhole and is located in an open area adjacent to (within the buffer) a section of permeable pavement and bio-retention basin #9. The top of rock is approximately 8 ft below existing grade and 16 to 22 ft below proposed grades. The stabilization methodology is anticipated to include further exploration of the conditions and construction of a reverse filter to promote drainage as appropriate. Design grades will be established using on-site soils compacted as appropriate.
7. Karst feature #7 was identified as a possible sinkhole and is located beneath a proposed dwelling; however, a section of permeable pavement traverses a portion of the 100 ft buffer. At this location the depth to rock is approximately 22 ft below existing grade, 13 ft below the proposed basement floor elevation and approximately 19 to 22 ft below the roadway elevation. Because of the conditions encountered at this location and the location within the building footprint the stabilization methodology is anticipated to consist of compaction grouting. The grouting would be terminated at an elevation slightly above the proposed lowest floor elevation and the lateral limits of treatment would be such that there would be no detrimental impact to the drainage soils beneath the pavement as required by the PA BMP Manual.
8. Karst feature #8 is located adjacent to Walker Road in the northeast portion of the project. The feature is actually comprised of 2 sinkholes that are located within or immediately adjacent to dwellings. The top of rock is approximately 9 to 13.5 ft below existing grade and 10.5 to 13 ft below proposed basement floor grades. The stabilization methodology is anticipated to include further exploration of the conditions and excavation to the top of rock and then backfilling the excavations with suitable on-site soils placed in appropriate layer thicknesses and compacted to re-establish dense/stiff soil conditions similar to the surrounding soils that are adequate for foundation support in the affected dwellings.
9. Karst feature #9 was identified as a possible sinkhole and is located within a building footprint in the western portion of the project. The top of rock is approximately 18.5 ft below existing grade and 15 ft below proposed lowest floor grades. Because of the conditions encountered at this location and the location within the building footprint the stabilization methodology is anticipated to consist of compaction grouting and soil exchange. The grouting would be terminated at an elevation as close to the proposed lowest floor elevation conditions will allow. Remediation will also include further exploration of the conditions and backfilling the excavations with suitable on-site soils placed in appropriate layer thicknesses and compacted to re-establish dense/stiff soil conditions similar to the surrounding soils that are adequate for foundation support in the affected dwellings.

10. Karst feature #10 was identified as a possible sinkhole and is located within the regional basin more than 50 ft from any bio-retention basin. The depth to rock is approximately 6 ft below existing and proposed grades. Since the regional basin is not an infiltration facility, the proposed stabilization methodology is anticipated to include further exploration of the conditions and excavation to the top of rock and then backfilling the excavation with suitable on-site soils placed in appropriate layer thicknesses and compacted to re-establish dense/stiff soil conditions similar to the surrounding soils.
11. Karst feature #11 was identified as a historical sinkhole and is located within a building footprint in the southwestern portion of the project. Because of the conditions encountered in the vicinity of this location and the feature location within a building footprint the stabilization methodology is anticipated to consist of compaction grouting and/or soil exchange. The grouting would be terminated at an elevation as close to the proposed lowest floor elevation conditions will allow. Remediation will also include further exploration of the conditions and backfilling the excavations with suitable on-site soils placed in appropriate layer thicknesses and compacted to re-establish dense/stiff soil conditions similar to the surrounding soils that are adequate for foundation support in the affected dwellings.
12. Karst feature #12 was identified as a historical sinkhole and is located within an area of the permeable pavement and adjacent bio-retention basins #8 and #9. Based on subsurface information in the vicinity the stabilization methodology is anticipated to include further exploration of the conditions and construction of a reverse filter to promote drainage as appropriate or another methodology that will not restrict the proposed infiltration. Design grades will be established using on-site soils compacted as appropriate.
13. Karst feature #13 is identified as being associated with a test pit excavated as part of the subsurface exploration program discussed previously and is located within an area of the permeable pavement in the south central portion of the site. The test pit will be re-excavated and backfilled with on-site soils placed in layers and properly compacted. Design grades will be established using on-site soils compacted as appropriate.
14. Karst feature #14 was identified as a historical sinkhole and is located within a landscaped area between permeable pavement and a structure. Remediation will include further exploration of the conditions and the stabilization methodology will be developed based on the conditions disclosed but is anticipated to include construction of a reverse filter to promote drainage as appropriate and/or a methodology that will not restrict the proposed infiltration. Design grades will be established using on-site soils compacted as appropriate.

As described in the Report, compaction grouting consists of the injection of a low-mobility (stiff, low slump grout confined to small areas). The purpose of compaction grouting is to increase the density of very soft, very loose soils, but not fill the voids in a soil mass unless it is an open void/cavern. An injection location is first drilled to, and in most cases into, rock at least 5 to 7 ft to verify the obstruction is not a cobble/boulder. The hole is then cased with steel casing to the top of the rock where grouting will be initiated. Prior to grouting the casing is lifted above the top of rock and then the injection of a very stiff, low-slump (1-2 in.) grout mix is injected under pressure. The grouting relies on the soil overburden pressure as a resisting force; therefore, the effective depth of grouting is usually more than 10 ft below the ground surface. Anything less than 10 ft, the ground begins to heave and the effectiveness of the grouting is lost. To maintain control of the placement of the grout injection, criteria are established that prevents over-grouting at an individual location.

These criteria include:

- defining a suitable injection pressure
- defining an injection volume based on an injection zone (not to exceed 1.5 cy for a 2 ft zone)
- ground heave
- grout around the casing
- grouting performed under the direction of a qualified engineer or geologist

The current design will not, within a reasonable degree of geotechnical engineering certainty, increase the risk for:

- groundwater contamination;
- formation and/or expansion of:
  - solution channels
  - sinkholes
- other potentially dangerous karst features
- formation of new karst features;
- occurrence of sinkhole activity on surrounding/adjacent properties;
- accelerated development of existing karst features, or
- unsafe conditions due to damage of structures as a result of subsidence.

It is our professional opinion the *Carbonate Geology Study for Wayne Glen and its recommendations reasonably address the provisions of* Tredyffrin Township Code 174 Attachment, Appendix B, Section A-5. The infiltration BMPs, both surface and subsurface, are designed to avoid formation of new karst features and to protect existing karst features from accelerated development. As stated previously, it is the intent of the applicant to remediate all known karst features at the on-set of construction, as well as any new karst features that may develop during construction. The combination of an engineered remediation as well as our designed loading ratio's provide engineering justification for the location of the systems and their proximities to existing karst features. Based on the results of the field explorations and field reconnaissance it is our professional opinion that site development is feasible and that interpreted site conditions are consistent with those typically associated with karst environments. At areas presently confirmed as karst features the design has been revised to provide a setback for the bio-retention basins or surface infiltration basins that should avoid formation of new karst features and protect any existing karst features from accelerated development.

It can be expected that the development of new sinkholes may arise during and after site work activities due to changes in surface drainage, as typically occurs in many karst development sites. For those sinkholes that have been identified to exist, it is our professional opinion that the proposed development will not likely pose a significant threat to ground water quality or the stability of surface structures, if proper remedial actions are implemented and preventative measures are used during construction. If, during construction, a sinkhole should develop or is discovered, it must be brought to the attention of the project geotechnical engineer immediately and remediated as soon as possible. If a sinkhole forms after construction and occupation of the site, a geotechnical engineer experienced with karst conditions must be contacted before any attempts at remediation. The sinkhole remediation method must be determined based on conditions encountered and the specific location of the activity. Based on our observations and experience with similar subsurface conditions it is our professional opinion that should a sinkhole occur the resultant profile will most likely be a small radius (up to 5 ft) and relatively shallow in depth due to the relative shallow thickness of the overburden soils. Typically, very thick soil mantles overlying soluble rock formations are more susceptible to the development of large scale features.

As with any development constructed on a carbonate rock formation, regardless of the intensity of an industry-standard subsurface exploration for geologic hazards, there is always some risk that remains. This is consistent throughout Tredyffrin Township. However, to minimize financial and public safety impacts to the future owners of the Wayne Glen development, the applicant is providing the following engineering justification to locate stormwater BMPs within 100 ft of the identified existing karst features and below structures (pavements) as prohibited within Chapter 174, Appendix B, A.5.b.

1. Completed subsurface explorations indicate any noted solution activity has not resulted in open voids below-grade;
2. Remediation methodologies proposed are examples of "industry standards" used by many practicing/licensed geotechnical engineers throughout the geographic region;
3. The collected water will infiltrate over a "wide area" versus concentrated area where sinkholes have a greater propensity to occur;
4. The subsurface conditions within the immediate vicinity of the features will be improved to be similar if not better than the surrounding soils;
5. The lateral dimensions of the existing features have not exceeded 6 ft at the locations (except for Feature #6) thereby providing credence that should a sinkhole develop, the affected area is expected to be shallow and narrow;
6. Prudent measures to control storm water have been implemented in the design to minimize the potential for sinkhole development.

To reasonably address the risks associated with development over carbonate rock formations we understand that the applicant further proposes to provide the following assurance plan in the event of the formation of sinkholes within the development during the life of the project:

1. The applicant will remediate any sinkhole that develops during construction;
2. The Homeowners Association (HOA) will be professionally managed;
3. A designated geotechnical and civil engineer will be on-call to provide inspection services and address subsidence issues, should they arise;
4. The HOA will obtain insurance;
5. The HOA will budget for maintenance and replacement reserves;
6. The HOA will have the ability to make special assessment of its members should there be costs in excess of reserves; and
7. The HOA will have the ability to charge an initial fee to each new owner that can be used to fund capital reserves.

It is our conclusion that for those areas defined by Chapter 174, Appendix B, A.5.b the potential for formation of new sinkholes is low, and existing karst features are protected from accelerated development based on the engineering justifications presented above. For any new karst feature that may develop and negatively impact this development an assurance plan is in place to mitigate and cover remaining risks.

Mr. Steve Burgo

Carbonate Geology Study

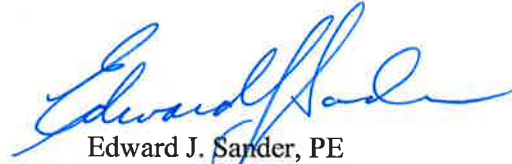
We trust that this letter contains the information you require at this time. Should you have any questions do not hesitate to contact this office.

Respectfully yours,

**PENNONI ASSOCIATES INC.**



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Project Geologist



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