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Figure 107.1 Sinkhole Collapse Stabilization

SECTION 107 - SINKHOLES AND KARST FEATURES

107.1 GENERAL

Greene County is located on the Springfield Plateau of the Ozarks physiographic region. This area is underlain by Mississippian Age limestone which is highly susceptible to solutional weathering. As a result, sinkholes, springs and caves are common.

In many areas of Greene County, special consideration must be given to flood hazards and potential for groundwater contamination due to the presence of sinkholes, caves, losing streams, springs, and other features associated with karst geology.

General standards and restrictions for sinkholes are set forth in Article IV, Section 28 "Sinkhole Use Standards" of the Greene County Zoning Regulations.

The requirements set forth herein are intended to provide specific criteria for design and construction for any site upon which sinkholes or other karst features are located.

107.2 POLICY

In keeping with the intent of Article IV Section 28 of the Zoning Regulations, this policy is set forth for development in areas containing sinkholes. Development in sinkhole areas will be based upon the following approach:

- 1. Avoidance**
- 2. Minimization**
- 3. Mitigation**

Construction in sinkholes shall be avoided. Exceptions will be made only in situations where it can be conclusively demonstrated that there are no practical alternatives to such construction.

In these cases, measures which will have minimal impact on the sinkhole or receiving water may be proposed. Plans for minimal alteration can be approved provided it is conclusively demonstrated that the proposed plan is the minimum practical alternative.

Potential impacts of construction on the sinkhole and receiving waters must be studied and assessed, and recommendations made for mitigation of potential impacts upon flooding, structural stability, and groundwater quality before the development plan can be approved. The degree and sophistication of study required will increase in proportion to the potential impacts.

107.3 DEFINITIONS

1. Sinkhole: Any depression in the surface of the ground, with or without collapse of adjacent rock, that provides a means through which surface water can come into contact with subsurface water (Article IV, Section 28 of the Zoning Regulations).

Sinkhole depressions may be gradual or abrupt; they may or may not have a well defined eye. While most sinkholes can be defined as the area within a "closed contour", some sinkholes, such as as those located on the sides of hills and in stream valleys, may not. All sinkholes provide discreet points of recharge to groundwater.

2. Sinkhole Watershed: The ground surface area that provides drainage to the sinkhole. This area extends beyond the sinkhole depression and generally crosses property boundaries.

3. Virgin Sinkhole: A sinkhole which has never been altered or disturbed.
4. Altered Sinkhole: A sinkhole which has been filled, excavated or otherwise disturbed.
5. Collapsed Sinkhole: A subsidence or cave-in of the ground surface caused when soil overburden can no longer be supported by underlying strata due to the presence of subsurface solution cavities.
6. Sinkhole Eye: Generally, a visible opening, cavity or cave in the bottom of a sinkhole, sometimes referred to as a swallow hole.
7. Sinkhole Rim: The perimeter of the sinkhole depression. The sinkhole rim will generally vary in elevation.
8. Sinkhole Cluster Area: An area containing two (2) or more sinkholes located in close proximity, generally interconnected by groundwater conduits.
9. Terminal Sinkhole: The lowest sinkhole in a sinkhole cluster to which any surface water overflowing from other sinkholes in the cluster will flow.
10. Sinkhole Flooding Area: The area inundated by runoff from a storm with an annual exceedance probability of one percent (1%) and a duration of twenty-four (24) hours (eight inches (8") in Greene County).
11. Qualified Geologist: A person registered to practice geology according to the laws of the State of Missouri, and who by reason of technical education and experience has a background in the fundamentals of storm drainage and karst geology.
12. Qualified Professional Engineer: A person registered to practice engineering according to the laws of the State of Missouri, and who by reason of technical education and experience has a background in the fundamentals of storm drainage and karst geology.
13. Heavy Equipment: Motorized equipment having a gross weight of more than six (6) tons.
14. Light Equipment: Motorized equipment weighing six (6) tons or less.

107.4 PERMITS REQUIRED

107.4.1 Grading Permit

A grading permit must be obtained prior to any alteration of sinkholes. Grading permit requirements are set forth in Article IV, Section 28 of the Zoning Regulations and in Section 114.3 of these Design Standards.

107.4.2 Other Permits

Other County, State or Federal may be required as outlined in Section 101 of these Design Standards, depending upon the size and nature of the proposed activity.

Some sinkholes are designated as Special Flood Hazard Areas (SFHA's) on the Flood Insurance Rate Maps (FIRM) for Greene County. A floodplain development permit must also be obtained for any development in these areas, in accordance with the requirements set forth in Article XIX of the Zoning Regulations.

107.5 GENERAL PLAN REQUIREMENTS

General requirements for showing sinkholes and karst features on sketch plans and preliminary and final plats are set forth in Article IV of the Subdivision Regulations.

General requirements for grading and drainage plans are set forth on Sections 103 and 114 of these Design Standards.

107.6 SINKHOLE EVALUATION REPORT

A written evaluation including the following information shall be made for all development sites upon which sinkholes are fully or partially located. The sinkhole evaluation report must include the following items:

1. Site Plan.
2. Area Map.
3. Flooding Evaluation (Section 107.7).
4. Water Quality Evaluation (Section 107.8).

107.6.1 Site Plan

The site plan shall meet the requirements of Section 103. In addition, the site plan must show the following items with respect to location of proposed construction, proposed or existing property lines, and existing structures:

A. Sinkholes

- 1) Location and limits of the area of the sinkhole depression as determined by field surveys or other reliable and accurate methods.

Location of sinkholes based solely upon USGS 7-1/2 Minute Series Quadrangle Maps will not be considered sufficient unless field verified.

- 2) Location and elevation of the sinkhole eye or low point.

3) Topographic contours at maximum intervals of two feet (2'), and spot elevations sufficient to determine the low point on the sinkhole rim and the profile of the potential overflow area.

Larger contour intervals may be used if deemed sufficiently accurate to define the sinkhole rim and volume.

4) Minimum elevation at which floodwaters can gain entry to any existing structures located within or on the sinkhole rim.

5) Elevation of any roadway located within or adjacent to the sinkhole.

B. Other Geologic Features

Location of caves, springs, faults, fracture trends, and geologic mapping units, based upon information from the Greene County Resource Management Department or other reliable sources.

C. Sinkhole flooding area determined as set forth in Section 107.7.

D. Existing watercourses, storm sewers or culverts which drain into the sinkhole.

E. Proposed discharge points: The location type and size of all points at which concentrated discharges of stormwater into the sinkhole are proposed. The drainage area to each point of concentrated discharge shall be delineated on the plan and the size of drainage area noted.

F. Existing and proposed wells or other water supply sources.

107.6.2 Area Map

An area map showing the sinkhole watershed area must be provided. Where the site is located in a sinkhole cluster area, the map area shall be extended to include in the watershed area any sinkholes located downstream of the site which may receive overflow drainage from the site. Requirements for drainage area maps are set forth in Section 104.

The approximate location of public or private water supply sources such as springs or wells within five hundred feet (500') of the site, and boundaries of any known recharge areas to wells, springs, or caves as determined from information available from the Greene County Resource Management Department, Watershed Committee of the Ozarks, Missouri Department of Natural Resources, Missouri Department of Conservation, or other reliable sources shall be shown.

107.7 FLOODING EVALUATION

Maximum estimated flooding elevations shall be determined for each sinkhole for both pre-project and post-project conditions, assuming no subsurface outflow from the sinkhole.

107.7.1 Runoff Volume

The volume of runoff considered shall be that which results from a rainstorm with an annual exceedance probability (AEP) of one percent (1%) (100-year storm) and a duration of twenty-four (24) hours (eight inches (8") for Greene County). The runoff volume shall be determined by the method set forth in Chapter 2 of the SCS TR-55 Manual (Reference 107.1).

107.7.2 Sinkhole Flooding Area

For sinkholes whose tributary drainage area is small enough that it is unlikely the entire sinkhole would flood, the sinkhole flooding area can be conservatively estimated as the area below the low point on the sinkhole rim without further analysis.

Where the estimated volume of runoff exceeds the volume of the sinkhole depression, the depth of overflow shall be estimated and the sinkhole flooding area can be estimated as the area below the maximum flooding elevation. Where the volume of the sinkhole is sufficiently large that storage in the sinkhole depression will materially affect estimated outflow rates, reservoir routing can be performed, if desired, to determine the maximum flood stage in the sinkhole.

In sinkhole cluster areas, the overflow volume shall be included in determining the maximum estimated flooding elevations in the next downstream sinkhole. This analysis shall continue downstream until the lowest sinkhole of the sinkhole cluster is reached or overflow reaches a surface watercourse.

107.7.3 Flooding Considerations

No further flooding analysis will be required provided that the post-project flooding area of any sinkhole which receives drainage from the site is located entirely on the development site.

Where the post-project sinkhole flooding area is not entirely located on the development site, a detailed flooding analysis as set forth in Section 107.7.4 will be required, unless:

- 1) the post-project flooding elevation is no more than one foot (1') higher than the pre-project flooding elevation and the minimum elevation at which floodwaters can gain entry to any existing structures is at least one foot (1') higher than the post-project flooding elevation. Where several properties drain to the sinkhole, the amount of increase allowed will be proportioned on the basis of the area of the development site versus the area of the watershed tributary to the sinkhole; and the increase in volume of runoff from the site does not cause the flooding depth on any existing public road to exceed the maximum depths set forth in Section 108; or,
- 2) the minimum elevation at which floodwaters can gain entry to any existing structures is at least one foot (1') higher than the post-project flooding elevation and a drainage easement covering the post-project flooding area is provided for any off-site sinkhole or portion of a sinkhole which receives increased peak rates of runoff from the site. If the receiving sinkhole is not contiguous to the site, an easement must also be provided for the waterway which connects

the site to the sinkhole; and the increase in volume of runoff from the site does not cause the flooding depth on any existing public road to exceed the maximum depths set forth in Section 108.

107.7.4 Detailed Flooding Analysis

In cases where the conditions set forth in Section 107.7.3 cannot be met, detention basins must be constructed outside of the sinkhole flooding area. The detention facility must have sufficient volume to store the increase in total runoff volume due to the development. Outflow rates cannot exceed pre-project values. Detention basins must be designed as set forth in Section 112.

107.7.5 Diversion to Surface Watercourse

As an alternative, where feasible, increased post-project runoff may be diverted to a surface watercourse, provided that

- 1) any increase in peak runoff rate in the receiving watercourse does not create or worsen existing flooding problems downstream; and
- 2) the diverted stormwater remains in the same surface watershed.

Storm sewers, open channels, and other appurtenances provided for diversions shall be designed in accordance with applicable sections of these Design Standards.

The effect of diverted water on downstream watercourses and developments, and requirements for additional detention facilities prior to release of runoff to the surface watercourses shall be determined as set forth in Section 112.

Effects of the diversion shall be shown by reservoir routing analysis. Routing of excess runoff shall be considered satisfactory when it can be demonstrated that the post-project flooding elevation in the sinkhole is at least one foot (1') below the minimum elevation at which floodwaters can gain entry to any existing structures and does not exceed the pre-project flooding elevation by more than one foot (1') in any case.

107.8 WATER QUALITY CONSIDERATIONS

Sinkholes provide direct recharge routes to groundwater. As a result, water quality in wells, caves, and springs may be affected by discharge of runoff from developed areas.

The Sinkhole Evaluation Report must consider potential impacts of the proposed construction on receiving groundwaters as well as the possible impacts of sediment from construction sites on the sinkhole and propose measures to mitigate such impacts.

With regard to groundwater quality, three (3) factors must be considered:

1. Receiving groundwater use.
2. Relative groundwater contamination hazard associated with the proposed development.
3. Water quality management measures to reduce pollutant levels.

107.8.1 Receiving Groundwater Use

The Sinkhole Evaluation Report shall identify whether the site lies within a critical area based upon information available from the Resource Management Department or other reliable sources.

Where disagreements may arise over whether a site is located within a particular recharge area, dye tracing may be required for confirmation of the destination of water discharged through the sinkhole.

A. Critical Areas

The following areas are classified as critically sensitive to contamination from urban runoff:

1. Areas with one hundred feet (100') of private water supply wells.
2. Areas with three hundred feet (300') of public water supply wells.
3. Areas within five hundred feet (500') of springs used for public or private water supply.
4. Areas within one thousand feet (1000') of caves providing habitat to rare or endangered species such as the Ozark cavefish.

The distances listed above may be extended in any instance where the recharge area for a well, spring, or cave has been determined by studies by a qualified engineer or geologist and approved by the Stormwater Engineer.

B. Sensitive Areas

All other sinkhole areas will be classified as sensitive for groundwater contamination.

107.8.2 Groundwater Contamination Hazard

The relative potential for groundwater contamination will be classified as moderate, high or very high, depending upon the type of land use, development density, and amount of directly connected impervious area.

A. Moderate Hazard

The following land uses are classified as posing a moderate hazard for groundwater contamination:

1. Residential developments on sewer (Zoning Districts R-1 and R-2), provided directly connected impervious areas discharging to the sinkhole is less than one (1) acre.
2. Parks and recreation areas.
3. Low density commercial and office developments (Zoning Districts C-1, C-3, and O-1) provided directly connected impervious areas discharging to the sinkhole is less than one (1) acre.
4. Discharge from land disturbance areas less than one (1) acre.

B. High Hazard

The following land uses are classified as posing a high hazard for groundwater contamination:

1. Concentrated discharge from streets, parking lots, roofs and other directly connected impervious areas having an area greater than one (1) acre and less than five (5) acres.
2. Multifamily residential developments and higher intensity office developments (Zoning Districts R-3, R-4 and O-2) provided the directly connected impervious areas discharging to the sinkhole is less than five (5) acres.
3. Discharge from land disturbance areas greater than one (1) acre and less than five (5) acres.

C. Very High Hazard

The following land uses are classified as posing a very high hazard for groundwater contamination:

1. Collector streets in industrial and manufacturing zones, all arterial streets and highways.
2. Railroads.
3. Concentrated discharge from streets, parking lots, roofs and other directly connected impervious areas having an area greater than five (5) acres.
4. Commercial, industrial and manufacturing areas in Zoning Districts C-2, M-1 and M-2.

5. Individual wastewater treatment systems.
6. Commercial feedlots or poultry operations.
7. Discharge from graded areas greater than five (5) acres.

107.8.3 Water Quality Management Measures

The majority of sinkholes drain a limited watershed area. For sinkholes where the surrounding drainage area is small enough that the area draining to the sinkhole flows predominantly as "sheet flow", potential impacts on water quality can be addressed in many cases by erecting and maintaining reliable silt control barriers around the sinkhole during construction and providing a vegetative buffer area around the sinkhole to filter out potential contaminants.

Where inflow is concentrated, the degree of effort required to capture and filter out contaminants increases significantly.

Concentrated inflow occurs naturally when the sinkhole watershed area reaches a sufficient size for watercourses leading into the sinkhole to form. Concentrated surface flows result as urbanization occurs due to construction of roads, storm sewers, and drainage channels. Subsurface flows can become concentrated through utility trenches.

Required water quality management measures are as set forth below:

A. Management Measures for Moderate Hazard Areas

1. Sediment and erosion control

Existing ground cover shall not be removed within twenty-five feet (25') of the sinkhole flooding area and a silt barrier shall be erected and maintained around the outer perimeter of the buffer area. Vegetative cover must be of sufficient quality and density to provide desired filtration.

A ditch check(s) meeting the requirements set forth in Section 114.6.3.E will be required at each point where concentrated flow is discharged into the sinkhole.

2. Permanent Management Measures

Where flow into the sinkhole occurs as sheet flow, water quality requirements can be satisfied by maintaining a permanent vegetative buffer area with a minimum width of twenty-five feet (25') around the sinkhole flooding area.

Concentrated flows may be discharged into the sinkhole through grassed swales and channels designed for non-erosive velocities. Temporary erosion control measures such as sodding or erosion control blankets shall be provided.

B. Management Measures for High Hazard Areas

1. Sediment & Erosion Control

A sediment basin will be required at each point where concentrated flows are discharged into the sinkhole. Sediment basins shall be designed according to the procedures set forth in Section 114.

2. Permanent Management Measures

Extended wet or dry detention basins designed as set forth in Section 115 shall be provided at all points of concentrated discharge. Other Best Management Measures may be specified provided that their performance is equal to that of extended detention basins.

C. Management Measures for Very High Hazard Areas

1. Sediment & Erosion Control

A sediment basin will be required at each point where concentrated flows are discharged into the sinkhole. Sediment basins shall be designed according to the procedures set forth in Section 114. Specific limits may be placed on the area which can be graded at any one time and on the length of time allowed from initial disturbance to stabilization.

2. Permanent Management Measures

a) Runoff from all areas must pass through extended wet or dry detention basins designed as set forth in Section 115. Other Best Management Measures may be specified provided that their performance is equal to that of extended detention basins.

b) Septic systems shall comply with the Greene County Standards for On-site Wastewater Treatment Systems.

107.9 DEVELOPMENT REQUIREMENTS

107.9.1 Stormwater Detention in Sinkholes

Where flooding considerations set forth in Section 107.7.1 and water quality considerations as set forth in Section 107.8 can be met, the volume of runoff storage in sinkholes can be counted toward stormwater detention requirements. The volume of required detention storage shall be determined as set forth in Section 112.

Excavation within the sinkhole flooding area to provide additional detention storage will not be

allowed.

107.9.2 Modification of Sinkholes to Increase Outflow Rates

Increasing outflow rates in sinkholes by excavating the sinkhole eye or installing disposal wells for diverting surface runoff to the groundwater system is prohibited, unless clear and imminent danger to public health and safety can be demonstrated.

107.9.3 Setbacks and Use Restrictions

The following setbacks and use restrictions are established:

1. No new construction of any of the following shall be permitted within twenty-five feet (25') of the sinkhole rim, unless special measures are approved to address structural and water quality concerns:

- A. Commercial or industrial structures.
- B. Streets, highways, or parking lots.
- C. Storage yards for materials, vehicles, and equipment.
- D. Sanitary sewer lines.

2. New construction of any of the following may be permitted within the sinkhole rim provided that they are set back a minimum of twenty feet (20') of the sinkhole flooding area:

- A. Residential structures, provided the lowest floor elevation is set a minimum of five (5) feet above the sinkhole flooding elevation, or one foot (1') above the lowest elevation on the sinkhole rim, whichever is less, and provided that a statement of a qualified engineer is submitted indicating that foundation conditions are suitable for residential structures.
- B. Swimming pools.
- C. Underground utilities other than sanitary sewer, if provisions are made to prevent migration of groundwater along the trench.

3. Individual Wastewater Systems. Setbacks and restrictions shall be as provided in the Greene County Standards for On-site Wastewater Systems.

4. Use of pesticides and fertilizers within twenty-five feet (25') of the sinkhole rim is prohibited, unless such usage is in accordance with a management plan approved by the Stormwater Engineer.

5. Use of heavy construction equipment in virgin sinkholes is prohibited.

6. Recreational facilities such as hiking, jogging, and bicycling trails, playgrounds, exercise courses, and grass playing fields are permitted within the sinkhole flooding area provided they are not located within the eye of the sinkhole.

7. Golf courses are permitted subject to approval of a management plan for use of pesticides and fertilizers.

8. Clearing and pruning of trees and undergrowth, and limited grubbing of roots is permitted.

9. Landscaping and minor gardening is permitted outside of the sinkhole eye provided erosion and sediment discharge is limited through use of minimum tillage and mulches.

10. Construction of light incidental landscaping and recreational structures such as playground equipment, etc., is permitted except in the sinkhole eye.

11. Facilities which involve storage or handling of hazardous or toxic materials shall not be permitted in sinkhole watershed areas.

107.9.4 Collapsed Sinkholes

Collapsed sinkholes may be stabilized and filled using approved techniques as shown in Figure 107.1 provided a sinkhole evaluation has been completed by a qualified geologist or engineer. A Grading Permit must be issued prior to performing any construction.

The probable cause of the collapse and potential adverse impacts of filling the collapse shall be investigated and information submitted with the Grading Permit application.

107.9.5 Altered Sinkholes

Filling or altering of sinkholes without a Grading Permit constitutes a zoning violation. In such cases where a sinkhole has been filled, corrective measures must be proposed within the time period specified in the Zoning Regulations for enforcement of such violations. No corrective or remedial measures shall be undertaken until the proposed remediation plan has been approved by the Stormwater Engineer and a Grading Permit issued.

No Building Permits will be issued, or zoning or subdivision approvals granted until the remedial measures specified in the Grading Permit have been completed and approved.

107.10 SPRINGS & CAVES

107.10.1 Springs

No new construction will be permitted within one hundred feet (100') of a spring unless a report,

prepared by a qualified engineer or geologist verifying that the quantity and quality of the spring flow will not be materially altered by the proposed construction, is submitted and approved by the Stormwater Engineer.

107.10.2 Caves

No new construction will be permitted within one hundred feet (100') of the known alignment of a cave unless a report, prepared by a qualified engineer or geologist verifying that the cave will not be materially altered by the proposed construction and that sound foundations or other support for the proposed construction will not be subject to collapse or undue settling, is submitted and approved by the Stormwater Engineer.

107.10.2.1 Security

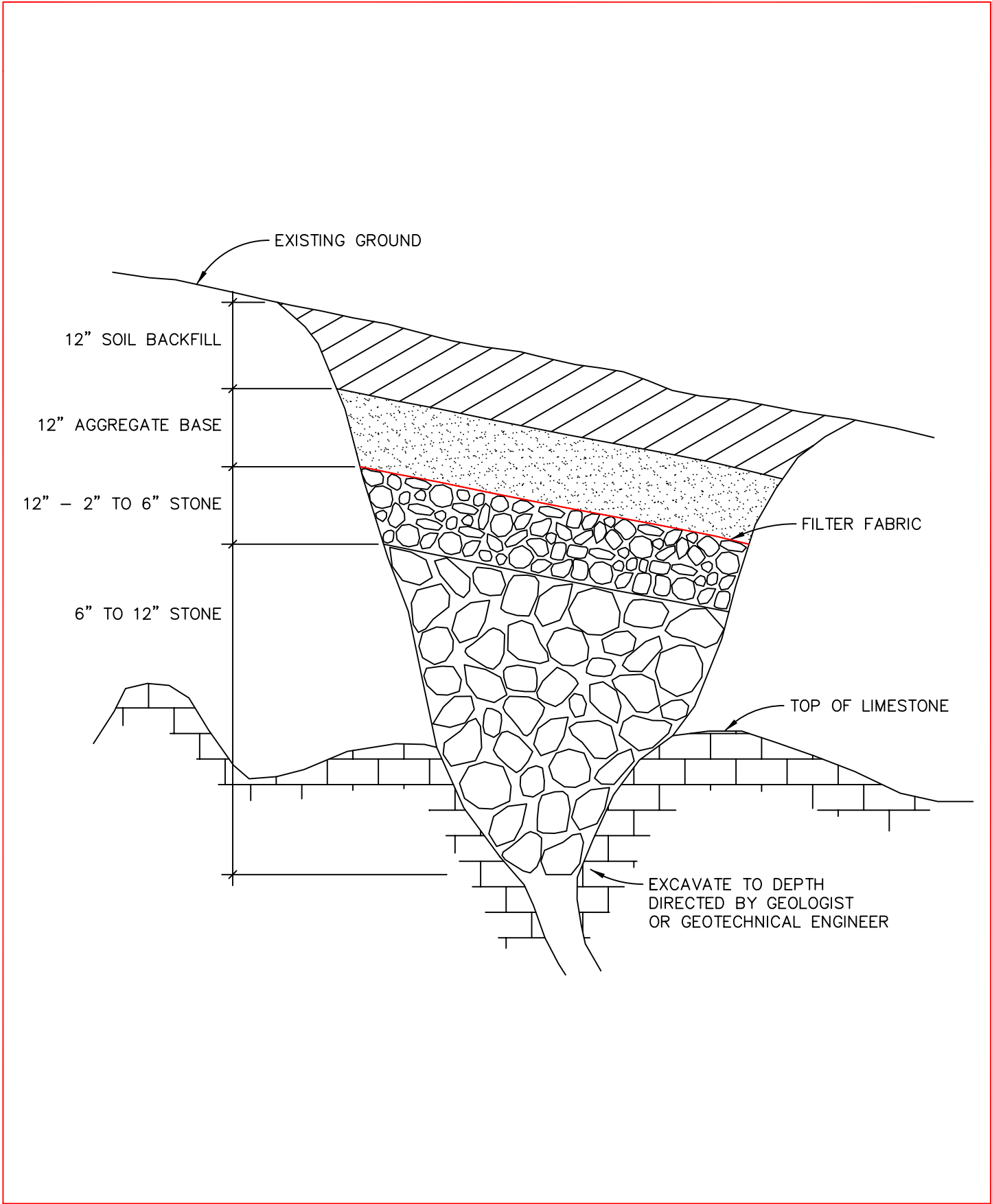
The entrances of caves shall be protected against unauthorized entry, while allowing for the unimpeded flow of groundwater and without disruption to habitat for cave-dwelling animal species. Plans for cave entrance protection must be approved by the Stormwater Engineer prior to construction.

107.11 REFERENCES

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GREENE COUNTY MISSOURI – STORM WATER DESIGN STANDARDS

SCHEMATIC SECTION
SINKHOLE COLLAPSE STABILIZATION

FIGURE 107.1

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