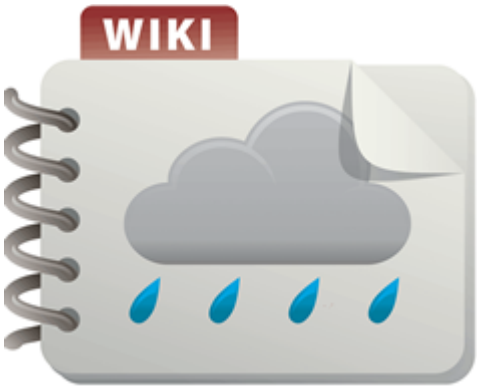

Procedures for investigating sites with potential constraints on stormwater infiltration

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Investigation	Shallow groundwater	Shallow bedrock	Soils with low infiltration capacity	Karst

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Preliminary site investigation	NA	NA	NA	The level of detail required will depend on the likelihood that karst is present and any local regulations. The preliminary site investigation should include, but not be limited to (Pennsylvania BMP, 2009): ▪ A review of aerial photographs, geological literature, sinkhole maps, previous soil borings, existing well data, and municipal wellhead or aquifer protection plans. ▪ A site reconnaissance, including a thorough field examination for features (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/groundwater/groundwater-basics/karst-in-minnesota.html) such as limestone pinnacles, sinkholes, closed depressions, fracture traces, faults, springs, and seeps. ▪ The site should be observed under varying weather conditions, especially during heavy rains and in different seasons to identify and map any natural drainageways.
Subsurface material investigation	The investigation is designed to determine the depth to seasonally saturated soils. Subsurface data for depth to seasonally saturated soil may be	The investigation is designed to determine the nature and thickness of subsurface materials, including depth to bedrock. Subsurface data for depth to	Soil testing is recommended for all proposed stormwater facilities that plan to have a recharge or infiltration component to their design. Testing can	The investigation should determine the nature and thickness of subsurface materials, including depth to bedrock and the water table. Subsurface data may be acquired by backhoe excavation and/or soil

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	acquired by soil boring or studying existing wells on the site, if present. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of the saturated soil formations under the surface. The data listed below should be acquired under the direct supervision of a qualified geologist, geotechnical engineer, or soil scientist who is experienced in conducting such studies. Pertinent site information should include the following: ▪ Known groundwater (water depth) depth ▪ Soil characteristics (type, thickness, mapped unit) ▪ Bedrock outcrop areas	bedrock may be acquired by soil boring or backhoe investigation. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of the bedrock formations under the surface. The data listed below should be acquired under the direct supervision of a qualified geologist, geotechnical engineer, or soil scientist who is experienced in conducting such studies. Pertinent site information should include the following: ▪ Known bedrock characteristics (type, geologic contacts, faults, geologic structure, rock surface configuration) ▪ Soil characteristics (type, thickness, mapped unit) ▪ Bedrock outcrop areas	be less rigorous than that for karst areas or sites with shallow bedrock and groundwater. The investigation is designed to identify and confirm the soil characteristics and determine their suitability, if any, for infiltration practices.	boring. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of karst formations under the surface. This is an iterative process that might need to be repeated until the desired detailed knowledge of the site is obtained and fully understood. The data listed below should be acquired under the direct supervision of a qualified and experienced karst scientist. Pertinent site information to collect includes the following: ▪ Bedrock characteristics (ex. type, geologic contacts, faults, geologic structure, rock surface configuration) ▪ Depth to the water table and depth to bedrock ▪ Type and percent of coarse fragements ▪ Soil characteristics (ex. color, type, thickness, mapped unit, geologic source/history) ▪ Photo-geologic fracture trace map ▪ Bedrock outcrop areas ▪ Sinkholes and/or other closed depressions ▪ Perennial and/or intermittent streams, and their flow behavior (ex. a stream in a karst area that loses volume could be

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				a good indication of sinkhole infiltration)
Location of soil borings	Borings should be located in order to provide representative area coverage of the proposed BMP facilities. The location of borings should be: ▪ Within each distinct major soil type present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records. ▪ Next to bedrock outcrop areas and/or in areas with known shallow groundwater if present. ▪ Near the edges and center of the proposed practice and spaced at equal distances from one another. ▪ Near any areas identified as anomalies from any existing geophysical studies.	Borings should be located in order to provide representative area coverage of the proposed BMP facilities. The location of borings should be: ▪ Within each distinct major soil type present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records. ▪ Next to bedrock outcrop areas and/or in areas with known shallow groundwater if present. ▪ Near the edges and center of the proposed practice and spaced at equal distances from one another. ▪ Near any areas identified as anomalies from any existing geophysical studies.	Borings should be located in order to provide representative area coverage of the proposed BMP facilities. The location of borings should be: ▪ Within each distinct major soil type present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records. ▪ Near the edges and center of the proposed practice and spaced at equal distances from one another. ▪ Near any areas identified as anomalies from any existing geophysical studies.	The local variability typical of karst areas could mean that a very different subsurface could exist close by, perhaps as little as 6 inches away. To accommodate this variability, the number and type of borings must be carefully assessed. If the goal is to locate a boring down the center of a sinkhole, the previous geophysical tests or excavation results can show the likely single location to achieve that goal. If the goal is to "characterize" the entire site, then an evaluation needs to occur to determine the number and depth needed to adequately represent the site. Again, the analyst must acknowledge the extreme variability and recognize that details can easily be missed. Some general guidance for locating borings include: ▪ Getting at least 1 boring in each distinct major soil type present, as mapped by the MGS and USGS and local county records. ▪ Placing an adequate number as determined by a site investigation near on-site geologic or geomorphic indications of the presence of sinkholes or related karst features. ▪ Locating along photo-geologic fracture

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				traces. ▪ Locating adjacent to bedrock outcrop areas. ▪ Locating a sufficient number to adequately represent the area under any proposed stormwater facility. ▪ Documenting any areas identified as anomalies from any existing geophysical or other subsurface studies.
Number of soil borings	The number of recommended borings is described below. ▪ Infiltration trenches, bioretention, and filters - a minimum of 2 per practice. ▪ Ponds/wetlands - a minimum of 3 per practice, or 3 per acre, whichever is greater. ▪ Additional borings – as needed to define lateral extent of limiting horizons, or site specific conditions, where applicable.	The number of recommended borings is described below. ▪ Infiltration trenches, bioretention, and filters - a minimum of 2 per practice. ▪ Ponds/wetlands - a minimum of 3 per practice, or 3 per acre, whichever is greater. ▪ Additional borings – as needed to define lateral extent of limiting horizons, or site specific conditions, where applicable.	The number of recommended borings is described below. ▪ Infiltration trenches, bioretention, and filters - a minimum of 2 per practice. ▪ Ponds/wetlands - a minimum of 3 per practice, or 3 per acre, whichever is greater. ▪ Additional borings – as needed to define lateral extent of limiting horizons, or site specific conditions, where applicable.	The number and depth of borings will depend entirely upon the results of the subsurface evaluation obtained from the observational, geophysical, and excavation studies, as well as other borings. There are no prescriptive guidelines to determine the number and depth of borings. These will have to be determined by the qualified staff conducting the BMP management evaluation and will be based upon the data needs of the installation. The borings must extend well below the bottom elevation of the designed BMP, however, to make sure that there are no karst features that will be encountered or impacted as a result of the installation.

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Depth of soil borings	Borings should be extended to a minimum depth of 5 feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered.	Borings should be extended to a minimum depth of 5 feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered.	Borings should be extended to a minimum depth of 5 feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered.	The number and depth of borings will depend entirely upon the results of the subsurface evaluation obtained from the observational, geophysical, and excavation studies, as well as other borings. There are no prescriptive guidelines to determine the number and depth of borings. These will have to be determined by the qualified staff conducting the BMP management evaluation and will be based upon the data needs of the installation. The borings must extend well below the bottom elevation of the designed BMP, however, to make sure that there are no karst features that will be encountered or impacted as a result of the installation. At least 1 subsurface cross section should be provided for the BMP installation, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed installation, using the actual geophysical and boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data.
Identification of material	All material penetrated by the boring should be identified, as follows:	All material penetrated by the boring should be identified, as follows:	All material penetrated by the boring should be identified, as follows:	All material identified by the excavation and geophysical studies and penetrated by the boring should be identified, as follows:

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	• Provide descriptions, logging, and sampling for the entire depth of the boring. • Note any stains, odors, or other indications of environmental degradation. • Perform a laboratory analysis of a minimum of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. • Identify soil characteristic including, at a minimum: color; mineral composition; grain size, shape, and sorting; and saturation. • Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed (sticky	• Provide descriptions, logging, and sampling for the entire depth of the boring. • Note any stains, odors, or other indications of environmental degradation. • Perform a laboratory analysis of a minimum of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. • Identify soil characteristic including, at a minimum: color; mineral composition; grain size, shape, and sorting; and saturation. • Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed (sticky	• Provide descriptions, logging, and sampling for the entire depth of the boring. • Note any stains, odors, or other indications of environmental degradation. • Perform a laboratory analysis of a minimum of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. • Identify soil characteristic including, at a minimum: color; mineral composition; grain size, shape, and sorting; and saturation. • Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed (sticky clay soils typically found	• Provide descriptions, logging, and sampling for the entire depth of the boring. • Note any stains, odors, or other indications of environmental degradation. • Perform laboratory analysis on a of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. • Identify soil characteristics including, as a minimum: color; mineral composition; grain size, shape, sorting and degree of saturation. • Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed should be provided. Be aware that ground water levels in karst can change dramatically in short periods of time and will not necessarily leave mottled or gleyed evidence. • Record water levels in all borings over a time-period reflective of anticipated water level fluctuation. That is, water levels in karst geology can vary dramatically and rapidly. The boring should remain fully

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	clay soils typically found in waterlogged soils). ▪ Measure water levels in all borings at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements. ▪ Estimate soil engineering characteristics, including “N” or estimated unconfined compressive strength, when conducting a standard penetration test (SPT).	clay soils typically found in waterlogged soils). ▪ Measure water levels in all borings at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements. ▪ Estimate soil engineering characteristics, including “N” or estimated unconfined compressive strength, when conducting a standard penetration test (SPT).	in waterlogged soils). ▪ Measure water levels in all borings at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements.	open to a total depth reflective of these variations and over a time that will accurately show the variation. Be advised that to get a complete picture, this could be a long-term period. Measurements could of course be collected during a period of operation of a BMP, which could be adjusted based on the findings of the data collection. ▪ Report an estimation of soil engineering characteristics including “N” or estimated unconfined compressive strength, when conducting a SPT

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Evaluation of findings	At least 1 figure showing the subsurface soil profile cross section through the proposed practice should be provided, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed practice, using the actual or projected boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data.	At least 1 figure showing the subsurface soil profile cross section through the proposed practice should be provided, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed practice, using the actual or projected boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data.	NA	At least 1 figure showing the subsurface soil profile cross section through the proposed practice should be provided, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed practice, using the actual or projected boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data.
Infiltration rate testing	NA	NA	Soil permeability should be determined in the field using the following procedure (MDE, 2000), or an accepted alternative method (http://stormwater.pca.state.mn.us/index.php/Determining_soil_infiltration_rates). ▪ Install casing (solid 6-inch diameter) to 36 inches below proposed BMP bottom. ▪ Remove any smeared soiled surfaces and	NA

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			provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester's discretion, a 2 inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring. Fill casing with clean water to a depth of 36 inches and allow to pre-soak for up to 24 hours. ▪ Refill casing with another 36 inches of clean water and monitor water level (measured drop from the top of the casing) for 1 hour. Repeat this procedure (filling the casing each time) 3 additional times, for a total of 4 observations. Upon the tester's discretion, the final field rate may either be the average of the 4 observations,	

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			or the value of the last observation. The final rate should be reported in inches per hour. ▪ May be done through a boring or open excavation that is protected from access by the public. ▪ The location of the test should correspond to the BMP location. Upon completion of the testing, the casings should be immediately pulled, and the test pit should be back-filled.	

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Geophysical and dye techniques	NA	NA	NA	Stormwater managers in need of subsurface geophysical surveys are encouraged to obtain the services of a qualified geophysicist experienced in karst geology. Some of the geophysical techniques available for use in karst terrain include: seismic refraction, ground-penetrating radar, and electric resistivity. The surest way to determine the flow path of water in karst geology is to inject dye into the karst feature (sinkhole or fracture) and watch to see where it emerges, usually from a spring. The emergence of a known dye from a spring grants certainty to a suspicion that ground water moves in a particular pattern. Dye tracing can vary substantially in cost depending upon the local karst complexity, but it can be a reasonably priced alternative, especially when the certainty is needed.