Memorandum

To: MIDS Work Group

From: Barr Engineering Company

Subject: Identify Restrictions for MIDS Practices to Protect Groundwater and Prevent Sinkholes (Work Plan 3, Item 2; MIDS Subtask 2.3

Date: Draft Memorandum December 17, 2010; Final Memorandum June 9, 2011

Project: 23621050 MIDS

The information presented in this memorandum is intended to provide assistance for practitioners implementing low impact development techniques or Minimal Impact Design Standards (MIDS) in less than ideal situations. First and foremost, the memorandum will identify instances where MIDS practices may be restricted or not feasible. However, there is not necessarily a line which clearly defines when these practices may or may not be used for most of the situations identified. In order to facilitate this "gray" area, this document will attempt to acknowledge the pitfalls that may occur with the use of MIDS practices in sensitive environments and provide possible solutions.

There are six key restricted situations that are applicable for MIDS practices in Minnesota:

- Karst Topography,
- Very High and Very Low Infiltrating Soils,
- Shallow Bedrock,
- Shallow Confining Layer/Rough Terrain,
- Shallow Groundwater, and
- Potential Stormwater Hotspots (PSHs).

These restrictions do not cover every possible circumstance and proper engineering judgment will remain crucial for the success of any MIDS practice. This document is not intended to eliminate a MIDS practice for a particular sensitive area, but instead to encourage good decision making and prudence in these areas. The majority of information presented in this memorandum can be found in Chapter 14 of the 2008 Minnesota Stormwater Manual. However, supplementary sources have been included to provide a fresh look at some of these circumstances.

Introduction

Low Impact Development (LID) practices have proven to be an effective option for stormwater treatment and volume control (EPA 2000). However, the attributes which make them effective can also lead to problems in some situations. Many of the practices utilize infiltration as a means to control volume and

provide treatment, i.e., permeable pavements and bioretention cells. If not properly designed, these practices can be a means to directly convey stormwater pollutants into the groundwater and, in some situations, our surface waters. Identifying circumstances where the geological or pollutant characteristics may play a role in groundwater and/or surface water contamination is a key to the success of any MIDS practice.

MIDS practices are most effective when located as far upstream in a watershed as possible. In many situations they can be considered source controls. This idea of source control will be a recurring theme in this document when dealing with problematic circumstances.

The following sections of this memorandum discuss six key restrictive areas for MIDS practices: karst topography, very high and very low infiltrating soils, shallow bedrock, shallow confining layer/rough terrain, shallow groundwater, and PSHs. Appendix A includes flowcharts intended to assist designers of MIDS practices. The flowcharts do not cover every possible circumstance or requirement, but are meant to summarize significant points of this memorandum for designers to consider.

Karst Topography

Karst topography is a geological environment that is characterized by a distinctive landscape developed on highly soluble rocks and a unique drainage pattern (Ritter 2002). Sinkholes are common in this landscape and streams may disappear and reappear unpredictably. This landscape is formed through the dissolution of soluble rocks by water. Water flows into the various cracks and voids available in the limestone and slowly dissolves the rock. This weathering creates sporadic openings and fissures beneath the landscape. In Minnesota, karst topography is generally associated with the southeastern portion of the state. Figure 1 provides a map of the known karst features in Minnesota.

Because of the variable nature of karst topography, the design of best management practices (BMPs) in this environment can be challenging. In some locations, there may be significant topsoil available for the filtering, absorption, and biological degradation of pollutants (Florida 2010). In other locations, an open fissure may be close or even intercept with the surface landscape, providing a direct path for contaminants to the groundwater. Practices that involve ponding water can be a particular problem. The increased hydrostatic pressure created by the standing water may cause a failure of the surface material into underground cavities. The formation of these sinkholes can drain a stormwater pond quickly, discharging the untreated water directly to the groundwater.

The stormwater runoff rates and volumes from areas with karst features can differ significantly from the areas without karst features due to the additional surface runoff losses into bedrock from sinkholes,

crevices and caves. Karst loss is a term that has been given to describe the surface runoff loss into bedrock strata in areas with underlying limestone formation (Virginia 1999). When conducting hydrologic analyses for development sites with no direct connection between surface runoff and karst features (e.g., visible sinkholes or cavities), karst losses are generally not accounted. Runoff from such sites is typically minimal because infiltration is controlled by the soil between the ground surface and the underlying karst features. However, if it is necessary to evaluate pre-development runoff or accurately model runoff for a regional watershed, it may be appropriate to include representation of karst losses. Technical Bulletin 2 of the Virginia Department of Conservation and Recreation Stormwater Management Handbook provides further discussion on this topic, including a method to adjust predicted runoff rates to account for areas of underlying karst based on standard hydrologic modeling techniques.

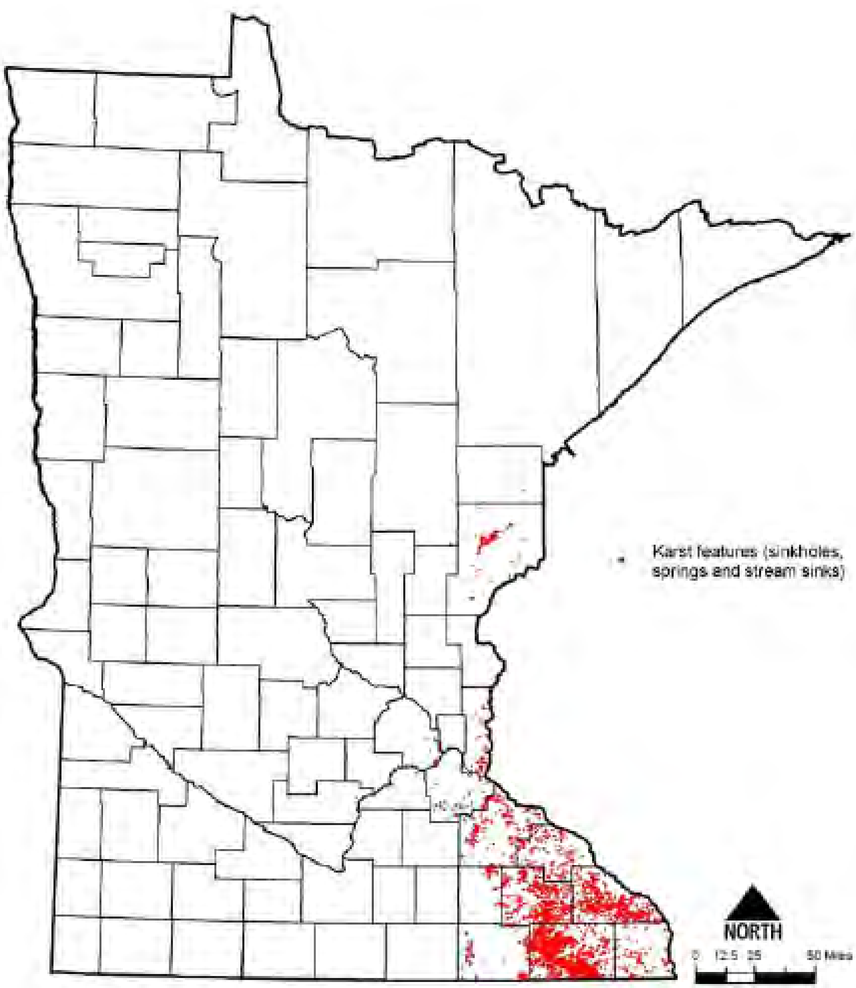


Figure 1. Minnesota's Known Karst Features, Source: MPCA 2008

Guidelines for the Use of MIDS Practices in Karst Terrain

The most important element in the design of any MIDS practice in karst terrain is sufficient investigation of the setting and site geology. Due to the highly variable nature of the terrain and the relatively small size of most MIDS practices, it is possible to be either entirely within or outside of karst terrain (Virginia 1999).

A preliminary, desktop investigation should be sufficient to identify the level of field study necessary. The preliminary investigation should include at minimum:

- Aerial photography (identification of sinkholes and erratic drainage patterns)

- Topographical maps
- County soil surveys
- County geologic atlases
- Local groundwater levels
- Speak with local landowners

The Minnesota Stormwater Manual divides karst terrain into three classifications: covered karst, transition karst, and active karst. Covered karst is defined as areas underlain by carbonate rock but with more than 100 feet of sediment cover. Transitional karst has 50 to 100 feet of sediment cover while active karst has less than 50 feet of sediment cover. If the location is identified as containing active karst, considerable care should be taken to accurately map the subsurface features. This can be done through borings, test trenches, seismic diffraction, ground penetrating radar, dye tracing, and electric resistivity (MPCA 2008). If a boring is conducted within the footprint of the BMP, it should be properly plugged to avoid direct contact with the groundwater (Florida 2010). It is important to note that while covered karst may not illicit great concern, its presence should prompt increased prudence due to the highly variable nature of karst. In areas identified as transitional, local discretion and the likelihood of karstic features will determine the level of detail necessary for geotechnical investigations (MPCA 2008).

Speaking with landowners or others knowledgeable about the site is a great way to learn about areas which contain sinkholes. If a sinkhole is identified, an easement or reserve area should be noted on the plans for future landowners (MPCA 2008). There is conflicting information about whether identified sinkholes should be remedied. Sinkholes can create a safety hazard if not remedied; however, filling a sinkhole can alter the subsurface hydrology, which can be very unpredictable (Virginia 1999). The Maryland Water Resource Management Manual recommends a three step approach to remediation: investigation, stabilization, and final grading. For smaller sinkholes, it may be possible to plug the hole with concrete and cover with several impermeable soil and geotextile layers and finish the surface with an impermeable layer and topsoil. Moderate sinkholes may require an engineered subsurface, while larger sinkholes may require a low-head berm (MPCA 2008) or other engineered solution. Prudence is important for sinkhole remediation in a karst landscape and should include the services of a qualified geologist specializing in karst. Plugging sinkholes with impermeable materials will eliminate the possibility for downward infiltration but could transfer the groundwater flow to another area that may have karst features. Stormwater management BMPs near plugged sinkholes, such as filtration practices, should attempt to mimic existing site hydrologic conditions and consider possible impacts of altering the subsurface hydrology.

Care should be taken when siting BMPs in active karst locations which require ponded water, such as stormwater ponds and wetlands. The increased hydrostatic pressure due to the ponded water may cause the collapse of the surface material into subsurface cavities (Florida 2010). Ponds and wetlands should include an impermeable liner, a minimum of three feet of fill between the BMP bottom and the bedrock, shallow water depths (less than 10 feet) (MPCA 2008), and inlet and outlets that diffuse the discharge of water (Virginia 1999). However, the use of an impermeable liner will no longer allow infiltration to occur, thus the pond or wetland can no longer provide volume reduction.

BMPs such as swales, bioretention, and vegetated filters that allow stormwater to soak into the soil and avoid concentrated flows can be appropriate for use in karst regions (MPCA 2008). Underdrains and/or an impermeable liner may be necessary for bioretention if contaminant levels remain high or water inflow presents a threat (MPCA 2008). Infiltration trenches and basins are typically not recommended in areas with active karst. In general, utilizing swales, bioretention, and vegetated filters for source control will allow for increased removal efficiencies, decreased chance for failure, and a lessened impact if failure does occur.

Very High and Very Low Infiltrating Soils

Soils play a pivotal role in the success or failure of most MIDS practices. Soils might have infiltration rates which are either too high or too low. Infiltration rates above 8.27 inches per hour (Virginia 1999) will infiltrate too quickly to provide the necessary time for filtration, absorption, and biological degradation necessary to properly treat the stormwater contaminants. Areas with high infiltration rates can be useful in providing stormwater volume reduction. However, it is important to know the pollutants that may be present in the stormwater being infiltrated. Infiltration rates below 0.2 inches per hour (MPCA 2008) are too slow to provide drainage for some infiltration practices in the required 48 hour time span and may clog easily.

Guidelines for Use of MIDS in Areas with Very High or Very Low Infiltrating Soils

Areas that have soils with too high or too low infiltration rates do not necessarily constitute elimination of implementing MIDS practices. Soils with low infiltration rates (soils in hydrologic soil group D) do still infiltrate stormwater, but installing basins on these sites would not always be practical because of the large, shallow areas required to meet required drain dry requirements. Bioretention basins can be constructed with under-drains for filtration and extended detention, and some infiltration will occur (Collins 2008). Likewise, media and vegetative filters can be a recommended practice for areas with low infiltration rates (MPCA 2008). Bioretention basins with under-drains in slow-draining soils are

essentially filters. They will provide water quality treatment and peak reduction, but will not provide volume reduction.

Constructed wetlands and wet ponds can also be used for contaminant treatment. The low infiltration rates of the soil will aid in maintaining a permanent pool. Practices that promote runoff reuse and evapo-transpiration are appropriate for volume control in areas with low infiltration capacity. These practices include: cisterns, rain barrels, green roofs, and evaporative systems (MPCA 2008).

The implementation of infiltration practices in areas with high infiltration rates will depend on the type of pollutant expected in the stormwater. In general, when treating stormwater for temperature, total nitrogen, and total phosphorus, slower rates are better (Hunt 2006). However, any rate is sufficient for treating total suspended solids, pathogens, and metals (Hunt 2006). The Potential Stormwater Hotspots section of this memorandum provides further information on MIDS design for areas of high pollutant loading.

As with design in karst terrains, proper implementation of MIDS practices in regions with soils having very high or very low infiltration rates requires accurate investigation. Desktop surveys can be conducted to identify the potential for slow draining soils. County soil surveys will provide enough information to determine whether Hydrologic Soil Group Class D soils are known to be present in the area. If Class D soils are known to exist in the area, detailed on-site soil surveys will be necessary. (It should be noted that on-site soil surveys will be necessary for any MIDS practice; however the level of detail will depend on the type of soils and practice).

Shallow Bedrock

Shallow bedrock is defined as locating within six feet of ground surface (MPCA 2008). For infiltration practices, sufficient soil depth is necessary for filtration, absorption, and bio-degradation of pollutants to occur (typically three feet minimum) (MPCA 2008). Many areas in Minnesota do not have the necessary soil depths to support practices requiring infiltration. The northeast portion of the state in particular is known for having a landscape with shallow bedrock. Figure 2 provides a map of Minnesota bedrock outcrops.

Bioretention and infiltration basins may not be feasible in these areas due to the lack of soil cover depth. If these practices are utilized and there is not the necessary media depth, pollutants can penetrate into cracks and move directly into the groundwater.

Due to the lack of necessary ponding depth, stormwater ponds and wetlands may also not be feasible in shallow bedrock areas. Underground detention and infiltration practices are challenging stormwater management practices in these areas as well due to the cost of installation in bedrock (MPCA 2008).

Installation cost is an important concern when considering MIDS practices in shallow bedrock areas. In order to achieve the necessary storage volume of these practices it may be necessary to blast the bedrock, which is an expensive process.

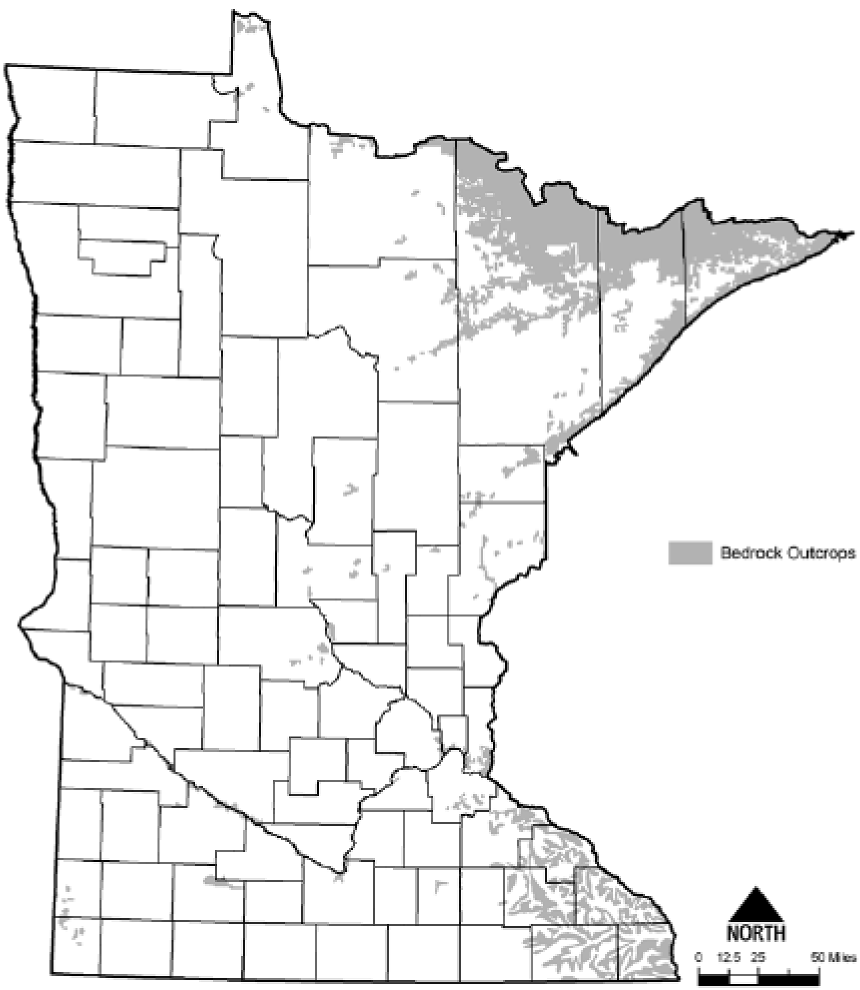


Figure 2. Minnesota Bedrock Outcrops, Source: MPCA 2008

Guidelines for the Use of MIDS in Areas of Shallow Bedrock

Areas with shallow bedrock create unique challenges for the implementation of MIDS practices. For bioretention practices, the necessary soil depth will vary depending on the pollutant being removed and the vegetation being installed. Hunt and Lord 2006 do not recommend a minimum media depth for total suspended solids (TSS) and pathogen removal, but do recommend a minimum media depth of 18 inches

for metal removal, 36 inches for temperature, 36 inches for total nitrogen removal, and 24 inches for total phosphorus removal. Necessary root depth of the plants being installed in a bioretention filter will also be a controlling factor in the media depth (Hunt 2006). For projects requiring a NPDES Construction Permit, the MPCA requires at least a three foot separation between the bottom of infiltration practices and the top of the bedrock (NPDES 2008).

Filters with an under-drain can be a recommended practice for areas with shallow bedrock (MPCA 2008). Similarly to installation in very high and very low infiltrating soils, these designs will not provide any volume reduction, only water quality treatment and peak reduction. Due to the lack of available depth, stormwater ponds may not be feasible in these landscapes. However, wetlands may be an option since they can perform well for pollutant removal with shallow water depths. These wetlands will require larger surface to drainage area ratios (MPCA 2008).

Sufficient geotechnical investigation of the subsurface material is necessary for the success of any MIDS practice. The investigation in an area of shallow bedrock should determine the nature and thickness of the subsurface material, including the depth to bedrock and water table (MPCA 2008). The data collected should include the bedrock characteristics (type, structure, faults, surface configuration), the soil characteristics, and identify the bedrock outcrop locations (MPCA 2008).

Shallow Confining Layer/Rough Terrain

The Decorah Edge, which is a shallow shale layer located in the southeastern portion of the state (near Rochester in Olmstead County), is another challenging environment for the infiltration of stormwater. Typically, water is infiltrated into the soil located above the impermeable shale layer. The water located in the upper aquifer is highly susceptible to contamination due to its proximity to the surface. This water moves along the impermeable shale layer until it encounters a hillside or break in the layer (Lee 2006). At these points water either moves back to the surface in the form of a wetland or continues infiltrating into the lower aquifer. An infiltration practice will be ineffective if it is located too near either the shale layer or a groundwater exit.

Rough terrain, i.e., steep topography, will add to the complexity of most MIDS practices. Ponds and wetlands built in rolling environments will typically involve the construction of a dam. Dams may require regulation, safety permits, and monitoring, which can increase costs. Dams that are six feet high or less, regardless of storage quantity, and dams that impound 15 acre-feet of water or less, regardless of the height, are exempt from the state dam safety rules. Dams which are less than 25 feet high and contain less than 50 acre-feet of water are also exempt, unless there may be loss of life if failure or misoperation were to occur (DNR 2010).

Guidelines for the Use of MIDS in Areas of a Shallow Confining Layer/Rough Terrain

Areas with a shallow confining layer contribute significantly to the groundwater recharge in areas such as the Decorah Edge. Thus, ensuring adequate treatment of stormwater pollutants before reaching the lower aquifer is very important. Maintaining adequate media depth in infiltration trenches and bioretention basins will ensure the water reaching the aquifers is clear of contaminants. In addition, ponds and wetlands may need to be lined to ensure leaching of pollutants does not occur in areas where the base of the BMP is close to the confining layer and/or the edge of the confining layer, i.e., a hillside.

Shallow Groundwater

Minnesota has greater than 50% of its land within areas of shallow groundwater (water table located less than three feet from the land surface) (MPCA). The issues involved with implementation of MIDS practices in areas with shallow groundwater are similar to those identified earlier, most notably, pollutant intercept with the groundwater before adequate treatment. Figure 3 is a map providing an estimate of Minnesota wetlands circa 1860 based on a study of hydric soils (DNR 1997). The map is originally attributed to Jeffrey Anderson and William Craig, "Growing Energy Crops on Minnesota's Wetlands: The Land Use Perspective". Hydric soils and wetlands can be an indication of shallow water table or the presence of a shallow water table at some time.

Special consideration is also needed for infiltration practices that may contribute to recharge of nearby wetlands and/or fens. In areas of shallow groundwater, it is possible for wetland recharge to occur without treatment if the infiltration practice is located too close to the wetland and in direct contact with groundwater. Calcareous fens, which may have a significant number of rare or endangered plant species, could be adversely affected by the pollutants present in stormwater. On the opposite side of the spectrum, if an infiltration BMP was designed appropriately, and was contributing to the groundwater recharge of a calcareous fen, regulators may want to give credit for that particular BMP.

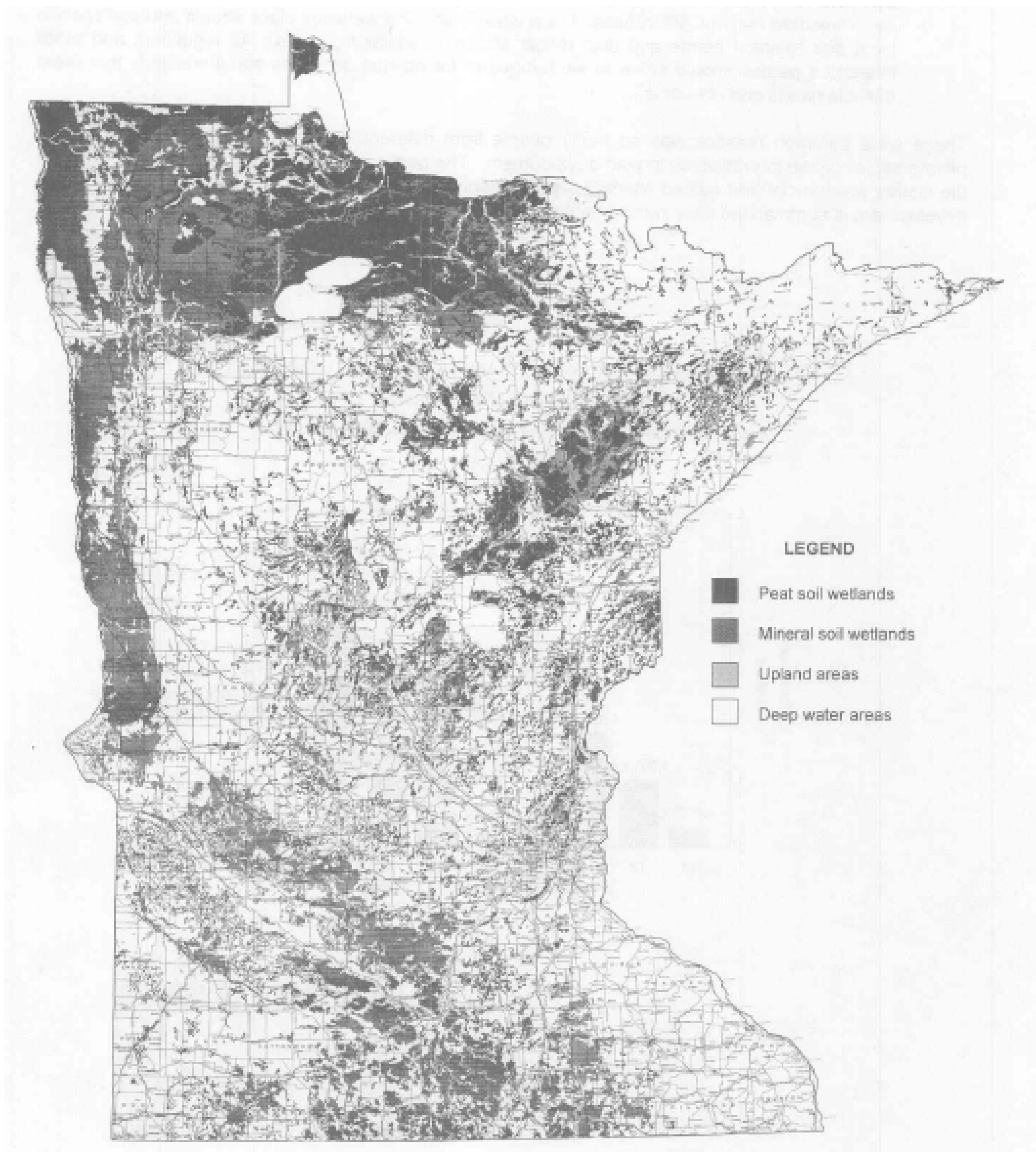


Figure 3. Estimate of Minnesota Wetlands Circa 1860's, Source: Minnesota Wetlands Conservation Plan 1997

Guidelines for the Use of MIDS in Areas with Shallow Groundwater

Minimizing the interaction of contaminants with groundwater is the challenge with any MIDS practice located in areas of shallow water table. For projects requiring a NPDES Construction permit, the MPCA requires a minimum of three feet of separation from the bottom of bioretention basins, infiltration basins, and infiltration trenches to the top of the seasonally saturated soils (NPDES 2008). These BMPs utilize this depth to treat the stormwater using filtration, absorption, and biological degradation. The soils need to be aerated so they can perform the biological and microbial treatment (MPCA 2008). As discussed in the shallow bedrock section of this memorandum, Hunt and Lord 2006 do not recommend a minimum media depth for TSS and pathogen removal, but do recommend a minimum depth of 18 inches for metal removal, 36 inches for temperature, 36 inches for total nitrogen removal, and 24 inches for total phosphorus removal. Necessary root depth of the plants being installed in a bioretention filter will also be a controlling factor in the media depth.

The design of ponds or wetlands installed in areas of shallow groundwater tables will require unique treatment depending on the potential contaminants being treated. Ponds and wetlands can intercept the groundwater table. Ponds and wetlands treat stormwater contaminants through settling and, if the retention is long enough, through biological processes (MPCA 2008). This is in contrast to practices employing infiltration which require filtration through an aerated media. However, if a stormwater hotspot is identified as a stormwater source an impermeable liner is recommended for the pond or wetland. The liner will reduce the concern of contaminant leaching to groundwater; however, stormwater volume reduction will not be achieved through use of this BMP.

Potential Stormwater Hotspots (PSHs)

Potential Stormwater Hotspots (PSHs) are sensitive areas which are anthropogenic in nature as opposed to the geological characteristics of the previously identified sensitive areas. PSHs are land uses which may produce high levels of contaminants. These land uses include commercial, industrial, institutional, municipal, and transportation operations. Whether a PSH is designated a “hotspot” will depend on the particular site, i.e., landowner practices, level of production. Designation as a PSH is merely a reminder to designers and reviewers that more careful consideration of a site is necessary (MPCA 2008). MIDS practices may not effectively treat stormwater contaminants in these areas due to elevated concentration levels or the use of pollutants not normally present in stormwater.

Examples of pollutant generating activities include vehicle operations (maintenance, repair, fueling), materials (salt and sand storage), waste management (dumpsters and landfills), physical plant practices (clean, maintain, or repair plants), turf and landscaping (fertilizers, pesticides, irrigation), and other

unique sources (hobby farms, racetracks, septic systems). The treatment of stormwater runoff associated with some of these examples by MIDS practices can cause degradation of our groundwater and/or surface water.

As infiltration practices become more prevalent, academic studies have begun to focus on their relationship with our groundwater. Pitt et al. 1999, in a study sponsored by the EPA, noted that reported instances of groundwater contamination associated with stormwater was rare where infiltration occurred through surface soils. However, groundwater contamination was more common in commercial and industrial locations which utilized subsurface infiltration practices. Pitt et al. noted that the contaminants of greatest concern for groundwater included nutrients, other organics (i.e. Volatile Organic Carbons), pathogens, heavy metals, and salts. Weiss et al. 2008 conducted a literature review of the potential for groundwater contamination by infiltration practices. Similarly to the Pitt study, Weiss found that contamination due to infiltration practices is a real concern; however, they went one step further and challenged practitioners to also consider the risk of “status quo” methods, i.e. discharging to surface water bodies.

Septic systems operate on similar principles as stormwater infiltration practices. Due to groundwater contamination, they have received significant attention. In 1985, septic systems contributed the largest volume of wastewater to the subsurface, 800 billion gallons per year, and are the most frequently reported cause for groundwater contamination disease outbreaks (Yates 1985). A more recent study in 1998 conducted by the MPCA in Baxter, Minnesota found significantly higher levels of median nitrate concentrations in areas with septic systems as compared to areas with municipal sanitary sewer (GWMAP 1999). All of the subsurface drinking water criteria exceedances were found in areas without municipal sanitary sewers. The Baxter area has a sensitive aquifer which in some cases intercepts with nearby surface waters, providing a direct path for pollutants to the surface waters. A significant difference to MIDS stormwater management practices is that septic systems located in areas with shallow bedrock or groundwater tables will typically be mounded. In this circumstance, a pump is required to raise the sewage from the cesspool to the drain field, which is located at or near the surface.

The introduction of pollutants to the groundwater through the use of infiltration practices for both stormwater treatment and septic systems raises concerns due to three main reasons: groundwater contamination is hard to detect immediately, groundwater contamination poses an immediate public health threat, and mitigation of groundwater contamination is difficult and expensive (MPCA 2008)

Guidelines for the use of MIDS in areas of Potential Stormwater Hotspots

Application and design of MIDS in areas which may involve potential stormwater hotspots will be dependent on the type of contaminant and its expected concentration. Thus, a proper understanding of the current and future uses of a site is crucial for the selection, siting, design, and maintenance of structural and non-structural BMPs.

Due to the wide variability in contaminants and the risk associated with treating these contaminants at a PSH, the most cost effective treatment option is source control through non-structural BMPs (MPCA 2008). To employ non-structural BMPs for pollution prevention and source control the designer must have a thorough knowledge of the site layout and uses. Important site considerations include (MPCA 2008):

- Providing a detailed map of site areas and uses,
- Separation of hotspot and non-hotspot activities,
- Prevention or confinement of drips and spills,
- Enclose or cover pollutant generating activities, provide spill prevention and clean-up equipment at specific locations,
- Provide pre-treatment and spill containment measures at necessary locations,
- Maintain equipment to minimize leaks, and
- Train and educate employees on minimizing pollutant loss to stormwater

All of these non-structural BMPs and practices will require coordination with the site users for them to be successful.

Once all of the potential non-structural BMPs are employed, the structural BMPs can be designed. Structural BMP design for sites designated as PSHs will require careful consideration of the pollutant characteristics and the receiving water and watershed designation, keeping in mind those structural BMPs which can be designated as source control will provide the greatest pollutant removal efficiencies. Notable considerations for structural BMP design at PSHs include (MPCA 2008):

- Treat the clean and dirty runoff separately,
- Infiltrate only the cleanest runoff,
- Pre-treat to greatly improve the lifespan of BMPs and protect receiving waters,
- Consider closed systems with liners because they are safer than infiltration practices for treatment purposes,
- Locate practices offline and minimize offsite run-on to reduce treatment volumes,

- Conduct timely maintenance and inspections to ensure the success of the BMP, and
- Overdesign the BMP to account for pollutant accumulation.

As noted in the previous section, infiltration practices with their direct tie to groundwater are of great concern in areas of PSHs. The Virginia Stormwater Manual does not suggest infiltration where high levels of sediment, grease, or oil loadings are present without pretreatment to prevent clogging. Infiltration of stormwater from turf areas, roofs, parking lots, and roadways is possible, however pre-treatment is essential and co-mingling of runoff from other higher pollutant loading areas should not occur. Infiltration is not typically recommended for areas associated with waste and material storage, loading docks, and fueling areas without spill containment and redundant treatment.

Miscellaneous Considerations and Restrictions

As with the previously discussed restrictions, proper BMP design and selection is necessary for successful stormwater management. The designer should observe state and local regulations, including wellhead protection zones and minimum setbacks. The Minnesota Department of Health recommends that infiltration should not be used within the one-year wellhead protection area and limited in vulnerable wells for the 10-year protection area (MPCA 2008). Minnesota Rule 4725.4350 requires a 50 foot setback between stormwater ponds and water supply wells, and if not otherwise regulated, a similar 50 foot setback for infiltration BMPs is advisable (MPCA 2008).

For sites with existing contaminated soils, the designer should consult with the MPCA to determine the appropriate BMP.

Application of Sensitive Areas Analysis to MIDS

MIDS practices have the potential to aid municipalities in the goal to reduce pollutant discharge into surface waters, reduce costs associated with stormwater conveyance and treatment, and achieve native runoff volumes. However, the very nature of the design that allows MIDS to achieve these goals also can lead to groundwater and surface water pollution in sensitive locations. MIDS practices utilize infiltration as a means of treatment and volume control, which can directly transport pollutants into the ground and surface waters in areas of shallow water tables, shallow bedrock, shallow confining layers and karst locations. The utilization of non-structural BMPs, source control, frequent maintenance, and proper engineering judgment can allow for their safe use. Thorough site and subsurface analysis will greatly aid the creation of a safe, effective design.

This memorandum is not meant to be exhaustive. In all circumstances, it is important to identify the risks associated with failure of the BMP and those associated with doing nothing or implementation of status quo methods.

References

Bureau of Resource Management. May 2007. Water Resource Management Manual, Carroll County, Maryland

Collins, Kelly, Allen Davis, Chris Kloss, Tom Simpson, Sarah Weammert. 2010. Infiltration and Filtration Practices, Definition and Nutrient and Sediment Reduction Effectiveness Estimates. Chesapeake Bay Program Nutrient Subcommittee and its Workgroups.

Environmental Protection Agency. 2000. Low Impact Development (LID), A Literature Review. Washington, DC.

Florida Department of Environmental Protection and Water Management Districts. 2010. Stormwater Quality Handbook Draft.

Ground Water Monitoring and Assessment Program (GWMAP). 1999. Effects of Septic Systems on Ground Water Quality – Baxter, Minnesota. Minnesota Pollution Control Agency. St. Paul, MN.

Hunt, William, William Lord. 2006. Urban Waterways, Bioretention Performance, Design, Construction, and Maintenance. North Carolina Cooperative Extension Service

Lee, Terry. 2006. The Decorah Edge: A Critical Water Supply Component, Olmstead Count, MN, Presentation

Minnesota Department of Natural Resources (DNR), Website. Accessed December 2010. http://www.dnr.state.mn.us/waters/surfacewater_section/damsafety/safety.html

Minnesota Department of Natural Resources (DNR). 1997. Minnesota Wetlands Conservation Plan. Version 1.0. St. Paul, MN

Minnesota Pollution Control Agency (MPCA). 2008. Minnesota Stormwater Manual, Version 2.

National Pollution Discharge Elimination System (NPDES). 2008. General Stormwater Permit for Construction Activity. Permit Number MN R 100001. Issued August 1, 2008

Pitt, Robert, Shirley Clark, Richard Field. 1999. Ground water Contamination Potential from Stormwater Infiltration Practices. Urban Water. Vol. 1, (1999), pp. 217-236.

Ritter, Dale F., R. Craig Kochel, Jerry R. Miller. 2002. Process Geomorphology. McGraw-Hill, New York, NY.

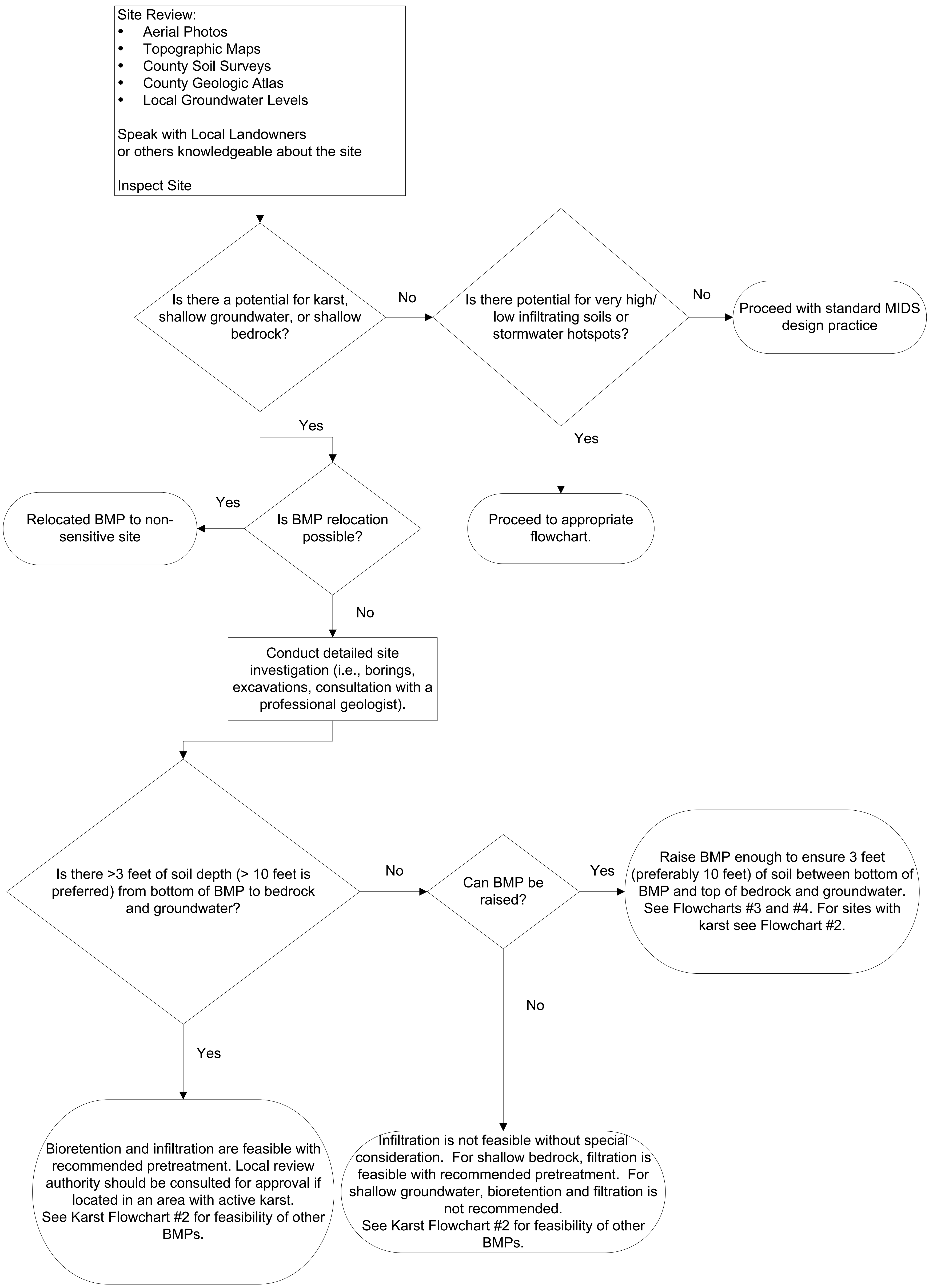
Virginia Department of Conservation and Recreation. 1999. Stormwater Management Handbook.

Weiss, Peter T., Greg LeFevre, John Gulliver. 2008. Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices: A Literature Review. St. Anthony Falls Laboratory Project Report #515. Minneapolis, MN.

Yates, Marylynn V. 1985. Septic Tank Density and Ground-Water Contamination. Ground Water. Vol. 23, No. 5, Sept.-Oct., pp. 586-591.

Appendix

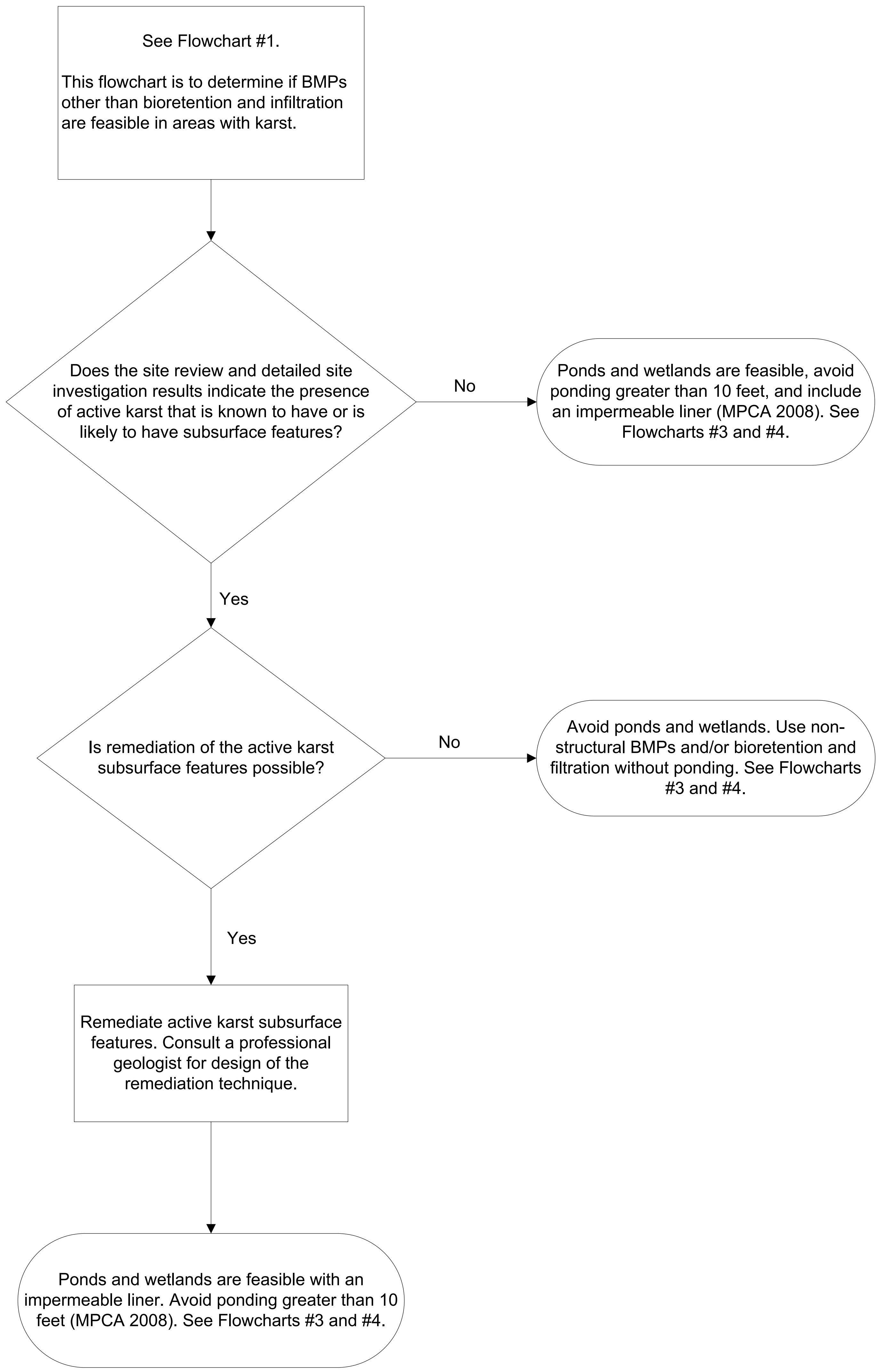
Overall BMP Decision Considerations



Note: This flowchart is not all-inclusive, nor does it include all of the caveats of specific sites.

Figure A.1
FLOWCHART #1
Overall BMP Decision Considerations

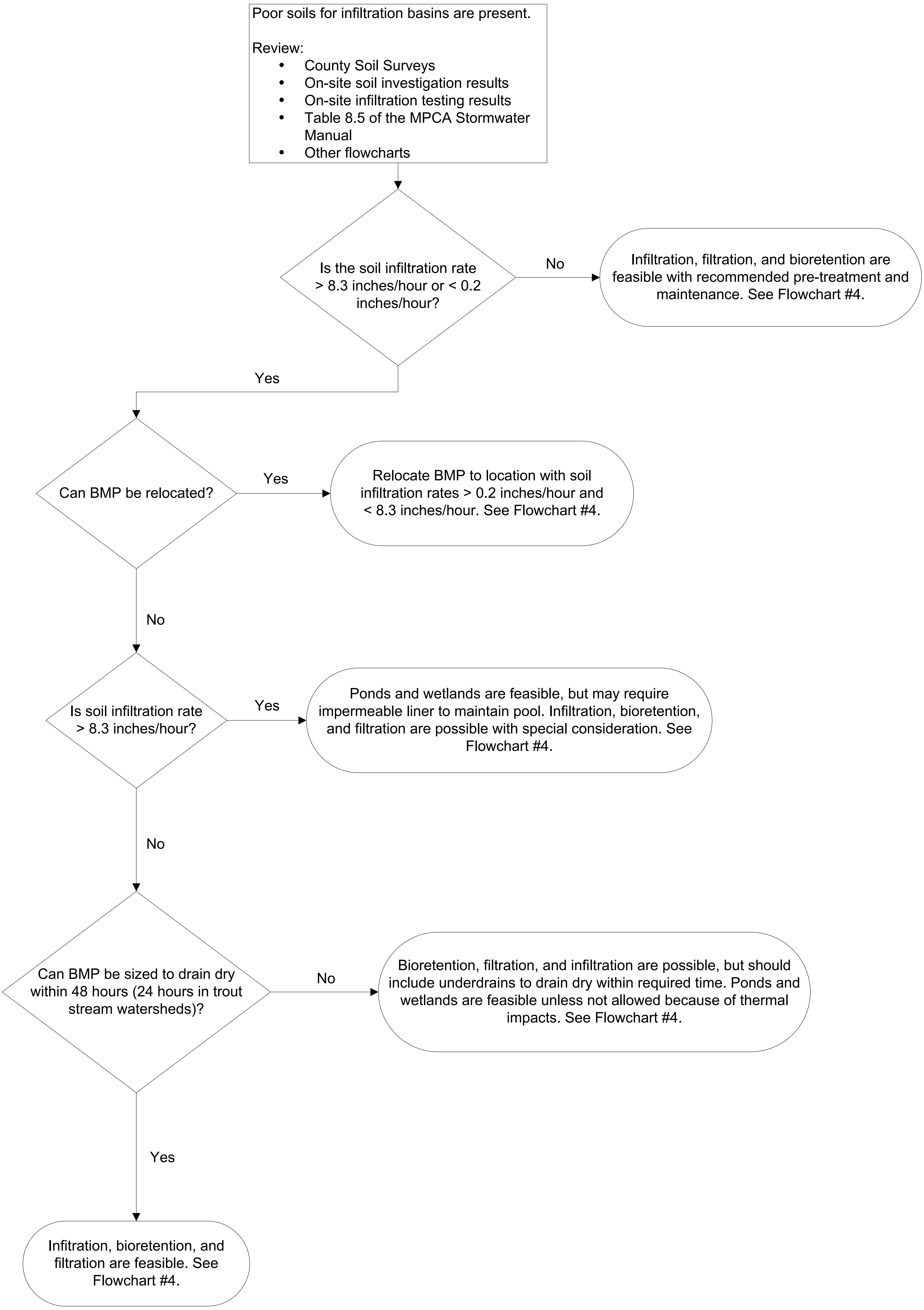
Pond and Wetland BMP Considerations for Sites with Karst



Note: This flowchart is not all-inclusive, nor does it include all of the caveats of specific sites.

Figure A.2
FLOWCHART #2
Pond and Wetland BMP Considerations for Sites with Karst

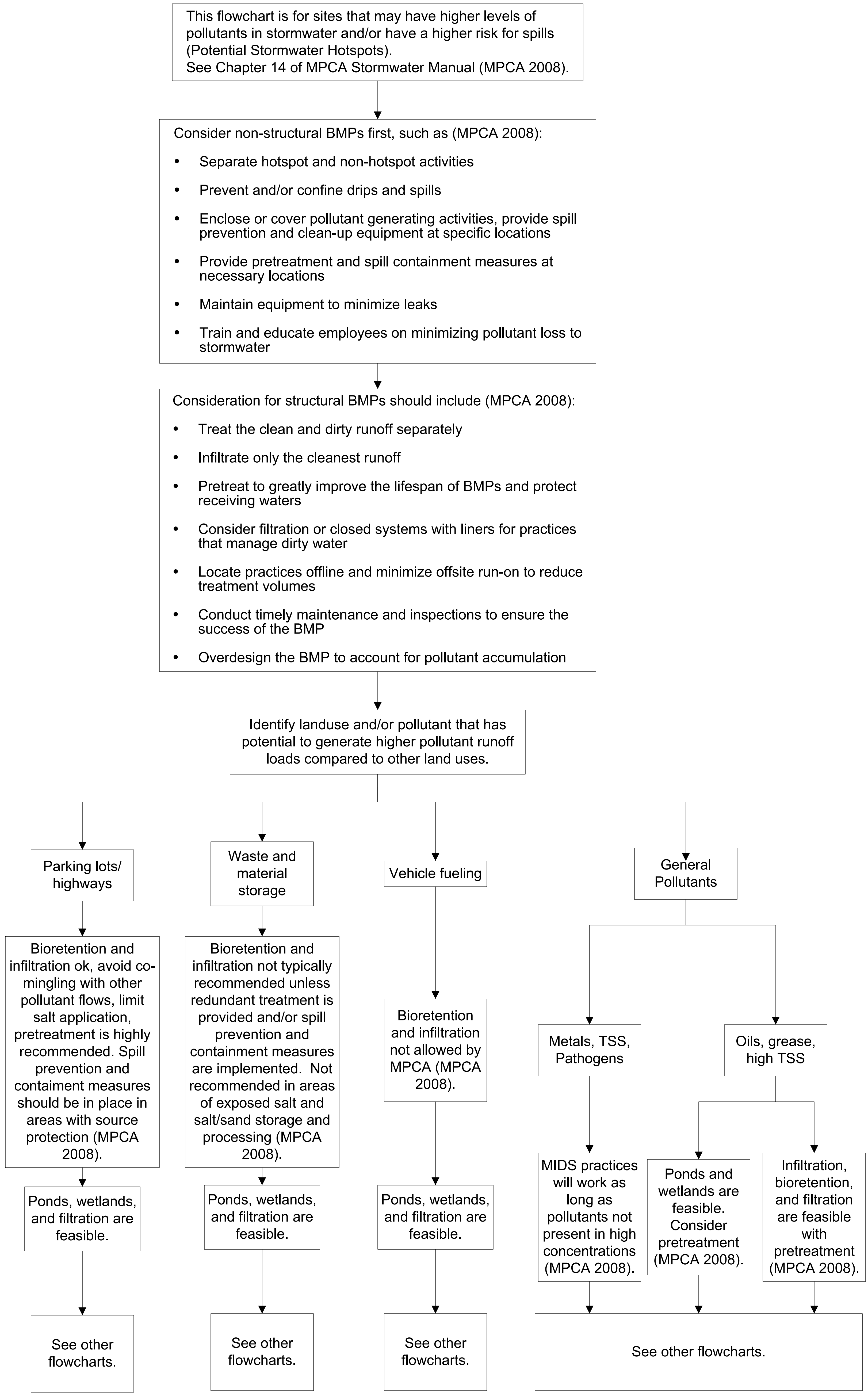
BMP Decision Considerations for Sites with Soils having Very High and Very Low Infiltration Rates



Note: This flowchart is not all-inclusive, nor does it include all of the caveats of specific sites.

Figure A.3
FLOWCHART #3
BMP Decision Considerations for Sites with Soils having Very High and Very Low Infiltration Rates

Considerations for BMPs in Potential Stormwater Hotspots



Note: This flowchart is not all-inclusive, nor does it include all of the caveats of specific sites.

Figure A.4
FLOWCHART #4
Considerations for BMPs in Potential Stormwater Hotspots