Groundwater investigations in karst areas

Petroleum Remediation Program

I. Introduction

This guidance document outlines procedures and techniques that should be used to implement accurate, reliable, and cost-effective ground water investigations in karst areas. Hydrogeologic characteristics depart significantly from those of porous media in karst aquifers. Variances from conventional hydrogeologic site characterization practices are therefore necessary in karst areas, due to the presence of hydrogeologic features and properties that cannot be characterized by porous media approximations.

Over the past decade, a large number of petroleum release sites have been investigated in the karst region of southeastern Minnesota, and remediation attempted at several. Unfortunately, many of these releases were incompletely characterized by conventional methods, with inadequate monitoring systems, and even failed remedial systems. Even in those cases where the situation was eventually remedied, needless expenditure of resources as well as environmental and public health risks resulted. The overall quality of the environmental response at such sites, both in terms of effectiveness and timeliness, was hence compromised.

Therefore, this document was developed to fill a long-standing need for guidance on hydrogeological investigations in the karst region of the state. This guidance document addresses the technical basics of characterizing both hydrogeology and ground water contamination risk in a karst setting. The final form of this guidance has been prepared based on a three year (1996-1999) field trial and comment period. It is expected that it will assist the consulting and regulated communities to produce cost-effective and technically valid ground water investigations at petroleum release sites in the karst region of Minnesota. This will promote efficient utilization of resources by both the state and responsible parties.

This document refers to ground water investigation procedures required to be applied only in the karst areas of Minnesota, as defined in Section II of this document. Investigations in other areas of the state do not need to comply with this document. However, this document may serve as a useful reference for investigations in non-karst areas of Minnesota where fracture flow occurs. In the region where this guidance does apply, the basic procedures of site characterization and ground water investigation not specifically addressed in this document should follow the appropriate standard MPCA Petroleum Remediation Program technical guidance.

II. Karst region of Minnesota

The carbonate bedrock in southeastern Minnesota has been subjected to at least 400 million years of karstification. Consequently, all these formations are karstified, with a wide range in the intensity of the karstification. This range is very poorly understood, is not well established, and is only now beginning to be mapped in the state. However, this is largely irrelevant to ground water contamination issues, since the presence of even minor solution features can lead to significant deviations from the porous media approximations on which conventional ground water investigations are based. Essentially, all of the carbonate bedrock aquifers are karst aquifers and both ground water and contaminant movement is best described and managed under discrete-flow or triple-porosity models, with conduit, fracture and matrix flow.

Figure 1 highlights the southeastern portion of Minnesota underlain by soluble carbonate bedrock of the Ordovician Prairie du Chien Group and stratigraphically higher carbonate formations. This area is subject to karst processes. Note that this 'southeastern portion of Minnesota' includes all but the northwestern portions of the Twin Cites metro area and extends as far southwest as Mankato and the corner of Martin County.

Figure 1.

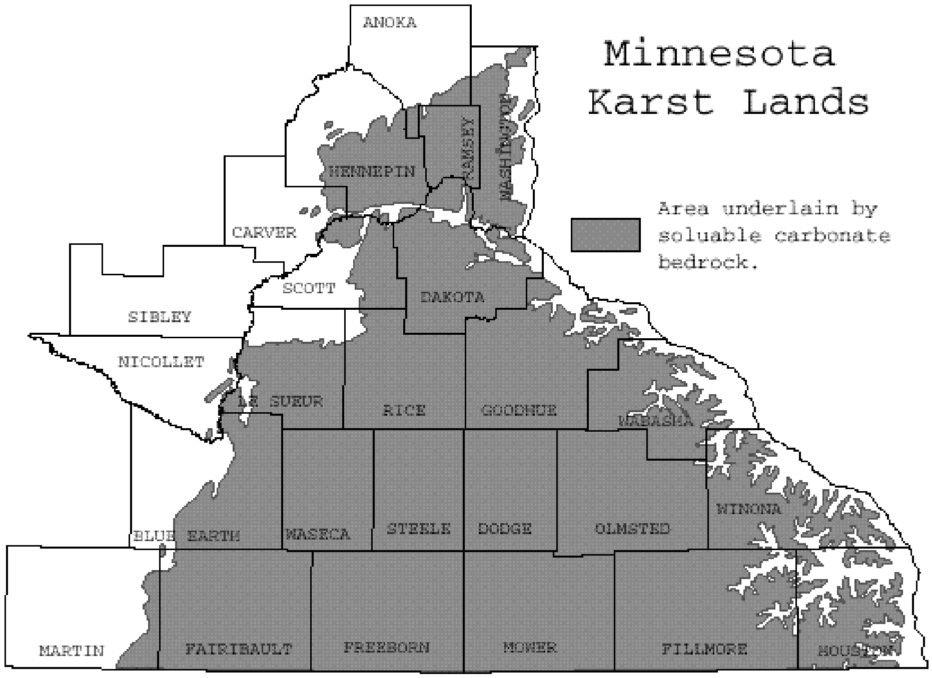
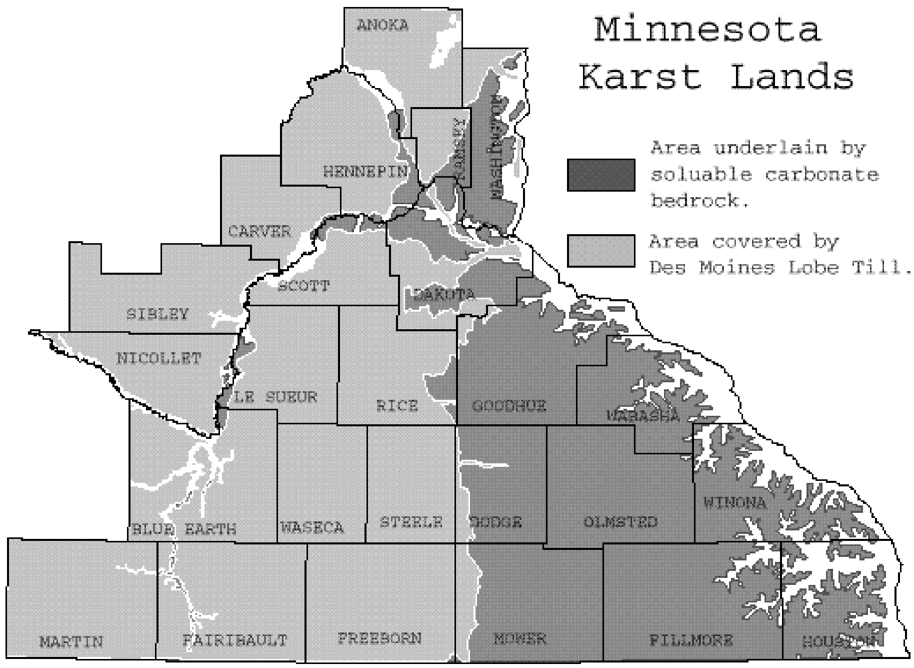


Figure 2 shows the extent of the latest Wisconsin age glacial ice cover in southeastern Minnesota's karst areas. The areas that had been covered by Wisconsin age ice are often, but not always, covered with relatively thick layers of glacially derived sediments. Conversely, the sediments in areas that had not been covered by Wisconsin age ice tend to be thin. All except the extreme eastern parts of Winona and Houston counties have been glaciated at least once during the Pleistocene. Even though all of the carbonate bedrock has been subject to karst dissolution and contains karst features, the most visible karst features are understandably concentrated in the areas that had not been covered by the Wisconsin ice. This also has resulted in absence of, or a relatively thin layer of, glacial sediment cover over these areas. Hence, these are also the regions of highest susceptibility to ground water contamination. As shown in the figure, this area covers all or parts of the following counties:

- Hennepin
- Scott
- Goodhue
- Olmsted
- Fillmore
- Ramsey
- Dakota
- Wabasha
- Winona
- Houston
- Washington
- Rice
- Dodge
- Mower

Figure 2.



III. Karst aquifers of Minnesota

In the previously listed 14 counties, the following geologic units should be treated as karst aquifers, and the ground water investigations should be based on the procedures outlined in this document:

Geological unit	Period	Approximately maximum thickness
Cedar Valley Group	Devonian	220 feet
Wapsipinicon Group	Devonian	75 feet
Maquoketa formation	Ordovician	70 feet
Dubuque formation	Ordovician	40 feet
Galena Group	Ordovician	230 feet
Decorah confining unit		
Platteville formation	Ordovician	35 feet
Glenwood confining unit		
St. Peter formation[1]	Ordovician	100 feet
Prairie Du Chien Group	Ordovician	300 feet

[1]**Not a carbonate unit, but significant karst features appear in it. Most likely as a result of the stopping upward of solution cavities originating in the underlying Shakopee Formation of the Prairie Du Chien Group.**

IV. Conducting the site investigations

Many of the procedures described in this section of the document have been field proven at petroleum release sites in southeastern Minnesota, and others are based on the ASTM standards. Professional judgment may still need to be exercised in selecting the applicable procedures at specific sites. Whenever felt necessary, MPCA staff should be consulted for site-specific decisions. However, some of these procedures have proven to be essential for a minimal characterization of a karst site, and should be performed at all appropriate sites as part of the remedial investigation (RI). The MPCA staff should be consulted beforehand if it is planned to exclude any of them from the RI. Application of further karst specific methods may be required based on the data obtained from these basic procedures. Some of these recommended additional procedures are outlined in shaded boxes to supplement the required procedures for each phase of the investigation.

1. Evaluating regional geology

Pre-existing information for the area must be examined and available information compiled and presented in the remedial investigation (RI) report for the site. Information commonly available includes, but is not limited to:

- Geologic maps
- Stratigraphic cross sections
- Topographic maps
- Topographic cross sections
- Geophysical logs
- Cave maps
- Aerial photographs
- Soil surveys
- Investigation results from other sites in the area – environmental, geotechnical, storm water etc.

2. Evaluating site geology

Field reconnaissance within a minimum one mile radius of the site should be completed early in the project to identify and evaluate features such as those listed below that which offer an insight into the geology and hydrology of the site.

- Bedrock outcrop properties
- Open fractures and joints
- Sinkholes
- Caves
- Springs
- Seeps
- Disappearing streams
- Karst windows
- Dry valleys

Bedrock outcrops should be examined to determine the stratigraphic position of seeps, springs, caves, zones of solution, and zones of fracturing – both horizontal and vertical. The relationship of shale beds or other low permeability units to hydrologic features should be determined.

Minor, structural features such as anticlines, synclines, monoclines and domes may alter the local dip of the nearly flat-lying bedrock formations. Such subtle features, particularly in areas of locally high permeability and low gradients can radically alter flow directions. The orientation of joint sets, particularly the largest and most systematic joints are equally important. Such structural information is rarely shown on published geologic maps, and hence evaluation of these is important during the site investigation.

In the absence of any suitable outcrops, some of this information can be obtained from core drilling. In case of inadequate core recovery or if destructive drilling is used, this information can be obtained with applicable geophysical techniques (such as gamma, resistivity, or conductivity for stratigraphy; and caliper or television for fractures). In areas of thin or absent overburden, the location of some high-angle fractures and large karst features can also be determined from topographic maps and aerial photographs.

3. Evaluating regional hydrogeology

In addition to the data examined during Step 1 – Evaluating regional geology, all existing hydrogeological information for the area should also be consulted. This should include compiling and studying all available ground water data for the area, and submitting the same in the RI report. Such data may include:

- Water table or potentiometric maps
- Water level records
- Water quality records
- Pump test data
- Well performance data
- Results of other groundwater/surface water investigations in the area

Ground water investigations at the site should then be designed and conducted in the context of this regional setting.

4. Evaluating site hydrogeology

a) Inventory: As described in Step 2 – Evaluating site geology, the presence within a radius of at least one mile of the site of surface karst landforms such as sinkholes, disappearing streams, dry valleys, springs, seeps, karst windows and subsurface karst features such as caves and solutionally enlarged joints should be recorded. The information from Step 2 and Step 4 should then be compiled into a **Karst Hydrogeologic Inventory** that must be completed and submitted with the RI report for all sites at which this guidance is applied.

In agricultural areas, drain tile systems should be examined. Such systems routinely drain to karst features or to surface waters that then sink into karst features.

b) Aquifer variability – Off-site: Hydraulic head, temperature and specific conductance at any nearby wells and discharge, temperature and specific conductance at natural discharge points such as springs should be measured. The purpose is to document the natural variability of the ground water system, especially in response to recharge events. This must be done for at least three major recharge events during the site characterization and prior to submitting the RI report. Refer to Step 5 – Contamination sampling schedule and frequency, for details on recharge event sampling. Such measurements can be done by hand but experience has shown that simple data logger systems are sufficiently robust and economical that they are normally the most cost-effective ways of obtaining the necessary information. Placement of automatic samplers at these sampling points provides another reliable and economical means of obtaining some of this data without necessitating repeated field visits.

The same parameters must also be measured at these points at all other routine site monitoring events (the standard quarterly schedule unless specified otherwise) to establish background values, so that comparisons can be made to determine system variability and response times. As required in standard Petroleum Remediation Program guidance, the RI report must include a minimum of two quarterly monitoring events.

c) Aquifer variability – On-site: The same measurements as specified for off-site water wells must also be conducted at site monitoring wells once they are installed, according to the same schedule as described above.

d) **Potentiometric map:** Along with the measurements conducted at site monitoring wells, the elevations of local base-level surface water bodies and elevations of springs should be used as data points for constructing a potentiometric map and determining the dominant groundwater flow direction. All available water wells in the area should also be used for water level measurements. Water levels from all points used should be checked against those from neighboring points to screen out any anomalous or non-representative water levels caused by vertical gradients or fracture flow. The water table configuration must be carefully evaluated. For example, 'stair step' or 'v' patterns versus smooth patterns can yield important information about discrete flow pathways. Potentiometric maps should be extended significantly beyond property boundaries in order to determine the likely extent and direction of contaminant travel, and to increase the accuracy of the map. For maximum accuracy and validity, the study area for determining the potentiometric surface must extend in all directions away from the site until either the water table is established by measurements to be consistently higher than at the vicinity of the site or a definite discharge boundary (such as a large perennial stream) is reached. The potentiometric map and ground water flow direction must be re-computed for all routine site-monitoring events, as well as for each of the recharge events.

The potentiometric surface should be used as a first approximation for delineation of ground water flow directions and basin boundaries. If required, this can be confirmed by properly conducted tracer tests.

5. Ground water sampling schedule and frequency

In order for samples to be representative of the conditions in the karst aquifer, frequency of sampling needs to be selected to reflect the inherent variability rather than at pre-specified, fixed intervals as is typically done. Therefore, during the RI, the standard quarterly frequency must be supplemented by sampling conducted initially for at least three major recharge events. These should be the same three events used to measure aquifer variability in Step 4 – Evaluating site hydrogeology.

The RI report should therefore include a minimum of two quarterly ground water monitoring rounds and a minimum of three recharge event monitoring rounds, conducted at all monitoring points. The basic quarterly sampling at these points will be expected to continue, unless specified otherwise by the MPCA. Additional recharge event sampling requirements should be decided based on the results of the preliminary three rounds, in consultation with the MPCA.

Recharge event contaminant sampling should consist of a sample taken during the event or immediately following it (no more than twelve hours should elapse between recharge event termination and monitoring), and another 3 to 5 days after its termination. If the field parameters during the post-recharge sampling show significant ongoing influence of the recharge event, a second sample should be taken another 3 to 5 days later. This same schedule and sampling events should also be used for measuring the aquifer variability as required in Step 4 – Evaluating site hydrogeology.

At the start of a recharge event, it is not possible to know how significant it will be. At the middle or end, it is often too late to collect samples that will definitely characterize the aquifer response to the event. Therefore, it is always preferable to commence sampling at the start of an event, and collect several rounds of samples spread out over the duration of the event. After the event, the decision of whether or not to analyze the samples, as well as the selection of which samples to analyze can be based on professional judgment and an evaluation of the significance of the event. Therefore, the most applicable data will be obtained from monitoring plans that include automated monitoring using equipment such as data loggers and automatic samplers. This allows 'remote' sampling, without the need to make repeated and precisely timed field visits, which may sometimes be in poor weather conditions.

Snowmelt events can be major recharge events for karst aquifers. Hence, spring thaw monitoring is encouraged in addition to that conducted after major rainfall events.

6. Establishing the ground water monitoring system

a) Preferred methods

Natural monitoring points such as springs, cave streams, and seeps identified during Step 1 through Step 4 as being potential discharge points for ground water from the site must be incorporated into the ground water monitoring network, as these discharge points typically intercept flow from a larger area than a monitoring well.

At some sites, it may be necessary to collect a select number of samples for background water quality at springs, cave streams, and off- site wells that yield water that is geochemically representative of the aquifer. These upgradient/background monitoring points can even be located in an adjacent ground water basin or surface watershed, since in fractured rock and karst aquifers ground water conduits can cross surface drainage divides.

When sampling from alternative monitoring points, samples should be collected as close to the discharge point as possible. Spring discharge must be determined during all sampling events, even if only based on a stage height measurement or a relative visual estimate. Visual parameters (such as turbidity, coloration, iron staining, sheen or odors) and the standard field parameters (such as temperature, pH, and specific conductance) must also be recorded, just as they would be while sampling from wells.

b) Conventional methods

Placement of monitoring wells must be based on the interpretation of data gathered during site characterization. Well placement and construction should account for the significant fluctuations in water table elevation that are typical of karst aquifers, as well as for the presence of discrete high-permeability zones that may transport the majority of ground water. The location of high permeability zones should guide the placement of monitoring wells even if this is at considerable distances off-site. Horizontal zones of high permeability along bedding planes can be the most important in karst aquifers. If site characterization has identified such zones of enhanced permeability, the wells should be designed to intersect them. If no such zones could be identified, the well should be cased to the depth where competent rock is encountered and left open below that for a minimum interval of ten (10) feet. Accurate knowledge of site geology is critical for designing such open-hole monitoring wells, since excessive open hole in a karst aquifer may provide pathways for contamination to reach previously uncontaminated zones. Additionally, by state law (Minnesota Rules, Chapter 4725) interconnection of aquifers otherwise separated by a confining layer is not permitted in Minnesota. In settings where the matrix blocks also have appreciable porosity, it will be necessary to monitor the blocks as well as the high-permeability zones, since the blocks may function as long term storage reservoirs for the contaminants.

Careful records should be maintained of stratigraphic zones where circulation was lost during drilling, where enhanced yields were obtained during well development or aquifer tests, and where open or mud-filled cavities were encountered during drilling.

It is recommended that video logging be used to determine the location and orientation of fractures and conduits to aid in the proper placement of monitoring well screen (s).

In many karst areas, substantial flow occurs at the soil bedrock interface and within the subjacent epikarst. Wells placed across this interface, or within the epikarst may only be intermittently saturated. However, these wells are likely to intercept the early movement of contaminants from the overlying source. At least one such well/lysimeter must be placed at or near the source area of contamination, if significant contamination exists in the overburden.

At most sites, it will be acceptable to initially install one monitoring well into the aquifer and one epikarst well (if deemed necessary), both at the source area. The RI should focus on combining the determination of source area contamination, flow dynamics, flow pathways, discharge points and receptors, and overall risk. The need for expanding the monitoring well network, further investigations and remediation should be based on this information.

The hydraulic connection of any additional monitoring wells with the contamination source area should be verified and demonstrated by hydraulic or tracer tests. 'Downgradient' monitoring wells cannot be assumed to intercept flow from the site unless a positive connection from the site to the monitoring point is demonstrated. Tests can be:

(a) Hydraulic tests: Packer tests and bore hole logging techniques should be used to locate both high-conductivity and low-conductivity zones within the aquifer. Pumping tests should be used to test the hydraulic connections between the various parts of the system. Using a pumping well at the source of the contamination, the response of individual monitoring wells to pumping (both rates of response and overall drawdown) should be used to determine connection to the monitoring site. Flow rates and directions can be determined from the results of aquifer-scale or site-scale tracer tests. Techniques such as flow logging and hydraulic conductivity logging can provide vital information at high risk and complex sites. Such hydrophysical logging and data analysis methods are becoming widespread and technical assistance from individuals and organizations with specialized expertise and equipment is available.

(b) Tracer tests: Tracer tests that monitor the presence or absence of tracer at monitoring points can also be used for determining flow directions and validating hydraulic connections. At sites with multiple potential discharge points or receptors, tracer tests should be used to eliminate those points from the monitoring scheme that do not receive the tracer. Tracer tests conducted using dye-tracing chemicals will require Minnesota Department of Health approval and granting of a variance. For this reason, consult MPCA staff prior to conducting any dye tracer tests in order to firmly establish the need.

Drilling methods and well construction techniques should be chosen so as to minimize loss of drilling fluids, cuttings, or construction materials to the formation. Air rotary is preferred, if circulation can be maintained. Rotary drilling should be conducted with over-shot casing to reduce loss of fluids to the formation. High turbidity, especially after recharge events, is an indicator that the well intersects a major conduit. Such wells will therefore require periodic development and maintenance to remove the accumulated sediments.

7. Determining aquifer characteristics for remedial systems at complex and high risk sites

All proposed remedial system designs for ground water in a karst aquifer must be based on a thorough characterization of aquifer properties and resolution of the many variables that are characteristic of this hydrogeology. Should a remediation design be necessary, the site characterization will typically have to be supported by additional detailed data gathered by one or more of the approaches recommended below, in addition to those already mentioned in previous sections of this document. This increased level of justification and more intensive hydraulic investigations are also likely to be required should site closure or passive monitoring be proposed at a higher risk site. Such sites could be those with high levels of ground water contamination, significant extent of contamination, an aquifer displaying highly variable behavior, close proximity to receptors, or a large number of receptors at risk.

Examining cores and bore hole logging data can identify the more productive portions of the aquifer. Packer tests in wells at successively lower depths can also be used for estimates of depth of karstification and location of higher permeability zones.

Packers can be used to segregate specific zones within the wells. Slug tests and single-well pumping tests can then be performed to determine transmission characteristics of different portions of the aquifer. Bore hole fluid logging can also help to characterize the producing zones within fractured-rock aquifers.

Surface geophysical methods such as ground-penetrating radar, electromagnetic or electrical resistivity surveys, natural potential (SP), microgravity, and seismic can be inexpensive and non-destructive means for establishing subsurface features such as depth to rock, depth to water table, buried channels, structural features, fracture orientations, areal variations in water quality, and major conduits. Significant features indicated by surface geophysics can then be used to site borings and wells.

Bore hole logging methods such as natural gamma, gamma-gamma, resistivity (or conductivity), and spontaneous potential can be used to identify strata and correlate between bore holes. These can be used to determine water bearing zones within a bore hole and for determining hydraulic properties of inclined and horizontal fractures.

Bore hole methods such as video, temperature, caliper, acoustic viewer, flow meter, bore hole fluid logging, and cross-hole tomography are best suited for locating and characterizing fractures and conduits.

8. Conducting the ground water and vapor receptor survey

Initially, locations for all wells located within a mile radius of the site should be obtained. This must be done not only by a search of the computerized County Well Index (CWI) database available from the Minnesota Geological Survey (MGS), but also by an actual examination of well records available with the MGS. This is important since the data in the CWI is not always complete or up to date. In addition, a field survey within the one-mile radius to locate properties that may have older, undocumented wells, and contact with the landowners to verify the presence of such wells (both potable and non-potable) must also be carried out. These older wells are usually shallow and may be the most quickly and significantly affected by the contamination.

Ground water discharge points such as springs and seeps must be located and characterized. Any receiving surface water bodies also have to be treated as receptors. Any impact or the potential thereof must be assessed and, if required, mitigated.

Information about ground water movement obtained by the site characterization methods described above should be used to identify those receptors that are at particular risk of intercepting contaminant transport from the site. The need to take measures to protect these receptors should be assessed and suitable steps implemented. Information gathered during the previous phases about distribution of conduits in the bedrock unit, and the degree of interconnection of these conduits with the surface or near surface should also be used to evaluate vapor risk to receptors like building structures and utility conduits.

The general receptor survey process as outlined in the appropriate MPCA Petroleum Remediation Program guidance document should also be followed along with these additional procedures.

Appendix A

References

The following is a general compilation of selected information about karst, as well as specific Minnesota karst areas. This list includes published works, as well as individuals and organizations who can be consulted for information about the area in which the site being investigated is located.

General karst hydrogeology

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Resource Organizations

Department of Geology & Geophysics
University of Minnesota
Minneapolis. MN

Minnesota Department of Natural Resources
Division of Waters
Region V
Rochester, MN

Minnesota Pollution Control Agency
Southeast Sub-District
Rochester, MN

Minnesota Geological Survey
University of Minnesota
St. Paul, MN

APPENDIX B

Suggested Karst RI report outline

To be submitted as attachment to the Investigation report form

Please complete and submit a Karst RI attachment using the suggested format given below. To avoid duplication, it will be acceptable if relevant sections of the Investigation report form are cross-referenced to the Karst RI attachment.

I. County in which site is located and impacted bedrock formation

II. Evaluating regional geology

Describe all pre-existing information compiled. List specifics.

Attach copies of all information compiled. Include all logs, figures, maps, photographs etc.

Attach your interpretation of compiled data and discuss regional geologic setting.

III. Evaluating site geology

Describe field reconnaissance procedures and define area covered.

Show the same in relation to the site on a USGS map.

List and describe all geologic features encountered.

Provide locations of all features in relation to site location on a USGS topographic map.

Interpret and discuss site geology.

IV. Evaluating regional hydrogeology

Describe field reconnaissance procedures and define area covered.

List and describe all hydrogeologic features encountered.

Provide locations of all features in relation to site location on a USGS topographic map.

Interpret and discuss site hydrogeology.

V. Karst hydrogeologic inventory

Complete listing, descriptions, and location of all features surveyed for III and IV can be submitted as a combined karst hydrogeologic inventory

VI. Evaluating site hydrogeology

a) Off-site

Location of area wells and discharge points (seeps, springs, etc.) in relation to the site on a USGS topographic map.

List all parameters measured at these points. Verify that at a minimum those listed in **Section 4, Part b of Guidance Document 4-09** were measured. If not, explain why.

List dates of measurement and state whether quarterly monitoring events (minimum 2 required for RI report submittal) or recharge event monitoring (minimum 3 required for RI report submittal).

Provide measurement values for all parameters and all points.

b) On-site

Provide monitoring well location and construction information.

List all parameters measured at the monitoring wells. Verify that at a minimum those listed in Section 4, Part b of Guidance Document 4-09 were measured. If not, explain why.

List dates of measurement and state whether quarterly monitoring events (minimum 2 required for RI report submittal) or recharge event monitoring (minimum 3 required for RI report submittal).

Provide measurement values for all parameters and all wells.

Verify that monitoring dates and parameters are identical for VI a) and b). If not, explain why.

VII. Potentiometric map

Provide locations in relation to the site and descriptions of all control points used to construct potentiometric map on a USGS topographic map.

Define study area used for potentiometric map construction and explain how the area boundaries were determined. Show the same on a USGS topographic map.

Provide all measurement dates and values.

Provide potentiometric maps and ground water flow direction for all monitoring rounds.

Verify that potentiometric maps and flow direction computed for at least all the monitoring events listed in VI a) and b).

If not, explain why.

Identify and analyze any points that provided anomalous measurements.

Interpret potentiometric maps and ground water flow directions and discuss implications on ground water and contaminant flow, contaminant migration, and risk to receptors.

VIII. Ground water sampling schedule

Verify that ground water sampling for contamination was conducted for a minimum of two quarterly rounds and three recharge events.

Verify that the contamination sampling rounds were the same as the monitoring rounds for VI a) and b).

Verify that contamination sampling was conducted at all points used for the monitoring in VI a) and b).

Describe recharge events – date, duration, relevant meteorological data and source.

Describe recharge event sampling procedure with accurate times and dates.

Provide all sample results from all points.

IX. Establishment of the monitoring network

Describe all monitoring wells installed and discuss how location and construction were determined from site characterization data.

Describe how the monitoring points selected for use in VI, VII, VIII, and IX were selected from all the points identified.

X. Status of site characterization

Discuss overall status of site characterization and degree of confidence that can be placed on geologic and hydrogeologic estimations made about the site.

Describe and discuss results of any additional methods (the listed optional methods in the guidance or any others) that may have been employed at the site.

If none were employed, discuss the need for any to increase the resolution and accuracy of site characterization.

Discuss overall risk from contamination – in terms of ground water, surface water and vapor.

XI. Detailed aquifer characterization.

If proposing a remedial system or site closure/passive monitoring at a higher risk site, provide detailed and specific hydraulic properties for the aquifer in justification.

Describe and discuss the methods selected to obtain the aquifer properties, as well as the justification for selection of these methods.

Discuss the proposed remedial method/site closure/passive monitoring in context of all site characterization data, aquifer properties, and risk.