Instructions to Geologists
for
Geologic Assessments
on the
Edwards Aquifer Recharge/Transition Zones

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TABLES

FIGURES

I. Overview and Changes From Previous Versions

The Edwards Aquifer rules [Title 30 Texas Administrative Code (TAC) Chapter 213] were revised June 1, 1999. If you have not reviewed a copy of the rules since that date, please obtain a copy of the current rules. Some significant changes in the rules include: The assessment of area geology is now called "*geologic assessment*." A downgradient geologic assessment is not required for Edwards Aquifer Protection Plans received on or after June 1, 1999. Some terms have been redefined and are included in the glossary.

These "Instructions to Geologists" have been revised to improve the effectiveness without compromising the efficiency of the geologic assessment of *sensitive features* in the Edwards Aquifer recharge zone.

The major changes to the instructions are:

(1) To eliminate the category "possibly sensitive". Geologists doing the assessment are not asked to express a high degree of certainty about flow characteristics and communication to the subsurface to rank features as sensitive, as uncertainty is already expressed in the language of the Edwards Aquifer rules.
(2) To simplify the assessment to include only three variables: a classification by feature type, orientation with respect to structure, a field-based assessment of relative *infiltration* rate,
(3) To increase emphasis on matching appropriate engineering responses to sensitive features,
(4) To evaluate features encountered during sewer construction to identify those where flow should be maintained,
(5) To increase the guidance provided in the instructions,
(6) To reduce variability in assessment by better defining the criteria on which to evaluate relative infiltration rate.

II. General Instructions

This section overviews the expectations for collecting information from the literature and detailed field observations for the entire geologic assessment. As specified in the rules, these instructions are intended to guide geologists in preparing geologic assessments, completing required forms, and determining which of the geologic and manmade features are sensitive. The purpose of this report is to identify all potential pathways for contaminant movement to the Edwards Aquifer and provide sufficient geologic information so that the appropriate Best Management Practices (BMPs) can be proposed in the Edwards Aquifer Protection Plan (EAPP).

The Edwards Aquifer rules require that this report is to be prepared by a geologist. The rules specify that the qualifications of the geologist are that he or she "has received a baccalaureate or post-graduate degree in the natural science of geology from an accredited university and has training and experience in groundwater hydrology and related fields, or has demonstrated such qualifications by registration or licensing by state, professional certification, or has completed an accredited university program that enables that individual to make sound professional judgments regarding the identification of sensitive features located in the recharge zone or the transition zone." After September 1, 2003, geologists conducting assessments are expected to be licensed according to the provisions of Texas Geoscience Practice Act. In addition, the geologist should be familiar with standard karst, hydrology, and Edwards recharge zone literature. Citations to some representative source are provided with these instructions.

More Edwards-specific information about terms in italics is provided in the Glossary provided with these instructions.

Single-family residential subdivisions constructed on less than 10 acres are exempt from this requirement. The assessment must include the path of any proposed sewer line that extends outside the Water Pollution Abatement Plan (WPAP) assessed area, plus 50 feet on either side.

Answer all questions. If some items do not apply, provide a brief explanation. The comments "Not applicable" or "See Item XX above" are not acceptable. The comment "See attached...." is only valid for referencing required plans or maps. The application will be returned to your client if all items on these instructions are not adequately addressed.

A. Procedure For Conducting A Geologic Assessment

The general procedure for conducting a geologic assessment is to perform the following steps: research information, perform a field survey, evaluate data, return to the site if necessary, make conclusions, and make a report with your feature assessments and recommendations. A geologic map, preliminary data input into the Geologic Assessment Table, notes, photographs and/or sketches should be made while in the field. These data may be used and included in your final report.

Research information

Published reports and maps of area geology should be studied prior to performing the field survey. A literature or database search should be conducted for the presence of documented caves or other *karst features* on the property or in proximity to the property boundary. Information may be found about known *caves*, such as mapped extent, depth or elevation or orientation, on the subject property or on adjacent tracts. Some commonly used data sources for geologic maps and cave location and interpretation are included in the "Citations for Sources of Further information" in these Instructions.

Evaluate former land use practices and modifications. Interview persons knowledgeable about historical activities such as well drilling, irrigation or water control ditches or trenches, pit or structure construction, episodes of brush clearing and tree pulling, and cave filling or excavation. In ranches that have been occupied for a long time, manmade features can be degraded and overgrown and be confused with natural features. Human activities also may obscure indicators of natural processes that otherwise could be used to determine the sensitivity of a feature.

Aerial photos may be examined for the presence of structural features that should be field checked and plotted on the map.

Perform a field survey

The entire subject site must be walked to survey the ground surface for the presence of geologic and manmade *features*. It is recommended that the site be walked systematically in spaced transects 50 feet apart or smaller, paying close attention to streambeds and structural features observed on aerial photographs. The transect pattern should be adapted to insure that the geologist is able to see features and will vary with topography and vegetation on the site. Streambeds, including dry drainages, are significant because runoff is focused to them. Not only are features in streambeds likely to receive large volumes of recharge, but they are likely to be part of hydrologically integrated flowpaths because past flow has preferentially enlarged and maintained conduits. Features in streambeds are likely to be obscured by transported soil or gravel (Swallets or swallow hole). Structural features such as faults and fracture zones have influenced karst processes in the Edwards recharge zone, and awareness of these structures may be helpful in completing a high-quality assessment. The assessment must include the path of any proposed sewer line that extends outside of the WPAP assessed area, plus 50 feet on either side. Any features identified should be marked where possible with flagging or stakes, accurately located, preferably using a GPS (see detailed instructions IIIB below), assigned a unique number, the location accurately plotted on the geologic map, data entered in the Geologic Assessment Table, and supplementary interpretative data recorded in the narrative description of site geology.

The intensity and schedule of investigations should be adapted by the geologist and his client to meet the specific requirements of the site. Effort should be focused in order to (1) efficiently and correctly separate sensitive from not sensitive features and (2) provide adequate information about the sensitive features to the engineer and site designer so that appropriate BMP's can be designed. In some sites, it is likely that a return visit to collect additional information about certain features will be needed to accomplish these goals.

Tests such as excavation, cave mapping, infiltrometer tests, geophysical studies, or tracer studies are not required for the geologic assessment of any feature. However, if initial assessment leaves significant uncertainty regarding the characteristics of a feature, the geologist is required by the rules to err on the side of being overly protective and rank the feature as sensitive where "potential for hydraulic interconnectedness exists and rapid infiltration may occur." Testing is described as a mechanism with potential for reducing the ranking of some features from sensitive to not sensitive that the geologist or his client can choose to perform. A feature can be described as not sensitive by showing that the feature is not permeable, does not have potential for interconnectedness between the surface and the Edwards aquifer, and that rapid infiltration cannot occur. Geologists and clients may choose to schedule a Phase I assessment that locates and evaluates all the features and a Phase II follow-up on specific features that refines the evaluation. A Phase II assessment is not required to complete a geologic assessment. However, if excavation, cave mapping, infiltrometer tests, tracer studies, geophysical studies, or other follow-up tests are conducted, the results must be presented as part of the geologic assessment.

Features in areas that are going to be protected, for example, drainageways that will receive only high-quality water or areas that will be protected with setbacks or karst preserves, require no especially elaborate or Phase II assessments. Characteristics of features in these areas should be mapped and described, but it is acceptable to use a designation of "zone" to save labor of assessing numerous associated and genetically similar features if an appropriately protective BMP will be implemented over an area.

Make note of the initial condition of the feature upon your first encounter, particularly the nature of undisturbed surface and sediment filling. Sketches or photographs may be appropriate. Does it appear to be in natural condition or has the area been disrupted by activities such as construction or surveying? These initial observations may be modified and improved as analysis of the feature continues.

Classify the feature according to type, and collect the data needed to complete the Geologic Assessment Table (see detailed instruction IIIA). In order to define the type and extent of the feature, at least a few minutes of probing (only use a non-conducting probe), hand clearing, or hand excavation will probably be required. Removal of loose rocks by hand (no backhoes or jack hammers) around a natural opening may be appropriate. Special attention should be given to the assessment of relative infiltration rate, as this factor is critical in determining whether a feature is sensitive. In some cases a return visit to use specialized equipment or to complete the investigation may be needed. If geologists and their clients decide that tracer or infiltration tests would be helpful for site assessments, the tests should be designed to use good scientific protocols. Testing may require permitting from TCEQ underground injection control (UIC) for a Class V injection well. Comments in the narrative description of site geology are expected for each feature to justify the relative infiltration rate assigned and to support your rating. Excavation with heavy equipment requires prior approval (see detailed instructions IIIC).

While still in the field, assess the feature in its geologic and physiographic context. This part of the assessment will provide information to the engineer to design the appropriate BMP. Is the feature elongated along a fracture? Are other features recognized along this trend? Is it part of an assemblage of karst-related features? In this case it should be classified as part of a zone and a BMP design applied to the whole area rather than isolated features. Drainage areas should be estimated in the field and checked against the best available contour maps. If additional information not apparent on the contour map is used to estimate a small drainage area, for example subtle geomorphic features, plot them on the map, add an additional map at a convenient scale, or explain in the narrative description. Identify the local topographic setting (for example, wall, hill top, hillside, drainage, floodplain, streambed), the extent to which water appears to have been directed toward the feature and the potential that it can be in a channel during high flow.

If caves are identified during the assessment, a map showing scale or dimensions should be made of its extent and relationship to surface features, and/or relationship to utilities or other manmade objects. The projected surface *cave footprint* should be marked on the site geologic map. If a cave is not entered and mapped, reasonable efforts should be made to determine the area assumed to be underlain by cave passage. This could be based on geophysical or hydrologic measurements or on the dimensions of typical cave footprints. Explain the source of data in your comments.

Evaluate data, make conclusions, and make a report

Evaluate your data by completing the Geologic Assessment Table and considering the results. Note that the Edwards Aquifer rules define sensitive features as those that have ***potential*** for interconnectedness between the surface and the Edwards aquifer and where rapid infiltration to the subsurface ***may*** occur (bold added). Geologists making the assessment are not asked to express a high degree of certainty that interconnectedness and rapid infiltration actually occur in order to rank features as sensitive. Observed variations in the topographic, geologic, and hydrologic setting of sensitive features should be provided by the geologist so that all variables can be considered when BMP's are designed.

B. Attachments

The geologic assessment form must include the following attachments:

- Soils description
- Site geologic map
- Stratigraphic column

Geologic assessment table
Narrative description of site geology

Soils description

For a soil's ability to transmit or impede fluid flow into the subsurface, use the hydrologic soil groups, as defined by SCS soil scientists in Appendix B (Soil Series and Hydrologic Soil Groups) of Urban Hydrology for Small Watersheds, Technical Release No. 55, engineering Division, Soil Conservation Service, US Department of Agriculture, January 1975.

Site geologic map

The site geologic map must illustrate the outcrop of surface geologic units and the location and extent of all geologic and manmade features. The map should specifically locate natural and manmade features listed in the Geologic Assessment Table as described below and any other features sensitive to pollution. It should show springs, all intermittent drainages and flowing streams, and the 100-year floodplain, if it has been mapped within the site. The site geologic map must be the same scale as the applicant will use for the WPAP site plan.

The site geologic map should be compiled from information gained from field observations. Published maps of the region should only be used as a general reference and should not be relied upon to be accurate for individual sites. If available, previous mapping should be cited. Mappable units for the site geologic map should, at minimum, be presented at the formation (Person, Kainer, etc.) level. USGS hydrogeologic units may be included where they have been mapped. Indicators of the dominant structural trend in the area (faults, fracture zones, lineaments, etc.), should be shown. Faults should be marked with a solid line where exposed, dashed where inferred, and dotted where buried. Core from construction borings may be helpful in mapping site geology.

Stratigraphic column

The stratigraphic column must show the formations, members, and thickness in the map area. The symbols and abbreviations used must match those used on the geologic map.

The following table lists commonly used stratigraphic nomenclature and abbreviations. Any variations should be justified and clearly described in the narrative description of site geology as well as in the stratigraphic column.

Table 1. Stratigraphic nomenclature and standard abbreviations.

Maverick Basin	Devils River Trend	San Marcos	North of the Colorado
Qal-Alluvium	Qal-Alluvium	Qal-Alluvium	Qal-Alluvium
Kau-Austin Chalk	Kau-Austin Chalk	Kau-Austin Chalk	Kau-Austin Chalk
Kef-Eagle Ford SH	Kef-Eagle Ford SH	Kef-Eagle Ford SH	Kef-Eagle Ford SH
Kbu-Buda LS	Kbu-Buda LS	Kbu-Buda LS	Kbu-Buda LS

Kdr-Del Rio Clay	Kdr-Del Rio Clay	Kdr-Del Rio Clay	Kdr-Del Rio Clay
*Kgt – Georgetown Formation	*Kgt – Georgetown Formation	*Kgt – Georgetown Formation	*Kgt – Georgetown Formation
*Ksa-Salmon Peak	*Kdvr-Devils River LS	*Kep - Person Formation	*Ked -Edwards Formation
*Kmk-McKnight		*Kek - Kainer Formation	Kcp- Comanche Peak Formation
*Kwn-West Nueces		*Kw - Walnut Formation	Kw -Walnut Formation
Kgr-Glen Rose	Kgr-Glen Rose	Kgr-Glen Rose	Kgr -Glen Rose

*Defined as part of the Edwards Aquifer in the rules.

<u>Geologic assessment table</u>

The geologic assessment table must be completed if geologic or manmade features were identified during the assessment. See Section III for detailed instructions on completing the table. Completing the table satisfies the requirement to describe and evaluate all geologic and manmade features, and to assess and determine if they are sensitive features. Each feature must have an identification number to match those on the site geologic map.

<u>Narrative description of site geology</u>

The site-specific geology description must discuss the stratigraphy, structure, and karstic characteristics of each map formation or member on the site. This should be based on what you have observed at the site, and not a repeat of the regional or area characteristics for the formations or members. The dominant structural trend(s) noted in the area should be recorded. Comments on each geologic and manmade feature assessing the probability that rapid infiltration to the subsurface could occur should be provided. Sketches or photographs that clarify what is written should be included. The inclusion of aerial photographs of the site is encouraged.

Additional comments supporting your findings for each feature should be added to the narrative description of site geology. This narrative does not need to be long or to repeat the contents of the table but should add any important descriptive information that does not fit on the table as well as justify interpretations. Below are some types of additional comments you should provide, if needed, for each feature:

Initial condition of the feature upon your first encounter, particularly the nature of undisturbed surface and feature infilling. Does it appear to be in natural condition or has the area been disrupted by activities such as construction or surveying?

Caves: Note all evidence regarding extent and/or depth of cave, and source of information.

Fault and fault zones: Note should be made regarding all supporting evidence for delineating the fault, i.e., field evidence, air photos, and/or published sources.

Manmade features: Describe type and condition of feature and the reason for your assessment, for example, from an interview or from your authorized excavation.

Relative infiltration rate: Present evidence that justifies assigned the probability of rapid infiltration at the feature.

Photographs or sketches to clarify and support verbal description.

Explanation of your thinking and needed detail to support design of a BMP.

III. Detailed Instructions For Elements Requiring Further Clarification

A. Completing the Geologic Assessment Table

This section clarifies terms and abbreviations and includes instructions for the appropriate usage of the geologic assessment table for describing and assessing geologic and manmade features. The numbered items listed below correspond to the numbered columns on the table.

1A. Feature ID

Assign identification numbers to the features identified in the assessment. On the Table and the site geologic map, number each geologic and manmade feature consecutively, for example, S-1, S-2, S-3, S-4.

If a literature search, personal knowledge, visual inspection, or other information source identifies downgradient features in proximity to the property boundary, then they should be noted in the report.

1B. Latitude and 1C longitude.

Provide coordinates in latitude and longitude in degrees, minutes, and decimal seconds for each feature either by GPS measurement or other appropriate measurement techniques. Provide details of location data collection following detailed instruction IIIB (GPS Requirements) below. For aerially extensive features such as zones or faults, list one point location in the table. Select a point that will uniquely identify the feature, for example center, corner, or a location where the feature is accessible or clearly visible. The extent of the feature should be shown on the map. Additional location information may be listed in the narrative.

2A. Feature type

Enter the abbreviation that best matches the feature from Table 2 using the definitions below. If more than one type is appropriate, you should hyphenate the feature type. Document uncertainties in the description of this feature in the narrative description of site geology. Regardless of size or classification, any feature where rapid infiltration to the subsurface is indicated should be mapped. The geologist is expected to be familiar with these features using the glossary, karst text books, course work, and field experience.

Table 2. Feature abbreviations, types, and points assigned

Abbreviation	Types	Points
C	Cave	30
SC	Solution cavity	20
SF	Solution-enlarged fracture(s)	20
F	Fault	20
O	Other natural bedrock features: vuggy rock, reef deposits	5
MB	Manmade feature in bedrock	30
SW	Swallow hole	30
SH	Sinkhole	20
CD	Non-karst closed depression	5
Z	Zone: clustered or aligned features	30

CAVE: A natural underground open space formed by dissolution of limestone that is large enough for an average-sized person to enter. Note that caves are commonly partly filled by collapse, loose rocks, debris, or soil; assessment requires sufficient investigation to define the dimensions of the feature defined by in-place bedrock. During approved construction activities, excavation with heavy equipment or trenching can open a formerly inaccessible space to permit entry; this possibility should be considered when describing karst features. The subsurface extent of the cave must be shown on the map. If a cave map is not available, you must conservatively estimate the amount of passage on the basis of geophysical or other measurements or on the dimensions of typical cave footprints of typical caves in the Edwards recharge zone. The cave footprint is not the same as a buffer zone around the cave entrance. BMP design in the Edwards Aquifer Protection Plan should consider appropriate methods for protecting the drainage area into the cave that may include a large area beyond the cave footprint.

SOLUTION CAVITY: A natural cavity or depression formed as a result of dissolution of limestone. This category is designed to capture features that are not large enough for a normal-sized person to enter but appear to be part of a system of interconnected voids that connect the surface with the subsurface (including features like vertical solution pipes). The size and geometry of the feature is defined by in-place bedrock; fill must be probed or excavated to determine the size of the feature. If cavity size appears to increase at depth, this observation should be used to classify the feature as a solution cavity or cave, depending on the inferred maximum size. Note that solution cavities include areas where dissolution has increased the opening size and permeability along bedding planes as well as fractures. Features that the geologist interprets as limited to the surface and soil zone (*karren*, weathering textures, and features formed on loose blocks) are not reported as solution cavities.

SOLUTION-ENLARGED FRACTURE(S): Only fractures that show evidence of being locally enlarged by dissolution of limestone need to be considered. Solution enlargement can be recognized by measurable (larger than hairline) openings and missmatched fracture surface shapes. Fractured slabs or blocks in the weathering profile are not listed as features unless the geologist interprets them as evidence of relationships between the surface and the subsurface.

FAULT: A fault is defined as a fracture along which there has been displacement of one side of the fracture relative to the other side. Outcrops of *faults* and fault zones are listed in the Edwards Aquifer rules, and their significance as recharge features should be evaluated on a case-by-case basis.

OTHER NATURAL BEDROCK FEATURES: Vuggy rock and reef deposits may contain large holes or vugs. These features are listed in the Edwards Aquifer rules, and their significance as recharge features should be evaluated on a case-by-case basis. Surficial weathering textures (*karren*) should not be reported as features. These features are defined and described in the glossary.

MANMADE FEATURE IN BEDROCK: Water wells, sanitary sewer lines, storm sewer lines, trenches, quarries, and other cultural features that intersect bedrock and can potentially increase the rate of recharge to the subsurface.

SWALLET OR SWALLOW HOLE: A focused recharge feature in an intermittent drainage or stream in karst terrain. Some swallow holes have a surface expression, for example, a cave opening or formation of a whirlpool in the stream at high flow. The general case is that fine soil and sediment as well as gravel are deposited over the bedrock feature during falling stages of flow thereby intermittently or frequently obscure it. During the geologic assessment, care must be taken to investigate the possibility that these highly sensitive features may be present in drainageways. The best method is to field test for infiltration or gauge the stream when it is flowing. Observation of rapid infiltration of pooled water at rates higher than background can help identify buried swallets. Indicators of the presence of karst features, for example, dipping or fractured bedrock indicating collapse can help to identify these sensitive features when they are obscured by gravel and sediments.

SINKHOLE: A shallow, broad topographic depression formed in response to karst processes. Sinkholes are pragmatically defined as features greater than 6 feet in diameter with more than 6 inches of topographic relief. Sinkholes are usually circular in map view. In cross section they may be subtle swales or funnel-shaped pits and some have exposed rimrock at the perimeter. It is common for sinkholes to have other karst openings in the floor. The presence of a sinkhole implies that processes including collapse, subsidence, and soil sapping over geologic time have caused the land surface to sink below the surrounding area. Fracture patterns and dipping beds in exposed bedrock can help identify sinkholes. Sinkholes can have subtle topographic expressions, so awareness of soil and vegetation characteristics can help the geologist locate them.

NON-KARST CLOSED DEPRESSION: A natural or non-natural topographic depression that is not formed by karst processes and is not bedrock floored. Feature larger than 6 feet in at least one direction and with 6 inches or more of topographic relief should be listed in the table. Examples of non-karst closed depressions include scoured pools in drainages, animal wallows, large animal burrows, large pits created by clearing tree stumps, dammed tanks, or other agricultural constructions that are soil floored and do not modify the topography on top of bedrock. Care must be taken to determine that the feature was not a karst feature that has been modified by human or animal activities or a scour that overlies a swallet. The reasons for determination that the feature is non-karst should be noted in the narrative description of site geology.

ZONE: An area in which any type of karst feature occurs along a trend or in a cluster can be described as a zone. Clustered or aligned features are more likely to be an indicator of an integrated flow system at depth than isolated features. Alignment is expected in areas where conduit flow is strongly influenced by structurally controlled fractures. Fracture control favors connection between the surface and the subsurface and integrates subsurface flowpaths to provide rapid flowpaths to the aquifer and to discharge points. Fracture zones are well developed adjacent to faults and may be more permeable than the fault plane itself. Zones of aligned features can be indicated by subtle evidence such as vegetation, changes in soil properties, and subtle topographic changes.

2B. Points for feature type

Insert points from Table 2 into column 2B. In case of combination or hyphenated feature types, use the higher point value assigned.

3. Geologic formation

In what geologic formation determined from your field mapping does this geologic or manmade feature occur? Use the standard abbreviations used the stratigraphic column and shown in Table 1 above or explain any deviation. Published maps for large areas should be used only as a general reference and not relied upon to be accurate at site scale.

4. Feature dimensions

Measure in feet, or decimal or fractions of feet, the maximum horizontal (X), maximum horizontal perpendicular to X (Y), and maximum vertical (Z) dimensions of the feature. In most cases the dimensions will be *aperture* (size of opening). The exceptions will be in outcrops of solution-enlarged fractures, other natural bedrock features such as outcrops of faults and fault zones, vuggy rock, reef deposits, and zones of karst features, in which case you will record the X and Y extent of the features in outcrop. Z will give the maximum depth of the features and may be small. For these exceptions, use density (6) and aperture (7) to describe individual features. Estimate dimensions if direct measurements are not practical. Sketches may be included in the narrative description of the site geology.

5. Trend

Lineaments and alignment of karst features are widely recognized as indicators of a high probability of subsurface interconnection along a well-integrated flowpath. The direction of elongation or alignment of individual features or a series of features should be shown as a compass direction, i.e., N60°E, 120°, NW, SE, etc. *Trend* is expected for fractures, zones, and faults and should be applied to other features if present. Subtle features such as topographic and vegetation alignment can also indicate a trend.

If the feature or trend orientation is approximately the same (±15°) as the dominant fracture set for the site or mapped faults in the general area as noted on the geologic map, also put 10 points in column 5A. If the orientation is more than 15° from the dominant structural trend, enter 0 in column 5A.

6. Density (applicable to SF, Z, and O)

For features characterized by numerous openings such as outcrops of solution-enlarged fractures, zones of solution cavities, and other features such as vugs that cannot be adequately described in field 4, show the measured or estimated *feature density* of openings along a transect in column 6. A transect can extend one or more times across the features in a direction that will adequately sample the observed features. Represent as a fraction in the units of number of features/foot.

7. Aperture (applicable to SF, Z, and O)

For features characterized by numerous openings, such as outcrops of solution-enlarged fractures, zones of solution cavities, and other features such as vugs that cannot be adequately described in field 4, show the measured or estimated aperture (maximum size) of openings in fractional or decimal feet. Note in the narrative description of site geology how the measurement represents the features shown on the outcrop.

8A. Infilling

Most features contain some amount of washed-in or remnant material. This material gives evidence of the dynamics of the feature with respect to surface water and recharge flow. A descriptive term for the dominant materials observed within the feature is entered in column 8A and then can be used as justification for the relative infiltration score given in 8B. Materials along the flowpath taken by water entering or moving through the feature that can be interpreted to estimate frequency of flow, flow volume, and flow velocity are the focus of this item. You may use more than one descriptive term if needed to describe the filling. If other materials are significant components of the infill, for example trash, you may designate them with “X” and describe them in the narrative comments. Comments in the narrative description of site geology regarding volume and characteristics of filling may be appropriate to justify the relative infiltration rate assigned.

Table 3. Feature infilling, key to column 8A. *Infillings* are further described in the glossary.

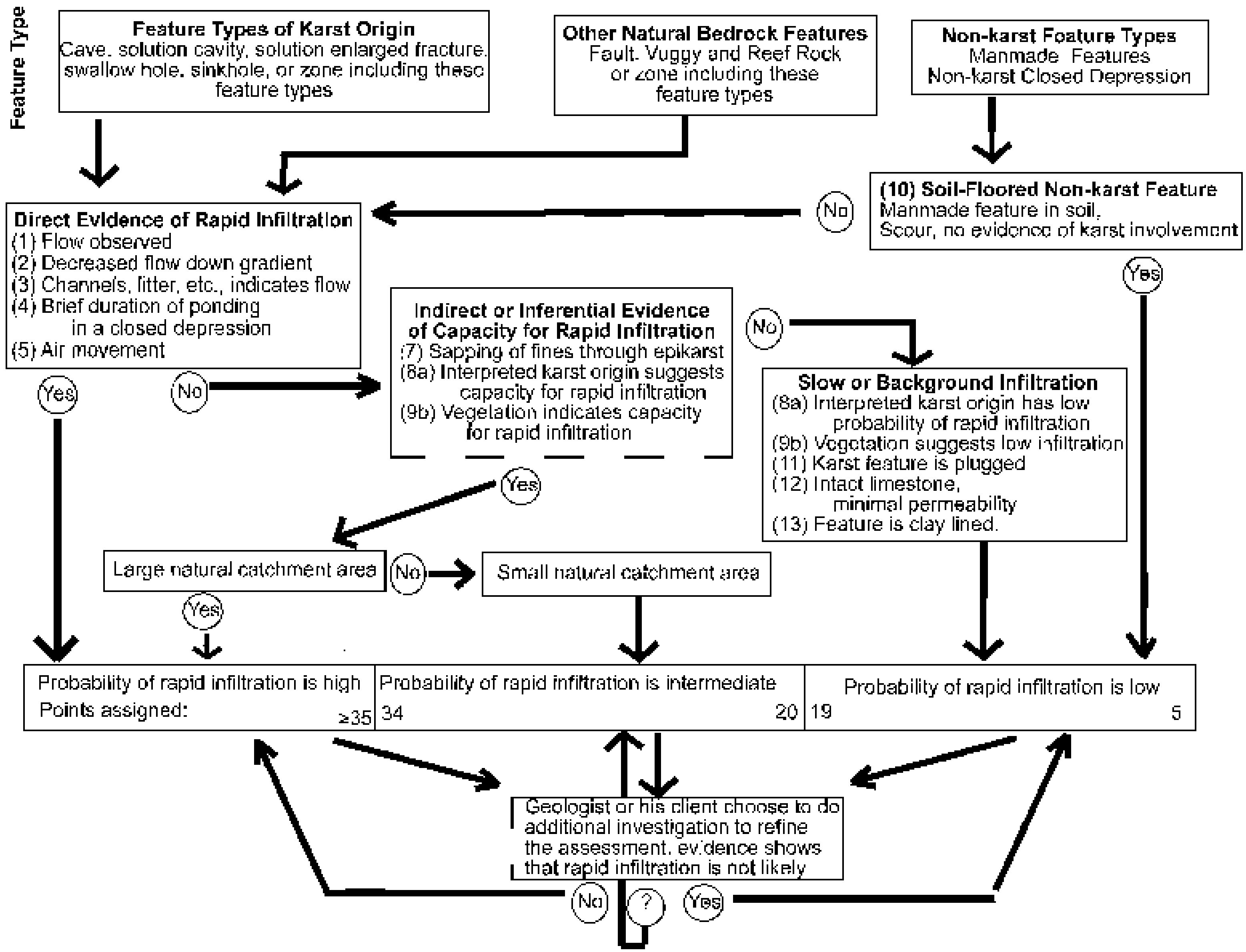
Code	Description
N	None, exposed bedrock
C	Coarse - cobbles, breakdown, sand, gravel
O	Loose or soft mud or soil, sticks, organics, leaves, dark colors
F	Fine-grained red or gray compacted clay-rich sediment, soil profile, terra rossa
V	Vegetation; give details in narrative description
FS	Dripstone, flowstone, cements, other cave deposits
X	Other materials; give details in narrative description

8B. Relative infiltration rate

Using professional judgment, estimate the probability that a feature is able to rapidly transmit fluids to the subsurface. Infiltration rate is dependent on many variables, such as hydrologic head, hydraulic conductivity, and water saturation. However, the purpose of the geologic assessment is to hypothesize where the potential for rapid infiltration has the highest probability of occurring using the information observed at the feature (or zone) and entered in the table. In the narrative description of each feature (or zone), describe indicators that by their presence or absence lead you to interpret that a feature has a rapid infiltration rate. Figure 1 provides a flowchart to help the geologist make this assessment using three categories of probability of rapid recharge: high (≥35 points), intermediate (34–20 points), and low (19–5 points). In this part of the assessment, consider what the infiltration rate would be if you brought a large tank of water to the feature and released water into the feature. (This is a mind-experiment only; no physical experiment is expected.)

Soil filling in a sinkhole, solution cavity, solution-enlarged fracture, or cave does not indicate that rapid infiltration cannot occur at the feature. Long-term maintenance of a cavity or depression is strong evidence that focused flow moves water out the drain in the floor of the depression with sufficient velocity to move soil. The drain may be in the subsurface beneath soil or limestone rubble and connected to the surface via drainage systems in the *epikarst*, or it may be exposed in the floor of the sinkhole. Soil in the floor of the cavity or sinkhole may be in temporary storage between the time it was moved into the feature and the time it will be moved through the drain. However, existence of a well-formed soil profile or gray or red colors in fine-grained fills are evidence that the soil has a long residence time and may be used as evidence that the feature is relict or inactive and has a low infiltration rate.

Figure 1: Assessing the Probabily that Rapid Infiltration May Occur at a Feature



High probability of rapid flow ($\geq$35 points) should be assigned where there is direct evidence of rapid flow or reason to interpret that rapid flow occurs into the feature. Direct evidence includes (1) observation of flow into the feature, (2) decreased flow downgradient from the feature, (3) evidence of flow into the feature (litter, elongated grass, etc.), and (4) brief duration of ponding in a closed depression. As an index against which to evaluate brief duration of ponding, unsaturated zone flow model simulations show that a conservative duration of ponding for 8 cm of water on a moderately dry clay loam soil over carbonate bedrock is 24 hours. Ponding will be somewhat longer if the soil is wet or finer grained. Shorter duration of ponding indicates relatively rapid flow into the subsurface, most likely related to conduit flow. Other evidence that geologists commonly use to support their judgment that there is a high probability of rapid recharge includes (5) air movement into or out of a cave, solution cavity, or fracture, indicating that a significant volume of underground passageway is interconnected. (6) A positive result for karst conduit or preferential flow response from a tracer or infiltration test is also a reason to assign high probability of rapid flow. Soil, sticks, leaves, and trash commonly accumulate in recharge features. Probing or excavation through these materials may be needed to determine the type and extent of the feature.

The absence of direct evidence of rapid infiltration is not sufficient to determine that a feature has a background infiltration rate because features capable of rapid recharge are commonly intermittently active and become plugged with soil, gravel, and vegetation that may be easily removed to reactivate the feature. Furthermore, appropriate conditions to cause rapid infiltration may not occur during the time that the assessment is being conducted. Other features are relict, and the flowpaths leading to them have been bypassed so that they are not critical to the current flow system. It is important that the geologist highlight inactive features that still retain capacity for rapid infiltration so that as surface-water flow is modified during development these features can be adequately protected. The most commonly used indirect indicators that rapid infiltration has occurred in the past and could occur again if water or contaminate were introduced at the surface are (7) transport of fines out of the feature, (8) interpreted feature origin, and (9) vegetation.

Correct identification of the potential for rapid recharge in partly soil-filled features is challenging but important. Thin soils typical of the Edwards recharge zone offer limited potential for protection of the aquifer, and the modification of the site topography or surface-water flow during development can further reduce the retardation function of the soil. Over geologic time geomorphic processes work to level and grade the landscape by filling depressions with materials such as weathering products and dust. Maintenance of an opening or depression at a cave, solution cavity, swallow hole, sinkhole, or fault is a common indicator in karst terrains that soil is being transported through a conduit beneath the feature. The subsurface transport of fines is commonly determined by a process of elimination. That is, if the depression is not formed by surface water (scour) or by biologic processes (human, animal, or vegetative), then transport of soil through a subsurface karst conduit is suspected and the feature should be ranked as having a high or intermediate probability of rapid infiltration. In cases where the confidence level of this process of elimination is inadequate for satisfactory BMP design, the geologist or his client may choose to do further assessment in order to revise the feature type or probability of rapid infiltration ranking.

Feature geometry is important in assessing the probability of rapid recharge.

Assessment of cave genesis (phreatic, vadose, and discharge features, for example) is commonly used to determine the most likely role of caves in infiltration. Geologists should obtain and apply in-depth knowledge of cave and karst feature genesis available from many resources. Experience with the features of Edwards caves may be of substantive help in assessment.

Vegetation is a very sensitive index of soil moisture. Geologists experienced in conducting geologic assessments carefully check the area under tall and large trees for features, because a feature focusing water flow to the root zone is a common reason for the successful growth and long life of the tree. Some trees can be used as clues to higher than average infiltration rates; for example, persimmon is reported to be common near fractures and karst features in some areas. Many caves have been discovered by uprooting a large shrub or cactus that was capitalizing on a favorable moisture environment in a solution cavity. Luxuriant grasses can also be indicators of infiltration and are commonly the first indicator that can be spotted to locate a subtle but significant soil-floored sinkhole. If a depression does not drain rapidly, grasses will be killed after heavy rains and prolonged ponding, so in a closed depression with a drainage area, preservation of grass is an indicator of rapid infiltration rates. Other vegetative patterns; however, are indicators that discharge is focused at a seep, and the hydrologic and geologic setting of these areas may document that they have low probability of rapid infiltration. Wetland vegetation can be used to determine that discharge or long-term ponding occurs at a feature. Vegetation generally reduces infiltration to the aquifer because the roots capture water that is then lost from the soil through evapotranspiration. Evapotranspiration can be used for aquifer protection to reduce recharge of low-quality water. However, vegetation as well as soil characteristics may be changed during development of the site. If the geologist interprets that evapotranspiration has an important role in water balance or the ecology of a feature, this information should be noted for consideration in BMP design.

The size of the catchment area is a factor that should be considered in assessing the probability that a feature is capable of rapid infiltration. Features that drain a catchment area ≥1.6 acres and, therefore, have potential to serve as a significant recharge feature should be given a high probability (≥35 points) of rapid infiltration. This assumption is based on the concept of feedback within a karst system—that is, when a flow path carries a lot of water, the openings that comprise that flow path are more likely to become enlarged and better connected through time than the openings on a flow path that has moved smaller volumes of water.

If the geologist considers the probability that rapid infiltration can occur at a feature intermediate between high and low, the feature is given 20 to 34 points. This ranking will commonly be given to features that have small, poorly defined catchments (<1.6 acres) and do not appear to be very active in current recharge so that their likely response to introduced contaminant is difficult to estimate. Typically features such as isolated solution cavities, solution-enlarged fractures, and small hydrologically inactive caves on hillsides, hilltops, or plateaus will fall into this category. Intermediate rankings may be suitable for many manmade features in bedrock where fractures and vugs are present, but it is difficult to determine how effectively they could transmit fluid. The geologist or his client can choose to conduct additional investigations in an attempt to better constrain the probability of rapid infiltration and revise the assessment as a result.

Several reasons may justify assigning a low or background probability of rapid infiltration rate to a feature: (10) the feature did not form through karst processes, and does not focus flow into the subsurface; (11) the karst feature is plugged by calcite cement or by compact terra rossa (red or gray clay), or a soil profile has formed in the sediment (loose *humus* or transported sediment or soil indicates recent plugging and does not qualify as a reason to assign a low probability of rapid infiltration to a feature); (12) the feature is formed in intact limestone with minimal leakage through hairline fractures, bedding planes, and matrix porosity; (13) the feature is lined with thick, well-indurated moist clay sediment that is protected from degradation. Karst features that were formed by discharge such as active or abandoned spring orifices may have low infiltration rates because discharge may be focused by a low-permeability rock unit. Prolonged ponding should be evaluated with care, because features like sinkhole ponds are known to be formed by temporary plugs in the sinkhole drain and may be reactivated during construction activities or by modification of the site hydrology. If the feature has been highly disturbed so that evidence of its recharge characteristics is not preserved, it cannot be ranked as having a low relative infiltration rate unless it is further investigated.

Features having low probability of rapid infiltration are given 5 to 19 points.

9. Total feature characteristic points

Add the points from Column 2B for the type of feature to the points for applicable columns 5A and 8B, and place the total in the column labeled total.

10. Sensitivity

Place the feature characteristic total in the appropriate box in Column 9. Features with <40 points are considered not sensitive, and those with ≥40 points are ranked as sensitive.

11. Catchment area

The areal extent in acres of the watershed that was directed into or toward the geologic or manmade feature under pre-development conditions. This includes the area on the project site as well as areas upgradient of the project site. Outlining the drainage area on a detailed contour map may complement field evaluation of the catchment area for small areas.

12. Topography

Indicate the topographic location of a geologic or manmade feature with respect to terrain. Mark only one of the following choices:

Cliff – vertical/near-vertical cliff above 100-year floodplain
Hilltop – low topographic relief at top of hill or ridge crest, low-relief plateau
Hillside – high slope area
Floodplain – on 100-year floodplain, if mapped, or as estimated by the geologist.
Streambed – in a drainage, or below the *ordinary high-water* mark on a larger creek

B. GPS Requirements

Feature positions in latitude and longitude (degrees, minutes, and decimal seconds) should be collected and entered into the geologic assessment table. The Edwards Aquifer regulations do not require the use of *Global Positioning System* (GPS) technology, but it is encouraged. The minimum data elements for feature location information collected by any method should include the following, included as an attachment to the table:

- The datum in which the positional information is collected (e.g.,WGS84 NAD83, NAD27, etc.)
- Method of collection (i.e., GPS [preferred], interpolation from USGS quadrangle map, etc.)
- Date of data collection
- Horizontal accuracy assessment – TCEQ requires at minimum data collected with GPS equipment should have a Root Mean Square (RMS) horizontal accuracy of 25 meters (82 ft) or better.
- Name of person(s) who made the measurement.

C. Instructions For Excavation Using Heavy Equipment

An additional step in assessing a feature in the field may be to excavate with heavy equipment. This level of investigation falls within the definition of “regulated activity” and requires written approval from the TCEQ prior to any excavation. This type of investigation is not required to complete the Geologic Assessment but may be chosen by the client in cases where additional assessment would be helpful for site planning, BMP design, or other activities. Excavation is sometimes used to collect enough information so that a feature can be classified as not sensitive. The reasons for determining that a feature is not sensitive are that it is not permeable, does not have potential for interconnectedness between the surface and the subsurface, and that rapid infiltration cannot occur. Requests for investigation of features using heavy equipment (jack hammers, backhoes, etc.) must be submitted to the appropriate TCEQ regional office for review prior to the anticipated start date of the investigation. Any such request should include the following information:

- Scope of Work - A description of the manner in which the investigation will be performed. Include extent of excavation, type of equipment to be used for excavating, and measures proposed to protect sensitive features and streams.
- Site Location - Information and maps of the site location should include a legible road map that is sufficient to enable the TCEQ field staff to locate, travel to, and inspect the site.
- Site Plan - Provide a site plan with a minimum scale of 1 inch = 400 feet showing the site boundaries and existing contours at no greater than 10-foot intervals. The site plan should show the location of the features, area to be excavated, storage sites for spoils, proposed locations for temporary erosion and sedimentation controls, and the location of nearby surface streams or other geologic features.
- Permanent Pollution Abatement - Describe the proposed manner for permanent disposal of spoil material. Describe measures to stabilize the feature and surrounding areas that will be disturbed during the investigation. Include a plan to secure the opening to the feature, if necessary.

You may be responsible for meeting other regulatory requirements in addition to those required by TCEQ for such activities.

D. Features Encountered During Sewer Construction

It is common for previously unsuspected solution-enlarged fractures, cavities, and caves to be discovered during construction of deep trenches for storm and sanitary sewer lines. Shallower trenches such as those typically constructed for utilities are more likely to be in the soil profile and are less likely to encounter large openings. The Edwards Rule 213.5(b)(4)(C)(IV) extends the requirement for maintaining natural flow to features encountered during excavation.

The highest level of concern for the geologist is to support the engineering issues regarding the structural integrity of the sewer pipe across the void and the structural integrity of the land surface. Introduction of potentially large quantities of poor quality water directly into the karst system over a long period of time through pipe failure is a scenario with high risk of aquifer and spring contamination. The impact of the breach created by the trench in the structural beam of the cave roof should be considered. There is a possibility that the risk of roof collapse could be increased and geologists reports should provide enough information about the cave geometry so that appropriate BMPs can be designed.

The same questions of whether a feature is active or relict and whether it meets the criteria in the rules to be considered sensitive apply to features encountered in trenches as to features exposed at the surface. The following checklist is provided for this assessment. If any of the features indicate that flow should be maintained, then the engineering solution should provide a mechanism for maintaining flow.

Table 4. Classification of features encountered during sewer construction

Characteristics that indicate feature flow characteristics should be maintained	Characteristics that indicate that the feature is not a major component of the flow system, fill acceptable
Flowing or ponded water observed	Compact red or gray clay completely fills voids
Deposits of organic material, leaves, dark soil, twigs, trash	Dry and dusty appearance
Evidence of flow, layered sediment on the cavity floor	Localized cave, opening narrows to small aperture down gradient
Close to a spring discharge point	Injection or tracer test showed background values of injectivity or no flow to spring
Active *Dripstone* or *Flowstone*	

Disturbed soils that backfill pipeline trenches can serve as preferential pathways for contaminant migration. Trench design should limit the potential for low-quality surface water to access the subsurface through the trench backfill.

IV. Glossary

Aperture Size of the opening into a fracture, cave, or solution cavity. Aperture can be measured with a tape or ruler for large openings or with a feeler gauge for small spaces.

BMP Best management practices - schedule of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of water in the State. BMPs also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. BMPs are those measures that are reasonable and necessary to protect groundwater and surface water quality, as provided in technical guidance prepared by the executive director or other BMPs that are technically justified based upon studies and other information that are generally relied upon by professionals in the environmental protection field and are supported by existing or proposed performance monitoring studies. These include, but are not limited to U.S. Environmental Protection Agency, American Society of Civil Engineers, and Water Environment Research Foundation guidance.

Breakdown Accumulation of angular clasts or blocks generated by cave collapse. Breakdown is usually permeable and flow may occur within breakdown even if the overlying cave floor is dry.

Catchment area The area that gathers water originating as precipitation and contributes to a feature. Traditionally this includes all the area bounded by a drainage divide or topographic break in slope between one basin and another. The catchment area of some hillside or plateau karst features is diffuse; however, it can be operationally defined by multiplying the width of the area that could plausibly drain to the feature times the distance to the top of the hill, plus any area in the downslope direction that drains to the feature. Channels are not required to define the catchment area. Outlining the drainage area on a 2-foot or other detailed contour map is recommended. Offsite areas must be included in the calculation of catchment area.

Cave A natural underground open space formed by dissolution of limestone that is large enough for an average-sized person to enter. Note that caves are commonly partly filled by breakdown, loose rocks, debris, or soil; assessment requires sufficient investigation to define the dimensions of the feature defined by in-place bedrock. Excavation or trenching can open a formerly inaccessible space to permit entry; this possibility should be considered when describing karst features.

Cave footprint Horizontal or plan view map of the cave, projected up to the surface to show that area of the site underlain by cave passage. The cave footprint is not the same as a buffer zone around the cave entrance. BMP design should consider appropriate methods for protecting the drainage area into the cave which may include a large area beyond the cave footprint. The radius of typical mapped cave footprints in the Edwards recharge zone is shown in Figure 2. Ninety percent of mapped Edwards cave footprints lie within a 150 ft circle centered on the opening. An additional area outside of this radius might be needed as a buffer. Note that cave mapping to document the extent of cave passage is likely to produce a more accurate and smaller footprint.

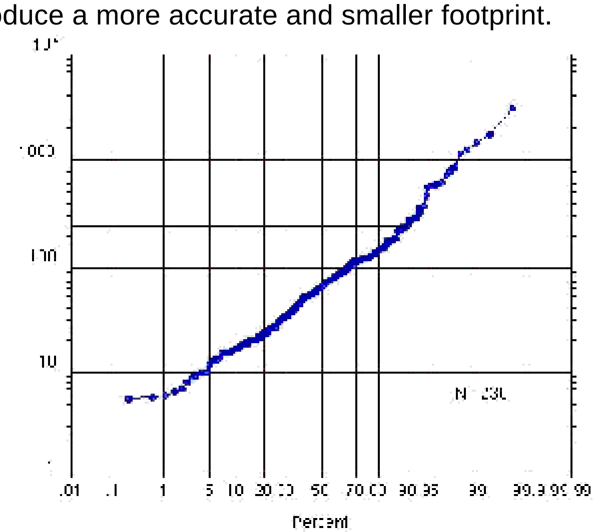


Figure 2. Cumulative frequency maximum radius of the cave footprint from the cave entrance

measured from 236 mapped caves in the Edwards recharge zone in the Texas Speleological Survey files.

Discharge feature Spring or seep where water is discharged from a local or regional groundwater system that may have an associated system of caves or solution cavities.

Dripstone Calcium carbonate or other minerals that precipitate on cave roofs or wall and cave floors from dripping water, stalactites, soda straws, etc.

Edwards Aquifer That portion of an arcuate belt of porous, waterbearing, predominantly carbonate rocks known as the Edwards (Balcones Fault Zone) Aquifer trending from west to east to northeast in Kinney, Uvalde, Medina, Bexar, Comal, Hays, Travis, and Williamson Counties; and composed of the Salmon Peak Limestone, McKnight Formation, West Nueces Formation, Devil's River Limestone, Person Formation, Kainer Formation, Edwards Group, and Georgetown Formation. The permeable aquifer units generally overlie the less-permeable Glen Rose Formation to the south, overlie the less-permeable Comanche Peak and Walnut formations north of the Colorado River, and underlie the less-permeable Del Rio Clay regionally.

Epikarst Upper part of the bedrock at the surface or beneath the soil that is characterized by increased fracturing and enhanced limestone dissolution. The epikarst is a zone of significant water storage and transport. Synonym for subcutaneous zone.

Fault Fracture along which there has been displacement of one side of the fracture relative to the other side. It is common in the Balcones fault zone for the displacement to occur across a fault zone composed of a number of faults and fractures. Some of the exposed Balcones faults are filled with cement and breccia and pulverized clay and limestone (fault gouge). Other fault zones are poorly exposed and are recognized by juxtaposition of different stratigraphic intervals, by topographic or vegetation patterns that suggest a structure beneath the soil (lineament), and by unusually abundant and strongly oriented fractures or fracture zones in exposed bedrock.

Feature density A measurement on a transect that extends one or more times across the feature in a direction that will adequately sample the number of observed features. Represent as a feature density as a fraction in the units of number of features/foot measured.

Features Geologic or manmade features on the recharge zone or transition zone with a superficial appearance that suggests that a potential for hydraulic interconnectedness between the surface and the Edwards Aquifer exists, and rapid infiltration to the subsurface may occur. These features include but are not limited to closed depressions, sinkholes, caves, faults, fractures, bedding plane surfaces, interconnected vugs, reef deposits, wells, borings, and excavations.

Flowstone Calcium carbonate or other minerals that precipitate on cave walls and cave floors from flowing water.

Geologic assessment A report prepared by a geologist describing site-specific geology. The focus of the geologic assessment is identification and evaluation of geologic and manmade features to determine which features are sensitive.

Geologist A person who has received a baccalaureate or post-graduate degree in the natural science of geology from an accredited university and has training and experience in groundwater hydrology and related fields, or has demonstrated such qualifications by registration or licensing by a state, professional certification, or completion of accredited university programs that enable that individual to make sound professional judgments regarding the identification of sensitive features located in the recharge zone or transition zone. After September 1, 2003, geologists conducting assessments are required to be licensed according to the Texas Geoscience Practice Act..

Global Positioning System (GPS) A low- to- moderate-cost portable device that is used to determine location in latitude and longitude or other coordinate system.

Humus Dark organic material in a soil typically includes humus.

Infilling in features Note the conditions when you visit the feature – does it appear to be in natural condition or has it been disrupted by activities on the site? Washed-in or remnant material in the feature that gives evidence of the dynamics of the feature with respect to surface water and recharge flow. Some features lack filling and can be described as bedrock floored. Coarse material that has been somewhat rounded by transport is described as cobbles or gravel. Nontransported slabs of rock collapsed into a karst feature is called breakdown. Typical loose or soft mud or soil infilling can also include organics, leaves, sticks, and humus and has gray to dark brown colors. Fine-grained compacted clay-rich sediment is distinguished from the loose and soft sediment by red or gray colors or by incipient soil profile development. Reddish clay-rich insoluble residue within karst can be described as terra rossa. Vegetation is a common component of infilling and may provide evidence of the hydrologic significance of the feature. Dripstone and flowstone are commonly formed in caves and can be either active or relict. Calcite or other cements can partly or completely fill vugs and fractures. Many other types of infillings may be observed and should be briefly described in the narrative.

Infiltration Movement of water into the pores and openings in soil and rock. Losses from a ponded water body can be by evaporation or by infiltration. The infiltration rate is measured in depth of water absorbed into the rock or soil per unit time under specified conditions. Modeled infiltration rates shown in Figure 3 for background conditions provide context for describing rapid infiltration.

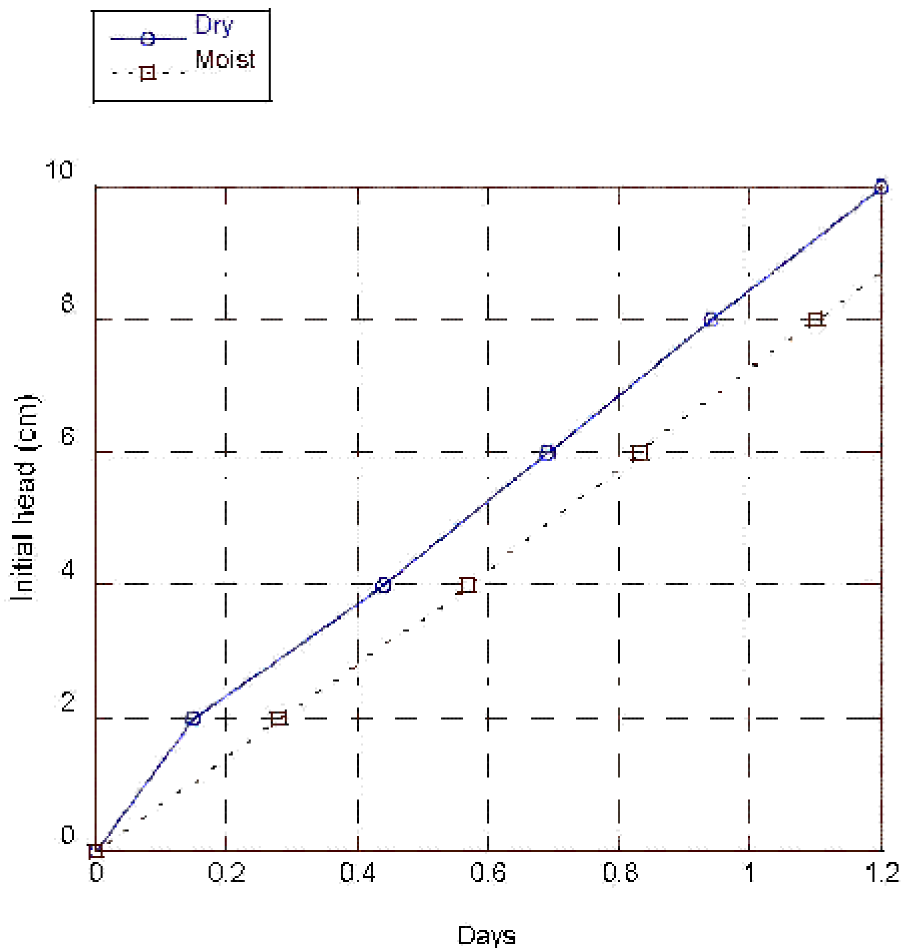


Figure 3. Modeling results showing time in days for ponded water of various initial heads to drain through soil under background conditions. Faster drainage qualifies as rapid relative to background. Hydrus-ID code (Simunek and others, 1998) on 5 m of clay loam (hydraulic conductivity 6cm/day). Dry conditions used matric potential of -1000 cm and moist conditions used -100 cm.

Karren Superficial (millimeter to meter depth) sculpture resulting from bedrock solution by direct rainfall, sheet wash, channel flow, and percolation under mantle to form channels, furrows, and pits separated by ridges or pinnacles. Karren, because of their superficial origin, are not sensitive features unless they are hydraulically connected to a feature that suggests connection to the subsurface or rapid infiltration.

Karst features Geomorphic, topographic, and hydrologic features formed by solution of limestone by water. Caves, solution cavities, sinkholes, swallow holes, solution-enlarged fractures are common types of karst features; many more can be found in a textbook or glossary of karst terms.

Manmade feature in bedrock Water wells, sanitary sewer lines, storm sewer lines, trenches, quarries, and other cultural features that intersect bedrock and can potentially increase the rate of recharge to the subsurface.

Non-karst closed depression A natural or non-natural topographic depression that is not formed by karst processes and is not bedrock floored. Features larger than 6 feet in at least one direction and with 6 inches or more of topographic relief should be listed in the table. Examples of non-karst closed depressions include scoured pools in drainages, animal wallows, large animal burrows, large pits created by clearing tree stumps, dammed tanks, or other agricultural constructions that are soil floored and do not modify the topography on top of bedrock. Care must be taken to determine that the feature was not a karst feature that has been subsequently modified by human or animal activities or a scour that overlies a swallet. The reasons for determination that the feature is non-karst should be noted in the narrative description of site geology.

Ordinary high-water mark On non-tidal rivers the line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank; shelving; changes in the character of soil; destruction of terrestrial vegetation; the presence of litter and debris; or other appropriate means that consider the characteristics of the surrounding areas.

Phreatic cave Cave initiated and developed by dissolution under conditions where all voids are water filled, usually below the water table. Progressive abandonment of phreatic caves usually occurs as erosion lowers valley floors and parts of the flooded system are drained. Phreatic caves can be recognized by evidence of dissolution not strongly controlled by gradient, including “blind” pockets on walls and ceilings. The most common phreatic passage form is a tube; however, modification of this passage shape commonly occurs by collapse when the void is dewatered and by reworking in the vadose zone.

Recharge zone Generally, that area where the stratigraphic units constituting the Edwards Aquifer crop out, including the outcrops of other geologic formations in proximity to the Edwards Aquifer, where caves, sinkholes, faults, fractures, or other permeable features would create a potential for recharge of surface waters into the Edwards Aquifer. The recharge zone is identified as that area designated as such on official maps located in the appropriate regional office and groundwater conservation districts.

Reef limestone Accumulations of the shells and shell fragments of rudists are characteristic of some parts of the Edwards Group. These rocks may be porous because space is preserved between coarse shell fragments or because rudist shell material has dissolved, forming large pores. The large and interconnected pores of reef limestone provide higher permeability than tight limestone; however, matrix permeability is probably an order of magnitude lower than fracture and karst permeability and, therefore, in most cases would be considered part of the background, non-focused recharge.

Sensitive feature Permeable geologic or manmade feature located on the recharge zone or transition zone where a potential for hydraulic interconnectedness between the surface and the Edwards Aquifer exists, and rapid infiltration to the subsurface may occur. Geologists doing the assessment are not asked to express a high degree of certainty that these conditions are met in order to rank features as sensitive.

Setback A buffer area widely used for protection of karst features. Setback usually implies that land use is restricted to activities that are protective of water quality and water quantity, and/or biologic or cultural aspects of the feature. Setback size and extent should be thoughtfully designed to accomplish a specified objective over a stated timeframe.

Significant recharge feature A karst feature with a well-defined surface opening (such as a cave) or a sinkhole (without a surface opening) that has a catchment area greater than 1.6 acres.

Sinkhole A shallow, broad topographic depression formed in response to karst processes. Sinkholes are pragmatically defined as features greater than 6 feet in diameter having more than 6 inches of topographic relief. Smaller karst features can be described as solution cavities. Sinkholes are usually circular or funnel shaped and sometimes have exposed rimrock at the perimeter. It is common for sinkholes to have other karst openings (caves, solution cavities, or solution-enlarged fractures) in the floor. Sinkhole implies that processes including collapse, subsidence, and soil sapping over geologic time have caused the land surface to sink below the surrounding area. Sinkholes can have very subtle topographic expressions, so awareness of soil and vegetation characteristics can help the geologist locate them. For well-developed sinkholes, the sinkhole geomorphology should be mapped to provide detail needed to support BMP design, including the drainage area, break in slope at the edge of the bowl, bowl volume, drain location(s), drain type and size.

Site The entire area included within the legal boundaries of the property described in the application. Regulated activities on a site that is located partially on the recharge zone and transition zone, where the natural drainage in the transition zone flows back to the recharge zone, will be treated as if the entire site is located on the recharge zone.

Soil profile Sediments that have been retained at the land surface will develop a soil profile that can be used to roughly estimate the age of the land surface. Soil profiles in the Edwards recharge zone typically have 6 to 18 inches of brownish-red or brownish-gray, granular to finely blocky soil underlain by redder clayey soil with a distinctly blocky fabric (ped structure) characteristic of soils. A fill without horizonation or without a well-formed blocky structure probably has not formed a soil profile and may be young.

Solution Cavity A natural cavity or depression formed as a result of dissolution of limestone. This category is designed to capture features that are not large enough for a normal-sized person to enter but appear to be part of a system of interconnected voids that connect the surface with the subsurface. The size and geometry of the feature is defined by in-place bedrock; fill must be probed or excavated to determine the size of the feature. If cavity size appears to increase at depth, this observation should be used to classify the feature as a solution cavity or cave, depending on the inferred maximum size. Note that cavities include areas where dissolution has increased the opening size and permeability along bedding planes as well as fractures. Features that the geologist interprets as limited to the surface and soil zone (karren, weathering textures, and features formed on loose blocks) are not reported as solution cavities.

Solution-enlarged fracture(s) Fractures that show evidence of being locally enlarged by dissolution of limestone. Solution enlargement can be recognized by mismatched fracture surface shapes on measurable (larger than hairline) openings.

Swallet or swallow hole A focused recharge feature in an intermittent drainage or stream in karst terrain. Some swallow holes have a surface expression, for example, a cave opening or formation of a whirlpool in the stream at high flow. The general case is that fine soil and sediment as well as gravel are deposited over the bedrock feature during falling stages of flow thereby intermittently or frequently obscure it. During the geologic assessment, care must be taken to investigate the possibility that these highly sensitive features may be present in drainageways. The best method is to field test for infiltration or gauge the stream when it is flowing. Observation of rapid infiltration of pooled water at rates higher than background can help identify buried swallets. Indicators of the presence of karst features, for example, dipping or fractured bedrock indicating collapse can help to identify these sensitive features when they are obscured by gravel and sediments.

Terra rossa Residual red soil of some karst areas. In the Edwards recharge zone it is generally considered to be a relict soil or old insoluble residue.

Transition zone That area where geologic formations crop out in proximity to and south and southeast of the recharge zone and where faults, fractures, and other geologic features present a possible avenue for recharge of surface water to the Edwards Aquifer, including portions of the Del Rio Clay, Buda Limestone, Eagle Ford Group, Austin Chalk, Pecan Gap Chalk, and Anacacho Limestone. The transition zone is identified as that area designated as such on official maps located in the appropriate regional office and groundwater conservation districts.

Trend Direction or bearing of the outcrop of structural features such as faults, fractures, or aligned karst features. Subtle features such as topographic and vegetation alignment can define a lineament and indicate a trend.

Vadose cave A cave that underwent most of its development above the water table. Within the vadose zone, drainage is free-flowing under gravity, and cave passages therefore have air above water. Characteristics are uneroded ceilings and continuous downhill gradients except for short perched sumps. The main passage forms are canyons with meanders and potholes, keyholes, and cylindrical shafts. Older higher passages have been abandoned by groundwater except in times of extreme aquifer recharge.

Vug Small cavity in limestone, smaller than a solution cavity but larger than normal intergranular pores (<1 foot >1/4 inch). Vugs in Edwards Limestone commonly occur where burrow fillings have preferentially weathered, creating “sponge work.” This effect is best developed at the near surface; at depth the burrow-filling calcite and dolomite are preserved, although they may be highly leached and permeable. Vugs rimmed with calcite crystals (dog-tooth spar) are common indicators that gypsum or anhydrite nodules have been dissolved. Large pores of vuggy limestone, if interconnected, provide higher permeability than limestone with smaller pores; however, matrix permeability is probably an order of magnitude lower than fracture and karst permeability and therefore in most cases would be considered part of the background non-focused recharge. Preservation of outcropping boulders of vuggy limestone may be evidence that flow has not been focused through these rocks in the epikarst. The area should be examined for evidence that the vuggy rock has preferentially formed karst features.

Zone Any type of karst feature that occurs along a trend or in a cluster can be described as a zone. Aligned or clustered features are more likely to be an indicator of an integrated flow system at depth than an isolated feature. Alignment is expected in areas where conduit flow is strongly influenced by structurally controlled fractures. Fracture control favors connection between the surface and the subsurface and integrates subsurface flowpaths to provide rapid flowpaths to the aquifer and to discharge points. Fracture zones are well developed adjacent to faults and may be more permeable than the fault plane itself. Zones of clustered or aligned features can be indicated by subtle evidence such as vegetation, changes in soil properties, and subtle topographic changes.

V. Citations For Sources of Further Information

Barrett, M. E., 1999, Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices: TCEQ, Field Operations Divisions, RG-348.

BMP design guidance for Edwards recharge zone

Center for Cave and Karst Studies, Western Kentucky University, Bowling Green. http://caveandkarst.wku.edu/index.html

Karst and groundwater related coursework and seminars, links

Clark, A. C., 2000, Vulnerability of groundwater to contamination, Edwards aquifer recharge zone, Bexar County, TX, 1998, USGS Water-Resources Investigations Report 00-4149.

Detailed regional vulnerability mapping using air photo interpretation and consideration of hydrogeologic unit, faults, sinkholes and caves, and slope and soil characteristics.

Collins, E. W., 2000, Geologic map of the New Braunfels 30" x 60" quadrangle: The University of Texas at Austin, Bureau of Economic Geology Miscellaneous Map 39, 1:100,000.

Geologic map of Edwards outcrop, western Hays County to Medina Lake.

Eckhardt, G. A., 2000, The Edwards aquifer homepage:

http://www.edwardsaquifer.net/.

Recently updated review of some of the issues and research relevant to understanding the Edwards aquifer.

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Extensive and updated (1998) glossary of karst terms.

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Karst geomorphology and hydrology: Unwin Hyman, London, 601 p.

Widely cited textbook containing chapters on karst landforms and karst hydrology with a brief overview of construction and pollution issues related to karst.

Ging, P. B., Judd, L. J., Wynn, K. H., 1997, Water-quality assessment of south-central Texas; occurrence and distribution of volatile organic compounds in surface water and ground water, 1983-94, and implications for future monitoring: U.S. Geological Survey, Water-Resources Investigations WRI 97-4028, 20 p.

Water quality data, San Antonio segment

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Klimchouk, A. B., Ford, D. C., Palmer, A. N., Dreybrodt, Wolfgang, eds., 2000, Speleogenesis; evolution of karst aquifers: Huntsville, Ala., National Speleological Society, 527 p.

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Mahler, B. J., Lynch, L., Bennett, P. C., 1999, Mobile sediment in an urbanizing karst aquifer; implications for contaminant transport, Environmental Geology: v. 39, no. 1, p. 25-38.

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Basic review paper on karst processes

Simunek, J., M. Sejna, and M. T. van Genuchten, 1998, The Hydrus-1D Software Package for Simulating the One-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media, *Users Manual, Version 2.0, U.S. Salinity Laboratory, Agricultural Research Service, 178 p*.

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Small, T. A., and Hanson, J. A., Hauwert, N. M.,1996, Geologic framework and hydrogeologic characteristics of the Edwards Aquifer outcrop (Barton Springs segment), northeastern Hays and southwestern Travis counties, Texas: U.S. Geological Survey, Water-Resources Investigations WRI 96-4306, p. 15 (1 sheet).

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Small, T. A., and Lambert, R. B., 1998, Geologic framework and hydrogeologic characteristics of the outcrops of the Edwards and Trinity aquifers, Medina Lake area, Texas: U.S. Geological Survey, Water-Resources Investigations WRI 97-4290, p. 17 (1 sheet).

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Stein, W. G., and Ozuna, George, 1995, Geologic framework and hydrogeologic characteristics of the Edwards Aquifer recharge zone, Bexar County, Texas: U.S. Geological Survey, Water-Resources Investigations WRI 95-4030, p. 8 (1 sheet).

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The Texas Speleological Survey is a non-profit corporation with a mission to collect, organize, and maintain information on Texas caves and karst.

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Veni, George, 1999, A geomorphological strategy for conducting environmental impact assessments in karst areas: Geomorphology, v. 31, Issues 1-4, December 1999, p. 151-180.

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White, W.B, 1988, Geomorphology and hydrology of karst terrains: Oxford University Press, 464 p.

Karst textbook

Figure 4. EAPP - Solution Cavity Form on the following pages.

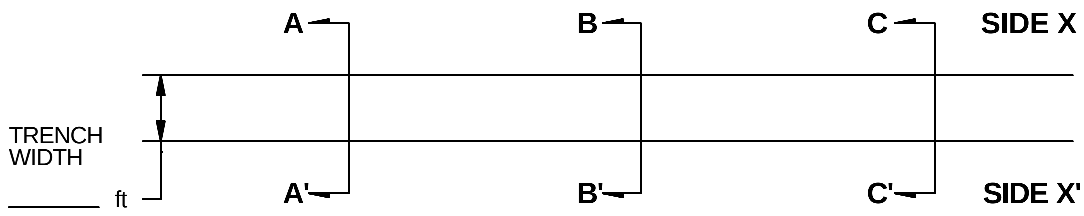
EAPP - Solution Cavity Form

- ☐ Sewage Collection System
- ☐ Water Line
- ☐ Other ______________________________

PROJECT: ______________________________

DATE OF FIND: ______________ DATE TNRCC NOTIFIED: ______________

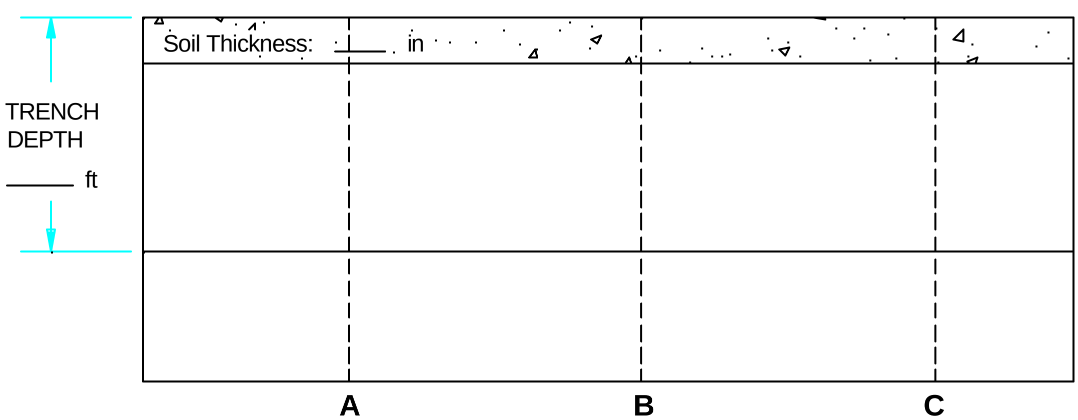
Plan View:



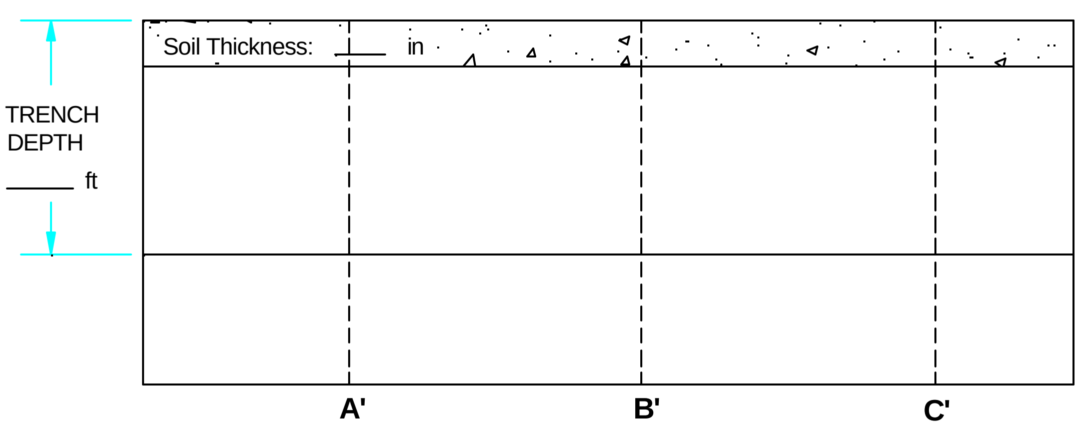
LINE: _____ STATION _____ + _____ _____ + _____ _____ + _____

Downgradient **POROSITY ZONE** Upgradient

Profile (Side X):



Profile (Side X'):



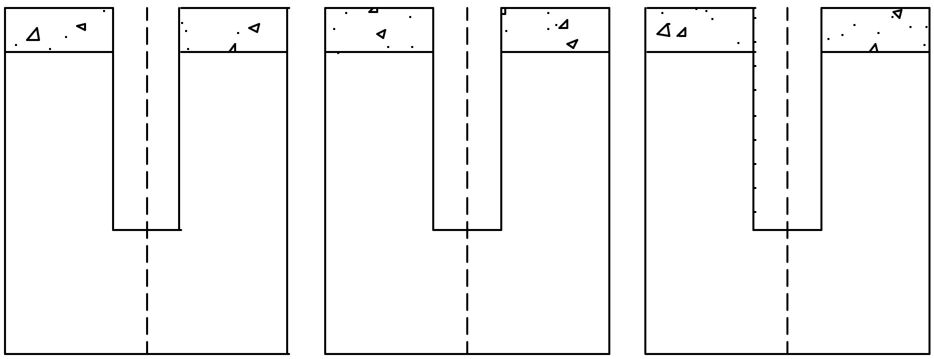
Sewage Collection System

Solution Cavity Form
TNRCC - EAPP

Notes:

- Include dimensioning
- Include illustrative pictures for complex features
- Attach additional pages if necessary.
- Identify case of feature (EAGD 96.004)

Cross-Section View:



Section A-A' Section B-B' Section C-C'

Line	Station	Feature	Case	Sensitivity

Notes: ____

____

____

____

____

____
Printed Name of Geologist

____ ______________
Signature of Geologist Date