Appendix H

KARST EVALUATION REPORT

KARST EVALUATION REPORT

US-50 NORTH VERNON BYPASS - EAST

JENNINGS COUNTY, INDIANA

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICIES

Title

LIST OF ACRONYMS AND ABREVEIATIONS

BMP	Best Management Practice
cfs	cubic feet per second
CN	curve number
CR	County Road
EMC	event mean concentration
gpm	gallons per minute
GPS	Global Positioning System
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IGS	Indiana Geological Survey
INDOT	Indiana Department of Transportation
NOAA	National Oceanic and Atmospheric Administration
NSQD	National Stormwater Quality Database
SCS	Soil Conservation Service
SR	State Route
TR-55	Technical Release 55
TSS	total suspended solids
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WRAP	Wetlands Regulatory Assistance Program

SECTION 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

This report has been prepared to review karst information relevant to the preferred corridor of the U.S. 50 North Vernon Bypass Project. The report documents the presence of karst features in and adjacent to the preferred alignment identified through evaluation of historical documents and a site reconnaissance; evaluation of impacts of the roadway on the identified karst features; and impact minimization and mitigation of unavoidable impacts. The study methodology was developed to be consistent with the objectives identified in the 1993 Memorandum of Understanding between the Indiana Department of Transportation (INDOT), the Indiana Department of Natural Resources (IDNR), the Indiana Department of Environmental Management (IDEM), and the U.S. Fish and Wildlife Service (USFWS) for the purpose of delineating guidelines for construction of transportation projects in karst regions of the State (included as Appendix A).

1.2 DESCRIPTION OF PROJECT

The U.S. 50 North Vernon Bypass project involves construction of a highway bypass around the city of North Vernon in Jennings County. Construction on the western half of the project, which consists of a new two-lane road from U.S. 50 northeast to State Route (SR) 3 north of North Vernon, began in March 2012. The approximate length of this roadway is 4.5 miles.

In July 2012, INDOT began the development of a proposed extension of the roadway currently under construction between County Route (CR) 400W and SR 3. This extension would run from SR 3 on the north side of North Vernon east and south to rejoin existing U.S. 50 east of North Vernon, thus completing a northern bypass of North Vernon.

When completed, the project will reduce congestion in and around North Vernon, improve safety, improve accessibility, and meet local and state planning objectives.

The purpose of this project is to resolve four documented transportation problems in the U.S. 50/North Vernon area. Specifically, the project will:

- Reduce congestion along U.S. 50 and SR 3/SR 7 through and around North Vernon;
- Provide a safer transportation facility for both truck and passenger vehicles through and around North Vernon;
- Provide an efficient transportation link between the existing and growing industrial area on the north side of North Vernon to U.S. 50; and
- Support state and local transportation planning.

1.3 REPORT ORGANIZATION

The description of the proposed roadway and the purpose and scope of this project is provided in Section 1. Section 2 presents a general description of the preferred alignment. The methodology of the karst evaluation is detailed in Section 3. Section 4 presents the results of the field reconnaissance. Annual pollutant load estimates are presented in Section 5. Mitigation measures are summarized in Section 6. Section 7 provides a summary of the results and conclusions. References are presented in Section 8. Appendix A presents the Memorandum of Understanding regarding karst feature impacts from roadway development projects between INDOT, IDNR, IDEM, and the USFWS. Appendix B is a photographic log of karst features identified during the field reconnaissance.

SECTION 2

DESCRIPTION OF PREFERRED ALTERNATIVE

2.1 STUDY AREA

The study area for the karst evaluation is the alignment of the preferred alternative for the U.S. 50 bypass running from SR 3 south of West County Road (CR) 350 North to existing U.S. 50 between East CR 150 North and North CR 75 East. The alignment is shown on Figure 2-1. Adjacent areas that would be expected to receive run off from the alignment were also evaluated.

2.2 LAND USE

Land use within the preferred alignment is varied. The portion of the alignment north and west of the Vernon Fork of the Muscatatuck River is largely forest, pasture and open field (Figure 2-2). A short stretch of this part of the alignment on the west side of North CR 20 West passes through support areas of a quarry. Some of the open field areas are under cultivation. Some of these areas are being marketed for light industrial development, and may have had some preliminary grading and drainage modification performed.

The eastern end of the preferred alignment is largely forest, with one residence surrounded by a small clearing. Between this forested tract and the CSX railroad tracks is a pasture. The area between the CSX railroad tracks and North Base Road is an open field with a few scattered trees. The small area between the Vernon Fork of the Muscatatuck River and North Base Road is occupied by older residences and out buildings.

2.3 PHYSIOGRAPHIC SETTING

The site is within the Muscatatuck Plateau physiographic unit of the Southern Hills and Lowlands region. The project area ranges in elevation from just over 750 feet mean sea level (MSL) near the east end of the preferred alignment to slightly less than 650 feet MSL at the Vernon Fork of the Muscatatuck River. Slopes are generally gentle, with steeper slopes near the support area for the local quarry. A bluff is present on the west bank of the Vernon Fork of the Muscatatuck River that is approximately 20 feet high.

2.4 GEOLOGIC SETTING

The study area is underlain by unconsolidated pre-Wisconsin glacial tills that overlay rocks of the Paleozoic Era. Digitized geologic mapping available from the Geographic Information System of the Indiana Geological Survey (IGS) (IGS, 2013) show that the uppermost bedrock in the study area is the New Albany Shale and the North Vernon Limestone (Figure 2-3).

In an investigation of potential dam sites performed approximately 15 miles to the south, Winslow (1960) reports that the rock units dip to the southwest at approximately 20 feet per mile.

2.4.1 Geologic Units

Pre-Wisconsin Till – Much of Jennings County has a cover of till from pre-Wisconsin glaciations and weathered bedrock (Schrader, 2004a). The till is predominantly clay with some silt and sand. Some sand lenses are locally present in the till, with thicknesses ranging from less than an inch to several feet. Schrader (2004a) reports that the thickness of the till and weathered bedrock is typically 15 to 40 feet thick.

In January 2013, 14 geotechnical borings were performed at several sites along the western end of the preferred alignment, between SR 3 and North CR 75 West. It is reported that the borings encountered highly weathered to decomposed shale as the uppermost bedrock at a depth ranging from 8 to 15 feet.

New Albany Shale – The New Albany Shale is the uppermost bedrock across much of Jennings County. The New Albany Shale is a fissile, black bituminous shale (Winslow, 1960). Shaver, *et. al* (2013) note that the unit can contain lesser amounts of dolomite and dolomitic quartz sandstone. Several members have been delineated, however, available mapping does not indicate if the members have been differentiated in the North Vernon area (Shaver, *et. al.*, 2013). The New Albany Shale is late Devonian to Mississippian in age (Shaver, *et. al.*, 2013). The thickness of the New Albany Shale in Jennings County ranges from 0 to 120 feet, with the greatest thickness in the southwest portion of the county (Schrader, 2004b). In the vicinity of the preferred alignment, mapping of the uppermost bedrock shows the New Albany shale occupying areas of higher elevation (IGS, 2013).

Winslow (1960) reported that he observed a number of sinkholes in areas where the New Albany Shale was the uppermost bedrock unit but was relatively thin. He attributed this to dissolution with the underlying North Vernon Limestone which led to a collapse of the overlying New Albany Shale. No exposures of the shale were observed as a part of the field reconnaissance for this study.

North Vernon Limestone – The North Vernon Limestone is a thin to medium bedded fossiliferous limestone that is a part of the Vernon Fork of the Muscatatuck Group of Devonian age (Shaver, *et. al.*, 2013). It varies from fine to coarse grained and gray to tan gray in color (Winslow, 1960). Within the area of the preferred alignment, the North Vernon Limestone is the uppermost bedrock unit in the area where the overlying New Albany Shale was eroded away by the Vernon Fork of the Muscatatuck River. Exposures of the limestone observed during the site reconnaissance were well weathered and were typically tan to brown. Bedding varied from several feet to approximately one inch. The exposed limestone appeared to be crystalline with a medium to fine grain. Differential dissolution was evident on the surfaces of the exposures. A bluff of approximately 15 feet was observed in the west bank of the Vernon Fork of the Muscatatuck River.

Winslow (1960) indicated that the North Vernon Limestone and the upper portion of the underlying Jeffersonville Limestone, which is very similar, are the units that contained the majority of the solution channels and sinkholes identified in his investigation. Schrader (2004b) indicated that the combined thickness of the Devonian and Silurian carbonates of the Muscatatuck Group is up to 200 feet.

2.5 HYDROGEOLOGIC SETTING

The availability of groundwater in Jennings County is relatively limited (IDNR, 2013a). The yields of water wells in Jennings County are generally less than 10 gallons per minute (gpm). Wells can be completed in both the unconsolidated till or in bedrock. Wells constructed in the unconsolidated materials are large-diameter bored wells that have a porous concrete lining. These wells have typical yields ranging from 0.5 to 4 gpm (Schrader, 2004a). The wells are adequate for domestic or stock watering due to the large storage volume in the large diameter well. Bedrock wells can be completed in the North Vernon Limestone and underlying carbonates of the Muscatatuck Group. These wells are typically 60 to 115 feet deep, and have yields of 2 to 15 gpm.

2.5.1 Water Supply

Water supply in the area of the preferred alignment is through a combination of domestic wells and public supplies. The IDNR online well inventory (IDNR, 2013b) was reviewed to identify wells in the vicinity of the preferred alignment. Six wells were identified in the database that were located within approximately 2,000 feet of the preferred alignment. It is likely that the database is not comprehensive; depending upon the starting date of the requirement to report well construction and the funding to update the database with new records. All six of the reported wells appear to be completed in bedrock. Well depths ranged from 51 to 115 feet.

Water for the City of North Vernon is obtained from the Vernon Fork of the Muscatatuck River at a low head reservoir that is located approximately one half mile downstream from the crossing of the preferred alignment. It is assumed that all areas within the city limits have access to city water. Jennings Water, Inc., a not-for-profit water association, also distributes water in the area. They obtain the water from a well field located in Jackson County, west of North Vernon. The water is then transmitted to Jennings County for distribution. The distribution lines cover much of the vicinity of the preferred alignment that is outside of the City of North Vernon.

2.5.2 Karst Groundwater

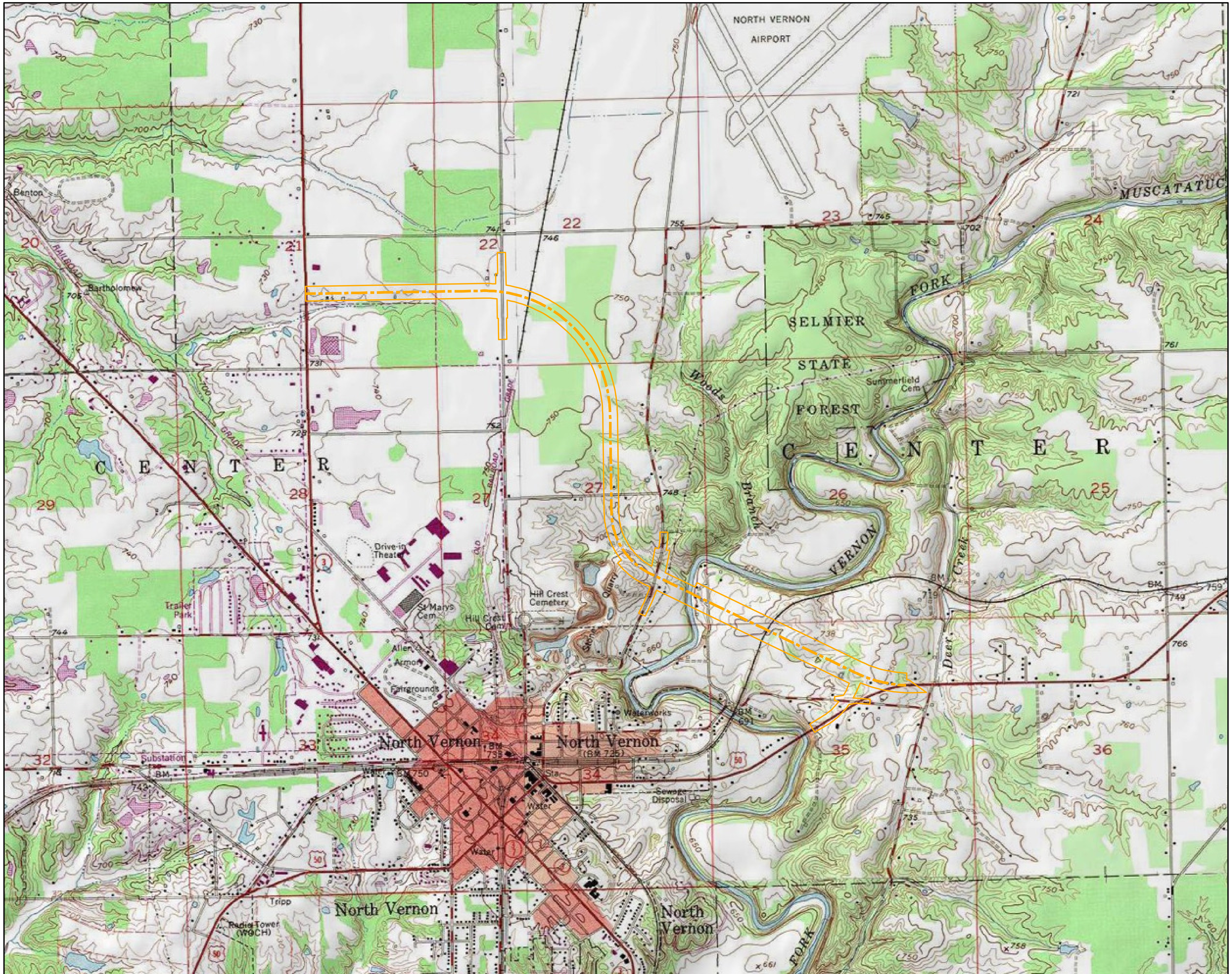
Solution features have developed in the limestone bedrock from the movement of water containing a mild acid due to the water interacting with carbon dioxide in the soil. The mild acid dissolves the carbonate in limestone, and to a lesser extent, in dolomite. The solution features can take a number of forms and can range from minor enlargement of existing fractures and bedding planes to the development of large caves and sinkholes (Schrader, 2004c). Together the features developed from the dissolution form a landscape that is termed karst. Karst features can include depressions termed sinkholes, streams that lose some or all of their flow to underground channels (sinking streams), caves, underground drainage channels or conduits, and enlarged joints and fractures.

Movement of groundwater in these solution enlarged channels can be quite rapid, and can bypass the buffering effect of the soil and aquifer matrix typically seen in flow in traditional porous media. Karst areas are vulnerable to contamination from both point sources (spills, leaking tanks, and septic systems) and from areal source contamination (road salts, pesticides, and fertilizers) (Schrader, 2004c).

Schrader (2004c) reports that the most extensive karst development in Jennings County is in the Devonian Muscatatuck Group, which includes the North Vernon Limestone, and occurs along the larger stream valleys, including the Vernon Fork of the Muscatatuck River. Like Winslow, Schrader notes that sinkholes can form in areas where the New Albany Shale is the uppermost bedrock from dissolution of the underlying limestone.

These general patterns are consistent with the findings of the field reconnaissance described in Section 4. Given the lack of springs identified in the area and the proximity of the sinkholes identified near the preferred alignment to the Muscatatuck River, it is likely that flow into the sinkholes emerge into the Vernon Fork of the Muscatatuck River. Given the large flow of the Vernon Fork of the Muscatatuck River, it may be difficult to positively detect dye from a dye trace that is discharged to the river due to the significant dilution that will occur.

Figure 2-1
Map Showing
Preferred Alignment



Centerline of Preferred Allignment

Edge of Preferred Alignment Right of Way

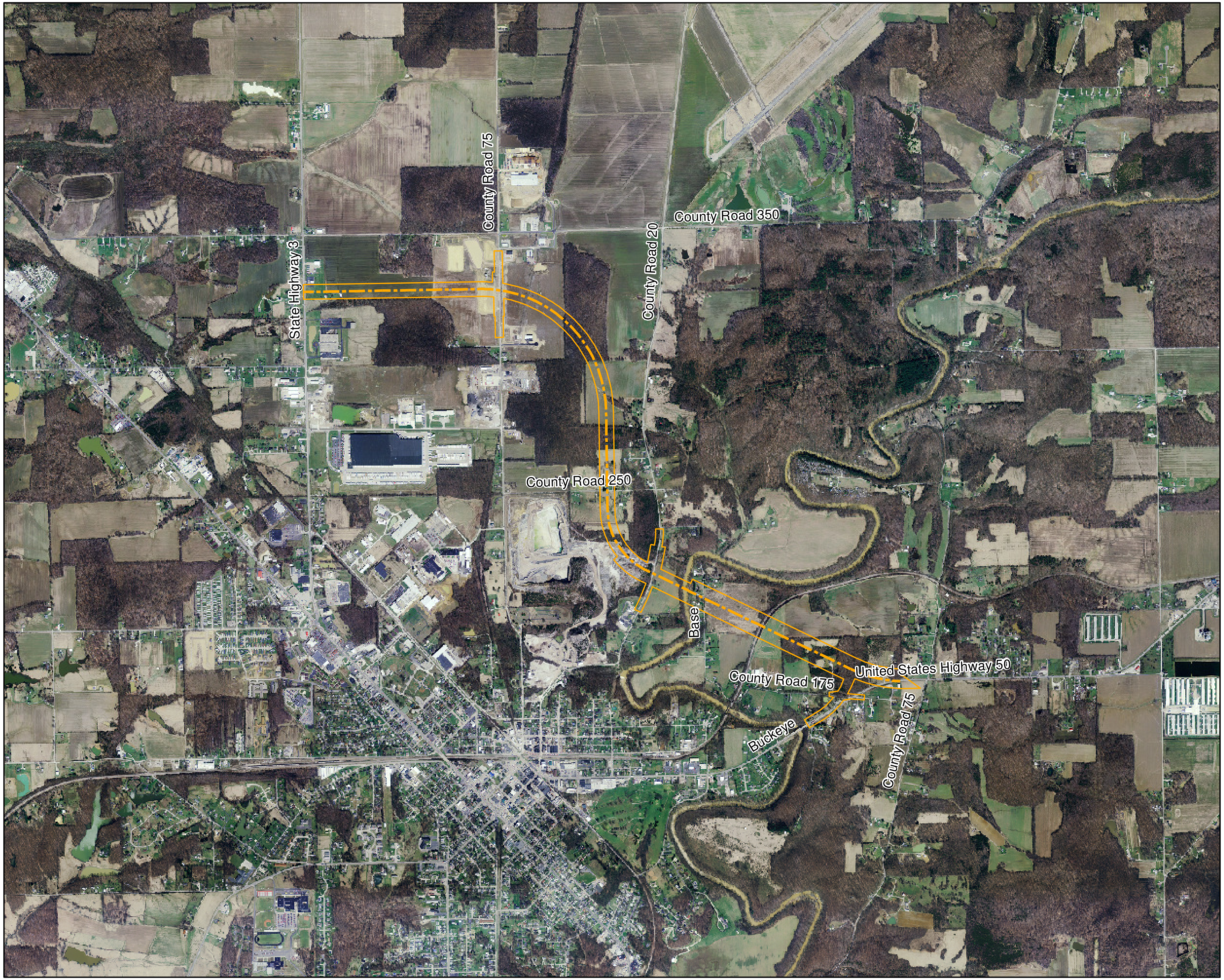
Butlerville (1994) and North Vernon (1993)
U.S.G.S. 7.5-Minute Quadrangles

N

1:24000

0 500 1,000 2,000 3,000 4,000
Feet

Figure 2-2
Aerial Photograph
Showing
Preferred Alignment



Centerline of Preferred Alignment
Edge of Preferred Alignment Right of Way
RoadClipSubset

Aerial Photography 2005
From Indiana Geological Survey MI 55

N

1:24000

0 500 1,000 2,000 3,000 4,000 Feet

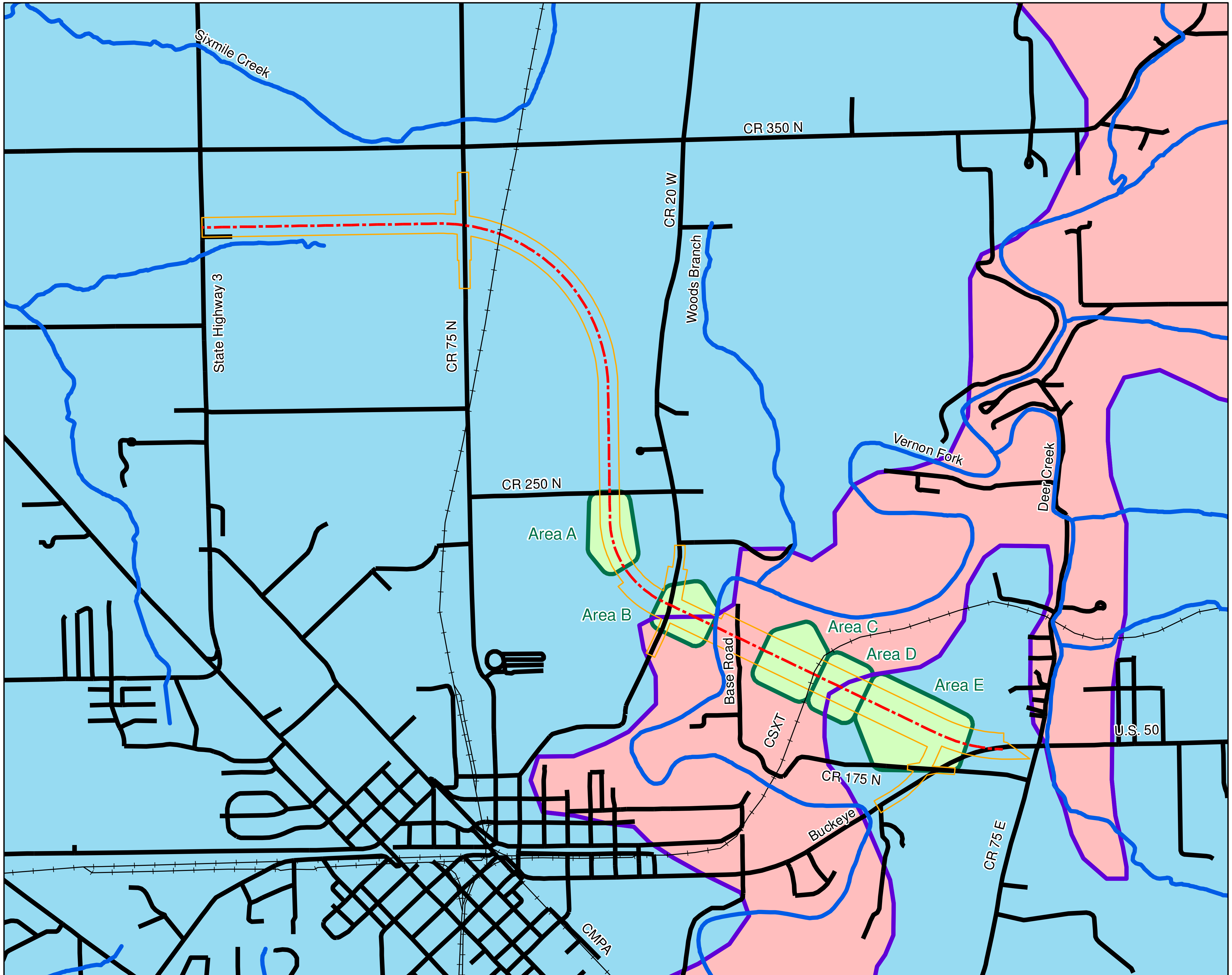


Figure 2-3
Stratigraphic Units
in Study Area

Centerline of Preferred Allignment
Edge of Preferred Alignment Right of Way
North Vernon Limestone
Devonian-Mississippian
Louisville Limestone
Area of Karst Features Identified in Site Reconnaissance

N

1:18000

0 500 1,000 2,000 3,000 Feet

SECTION 3

KARST FEATURE IDENTIFICATION METHODOLOGY

3.1 REVIEW OF GEOLOGICAL REPORTS

The online directory of Indiana Geological Survey publications was searched to identify reports, maps and other information related to the geology of the North Vernon area. Copies of the documents that were identified were ordered from the Indiana Geological Survey and were reviewed prior to performing the site reconnaissance. In addition, telephone discussions with Shawn Naylor, a geologist with the IGS were helpful in understanding the local geology.

One of the more helpful documents reviewed was *Preliminary Engineering Geology Report of Dam Sites on the East Fork of the Muscatatuck River in Scott, Jennings, and Jefferson Counties, Indiana* (Winslow, 1960). The focus area for this report was located approximately 10 miles south of the project area for the U.S. 50 Bypass. However, the report provided descriptions of the lithologic units present in the area of this study. In addition to the general description of each unit, the report identified any karst characteristics present.

Karst features mapped at a scale of 1:250,000 were reviewed from the publication *Distributions of Sinkholes, Sinking-Stream Basins, and Cave Openings in Southeastern Indiana* (Powell, Frushour, and Harper, 2002). The features indicated on the map were consistent with the findings of the field reconnaissance.

Geographic Information System data for geology and karstic features was obtained from the Indiana Geological Survey. These data layers were examined in detail in preparation for the field reconnaissance. The karst features were included on aerial photograph plots at a scale of 1:3,000 (250 feet to the inch) for use during the field reconnaissance.

Descriptions of the geologic units indicated for the project area were obtained from the Indiana Geological Survey website.

3.2 OUTREACH TO ORGANIZATIONS

The scope of work for this karst evaluation was offered to INDOT for review during the planning stages of the evaluation. The USFWS was consulted during the initial environmental assessment of the potential alignments.

In preparation for the field reconnaissance, an email was sent to the Indiana Cave Survey inviting them to provide any local knowledge regarding caves and karst features in the North Vernon area. No response was received from the Indiana Cave Survey.

3.3 AERIAL PHOTOGRAPHY AND TOPOGRAPHIC MAP REVIEW

The area of the preferred alignment is included on the North Vernon and Butlerville U.S. Geological Survey (USGS) 7.5-minute topographic maps. The North Vernon map is dated 1993. The Butlerville map is dated 1994. The area near the preferred alignment was reviewed closely in preparation for the field reconnaissance. Several small areas with closed contours were identified which were interpreted as being potential sinkholes. None of these features were directly within the preferred alignment. However, several were in areas that could receive runoff from the preferred alignment. These areas were noted for evaluation during the field reconnaissance.

High resolution aerial imagery for Jennings County was obtained from the Indiana Geological Survey for review prior to the field reconnaissance. The imagery was dated 2005 (IGS, 2005). The images were printed at a scale of 1:3000 (250 feet to the inch) for review. The preferred alignment was superimposed on the imagery to allow the evaluation to be focused on the preferred alignment. A number of features were identified that had the potential to be karst features. These were noted for evaluation during the field reconnaissance.

Field notes and maps from the Biological Assessment of the preferred alignment, prepared by Eco-Tech Consultants, Inc. were reviewed. The personnel who performed the assessment were interviewed to provide a description of any karst features noted along with details of the location of the features.

3.4 FIELD RECONNAISSANCE

To perform the karst feature survey, Parsons conducted a field reconnaissance of the study area defined in Section 2.1 of this report to identify the presence of surficial karst features. The field reconnaissance was conducted on February 5 and 6, 2013 by Mr. Lee Gorday and Mr. Lucas White, both licensed professional geologists. The proposed roadway alignment was traversed on foot ensuring that the entire area was seen visually by one of the two field team members. Adjacent areas that might be impacted by runoff from the alignment were also evaluated. Karst features identified in the study area were assessed and their locations documented on aerial photographs and marked using resource grade global positioning system (GPS) units. Brief descriptions of the features were documented and photographs were taken.

A small amount of snow was on the ground (approximately 1-inch or less) during the initial part of the field reconnaissance. The snow cover diminished over the two days of the field reconnaissance as temperatures were slightly above freezing. The light snow cover was generally helpful in providing brightened visual conditions in the forested areas, allowing for a greater sight distance. The snow cover was observed to typically be either absent in the bottom of sinkholes, especially those with swallow holes, or concentrated in the bottom of the sinkholes.

SECTION 4

RESULTS

Sixty distinct karst features were identified and marked using the GPS device; additionally four generally broad areas were marked using the “track” feature of the GPS unit. The areas that were “tracked” are not necessarily distinct from the 60 other features, but may encompass several of the distinct features within a well defined grouping. Almost all of the karst features identified are sinkholes. In several locations, especially within Area E described below, the high density of karst features necessitated that multiple features were identified with a single GPS coordinate and description. Several seeps were identified, however, no springs of any consequence were observed. Several small openings were identified that are termed caves in the notes. However, none of these features were large enough to allow human entry.

Table 4-1 contains a table that provides the coordinates and descriptions of each marked feature. Based on the karst features identified during the site reconnaissance, seven geographic areas are defined and described in this section. Two of the geographic areas (Section 4.1) are areas that do not exhibit any karst features identifiable at the surface. Five geographic areas (Sections 4.2 through 4.6) of karst features were identified. The karst features within each of these five areas shared similar characteristics; therefore, the boundaries of each are not clearly defined. Figure 4-1 shows the location of each area.

4.1 AREAS NOT EXHIBITING KARST FEATURES

Two areas along the proposed bypass route were identified where no karst features were observed. These two areas can be seen on Figure 4-1.

4.1.1 North of West CR 250 North

One area of the proposed bypass route that did not exhibit any surficial karst features is the area that lies north of West CR 250 North. This portion of the proposed route is generally uninhabited and consists primarily of agricultural fields and hardwood forests. The landscape is generally flat with drainage consisting primarily of overland sheet flow (with the exception of a few shallow drainage swales). The southernmost portion of this area is the only portion that is inhabited (one home along West CR 250 North), and the land consists of a relatively steep grade with the county road at the lowest point and deeply cut drainage swales through pastureland.

4.1.2 East of the Vernon Fork of the Muscatatuck River, Immediately Adjacent to North Base Road

The second area of the proposed bypass route that did not exhibit any surficial karst features lies between the areas denoted as Area B and Area C (Sections 4.3 and 4.4 below). This portion of the proposed route is inhabited by several residents and is bisected by North Base Road. The topography is generally sloping from the east, down to the Vernon Fork of the Muscatatuck River on the west edge and is drained by both natural and manmade swales and ditches.

Table 4-1 - Karst Features Identified in the Field Reconnaissance

ID	Northing	Easting	Description
A-01	619669	4319813	Joints in creek bed. Primary joints at 160-170 degrees with secondary joint at 80 degrees.
A-02	619587	4319845	Sinkhole approximately 8 to 10 feet diameter and 4 feet deep with small swallow hole obscured by limbs and leaves.
A-03	619547	4319843	Small sinkhole approximately 6 feet in diameter and 3 feet deep, slightly oblong with no distinct swallow hole.
A-04	619648	4319945	Swallow hole next to rock exposed in soil, no depression.
A-05	619620	4319962	Small depression approximately 10 feet by 4 feet and 2 feet deep.
A-06	619603	4320012	Two small sinkholes, which swallow overflow from adjacent pond, both approximately 6 feet in diameter and 3 feet deep.
A-07	619616	4320060	Sinkhole with obscured swallow hole. Creek enters area where tree was pushed over.
A-08	619642	4320035	Line of small coalesced sinkholes, approximately 20 feet by 5 feet and 2 feet deep.
B-01	619863	4319557	Sinkhole with obscured swallow hole. Large catchment, approximately 120 feet in diameter.
B-02	620042	4319561	Very small cave mouth with slight discharge.
B-03	620055	4319556	Sinking stream. Flow from cave mouth spring disappears into hole at base of tree.
B-04	620001	4319642	Seepage emerging from beneath pile of felled trees.
C-01	620391	4319418	Large broad sinkhole, very shallow, silt filled, no apparent swallow area has many low vegetation (track 1).
C-02	620420	4319375	Small compact sinkhole, approximately 12 feet in diameter, 4 feet deep, filled with piled sticks, has 8 to 10 potholes 2 feet in diameter and 1 foot deep on north side of main sink.
C-03	620446	4319413	Large broad silt filled sinkhole with several distinct 2 foot diameter x 2 foot deep swallow holes approximately 80 long x 40' wide with a depth of approximately 5 feet (track 2).
C-04	620466	4319383	Distinct pot sinkhole adjacent to a broad sinkhole. One main swallow hole with pair of silt filled swallows.
C-05	620516	4319453	Broad, shallow sinkhole with silt bottom and no apparent swallow hole approx 30 feet in diameter x 3 to 4 feet deep.
C-06	620533	4319378	Pair of discrete sinkholes. One is 6 feet in diameter and 3 feet deep, the other is 5 feet by 12 feet and 3 feet deep.
C-07	620365	4319271	Distinct sinkhole approximately 10 feet by 15 feet and 4 feet deep.
D-01	620684	4319258	Broad, shallow sinkhole, approximately 30 feet in diameter, several feet deep. A mass of trees is present in the depression.
D-02	620637	4319187	Three-inch diameter open holes with no significant depression.
D-03	620659	4319178	Three-inch diameter open holes with no significant depression.
D-04	620660	4319172	Small diameter open hole without a depression marked with tree limbs.
D-05	620640	4319156	Small diameter open hole without a depression marked with tree limbs.
D-06	620668	4319138	Shallow depression with signs of having been filled (by man), approximately 30' diameter, 1' deep.

D-07	620688	4319110	Sinkhole approximately 15 feet in diameter sinkhole with round bottom.
D-08	620694	4319110	Sinkhole approximately 20 feet by 10 feet with 2 swallow holes.
D-09	620705	4319106	Set of 3 sinkholes approximately 10 feet in diameter and 7 feet deep with large swallow holes.
D-10	620696	4319080	Sinkhole with double inlet approximately 10 feet by 25 feet, and 4 to 5 feet deep.
D-11	620712	4319089	Sinkhole approximately 15 feet by 25 feet and 10' deep with 2 swallow holes. Nearby small shallow depression with no swallow hole.
E-01	620794	4319081	Single sinkhole approximately 10 feet by 15 feet with a small swallow hole. Several streams lead into the sinkhole.
E-02	620801	4319051	Very shallow depression with no swallow hole.
E-03	620881	4318946	Single sinkhole approximately 25 feet in diameter, with a small swallow hole.
E-04	620935	4318950	Sinkhole approximately 15 feet by 25 feet and 5 feet deep. Corrugated (tin) roofing panels embedded in bottom.
E-05	620951	4318943	Small sinkhole, south of line of sinks, with no distinct opening.
E-06	620959	4318957	Line of sinkholes aligned on 230 degrees with a losing stream, 6 openings all fairly large, some inhabited by rabbits.
E-07	620871	4319016	Single sinkhole approximately 25 feet in diameter with open swallow approximately 5 feet deep.
E-08	620873	4319026	Cluster of 4 sinkholes with 3 aligned at 180 degrees, each is approximately 10 feet in diameter and 5 feet deep, with open swallows.
E-09	620878	4319033	Cluster of 4 sinkholes with 3 aligned at 180 degrees, each is approximately 10 feet in diameter and 5 feet deep, with open swallows.
E-10	620869	4319066	Small basin adjacent to major sinkhole.
E-11	620872	4319057	Small basin adjacent to major sinkhole.
E-12	620863	4319068	Small basin adjacent to major sinkhole.
E-13	620873	4319077	Major sinkhole with multiple openings, basin approximately 80 feet in diameter and 10 feet deep.
E-14	620888	4319082	Major sinkhole with multiple openings, basin approximately 80 feet in diameter and 10 feet deep.
E-15	620886	4319062	Vertical fracture intersection with long dimension aligned at 235 degrees.
E-16	620899	4319066	Sheer wall in side of sinkhole with large opening.
E-17	620915	4319096	Sinkhole north of cluster of sinkholes (E-18-20).
E-18	620925	4319085	Cluster of sinkholes with multiple large swallow holes. Each approximately 15 feet in diameter and 5 feet deep.
E-19	620929	4319083	Cluster of sinkholes with multiple large swallow holes. Each approximately 15 feet in diameter and 5 feet deep.
E-20	620927	4319084	Cluster of sinkholes with multiple large swallow holes. Each approximately 15 feet in diameter and 5 feet deep.
E-21	621087	4319105	Seep with very low flow emerging from rock seam in creek bed.
E-22	621244	4319024	Very slight depression with no evidence of swallow hole.
E-23	621148	4318899	Small spring emerging from rocks near base of a tree (also a 55-gal drum embedded into side of the hill nearby).

E-24	621147	4318857	Low flow seep.
E-25	620885	4318903	Two small sinkholes, both at base of trees, with no visible swallow holes.
E-26	620873	4318862	Large sink approximately 30 feet in diameter and 6 feet deep. Sinkhole has PVC pipe draining into the feature.
E-27	620888	4319087	Swallow hole in major sink with multiple openings, basin approximately 80 feet in diameter and 10 feet deep.
E-28	620884	4319081	Swallow hole in major sink with multiple openings, basin approximately 80 feet in diameter and 10 feet deep.
E-29	620880	4319083	Swallow hole in major sink with multiple openings, basin approximately 80 feet in diameter and 10 feet deep.
E-30	620872	4319078	Swallow hole in major sink with multiple openings, basin approximately 80 feet in diameter and 10 feet deep.

The land lies on the inside bend of a meander in the river directly across from a bluff on the river where multiple karst features were observed (as described in Section 4.3 below).

4.2 AREA A (SOUTH OF WEST CR 250 NORTH)

Eight distinct karst features were identified in Area A. The location of each feature is shown on Figure 4-2, and photographs are in Appendix B. The karst features in Area A are all associated with natural drainage. With the exception of Feature A-01, all of the karst features in Area A are small pit sinkholes with swallow holes and no observed bedrock exposure. Feature A-01 is a grouping of open vertical joints in the exposed bedrock of the creek bed. Features A-01 through A-03 all lay adjacent to, or in, a creek that drains the area from west to east toward Area B and the Vernon Fork of the Muscatatuck River. The joints observed at feature A-01 were in the bed of the creek, but showed no indication that they would accept water flow. Features A-02 and A-03 appeared to have swallow holes that would allow the sinkhole to readily accept water. However, these features were not in the creek bed, and would drain only the closely surrounding area. The remaining features (A-04 through A-08) all lay along a natural drainage swale that accepts overland flow from the area of slightly higher elevation to the north (north of West CR 250 North) and small (less than 1-acre) manmade impoundments. Features A-04 through A-08 appeared to be capable of accepting much of the flow of the drainage leading into them during low to moderate flow conditions. Each of these features had a larger flow channel leading to the feature than was present on the down slope side of the feature. It is estimated that the drainage in which sinkholes A-04 to A-08 were observed covers an area of approximately 66 acres.

Land use in Area A is mixed between open hay/pastureland on the north; hardwood forest along a steeply embanked creek bisecting the Area east to west; and rock quarry debris, tailings, and roads on the south. General slope of the Area is eastward toward Area B and the Vernon Fork of the Muscatatuck River.

4.3 AREA B (WEST OF THE VERNON FORK OF THE MUSCATATUCK RIVER)

Site reconnaissance identified four karst features along the proposed bypass route in Area B. Additionally, a fairly large (approximately 0.1 acre) slight depression was identified and was marked using the tracking feature of the GPS unit. All of the karst features identified in Area B are shown on Figure 4-3, and photographs are in Appendix B. The four primary unique features identified were all related to a drainage feature – a natural ditch that has been modified by man to accept the runoff flow associated with North CR 20 West. The features include a small cave opening with a low flow stream exiting from the mouth, an assumed spring emerging from beneath a pile of felled trees, and a disappearing stream. The largest of the features is a broad shallow depression on the east side of North CR 20 West (photo 30). Because of the extent of two of the features, the tracking feature of the GPS unit was used to identify the lateral extent of the feature. It is identified on Figure 4-3 as B-T1. This depression does not have a discernable swallow hole. Feature B-01 (photos 21 and 22) is a relatively large sink hole with an obscured swallow hole. It is located on the west side of North CR 20 West. It can receive runoff from a short stretch of the roadway.

The three other features noted in Area B are smaller. A small spring emerged from beneath a pile of downed trees. The flow from the spring despite the melting snow was generally small (less than a couple of gpm). Feature B-02 (photos 23 through 25) is a small opening in a rock exposure that is generously termed here as a cave. The opening is too small for a person to enter.

A small flow of water (less than a couple of gpm) was issuing from the feature. The water flowed to a small swallow hole near the base of a tree (Feature B-03, photos 26 and 27).

Most of the land in Area B is open agricultural crop land with a tree line along the bluff of the Vernon Fork of the Muscatatuck River on the eastern edge. The natural slope of the area is eastward toward the river. An area with no observed karst features is present between Areas A and B. This area is a staging and or spoil area for the quarry to the west and southwest. The land surface in this area has been highly modified such that any karst features would have been covered or leveled.

4.4 AREA C (BETWEEN NORTH BASE ROAD AND THE CSX RAILROAD TRACKS)

The field team observed seven surficial karst features within Area C. Because of the extent of two of the features, the tracking feature of the GPS unit was used to identify the lateral extent of each. Each feature can be seen on Figure 4-4, and photographs are in Appendix B. The features (sinkholes) in this area have a generally large footprint and have multiple swallow holes that are typically silt filled. Feature C-01 (photos 31 through 33) was a large broad shallow depression with no apparent swallow hole. It was filled with silt and had an abundance of low vegetation. A track of the extent of the depression was made using a GPS unit. The depression covers an area of approximately 0.4 acres. Sinkhole C-03 (photos 38-41) is also a large, broad silt filled sinkhole. The depression was estimated to have a depth of approximately 5 feet. Unlike feature C-01, it has several distinct swallow holes that are approximately 2 feet in diameter and 2 feet deep. A track of the margin of this sinkhole was performed and indicates that the area of the sinkhole is approximately 0.3 acres.

Feature C-05 (photos 46 and 47) is a broad, shallow sinkhole with a silt bottom that lacked an apparent swallow hole. This sinkhole is smaller than Features C-01 and C-03, with a diameter of approximately 30 feet. The other features in Area C (Features C-02, C-04, C-06 and C-07) are relatively small sinkholes with steeper margins. These sinkholes have apparent swallow holes and are approximately 3 to 4 feet deep.

Topography in Area C is gently undulating with ridges and valleys running generally east-west, and a general downward slope from the CSX Railroad tracks in the east toward the Vernon Fork of the Muscatatuck River in the west. The land is primarily open grassland with stands of brush and trees surrounding the sinkholes.

4.5 AREA D (EAST OF THE CSX RAILROAD TRACKS)

Eleven karst features were identified along the proposed route during the site reconnaissance in Area D. Figure 4-5 shows the location of each feature on aerial photography, and photographs are in Appendix B. In some instances the identified karst features are multiple sinkholes that have coalesced to a single feature. In the vicinity of features D-07 through D-11, several sinkholes were identified as a single feature due to the close proximity of the sinkholes to each other. The features observed in this area are generally broad shallow sinks or depressions.

Feature D-01 (photos 56 through 59) is a sinkhole that is approximately 30 feet in diameter and several feet deep. It is surrounded by a mass of trees. Some debris has been disposed of in the sinkhole. It has at least one distinct swallow hole that is approximately 2 feet by 4 feet and 1 to 2 feet deep. Feature D-06 is a sinkhole with a similar diameter, but which shows evidence that it has been largely filled, with a broad depression remaining that is approximately 1-foot deep.

Features D-07 through D-11 lie at the edge of a hardwood forest. These sinkholes (photos 67 through 78) are smaller in horizontal extent than Features D-01 and D-06, but are significantly deeper, with depths of up to 10 feet noted. Four of the five contain visible swallow holes, with multiple swallow holes present in several of the features. The close proximity of these sinkholes to each other leads to a very hummocky terrain in the area. Several of these features appear to have initially formed as multiple smaller sinkholes that coalesced over time into a single feature. Within the area of Features D-07 through D-11, it appears that the swallow holes would capture all runoff.

There are also a number of open holes in the ground surface (typically about three or four inches in diameter) without noticeable associated depressions. Several of these holes are mapped as Features D-02 through D-05 (photos 60 through 66); with several of the mapped features representing several of these open holes in close proximity. Because of the lack of a surrounding depression, these open holes would not be expected to capture a significant percentage of the runoff in the area.

The topography of Area D is slightly undulating with an exception at the eastern edge where it is best described as hummocky. The eastern edge of the area is wooded while the rest of the area is predominantly hay or pastureland. The general slope is toward the northwest.

4.6 AREA E (NORTH OF EAST CR 160 NORTH)

Thirty unique karst features, along with one broad sink feature that encompassed multiple distinct features, were identified by the field team in Area E. Figure 4-6 shows the location of each feature identified in Area E, and photographs are in Appendix B. The features identified in this area are generally steep walled sinkholes with bedrock exposures and multiple open swallow holes of various sizes. It was also observed that many of the features are likely coalesced into a network of connected solution cavities. There are a few exceptions, however; a few of the sinkholes in this area have no visible swallow holes, and a few have very shallow depressions rather than steep walls. Three small springs were also identified in Area E.

Features E-13, E-14, and E-27 through E-30 (photos 106 to 111) are all distinct sinkholes that have coalesced to form a combined depression with a diameter of approximately 80 feet in diameter. The basin (track D-T1), indicated by the line on Figure 4-6, has a depth of approximately 10 feet. Multiple swallow holes were observed along with exposed bedrock with prominent jointing. A cluster of three sinkholes (Features E-18 through E-20, photos 118 through 126) were identified to the east of the larger cluster. These sinkholes were each approximately 15 feet in diameter and 5 feet deep. They had steep sides with multiple large swallow holes. Some debris had been disposed in the sinkholes. Three smaller sinkholes (Features E-10 through E-12, photos 102 through 105) were identified on the southern edge of the larger basin. Although these are smaller sinkholes, they had exposed bedrock and large swallow holes.

Features E-01 (photos 79 through 81) and E-02 (photo 82) are located at the western edge of Area E. Feature E-01 is a moderate sized sinkhole (approximately 10 feet by 15 feet) with a small open swallow hole. Several small drainages empty into this sinkhole. Feature E-02 is a shallow depression that lacked a swallow hole. There were no other karst features observed in the vicinity of these two features.

A cluster of sinkholes is present at Features E-08 and E-09 (photos 97 through 101). This cluster is comprised of three sinkholes aligned along a north-south axis and a fourth immediately to the side. Each of these sinkholes is approximately 10 feet in diameter and 5 feet deep. They have relatively steep sides and open swallow holes, with bedrock exposed in the walls of the sinkholes. Feature E-07 (photos 95 and 96), located nearby, is a single sinkhole that is larger, with a diameter of approximately 25 feet and a depth of approximately 5 feet. Bedrock is exposed in the bottom of the sinkhole.

Features E-04, E-05 and E-06 are sinkholes located south of the extent of the proposed right of way. It is expected that they might receive runoff from the proposed alignment. Feature E-04 (photos 86 and 87) is a sinkhole that is approximately 15 feet by 25 feet and has a depth of approximately 5 feet. At the time of the reconnaissance, a piece of corrugated metal was in the bottom of the sinkhole. Feature E-05 (photo 88) is a small sink located south of the line of sinks that comprise Feature E-06. It does not have an apparent swallow hole. Feature E-06 (photos 89 through 94) is a northeast-southwest line of sinks that captures a losing stream. The sinkhole cluster had at least 6 swallow holes observed, some of which were large enough to provide refuge for rabbits, as indicated by the tracks in the snow. Bedrock is exposed in multiple locations.

Three additional features were observed further south of the preferred alignment. Feature E-03 (photos 83 to 85) is a fairly broad sinkhole with a diameter of approximately 25 feet. It is several feet deep and has a small swallow hole. Feature E-25 (photos 134 – 136) is a sinkhole pair, both at the base of trees with no observed swallow hole. There was no recognizable depression surrounding the small sinks. Feature E-26 (photos 137 – 141) is a large sinkhole with a diameter of approximately 30 feet and a depth of approximately 6 feet. The sinkhole has a number of medium-sized trees growing in it. There is some debris in the sinkhole and a pipe was observed entering the sinkhole from the east. The pipe had a small flow of water draining into the sinkhole.

Three small seeps were identified in the eastern part of Area E. The flow from each of these seeps was very small, probably on the order of a gallon per minute or less. There were no sinkholes in the immediate vicinity of these seeps. This portion of Area E appeared to have several small established stream channels, unlike the portion of Area E to the west that had a high density of sinkholes. One slight depression (Feature E-22, photo 129) was identified significantly east and topographically uphill from the seeps.

The terrain in Area E is the most rugged of areas along the proposed bypass route. It has a central ridge that runs east-west with wooded ravines on both the north and south sides. These ravines are where the majority of the karst features were observed. The ravines are natural drainage for the ridge and get lower in elevation toward the west. However, at the western edge of Area E, the ravines taper out into relatively flat, somewhat undulating topography. The overland flow from the east, and from the ridge top, is all lost into the numerous sinkholes in this area.

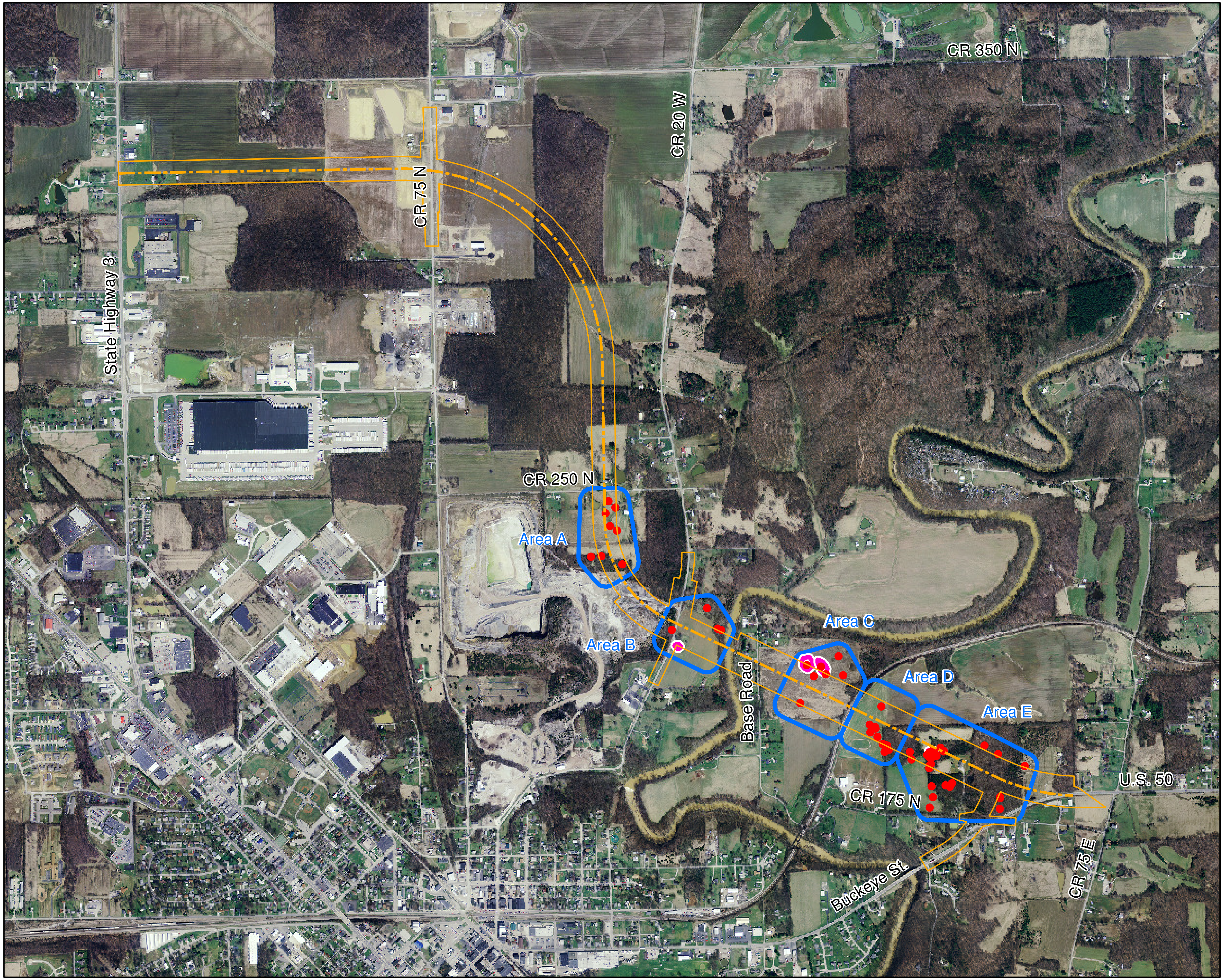


Figure 4-1
Areas with Identified Karst Features

Karst Features
Trace of Edge of Broad Sinkhole Area
Centerline of Preferred Allignment
Edge of Preferred Alignment Right of Way
Area of Karst Features Identified in Site Reconnaissance

Aerial Photography 2005
From Indiana Geological Survey MI 55

N

1:15000

0 500 1,000 2,000 Feet

Figure 4-2
Map of
Karst Features
in Area A

Karst Features in Area A
Karst Feature in Adjacent Area
Trace of Edge of Broad Sinkhole Area
Centerline of Preferred Allignment
Edge of Preferred Alignment Right of Way
Area of Karst Features Identified in Site Reconnaissance

Aerial Photography 2005
From Indiana Geological Survey MI 55

N

1:1800

0 100 200 Feet

Figure 4-3
Map of
Karst Features
in Area B

Karst Features in Area B
Karst Feature in Adjacent Area
Trace of Edge of Broad Sinkhole Area
Centerline of Preferred Allignment
Edge of Preferred Alignment Right of Way
Area of Karst Features Identified in Site Reconnaissance

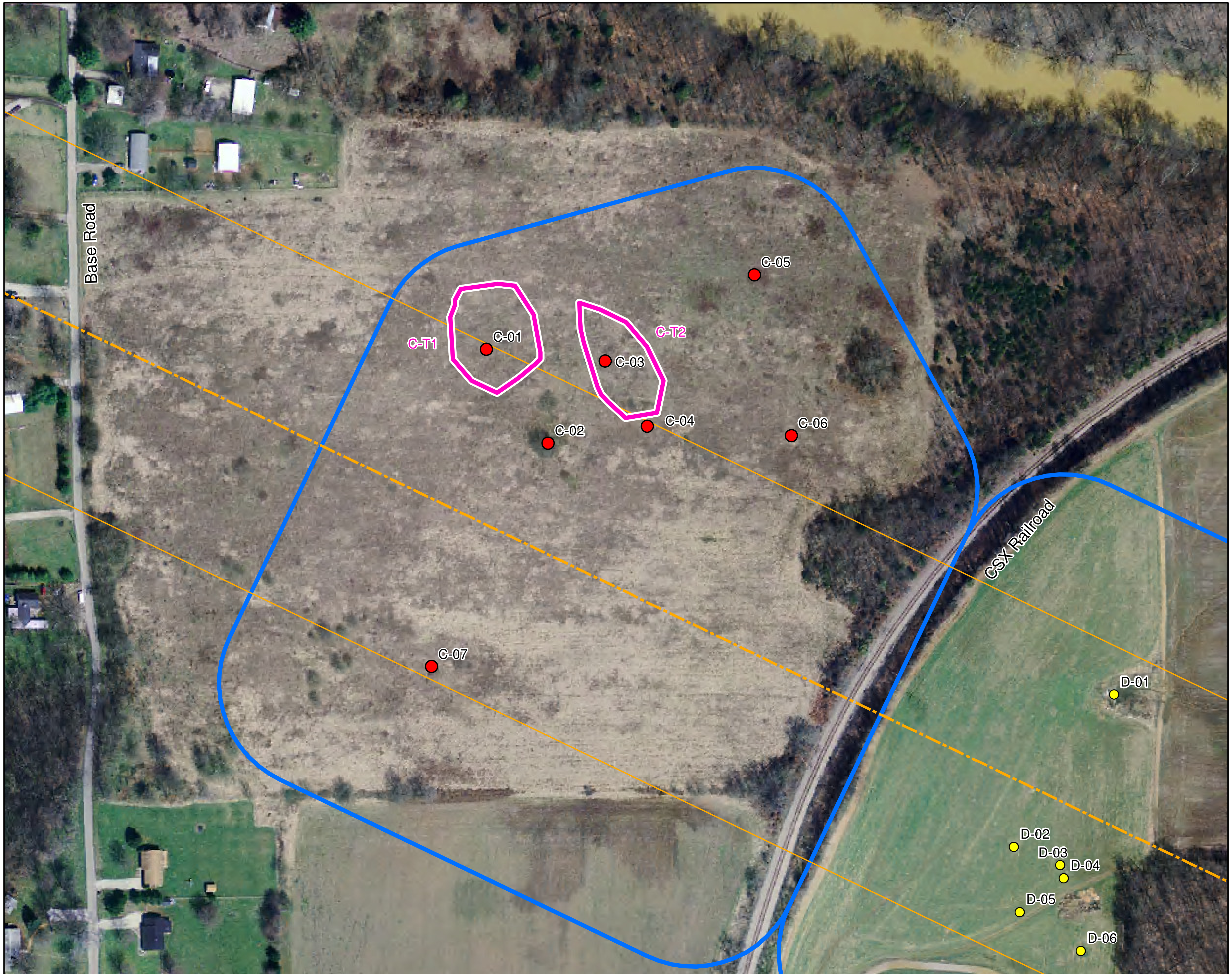
Aerial Photography 2005
From Indiana Geological Survey MI 55

N

1:1800

0 100 200 Feet

Figure 4-4
Map of
Karst Features
in Area C



Karst Features in Area C
Karst Feature in Adjacent Area
Trace of Edge of Broad Sinkhole Area
Centerline of Preferred Allignment
Edge of Preferred Alignment Right of Way
Area of Karst Features Identified in Site Reconnaissance

Aerial Photography 2005
From Indiana Geological Survey MI 55

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Figure 4-5
Map of Karst Features in Area D

Karst Features in Area D
Karst Feature in Adjacent Area
Trace of Edge of Broad Sinkhole Area
Centerline of Preferred Allignment
Edge of Preferred Alignment Right of Way
Area of Karst Features Identified in Site Reconnaissance

Aerial Photography 2005
From Indiana Geological Survey MI 55

N

1:1800

0 100 200 Feet

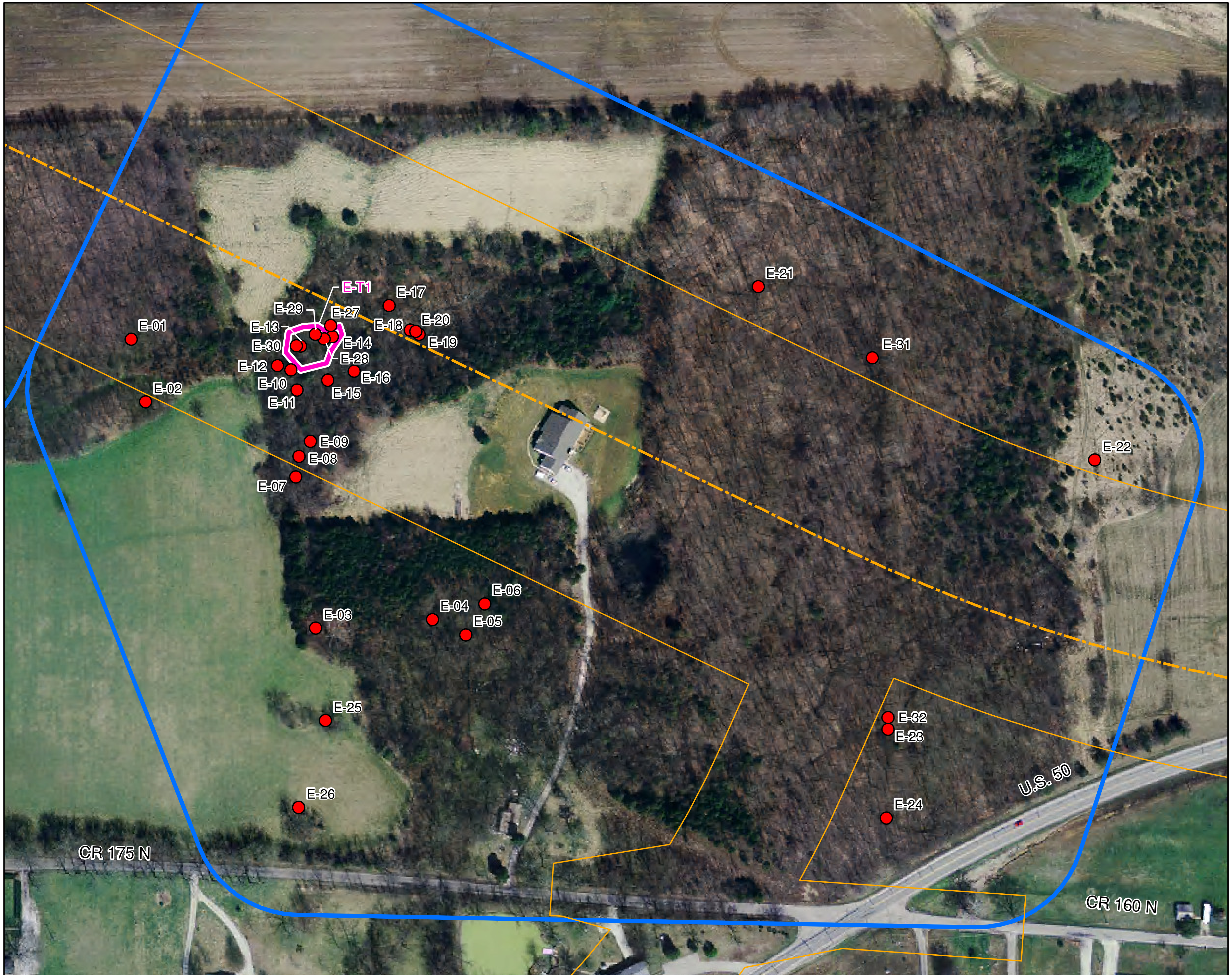

Figure 4-6
Map of
Karst Features
in Area E

- Karst Feature in Area E
- **Karst Feature in Adjacent Area**
- **Trace of Edge of Broad Sinkhole Area**
- **Centerline of Preferred Allignment**
- **Edge of Preferred Alignment Right of Way**
- **Area of Karst Features Identified in Site Reconnaissance**

Aerial Photography 2005
From Indiana Geological Survey MI 55

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0 100 200 Feet

SECTION 5

ANNUAL POLLUTANT LOAD ESTIMATES

5.1 METHODOLOGY

The purpose of the assessment was to determine the change in ambient water quality loading and concentrations from a pre-development condition to conditions during construction and post-development. Nine water quality parameters of interest are reported. The assessment was based on methodology defined in the United States Department of Agriculture's (USDA) Technical Release 55 (TR-55), (USDA, 1986), rainfall data from the Precipitation Frequency Data Server hosted by National Oceanic and Atmospheric Administration (NOAA) (NOAA, 2013), and land use-based water quality loading parameters reported in the National Stormwater Quality Database (United States Environmental Protection Agency [USEPA], 2005) as well as a review of published data for construction level water quality loading parameters (Lin, 2004).

The Soil Conservation Service (SCS) provides simplified procedures to calculate storm runoff volume in small watersheds, known as the SCS Method, which is applicable in urbanizing areas in the United States. A rainfall amount, derived from NOAA rainfall data, is uniformly imposed on the watershed. How much of the rainfall that actually generates runoff is estimated by a runoff curve number (CN) that converts the rainfall to mass runoff, which is based on soils, plant cover, amount of impervious areas, interception, and surface storage. Once the volume of runoff is estimated, the concentration of each constituent is applied using a mass balance approach to determine loading on an annual basis. The USEPA funded National Stormwater Quality Database (NSQD) was referenced for stormwater characteristics for the different type of land uses. The load is the product of the concentration and the volume of runoff. A mass balance approach was again used to estimate the cumulative effect of the different loads for the three different conditions: pre-development, post-development, and during construction. The calculations worksheets are included in Appendix C. Appendix C also contains a detailed description of the calculations for total suspended solids (TSS) for the A-04 feature watershed.

Predevelopment is the condition where the entire project area is untouched, in other words, all of the land in this condition is unimpacted. The load and concentration in this condition are considered the benchmark case from which change is measured. Under predevelopment conditions, the pollutant loading assumes that all of the area of the watershed draining to the sinkholes has the same characteristics. The post highway construction calculation follows a similar method with two sets of calculations made in parallel for both the impacted and unimpacted land uses. The post-highway construction loading is the sum of the loading from the unchanged area plus the high runoff conditions of the impervious surface.

The impact from construction follows the same method as for the post-development calculations. The unimpacted area is reduced because more of the land is impacted because now the entire right-of-way is considered as a dirt road. The NSQD did not report water quality data for construction. In addition, literature values for a complete set of constituent concentrations for construction are not readily available at the national level. However, there is a summary report through the Wetlands Regulatory Assistance Program (WRAP) that offers national values for TSS. Although the other parameters are not reported, TSS is an important indicator, as most water quality constituents are carried in the sediment (i.e., suspended solids). Thus, increases in TSS can be considered positively correlated with the other constituents, allowing TSS to be used as a proxy for the other parameters. The calculations in Appendix C are only performed for TSS. The tables in Section 5.4 for the construction scenario were developed by assuming that the change in the other water quality parameters was proportional to the change in TSS.

5.2 KARST FEATURES RECEIVING HIGHWAY RUNOFF

Five karst features and/or areas of karst were identified as having the potential to receive runoff from the highway identified in the preferred alternative. Feature A-04 is the furthest downstream sinkhole in a cluster that includes Features A-05, A-06, A-07, and A-08. Although some of the highway runoff might discharge to feature A-08, it was assumed for the purpose of the load calculations that all flow would discharge to A-04. This is a reasonable approximation for the total highway runoff that could enter sinkholes in this area. The highway right-of-way drainage area assumed to flow to feature A-04 is 8.6 acres. The highway impervious surface (highway lanes plus shoulders), is estimated to be 1.5 acres. The overall drainage area to feature A-04 is estimated to be 55.4 acres.

It was assumed for the purposes of the load calculations that highway runoff in Area B would be diverted through ditches and piping to the Vernon Fork of the Muscatatuck River rather than being discharged to any of the identified karst features. An agreement between INDOT and the City of North Vernon call for highway runoff in the portion of the preferred alternative from the Vernon Fork of the Muscatatuck River west to a point approximately 1,000 feet west of CR 20 W to be transmitted via pipes and ditches to discharge to the Vernon Fork of the Muscatatuck River south of the low head dam that forms the reservoir for the water intake for the City of North Vernon water supply.

The agreement between INDOT and the City of North Vernon also covers the area of the preferred alignment located between the CSX railroad tracks and the Vernon Fork of the Muscatatuck River. Highway runoff along this segment will be diverted through ditches and pipes to discharge to the river south of the water intake reservoir. Therefore, it is assumed that there will be no highway runoff entering the identified karst features in Area C. Calculations for loading were performed for features C-01, C-03, and C-04 as a combined feature in Appendix C. However, because of the diversion of highway runoff, the loading to these features is not included in the results tables in the body of this report and in the discussions that follow.

The loading from the preferred alternative highway in Area D was considered as a whole rather than calculating loading to individual features. This approach was used because it was not clear without details of the highway design which specific karst feature(s) would receive the discharge(s). The highway right-of-way drainage area was assumed to be 9.2 acres, of which approximately 1.0 acres is impervious surface. The overall drainage area of Area D is estimated to be 12.7 acres.

Three discharge basins were identified in Area E for calculation of loading. These include discharge to features E-01 and E-02, discharge to features E-07 and E-08, and discharge to feature E-06. Features E-01 and E-02 has an overall basin area of approximately 3.5 acres. The highway right of way drainage area to features E-01 and E-02 is estimated to be 3.0 acres, of which approximately 0.3 acres is impervious surface. Features E-07 and E-08 have an overall basin drainage basin of approximately 6.8 acres. The highway right of way drainage area of features E-07 and E-08 is approximately 5.2 acres, of which approximately 0.5 acres is impervious surface. Feature E-06 has an overall basin area of approximately 12.0 acres. The highway right of way drainage area is approximately 6.9 acres, of which approximately 0.7 acres is impervious surface.

5.3 INPUT PARAMETERS

A number of input parameters were required for the contaminant loading calculations. The Rainfall amount was derived from NOAA rainfall data. The same rainfall amount was assumed for all of the watersheds. The amount of rainfall that actually generates runoff was determined using the CN. The CN used varied based on the nature of the basin. Event mean concentration (EMC) is a measure of the contaminant generated in the runoff. EMC varied by land use and by parameter. The values utilized were obtained from Lin (2004). As would be expected, the EMC is much higher for the construction scenario than for unimpacted land uses.

Table 5-1 indicates the input parameters used in the analysis other than drainage areas.

Table 5-1 –Input Parameters

Parameter	Minimum Value	Maximum Value
24- Hour Return Period Rainfall (inches/year)	2.49	2.49
Curve Number [Unimpacted Land Use] (inches)	73	79
Curve Number [Impacted Land Use] Inches	98	98
EMC for Open Space Land Use		
TSS	48.50	48.50
Total Nitrogen	1.51	1.51
Total Phosphorus	0.31	0.31
Cadmium	0.38	0.38
Chromium	5.40	5.40
Copper	10.00	10.00
Lead	10.00	10.00
Zinc	200.00	200.00
EMC for Freeway Land Use		
TSS	99.00	99.00
Total Nitrogen	3.35	3.35
Total Phosphorus	0.25	0.25
Cadmium	1.00	1.00
Chromium	8.30	8.30
Copper	34.70	34.70
Lead	25.00	25.00
Zinc	200.00	200.00
EMC for Pasture and Wooded Land Use		
TSS	84.00	113.00
EMC for Construction –II		
TSS	985.00	985.00

Basin drainage areas are presented in Table 5-2.

Table 5-2 – Basin Drainage Areas

Parameter	A-04	Area D	E-01 & E-02	E-06	E-07 & E-08
Highway Drainage Basin					
Overall Drainage Area (acres)	55.4	12.7	3.5	12.0	6.8
Right of Way Drainage Area (acres)	8.6	9.2	3.0	6.9	5.2
Impervious Drainage Area (acres)	1.5	1.0	0.3	0.7	0.5

5.4 PREDICTED CONTAMINANT LOADS

The results of the contaminant loading prior to the development of the proposed U.S. 50 East Bypass of North Vernon are presented in Table 5 3.

Table 5-3 – Pre Highway Development Annual Runoff Volume and Contaminant Loads

Parameter	A-04	Area D	E-01 & E-02	E-06	E-07 & E-08
Runoff Volume (acre feet)	3.84	0.73	0.16	0.56	0.32
Suspended Solids (mg/L)	48.5	48.5	48.5	48.5	48.5
Suspended Solids (kg)	229.4	43.6	9.8	33.6	19.1
Total Nitrogen (mg/L)	1.51	1.51	1.51	1.51	1.51
Total Nitrogen (kg)	7.14	1.36	0.31	1.05	0.59
Total Phosphorus (mg/L)	0.31	0.31	0.31	0.31	0.31
Total Phosphorus (kg)	1.47	0.28	0.06	0.21	0.12
Cadmium (µg/L)	0.38	0.38	0.38	0.38	0.38
Cadmium (g)	1.80	0.34	0.08	0.26	0.15
Chromium (µg/L)	5.40	5.40	5.40	5.40	5.40
Chromium (g)	25.54	4.85	1.09	3.74	2.12
Copper (µg/L)	10.00	10.00	10.00	10.00	10.00
Copper (g)	47.30	8.99	2.02	6.93	3.93
Lead (µg/L)	10.00	10.00	10.00	10.00	10.00
Lead (g)	47.30	8.99	2.02	6.93	3.93
Zinc (µg/L)	80.00	80.00	80.00	80.00	80.00
Zinc (g)	378.4	71.9	16.2	55.5	31.4

After construction of the highway, contaminant loads will generally increase due to the combination of greater runoff from the impervious surface and additional contaminants from the traffic. As noted in Section 5.1, the water reaching the sinkholes consists of both, water from the unimpacted drainage basin and from the highway runoff. Calculated contaminant loading to the sinkholes following the construction of the highway are presented in Table 5 4.

Table 5-4 – Post Highway Development Annual Runoff Volume and Contaminant Loads

Parameter	A-04	Area D	E-01 & E-02	E-06	E-07 & E-08
Runoff Volume (acre feet)	4.01	0.86	0.21	0.66	0.39
Suspended Solids (mg/L)	52.1	59.6	62.3	58.6	60.7
Suspended Solids (kg)	257.7	63.2	15.9	47.8	26.2
Total Nitrogen (mg/L)	52.1	59.6	62.33	58.6	60.7
Total Nitrogen (kg)	8.12	2.03	0.51	1.53	0.94
Total Phosphorus (mg/L)	0.31	0.30	0.29	0.30	0.30
Total Phosphorus (kg)	1.51	0.31	0.07	0.24	0.14
Cadmium (μg/L)	0.42	0.52	0.55	0.50	0.53
Cadmium (g)	2.10	0.55	0.14	0.41	0.25
Chromium (μg/L)	5.60	6.04	6.19	5.98	6.10
Chromium (g)	27.74	6.40	1.58	4.88	2.93
Copper (μg/L)	11.74	15.41	16.76	14.93	15.98
Copper (g)	58.11	16.34	4.27	12.17	7.67
Lead (μg/L)	11.06	13.29	14.11	12.99	13.63
Lead (g)	54.73	14.09	3.59	10.60	6.54
Zinc (μg/L)	88.45	106.30	112.85	103.93	109.03
Zinc (g)	437.9	112.7	28.7	84.8	52.4

Table 5 5 presents a summary of the changes in constituent loading and ambient water quality for the pre-highway development versus post-highway development condition. The relative amount of difference among all parameters depends largely on the percentage of the overall drainage area to the sinkhole occupied by the highway. Feature A-04 has a large drainage area that lies outside of the highway footprint, whereas the other features have a much larger portion of the drainage area within the highway footprint. The relatively high percentage of the overall drainage basin of features E-01 and E-02 taken up by the roadway results in a large percentage difference in both runoff volume and overall contaminant loads.

In general, the change in phosphorus had the smallest percent change in contaminant mass of any on the contaminants. The overall concentration of phosphorus declined slightly, but due to the larger runoff volume, the total mass increased. Copper typically had the highest increase in concentration of the contaminants evaluated. When combined with the increased runoff volume, this resulted in significant increases in the total mass. For feature E-01 and E-02, the total mass increased approximately 111 percent. Overall the mass increases were roughly twice the percentage difference of the concentration increases.

The calculated increases in contaminant loading following construction of the proposed highway assume that no mitigation measures are utilized. Although the water being discharged to the five sinkhole clusters will contain higher contaminant loading, it should be recognized that a number of other sinkholes nearby will not have any impact from the new highway. Thus, the changes to overall water quality will be significantly lower that the changes predicted at these five sinkholes.

Table 5-5 – Post Highway Construction Change in Annual Contaminant Load

Parameter	A-04	Area D	E-01 & E-02	E-06	E-07 & E-08
Runoff Volume (%)	4.4	17.8	31.3	17.9	21.9
Total Suspended Solids concentration (%)	7.3	22.8	28.5	20.8	25.2
Total Suspended Solids mass (%)	12.3	44.9	61.8	42.0	53.0
Total Nitrogen concentration (%)	8.6	26.7	33.4	24.3	29.5
Total Nitrogen mass (%)	13.6	49.5	67.9	46.2	58.2
Total Phosphorus concentration (%)	-1.4	-4.2	-5.3	-3.9	-4.7
Total Phosphorus mass (%)	3.2	13.0	19.2	13.1	16.5
Cadmium concentration (%)	11.5	35.8	44.7	32.5	39.5
Cadmium mass (%)	16.7	60.2	82.1	55.9	70.5
Chromium concentration (%)	3.8	11.8	14.7	10.7	13.0
Chromium mass (%)	8.6	31.9	44.4	30.2	38.1
Copper concentration (%)	17.4	54.1	67.6	49.3	59.8
Copper mass (%)	22.9	81.8	111.0	75.6	95.2
Lead concentration (%)	10.6	32.9	41.1	29.9	36.3
Lead mass (%)	15.7	56.8	77.6	52.8	66.6
Zinc concentration (%)	10.6	32.9	41.1	29.9	36.3
Zinc mass (%)	15.7	56.8	77.6	52.8	66.6

Table 5 6 presents a summary of the runoff and TSS loading for the construction period and the change in these parameters compared to the pre highway development conditions. As noted in Section 5.1, EMC values were not available for the metals, phosphorus, or nitrogen. Changes to the metals, phosphorus, and nitrogen are assumed to be proportional to changes in TSS. Large increases in both the TSS concentration were expected based on the large increase in the EMC values for the construction scenario as compared to the baseline conditions. The marked increase in TSS concentration along with the significant increase in runoff let to TSS mass increases of over an order of magnitude in each of the features except for A-04, which had a smaller increase due to the large area of the overall basin that would be undisturbed during construction.

Table 5-6 –Annual Contaminant Load During Highway Construction

Parameter	A-04	Area D	E-01 & E-02	E-06	E-07 & E-08
Runoff Volume (acre feet)	4.28	1.31	0.38	1.07	0.70
Runoff Volume (% change)	11.5	79.5	137.5	91.1	118.8
Total Suspended Solids (kg)	1594	1367	442	1043	772
Total Suspended Solids (% change)	301	1712	1836	1232	1638
Total Suspended Solids concentration (mg/L)	302	847	932	790	891
Total Suspended Solids concentration (% change)	260	908	725	599	689

Although the water being discharged to the five sinkhole clusters will contain higher contaminant loading, it should be recognized that a number of other sinkholes nearby will not have any impact from the new highway or the construction of the highway. Thus the changes to overall water quality will be significantly lower than the changes predicted at these five sinkholes. The field survey indicated a lack of caves in the vicinity. Thus there are no known fauna that would be affected by the changes in contaminant loading. Residences in the area are typically served by public water supplies, so any changes in overall water quality would have a limited potential to impact human receptors.

SECTION 6

POTENTIAL MEASURES TO OFFSET IMPACTS TO KARST

One of the major objectives of the 1993 Memorandum of Understanding is to minimize the impacts of highway construction and operation on karst resources, including habitat of all species, groundwater quality, and public health and safety. Four strategies to meet this goal include: avoidance, alternative drainage, mitigation/treatment, and operation and maintenance.

6.1 AVOIDANCE

The preferred alignment has been selected based on a careful review of a number of factors including environmental factors, constructability, effectiveness to meet the transportation goals, and cost. Within the preferred alignment, there is a limited ability for the construction process and highway to avoid some of the karst features identified in the field reconnaissance.

6.2 ALTERNATIVE DRAINAGE

Alternative drainage is an important strategy to minimize the impacts of the highway construction and operation on karst resources. The roadway design must consider the collection and management of highway runoff. It may not be possible to redirect the highway runoff away from all of the karst features that were identified during the site reconnaissance. However, many of the karst features that were identified will lie underneath the pavement and actual construction footprint of the highway. These features will have to be filled and stabilized as a part of the construction process, which will eliminate them as potential pathways for the migration of highway runoff. The redirection of runoff and the elimination of the inflow to the sinkholes that will be filled and stabilized could impact aquatic species within the karst system. However, cave features that would support the aquatic species were not identified during the field reconnaissance.

Runoff from the highway from approximately 1,000 feet west of CR20 to the CSX railroad tracks will be collected and diverted through ditches and pipes to the Vernon Fork of the Muscatatuck River south of the dam that creates a reservoir for the North Vernon Water intake. This alternative drainage would prevent highway runoff from reaching the karst features in Areas B and C.

6.3 MITIGATION/TREATMENT

Where avoidance of the karst feature and engineering the drainage from the roadway to avoid the karst feature is not possible, mitigation and treatment of the runoff should be considered. Mitigation measures for highway runoff include the implementation of peat and sand filters, gravel filters, vegetative buffers, and lined spill or runoff containment structures. These measures can be implemented to detain and treat the runoff prior to discharge to a karst feature. Monitoring of the discharges from these treatment measures may be required to evaluate their effectiveness in mitigating the impact of the highway runoff.

Mitigation measures will be utilized during construction of the highway. These may include such measures as silt fencing, temporary berms, accelerated vegetation of completed areas, and other erosion control measures. The construction project will require a Rule 5 Permit from IDEM.

6.4 OPERATION AND MAINTENANCE

Maintenance of the highway and the associated treatment/mitigation measures should be performed to ensure that the impacts to karst features are minimized. Routine maintenance and inspection of filters, buffers and containment structures should be performed and any deficiencies or problems should be corrected at the earliest possible time. Examination of drainage features in areas adjacent to karst areas should be performed periodically to identify any emerging karst features. Consideration should be given to implementation of no mowing and no spray zones to increase vegetative cover and buffering of runoff. Advances in treatment and mitigation technology should be monitored for potential application.

SECTION 7

SUMMARY AND CONLUSIONS

A karst evaluation was performed of the area in and surrounding the preferred alignment for the U.S. 50 bypass of North Vernon, Indiana. The preferred alignment runs from SR 3 north of North Vernon to the existing U.S. 50 alignment near CR 175 North. A review of literature on the geology and hydrogeology of the area of the preferred alignment was performed prior to performing a field reconnaissance. Over 60 karst features were located using a resource-grade GPS unit during the field reconnaissance. Several of the mapped locations included multiple small sinkholes.

Almost all of the karst features identified are sinkholes. Several seeps were identified; however, no springs of any consequence were observed. Several small openings were identified that are termed caves in the notes. However, none of these features were large enough to allow human entry.

Two areas of the preferred alignment lacked any observed karst features. These areas included an interval between the SR 3 end of the alignment and West CR 250 North, and the area between North Base Road and the Vernon Fork of the Muscatatuck River.

Five geographic areas of karst features were identified. Within each of these areas, the karst features identified typically shared similar characteristics. Area A is located north of the quarry and south of West CR 250 North. A total of eight karst features were mapped in this area, seven of which were sinkholes. Area B is located west of the Vernon Fork of the Muscatatuck River extending to just west of North CR 20 West. Five karst features were identified in this area. Two of the features were sinkholes, one was a swallow hole for a small drainage, one was a small cave mouth (not large enough to be entered by humans), and one was a spring with a small flow.

Seven karst features were identified within Area C, located west of the CSX railroad tracks and east of North Base Road. All of the features were sinkholes. Area D is located east of the CSX railroad tracks. Eleven karst features were mapped in Area D, some of which contain multiple sinkholes. Area E is located at the eastern end of the preferred alignment. Thirty karst features were located in the area, a number of which represented multiple sinkholes. Most of the features were sinkholes. Three of the features were small seeps with low flow rates. The density of the features in Area E was significantly higher than in other areas. The features typically exhibited steep sides.

It is noteworthy that there were no springs with a flow of greater than a couple of gallons per minute identified during the field reconnaissance. There was enough snow melting occurring during the field reconnaissance that springs, if present, would have been expected to have a reasonable flow. This fact suggests that inflow to the identified sinkholes is likely to discharge to the Vernon Fork of the Muscatatuck River. Although a dye trace could confirm that this is the case, mixing of dye emerging into the large flow in the river would dilute the concentration of dye, making detection of the flow difficult. This might lead to false negative results.

The annual contaminant loading that will reach sinkholes was estimated for baseline conditions prior to development of the highway, after construction of the highway and conditions during construction of the highway. Five sinkholes and/or areas with multiple sinkholes were identified as being likely to receive highway runoff. During construction of the highway, TSS would be expected to increase in four of the five sinkholes by over an order of magnitude in the absence of sedimentation controls. This large increase is due to a combination of higher TSS concentrations due to the land disturbance as well as significant increases in runoff volume. The loading of nitrogen, phosphorus and metals would be expected to increase in proportion to the TSS.

Following construction of the highway, much more modest increases in contaminant loads are predicted. The increases in concentration and contaminant loading are lowest for feature A-04 due to the relatively small portion of the drainage area of the sinkhole occupied by the highway. Contaminant loading for phosphorus exhibits the least impact from the highway, with marginally lower concentrations offset by the larger runoff volume. The contaminant with the greatest change in concentration was copper, which, when coupled with the increased runoff volume led to a copper loading that slightly more than doubled for the combined basin of features E-01 and E-02. Although the five sinkholes/sinkhole areas that received highway runoff will receive substantially higher contaminant loads, it is important to note that there are a much greater number of sinkhole basins that will not be impacted by the highway construction or highway runoff. Thus, the overall impact to groundwater quality in the area will be much lower.

The absence of caves in the area suggests that there is limited reason to expect sensitive cave species and habitats that would potentially be impacted by runoff from the proposed bypass that drains to the five sinkhole areas. Most of the residences in the area are supplied by public water from either the City of North Vernon or Jennings Water, Inc. Therefore, there is limited potential for domestic supplies to be impacted by the proposed bypass. The water supply for the City of North Vernon is from a low head dam located just downstream of the preferred alignment.

An agreement between INDOT and the City of North Vernon calls for highway runoff from the portion of the preferred alternative between approximately 1,000 feet west of CR 20 W to the CSX railroad tracks to be conveyed using ditches and piping to the Vernon Fork of the Muscatatuck River downstream of the low head dam that forms the reservoir for the water intake for the City of North Vernon water supply. As a result of this agreement, sinkholes in Areas B and C will not receive highway runoff. Therefore, calculations of the volume of runoff and contaminant loadings were not performed for these areas.

Highway runoff that is captured by features A-04, E-01 & E02, E-06 and E-07 & E-08, and by the features in Area D is likely to flow through the upper limestone and discharge to the Vernon Fork of the Muscatatuck River. Along this pathway, the concentrations of contaminants will be diluted by runoff not associated with highway runoff that enters sinkholes. When this water discharges to the river, it will be diluted by the flow of the river.

SECTION 8

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APPENDIX A

MEMORANDUM OF UNDERSTANDING

Memorandum of Understanding

(Retyped of original text 3/14/2007)

This Memorandum of Understanding is made and entered into this thirteenth day of October, 1993, between the Indiana Department of Transportation (INDOT), the Indiana Department of Natural Resources (IDNR), the Indiana Department of Environmental Management (IDEM) and the U.S. Fish and Wildlife Service (USFWS) for the purpose of delineating guidelines for construction of transportation projects in karst regions of the State.

Whereas, INDOT, IDNR, IDEM and the USFWS wish to cooperate in the identification, study and treatment of drainage in karst regions related to the construction of transportation projects and

Whereas, INDOT, IDNR, IDEM and the USFWS accept responsibility to ensure the transportation needs of Indiana are met in an environmentally sensitive manner that protects the habitat of all species and

Whereas, design and construction practices must protect ground water quality, public health and safety, and the environment.

Whereas, the Indiana Department of Natural Resources will conform to the terms and conditions within this MOU for their transportation projects. Likewise, it will be IDNR's responsibility to provide standard biological review for projects in the karst region.

Therefore, in consideration of the terms and conditions set forth herein the INDOT, IDNR, IDEM and USFWS agree as follows:

1. INDOT in cooperation with the IDNR, IDEM and USFWS shall determine the location of sinkholes, caves, underground streams, and other related karst features and their relationship prior to proposed alterations or construction in karst regions of the state, a consultant with expertise in karst geology/hydrology may assist in the identification and characterization of the karst features. The choice of the consultant retained by INDOT will be subject to the review of IDNR, USFWS and IDEM.

2. Tasks to accomplish this work will include:

   Research public and private information sources for information relative to karst features.

   Conduct field check karst and cave features that appear from the first task and identify any additional karst features.

   Prepare a draft report, with photographs and maps, drainage areas, and land use of that drainage area for each sinkhole or karst feature, dye-tracing and/or other geotechnical information to determine subsurface flow of water in the project area and surface water drainage patterns of the area. Calculations of estimates of annual pollutant loads from the highway and drainage with the right-of-way will be made, including prior to, during and post construction estimates. The design of the treatment of the karst features will take into consideration treatments necessary to meet the standards of the monitoring and maintenance plan.

That report will be used as a tool to assist in determining the proposed highway alignment. The intent of INDOT is to avoid karst areas and use alternate drainage where possible.

3. IDNR, IDEM and USFWS will be requested to review and comment on the findings at the early coordination phase of project development.

4. INDOT, using the input from IDNR, IDEM and USFWS will begin to formulate appropriate measures to offset unavoidable impacts to the karst features. It is understood by all parties that some of the methods proposed at this time will be generic and could be applied throughout the length of the corridor. Other methods may be specific to a particular cave or karst feature. Some of the approaches may require additional investigations to determine their necessity and/or their feasibility. A revised draft report will be prepared by INDOT's consultant and provided to the IDNR, IDEM and the USFWS as part of the design review process.

5. Drainage entering from beyond the right-of-way will be treated according to the same process as drainage generated by the project.

6. As the project progresses further into the design phase, the IDNR, IDEM and USFWS will be invited and will attend field checks and meetings dealing with efforts to negate or minimize adverse impacts.

7. Hazardous materials traps (HMT's) will be constructed at storm water outfalls and other locations that will protect karst features from spill contamination.

8. INDOT agrees to develop a monitoring and maintenance plan for the affected karst features. IDNR, IDEM and USFWS will be provided an opportunity to review this plan. The establishment of water quality and a point at which a standard is established for remediation will be a part of each monitoring plan. The results of the monitoring will be submitted to IDNR, USFWS and IDEM on a regular basis.

9. A low salt and no spray strategy will be developed for each future project. A signing strategy for these items will also be developed for each project.

10. Prior to acceptance of the final design plans an agreement will be developed which will set out t6he appropriate and practicable measures to offset unavoidable impacts to karst features. This agreement will be signed by the Department Director of IDNR, the Commissioner of the IDEM, the Commissioner of INDOT and the Supervisor of the USFWS Bloomington, Indiana Field Office. The agreement will become a part of

the contract documents for the project, will be discussed at the pre-construction conference and will be on file at the office of the project administrator.

11. INDOT will assure that the terms of the agreement will be completed with all safeguards given to the karst area. Special provisions, which are binding provisions that are a part of the contract, will be included outlining the precautions to be taken. Construction and design strategies for handling karst features will be discussed with the contractor(s) and project administrator during the pre-construction conference. Project administrator shall ensure that the contractor is following the new erosion control standards that meet Rule 5 of 327 IAC 13 and any special precautions outlined in the design plans that the sinkhole treatment is being handled correctly. The erosion control plan must be available at the project administrator's office. An emergency response plan will be made a part of the contract documents. In addition, the contract documents will contain a strategy for signing to alert the public to the fact that all types of spills are potentially hazardous to the karst environment. For INDOT, this plan would be procedure 20 of the Field Operations Manual dated 6/24/1992. [Currently in the Construction Activities Environmental Manual].

12. The location and nature of the sinkholes and drainage schematic will be provided to the IDEM. They will provide the information to the appropriate local authorities and the Hazmat teams. An emergency response plan will be followed. This constitutes procedure 20. Included in this information is an understanding that all types of spills are potentially hazardous to karst regions.

13. IDNR, IDEM and USFWS personnel will monitor construction and maintenance to the agreed upon terms, as deemed necessary.

14. If during construction it is found that the mitigation agreement must be altered, all of the agencies will be contacted and agreement reached prior to work continuing in that specific area of the project. In order to not unduly delay projects, a two working days response time is needed from the resource agencies.

15. Treatments will be maintained during construction by means of a visual inspection on a weekly basis or after every rain. Corrective action will be taken as needed.

16. If after the above procedure is followed and a state/federal endangered/threatened species is found during construction, work in that area of the project will stop. The IDNR and USFWS will be immediately notified. The IDNR and USFWS will promptly investigate the situation, advise the project administrator and assume responsibility for protecting the endangered species and taking the appropriate action.

17. This document will be reviewed annually or more frequently at the request of any of the foregoing agencies.

MR. FREDERICK C. P'POOL, COMMISSIONER
INDIANA DEPARTMENT OF TRANSPORTATION

MR. PATRICK R. RALSTON, DIRECTOR
INDIANA DEPARTMENT OF NATURAL RESOURCES

MS. KATHY PROSSER, COMMISSIONER
INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

MR. DAVID C HUDAK, FIELD SUPERVISOR, BLOOMINGTON FIELD OFFICE
U. S. FISH AND WILDLIFE SERVICE


St Joseph
Elkhart
Lagrange
Steuben
La Porte
Lake
Porter
Noble
Dekalb
Marshall
Kosciusko
Starke
Whitley
Allen
Pulaski
Fulton
Jasper
Newton
Wabash
Huntington
Cass
White
Adams
Wells
Miami
Carroll
Benton
Grant
Jay
Howard
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Hendricks
Fayette
Rush
Union
Morgan
Shelby
Vigo
Johnson
Franklin
Clay
Decatur
Owen
Bartholomew
Brown
Dearborn
Sullivan
Ripley
Monroe
Jennings
Greene
Ohio
Jackson
Lawrence
Switzerland
Jefferson
Davies
Martin
Scott
Knox
Washington
Orange
Clark
Pike
Gibson
Dubois
Crawford
Floyd
Harrison
Warrick
Perry
Vanderburgh
Posey
Spencer
Potential Karst Features Region

APPENDIX B

PHOTOGRAPH LOG

Photo 1: A-01, Joints in creek bed at 160-170 degrees with a secondary joint at 80 degrees

Photo 2: A-01, Joints in creek bed at 160-170 degrees with a secondary joint at 80 degrees

Photo 3: A-02, Pit, approximately 8-10' diameter 4' deep . Small swallow hole obscured by limbs and leaves.

Photo 4: A-02, Pit, approximately 8-10' diameter 4' deep. Small swallow hole obscured by limbs and leaves.

Photo 5: A-03, Small pit, approximately 6' diameter 3' deep slightly oblong no distinct swallow hole.

Photo 6: A-03, Small pit, approximately 6' diameter 3' deep slightly oblong no distinct swallow hole.

Photo 7: A-04, Swallow hole next to rock exposed in soil, no depression.

Photo 8: A-04, Swallow hole next to rock exposed in soil, no depression.

Photo 9: A-05, Small depression approximately 10' x 4', 2' deep, snow covered.

Photo 10: A-05, Small depression approximately 10' x 4', 2' deep, snow covered.

Photo 11: A-06, 2 small sinkholes, which swallow overflow from adjacent pond, both approximately 6' diameter, 3' deep.

Photo 12: A-06, 2 small sinkholes, which swallow overflow from adjacent pond, both approximately 6' diameter, 3' deep.

Photo 13: A-06, 2 small sinkholes, which swallow overflow from adjacent pond, both approximately 6' diameter, 3' deep.

Photo 14: A-06, 2 small sinkholes, which swallow overflow from adjacent pond, both approximately 6' diameter, 3' deep.

Photo 15: A-07, Obscured swallow hole, creek enters area where tree was pushed over.

Photo 16: A-07, Obscured swallow hole, creek enters area where tree was pushed over.

Photo 17: A-08, Line of small depressions, approximately 20' long x 5' wide x 2' deep, snow covered.

Photo 18: A-08, Line of small depressions, approximately 20' long x 5' wide x 2' deep, snow covered.

Photo 19: A-08, Line of small depressions, approximately 20' long x 5' wide x 2' deep, snow covered.

Photo 20: A-08, Line of small depressions, approximately 20' long x 5' wide x 2' deep, snow covered.

Photo 21: B-01, Sinkhole with swallow hole obscured. With large catchment, approximately 120' diameter.

Photo 22: B-01, Sinkhole with swallow hole obscured. With large catchment, approximately 120' diameter.

Photo 23: B-02, Cave mouth slight discharge from mouth.

Photo 24: B-02, Cave mouth slight discharge from mouth.

Photo 25: B-02, Cave mouth slight discharge from mouth.

Photo 26: B-03, Flow from cave mouth spring disappears into hole at base of tree .

Photo 27: B-03, Flow from cave mouth spring disappears into hole at base of tree .

Photo 28: B-04, Spring emerging from beneath pile of felled trees.

Photo 29: B-04, Spring emerging from beneath pile of felled trees.

Photo 30: B-T1, Broad shallow depression in open field No swallow is apparent.

Photo 31: C-01 & C-T1, Large broad sinkhole, very shallow, silt filled, no apparent swallow hole. The area has an abundance of low vegetation.

Photo 32: C-01 & C-T1, Large broad sinkhole, very shallow, silt filled, no apparent swallow hole. The area has and abundance of low vegetation.

Photo 33: C-01 & C-T1, Large broad sinkhole, very shallow, silt filled. There is no apparent swallow hole. The area has an abundance of vegetation.

Photo 34: C-02, Small compact sinkhole, approximately 12' diameter, 4' deep, filled with piled sticks, has 8-10 potholes 2' diameter x 1' deep on north side of main sink.

Photo 35: C-02, Small compact sinkhole, approximately 12' diameter, 4' deep, filled with piled sticks, has 8-10 potholes 2' diameter x 1' deep on north side of main sink.

Photo 36: C-02, Swallow hole of a small compact sinkhole, approximately 12' diameter, 4' deep, filled with piled sticks, has 8-10 potholes 2' diameter x 1' deep on north side of main sink.

Photo 37: C-02, Small compact sinkhole, approximately 12' diameter, 4' deep, filled with piled sticks, has 8-10 potholes 2' diameter x 1' deep on north side of main sink.

Photo 38: C-03 & C-T2, Large broad silt filled sinkhole with several distinct 2' diameter x 2' deep swallow holes approx 80 long x 40' wide with 5' total depth.

Photo 39: C-03 & C-T2, Swallow hole within large broad silt filled sinkhole with several distinct 2' diameter x 2' deep swallow holes approx 80 long x 40' wide with 5' total depth.

Photo 40: C-03 & C-T2, Swallow hole within a large broad silt filled sinkhole with several distinct 2' diameter x 2' deep swallow holes approx 80 long x 40' wide with 5' total depth.

Photo 41: C-03 & C-T2, Swallow hole within a large broad silt filled sinkhole with several distinct 2' diameter x 2' deep swallow holes approx 80 long x 40' wide with 5' total depth.

Photo 42: C-04, Distinct pot sink adjacent to a broad sink with one main swallow hole with pair of silt filled swallows.

Photo 43: C-04, Distinct pot sink adjacent to a broad sink with one main swallow hole with pair of silt filled swallows.

Photo 44: C-04, Distinct pot sink adjacent to a broad sink with one main swallow hole with pair of silt filled swallows.

Photo 45: C-04, Swallow hole within a distinct pot sink. Pot sink is adjacent to a broad sink .

Photo 46: C-05, Broad, shallow sink with silt bottom and no apparent swallow hole approximately 30' diameter x 3-4' deep.

Photo 47: C-05, Broad, shallow sink with silt bottom and no apparent swallow hole approximately 30' diameter x 3-4' deep.

Photo 48: C-06, Pair of discrete sinks ; one is 6' diameter x 3' deep other is 5' x 12' x 3' deep.

Photo 49: C-06, Pair of discrete sinks ; one is 6' diameter x 3' deep other is 5' x 12' x 3' deep.

Photo 50: C-06, Pair of discrete sinks with some sticks accumulated at swallow hole.

Photo 51: C-06, Pair of discrete sinks .

Photo 52: C-07, Distinct sinkhole approximately 10' x 15' x 4' deep with accumulation of sticks.

Photo 53: C-07, Sinkhole approximately 10' x 15' x 4' deep.

Photo 54: C-07, Distinct swallow hole in sinkhole approximately 10' x 15' x 4' deep.

Photo 55: C-07, Distinct sinkhole approximately 10' x 15' x 4' deep.

Photo 56: D-01, Broad, shallow sinkholes, approximately 30' diameter, several feet deep. A mass of trees surrounds.

Photo 57: D-01, Swallow hole in a broad, shallow sinkhole, approximately 30' diameter, several feet deep surrounded by a mass of trees surrounds.

Photo 58: D-01, Swallow hole in a broad, shallow sinkhole, approximately 30' diameter, several feet deep. Debris is near swallow hole.

Photo 59: D-01, Broad, shallow sinkhole, approximately 30' diameter, several feet deep surrounded by a mass of trees.

Photo 60: D-02 & D-03, open holes with no significant depression.

Photo 61: D-02 & D-03, 3" diameter open holes with no significant depression.

Photo 62: D-02 & D-03, 3" diameter open holes with no significant depression.

Photo 63: D-02 & D-03, Area surrounding 3" diameter open holes with no significant depression.

Photo 64: D-02 & D-03, Area surrounding 3" diameter open holes with no significant depression.

Photo 65: D-04, Small diameter open hole, marked with tree limbs.

Photo 66: D-05, Small diameter open hole, marked with tree limbs.

Photo 67: D-07, 15' diameter sinkhole with round bottom.

Photo 68: D-08, 20' x 10' sinkhole with 2 inlets.

Photo 69: D-08, 20' x 10' sinkhole with 2 inlets.

Photo 70: D-08, Swallow hole in 20' x 10' sinkhole.

Photo 71: D-09, Swallow hole in set of 3 sinkholes approximately 10' diameter 7' deep.

Photo 72: D-09, Set of 3 sinkholes approximately 10' diameter 7' deep with large swallow holes.

Photo 73: D-09, Set of 3 sinkholes approximately 10' diameter 7' deep with large swallow holes.

Photo 74: D-10, Sinkhole with double inlet 10' x 25' , 4-5' deep.

Photo 75: D-10, Sinkhole with double inlet 10' x 25' , 4-5' deep.

Photo 76: D-11, Sinkhole approximately 15' x 25' x 10' deep with 2 swallow holes. Nearby small shallow depression with no swallow hole.

Photo 77: D-11, Sinkhole approximately 15' x 25' x 10' deep with 2 swallow holes with a nearby small shallow depression with no swallow hole.

Photo 78: D-11, One of two swallow holes in a sinkhole approximately 15' x 25' x 10' deep.

Photo 79: E-01, Single sink with small swallow hole with several streams leading into sink, approximately 10' x 15‘.

Photo 80: E-01, Single sink with small swallow hole with several streams leading into sink, approximately 10' x 15‘.


Photo 81: E-01, Swallow hole in a single sink with several streams leading into sink, approximately 10' x 15‘.


Photo 82: E-02, Very shallow depression with no swallow hole.

Photo 83: E-03, Single sinkhole approximately 25' diameter, with small swallow hole.

Photo 84: E-03, Single sinkhole approximately 25' diameter, with small swallow hole.

Photo 85: E-03, Small swallow hole in a single sinkhole approximately 25' diameter.

Photo 86: E-04, 15' x 25' sinkhole, approximately 5' deep. Corrugated (tin) roofing panels embedded in bottom.

Photo 87: E-04, 15' x 25' sinkhole, approximately 5' deep. Corrugated (tin) roofing panels embedded in bottom.

Photo 88: E-05, Small sink, south of line of sinks, with no distinct opening.

Photo 89: E-06, Line of sinks aligned on 230 degrees with a losing stream, 6 openings all fairly large, inhabited by rabbits.

Photo 90: E-06, Swallow hole in line of sinks aligned on 230 degrees with a losing stream, inhabited by rabbits.

Photo 91: E-06, One of six openings in a line of sinks aligned on 230 degrees with a losing stream.

Photo 92: E-06, One of six openings in a line of sinks aligned on 230 degrees with a losing stream.

Photo 93: E-06, Swallow hole in a line of sinks aligned on 230 degrees with a losing stream.

Photo 94: E-06, Swallow hole in a line of sinks aligned on 230 degrees with a losing stream.

Photo 95: E-07, Single sinkhole approximately 25' diameter with open swallow approximately 5' deep.

Photo 96: E-07, Swallow hole in a single sinkhole approximately 25' diameter approximately 5' deep.

Photo 97: E-08 & E-09, Swallow hole in a cluster of 4 sinks with 3 aligned 180 degrees, each approximately 10' diameter and 5' deep.

Photo 98: E-08 & E-09, Cluster of 4 sinks with 3 aligned 180 degrees, each approximately 10' diameter and 5' deep, with open swallows.

Photo 99: E-08 & E-09, Swallow hole in a cluster of 4 sinks with 3 aligned 180 degrees, each approximately 10' diameter and 5' deep.

Photo 100: E-08 & E-09, Swallow hole in a cluster of 4 sinks with 3 aligned 180 degrees, each approximately 10' diameter and 5' deep.

Photo 101: E-08 & E-09, Swallow hole in one of a cluster of 4 sinks with 3 aligned 180 degrees, each approximately 10' diameter and 5' deep.

Photo 102: E-10, E-11 & E12, Swallow hole in a small basin adjacent to major sink.

Photo 103: E-10, E-11 & E12, Smaller basin adjacent to major sink.

Photo 104: E-10, E-11 & E12, Small basin adjacent to major sink.

Photo 105: E-10, E-11 & E12, Swallow hole in small basin adjacent to major sink.

Photo 106: E-13 , E-14, E-27, E-28, E-29 & E-30, Major sink with multiple openings, basin approximately 80' diameter, 10' deep.

Photo 107: E-13 , E-14, E-27, E-28, E-29 & E-30, Major sink with multiple openings, basin approximately 80' diameter, 10' deep.

Photo 108: E-13, E-14, E-27, E-28, E-29 & E-30, swallow hole in major sink with multiple openings. Basin is approximately 80' diameter, 10' deep.

Photo 109: E-13 , E-14, E-27, E-28, E-29 & E-30, Portion of major sink with multiple openings.

Photo 110: E-13, E-14, E-27, E-28, E-29 & E-30, Swallow hole in major sink with multiple openings. Basin is approximately 80' diameter, 10' deep.

Photo 111: E-13, E-14, E-27, E-28, E-29 & E-30, Swallow hole in major sink with multiple openings.

Photo 112: E-15, Vertical fracture intersection with long dimension aligned at 235 degrees.

Photo 113: E-15, Vertical fracture intersection with long dimension aligned at 235 degrees.

Photo 114: E-15, Vertical fracture intersection with long dimension aligned at 235 degrees.

Photo 115: E-16, Sheer wall in side of sinkhole with large opening .

Photo 116: E-16, Sheer wall in side of sinkhole with large opening.

Photo 117: E-16 Steep sides of sinkhole with large opening .

Photo 118: E-18, E-19 & E-20, Swallow hole in one of a cluster of sinkholes with multiple large swallow holes. Each approximately 15' diameter and 5' deep.

Photo 119: E-18, E-19 & E-20, Cluster of sinkholes with multiple large swallow holes. Each approximately 15' diameter and 5' deep.

Photo 120: E-18, E-19 & E-20, Swallow hole with debris in one of a cluster of sinkholes with multiple large swallow holes.

Photo 121: E-18, E-19 & E-20, Swallow hole littered with debris in one of a cluster of sinkholes with multiple large swallow holes.

Photo 122: E-18, E-19 & E-20, Sinkhole that is part of a cluster of sinkholes with multiple large swallow holes.

Photo 123: E-18, E-19 & E-20, One of several swallow holes within a cluster of sinkholes with multiple large swallow holes.

Photo 124: E-18, E-19 & E-20, One of several swallow holes within a cluster of sinkholes with multiple large swallow holes.

Photo 125: E-18, E-19 & E-20, One of several sinkholes that form a cluster of sinkholes with multiple swallow holes.

Photo 126: E-18, E-19 & E-20, One of a cluster of sinkholes with multiple large swallow holes.

Photo 127: E-21, Very low flow seep emerging from rock seam in creek bed.

Photo 128: E-21, Area of a very low flow seep emerging from rock seam in creek bed.

Photo 129: E-22, Very slight depression with no evidence of swallow hole.

Photo 130: E-23, Small spring emerging from rocks near base of a tree (also a 55-gal drum embedded into side of the hill nearby).

Photo 131: E-23, Small spring emerging from rocks near base of a tree (also a 55-gal drum embedded into side of the hill nearby).

Photo 132: E-23, Area of small spring emerging from rocks near base of a tree (also a 55-gal drum embedded into side of the hill nearby).

Photo 133: E-23, Area of small spring emerging from rocks near base of a tree (also a 55-gal drum embedded into side of the hill nearby).

Photo 134: E-25, Two small sinkholes, both at base of trees, no visible swallow holes.

Photo 135: E-25, Two small sinkholes, both at base of trees, no visible swallow holes.

Photo 136: E-25, Two small sinkholes, both at base of trees, no visible swallow holes.

Photo 137: E-26, Large sink approximately 30' diameter, 6' deep, has PVC pipe draining into sinkhole.

Photo 138: E-26, Large sink approximately 30' diameter, 6' deep, has PVC pipe draining into sinkhole and some debris piles.

Photo 139: E-26, Debris pile in large sink approximately 30' diameter, 6' deep.

Photo 140: E-26, Large sink approximately 30' diameter, 6' deep, has PVC pipe draining into sinkhole and a pile of debris.

Photo 141: E-26, PVC draining into a large sink approximately 30' diameter, 6' deep.

Photo 142: E-T1, Major sink with multiple openings, basin approximately 80' diameter, 10' deep .

Photo 143: E-T1, Major sink with multiple openings, basin approximately 80' diameter, 10' deep .

Photo 144: General, Typical exposed bedrock of the area – limestone with large volume of vugs and fractures.

Photo 145: General, Typical exposed bedrock of the area – limestone with large volume of vugs and fractures.

APPENDIX C

CONTAMINANT LOADING CALCULATIONS

Appendix C – Annual Pollutant Load Calculations

Example Calculations

The following is an example for one constituent for a single watershed that follows the calculation sets found in this Appendix (I. Before Highway Development, II. After Highway Construction, III. Change, and IV. Construction Condition).

I. Before Highway Development

Subwatershed A-04 is composed of 55.4 acres of pasture/grass land (associated CN value is 79). Based on TR-55 Equation 2-4, the potential maximum soil storage (S) after runoff begins is 2.66 inches (soil storage is not to be confused with what is lost before rainfall begins due to storage in recessions in the landscape). The annual rainfall in the area according to NOAA data is 2.49 inches. Knowing annual precipitation and soil storage, Equation 2-3, tell us that on an annual basis roughly one third of every inch of rainfall that falls becomes runoff . This normalized factor (equivalent runoff coefficient, C) can then be applied to any amount of annual rainfall (P_t). Thus the 2.49 inches of annual rainfall actually becomes 0.83 inches of runoff (Pt x C = 0.33 x 0.83). Appling Equation 1, the area of watershed A-04 (8.6 acres) gives a total annual generated runoff volume (Rv) of 0.83 acre feet of water per year (ac-ft/yr). The closest National Stormwater Quality Database (NSQD) land use category related to this area is "open space." Open space event mean concentration (EMC)[1] for total suspended solids (TSS) is 48.50 milligrams per liter (mg/L), which gives, after some conversion of units, an annual constituent load (L) of 229.4 kilograms per year of TSS (kg/yr). Equation 2 is used for parameters reported in mg/L (results in kg/y) and Equation 3 is used for parameters reported in micro grams per year (ug/L), with result reported in grams per year (g/yr). The ambient water quality concentration (AC) of each constituent is the same as the EMC since there was no change in the land use. It is not shown in the pre-development condition as it would be the same as the table in step I.e.

II. Following Highway Construction

The post-development calculation follows a similar method with two sets of calculations made in parallel for both the impacted and unimpacted land uses. The pre-development 55.4 acres of pasture/grassland became 53.9 acres of unimpacted area and 1.5 acres of impacted area (i.e., highway). Although the entire right-of-way will be impacted during construction, it is assumed that the area in the right-of-way away from the road surface will return back to its original state, leaving only the actual road surface as the impacted area. The equivalent runoff coefficient (C_U) is unchanged for the unimpacted area, while the new land use (CN = 98) changes the value for impacted land uses to 0.91 (C_I). This means that nearly 91 percent of the rainfall that fall on the highway becomes runoff. The reason is that the roadway is nearly perfectly impervious and it does not allow water to soak into the soil. The runoff volume for unimpacted land use is 3.73 ac-ft/yr and 0.28 ac-ft/yr for impacted land use, Rv_U and Rv_I respectively, which gives a total runoff volume (Rv_T) of 4.01 ac-ft/yr, a value greater than the pre-development volume due to the increased impervious cover. The TSS EMC for highways from the NSQD is 99 mg/L. The load for both the impacted and unimpacted land is calculated using Equation 4 for a total load (L_T) of 257.69 kg/yr. The composite ambient water quality concentration (AC) is

[1] EMC is defined as the total constituent mass discharge divided by the total runoff volume. It is the average concentration for the storm event being considered.

calculated using a mass balance approach. The total runoff volume can be divided into the total load to give the AC (Equation 5). The TSS concentration for the post-developed area is 52.06 mg/L.

III. Change

The percent change in load and concentration in the watershed is based on Equation 6 and 7, respectively. The pre-development TSS load was 229.401 kg/yr while the post-development load was 257.69 kg/yr, which gives a percent increase of 12.3 percent. There was a 7.3 percent increase from 48.5 mg/L of TSS to 52.06 mg/L of TSS.

IV. Construction Condition

The Construction Condition is a combined version of calculation set I. Pre-development and II. Post-development. The runoff volumes coefficients for the unimpacted are was same, but the impacted area is different because the land use is considered dirt road (CN value of 89) and the area considers more than just the paved roadway. A complete dirt road surface is considered the worst case during construction. The pre-development total runoff volume for watershed A-04 remains at 3.84 ac-ft/yr. The construction unimpacted runoff volume decreases from 3.73 ac-ft/yr to 3.24 ac-ft/yr. However, the dirt road land uses causes the construction runoff for the impacted area to increase from 0.28 ac-ft/yr to 1.04 ac-ft/yr for a total construction runoff volume of 4.28 ac-ft/yr (up from the 4.01 ac-ft/yr of the post-development). The decrease is expected because of the change in impervious surface.

To calculate the relative difference in water quality using the new data set, the TSS EMC benchmark for pasture land was changed from 48.5 mg/L to either 84.0 mg/L for pasture or 113 mg/L for wooded areas. The finished highway was replaced with general road construction (a change from 99 mg/L of TSS to a TSS of 985 mg/L). The loading was calculated using the same methodology. The TSS loading for the pre-development changed from 229.40 kg/yr to 397.31 kg/yr. The TSS load during construction (1594.45 mg/L) was 301 percent higher than the pre-development condition. The composite ambient water quality rose by 260 percent from 84.0 mg/L to 302.35 mg/L.

I. Pre-Development Conditions

a. Unimpacted land use:

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Land Use	Pasture / grassland	Hardwood forest	Hardwood forest	Hardwood forest	Hardwood forest	
Area (A)	55.4	12.7	3.5	12.0	6.8	acres

b. Impacted land use:

Area (A)	0.0	0.0	0.0	0.0	0.0	acres

c. Equivalent runoff coefficient:

$$S = \frac{1000}{CN} - 10$$ [eq. 2-4][A]

$$C = 1 - \frac{S}{P_t}\left(1.2 - \left(\frac{S}{P_t + 0.8S}\right)\right)$$ [normalized based on Pt, eq. 2-3][A]

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
24 hour return period rainfall amount (Pt)	2.49	2.49	2.49	2.49	2.49	inches/yr[B]
Unimpacted land use:	U= unimpacted					
Unimpacted (CN, weighted)	79	76	73	73	73	(Table 2-2c[A])
Soil storage (S) =	2.66	3.16	3.70	3.70	3.70	inches
Equivalent runoff coefficient (C_U) =	0.33	0.28	0.23	0.23	0.23	

d. Calculate annual runoff volume:

$$Rv = A \cdot P_t \cdot C\left(\frac{1\ ft}{12\ in}\right)$$ [eq. 1]

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Unimpacted land use:	U= unimpacted					
Annual generated runoff (Pt * C_U) =	0.83	0.69	0.56	0.56	0.56	inches
Annual generated runoff volume (Rv_U) =	3.84	0.73	0.16	0.56	0.32	ac-ft/yr

e. Event mean concentration (EMC):

EMC from unimpacted land use (from **Table 3** for Open Space[C])

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Total Suspended Solids (TSS)	48.5	48.5	48.5	48.5	48.5	mg/L
Total Nitrogen (TN)	1.51	1.51	1.51	1.51	1.51	mg/L
Total Phosphorus (TP)	0.31	0.31	0.31	0.31	0.31	mg/L
Cadmium (Cd)	0.38	0.38	0.38	0.38	0.38	ug/L
Chromium (Cr)	5.40	5.40	5.40	5.40	5.40	ug/L
Copper (Cu)	10.0	10.0	10.0	10.0	10.0	ug/L
Lead (Pb)	10.0	10.0	10.0	10.0	10.0	ug/L
Zinc (Zn)	80.0	80.0	80.0	80.0	80.0	ug/L

f. Calculate loading:

Load (L) by pollutant parameter per land use:

$$L = Rv \cdot EMC = \left(Rv\ ,\frac{ac-ft}{yr}\right)\cdot\left(\frac{43{,}560\ ft^2}{ac}\right)\cdot\left(\frac{7.48\,gal}{ft^3}\right)\cdot\left(\frac{3.785\,liter}{gal}\right)\cdot\left(\frac{\{pollu\tan t\}mg}{liter}\right)*\left(\frac{1kg}{10^6\,mg}\right)$$ [eq. 2 for kg/year]

$$L = Rv \cdot EMC = \left(Rv, \frac{ac-ft}{yr}\right)\cdot\left(\frac{43{,}560\ ft^2}{ac}\right)\cdot\left(\frac{7.48gal}{ft^3}\right)\cdot\left(\frac{3.785liter}{gal}\right)\cdot\left(EMC, \frac{mg}{liter}\right)\cdot\left(\frac{1g}{10^6\,\mu g}\right)$$ [eq. 3 for g/year]

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Total Suspended Solids (TSS)	229.4	43.6	9.8	33.6	19.1	kg/yr
Total Nitrogen (TN)	7.14	1.36	0.31	1.05	0.59	kg/yr
Total Phosphorus (TP)	1.47	0.28	0.06	0.21	0.12	kg/yr
Cadmium (Cd)	1.80	0.34	0.08	0.26	0.15	g/yr
Chromium (Cr)	25.54	4.85	1.09	3.74	2.12	g/yr
Copper (Cu)	47.30	8.99	2.02	6.93	3.93	g/yr
Lead (Pb)	47.30	8.99	2.02	6.93	3.93	g/yr
Zinc (Zn)	378.4	71.9	16.2	55.5	31.4	g/yr

[A] SCS TR55, Urban Hydrology for Small Watershed
[A] SCS TR55, Urban Hydrology for Small Watershed
[C] USEPA, The National Stormwater Quality Database, Version 1.1, September 4, 2005

II. Post-Development Conditions

a. Unimpacted land use:

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Land Use	Pasture / grassland	Hardwood forest	Hardwood forest	Hardwood forest	Hardwood forest	
Area (A)	53.9	11.7	3.2	11.3	6.3	acres

b. Impacted land use:

Land Use	Highway	Highway	Highway	Highway	Highway	
Area (A)	1.5	1.0	0.3	0.7	0.5	acres
	2.7%	7.9%	8.6%	5.8%	7.4%	

c. Equivalent runoff coefficient:

$$S = \frac{1000}{CN} - 10$$ [eq. 2-4][A]

$$C = 1 - \frac{S}{P_t}\left(1.2 - \left(\frac{S}{P_t + 0.8S}\right)\right)$$ U= unimpacted, I=impacted [normalized based on Pt, eq. 2-3][A]

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
24 hour return period rainfall amount (Pt)	2.49	2.49	2.49	2.49	2.49	inches/yr[B]
Unimpacted land use:						
Unimpacted (CN, weighted)	79	76	73	73	73	(Table 2-2c[A])
Soil storage (S) =	2.66	3.16	3.70	3.70	3.70	inches
Equivalent runoff coefficient (C_U) =	0.33	0.28	0.23	0.23	0.23	
Impacted land use:						
Unimpacted (CN, weighted)	98	98	98	98	98	(Table 2-2a[A])
Soil storage (S) =	0.20	0.20	0.20	0.20	0.20	inches
Equivalent runoff coefficient (C_I) =	0.91	0.91	0.91	0.91	0.91	

d. Calculate annual runoff volume:

$$Rv = A \cdot P_t \cdot C\left(\frac{1\ ft}{12\ in}\right)$$ U= unimpacted, I=impacted, T=total [Eq 1]

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Unimpacted land use:						
Annual generated runoff (Pt * C) =	0.83	0.69	0.56	0.56	0.56	inches
Annual generated runoff volume (Rv_U) =	3.73	0.67	0.15	0.53	0.30	ac-ft/yr
Impacted land use:						
Annual generated runoff (Pt * C) =	2.26	2.26	2.26	2.26	2.26	inches
Annual generated runoff volume (Rv_I) =	0.28	0.19	0.06	0.13	0.09	ac-ft/yr
Total Annual generated runoff volume (Rv_T) =	4.01	0.86	0.21	0.66	0.39	ac-ft/yr

e. Event Mean Concentration (EMC):

EMC from unimpacted landuse (from **Table 3** for Open Space[C])

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Total Suspended Solids (TSS)	48.5	48.5	48.5	48.5	48.5	mg/L
Total Nitrogen (TN)	1.51	1.51	1.51	1.51	1.51	mg/L
Total Phosphorus (TP)	0.31	0.31	0.31	0.31	0.31	mg/L
Cadmium (Cd)	0.38	0.38	0.38	0.38	0.38	ug/L
Chromium (Cr)	5.40	5.40	5.40	5.40	5.40	ug/L
Copper (Cu)	10.0	10.0	10.0	10.0	10.0	ug/L
Lead (Pb)	10.0	10.0	10.0	10.0	10.0	ug/L
Zinc (Zn)	80.0	80.0	80.0	80.0	80.0	ug/L

EMC from impacted land use (from **Table 3** for Freeway[C])

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Total Suspended Solids (TSS)	99.0	99.0	99.0	99.0	99.0	mg/L
Total Nitrogen (TN)	3.35	3.35	3.35	3.35	3.35	mg/L
Total Phosphorus (TP)	0.25	0.25	0.25	0.25	0.25	mg/L
Cadmium (Cd)	1.00	1.00	1.00	1.00	1.00	ug/L
Chromium (Cr)	8.30	8.30	8.30	8.30	8.30	ug/L
Copper (Cu)	34.7	34.7	34.7	34.7	34.7	ug/L
Lead (Pb)	25.0	25.0	25.0	25.0	25.0	ug/L
Zinc (Zn)	200.0	200.0	200.0	200.0	200.0	ug/L

f. Calculate loading:

Total load (L_T) by pollutant parameter per land use:

$$L = Rv \cdot EMC = \left(Rv, \frac{ac-ft}{yr}\right) \cdot \left(\frac{43{,}560\, ft^2}{ac}\right) \cdot \left(\frac{7.48 gal}{ft^3}\right) \cdot \left(\frac{3.785 liter}{gal}\right) \cdot \left(EMC, \frac{mg}{liter}\right) \cdot \left(\frac{1kg}{10^6\, mg}\right)$$ [eq. 2 for kg/year]

$$L = Rv \cdot EMC = \left(Rv, \frac{ac-ft}{yr}\right) \cdot \left(\frac{43{,}560\, ft^2}{ac}\right) \cdot \left(\frac{7.48 gal}{ft^3}\right) \cdot \left(\frac{3.785 liter}{gal}\right) \cdot \left(EMC, \frac{mg}{liter}\right) \cdot \left(\frac{1g}{10^6\, \mu g}\right)$$ [eq. 3 for g/year]

$$L_T = L_U + L_I = Rv_U \cdot EMC_U + Rv_I \cdot EMC_I$$ U= unimpacted, I=impacted, T=total [eq. 4]

Total Suspended Solids (TSS)	257.7	63.2	15.9	47.8	29.2	kg/yr
Total Nitrogen (TN)	8.12	2.03	0.51	1.53	0.94	kg/yr
Total Phosphorus (TP)	1.51	0.31	0.07	0.24	0.14	kg/yr
Cadmium (Cd)	2.10	0.55	0.14	0.41	0.25	g/yr
Chromium (Cr)	27.7	6.4	1.6	4.9	2.9	g/yr
Copper (Cu)	58.1	16.3	4.3	12.2	7.7	g/yr
Lead (Pb)	54.7	14.1	3.6	10.6	6.5	g/yr
Zinc (Zn)	437.8	112.7	28.7	84.8	52.4	g/yr

g. Calculate composite ambient water quality concentrations (AC):

AC by constituent parameter per land use:

$$AC = L_T / Rv_T = \frac{(L_T, kg \text{ or } g) \cdot \left(\frac{10^6 mg}{1kg} \text{ or } \frac{10^6 \mu g}{1g}\right)}{\left(Rv_T, \frac{ac-ft}{yr}\right) \cdot \left(\frac{43{,}560\, ft^2}{ac}\right) \cdot \left(\frac{7.48 gal}{ft^3}\right) \cdot \left(\frac{3.785 liter}{gal}\right)}$$ [eq. 5]

Total Suspended Solids (TSS)	52.1	59.6	62.3	58.6	60.7	mg/L
Total Nitrogen (TN)	1.64	1.91	2.01	1.88	1.96	mg/L
Total Phosphorus (TP)	0.31	0.30	0.29	0.30	0.30	mg/L
Cadmium (Cd)	0.42	0.52	0.55	0.50	0.53	ug/L
Chromium (Cr)	5.60	6.04	6.19	5.98	6.10	ug/L
Copper (Cu)	11.7	15.4	16.8	14.9	16.0	ug/L
Lead (Pb)	11.1	13.3	14.1	13.0	13.6	ug/L
Zinc (Zn)	88.4	106.3	112.9	103.9	109.0	ug/L

[A] SCS TR55, Urban Hydrology for Small Watershed
[B] NOAA/NWS/OHD/HPSC Created: Aug 24, 2013
[C] USEPA, The National Stormwater Quality Database, Version 1.1, September 4, 2005

III. Changes in Ambient Water Quality

a. Calculate change in loads for each parameter:

$$Change = \left(\frac{\text{Postdevelopment } L_T - \text{Predevelopment } L_T}{\text{Predevelopment } L_T} \right) * 100$$ [eq. 6]

Pre-development annual load *(from I.f)*

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Total Suspended Solids (TSS)	229.4	43.6	9.8	33.6	19.1	kg/yr
Total Nitrogen (TN)	7.14	1.36	0.31	1.05	0.59	kg/yr
Total Phosphorus (TP)	1.47	0.28	0.06	0.21	0.12	kg/yr
Cadmium (Cd)	1.80	0.34	0.08	0.26	0.15	g/yr
Chromium (Cr)	25.54	4.85	1.09	3.74	2.12	g/yr
Copper (Cu)	47.30	8.99	2.02	6.93	3.93	g/yr
Lead (Pb)	47.30	8.99	2.02	6.93	3.93	g/yr
Zinc (Zn)	378.4	71.9	16.2	55.5	31.4	g/yr

Post-development annual load: *(from II.f)*

Total Suspended Solids (TSS)	257.7	63.2	15.9	47.8	29.2	kg/yr
Total Nitrogen (TN)	8.12	2.03	0.51	1.53	0.94	kg/yr
Total Phosphorus (TP)	1.51	0.31	0.07	0.24	0.14	kg/yr
Cadmium (Cd)	2.10	0.55	0.14	0.41	0.25	g/yr
Chromium (Cr)	27.74	6.40	1.58	4.88	2.93	g/yr
Copper (Cu)	58.11	16.34	4.27	12.17	7.67	g/yr
Lead (Pb)	54.73	14.09	3.59	10.60	6.54	g/yr
Zinc (Zn)	437.8	112.7	28.7	84.8	52.4	g/yr

Change in annual load:

Total Suspended Solids (TSS)	12.3%	44.9%	61.8%	42.0%	53.0%
Total Nitrogen (TN)	13.6%	49.5%	67.9%	46.2%	58.2%
Total Phosphorus (TP)	3.2%	13.0%	19.2%	13.1%	16.5%
Cadmium (Cd)	16.7%	60.2%	82.1%	55.9%	70.5%
Chromium (Cr)	8.6%	31.9%	44.4%	30.2%	38.1%
Copper (Cu)	22.9%	81.8%	111.0%	75.6%	95.2%
Lead (Pb)	15.7%	56.8%	77.6%	52.8%	66.6%
Zinc (Zn)	15.7%	56.8%	77.6%	52.8%	66.6%

b. Calculate change in ambient water quality concentration for each parameter:

$$Change = \left(\frac{\text{Postdevelopment AC} - \text{Predevelopment AC}}{\text{Predevelopment AC}} \right) * 100$$ [eq. 7]

Pre-Development ambient concentration *(from I.g)*

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Total Suspended Solids (TSS)	48.5	48.5	48.5	48.5	48.5	mg/L
Total Nitrogen (TN)	1.51	1.51	1.51	1.51	1.51	mg/L
Total Phosphorus (TP)	0.31	0.31	0.31	0.31	0.31	mg/L
Cadmium (Cd)	0.38	0.38	0.38	0.38	0.38	ug/L
Chromium (Cr)	5.40	5.40	5.40	5.40	5.40	ug/L
Copper (Cu)	10.0	10.0	10.0	10.0	10.0	ug/L
Lead (Pb)	10.0	10.0	10.0	10.0	10.0	ug/L
Zinc (Zn)	80.0	80.0	80.0	80.0	80.0	ug/L

Post-Development ambient water quality concentration: *(from II.g)*

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Total Suspended Solids (TSS)	52.1	59.6	62.3	58.6	60.7	mg/L
Total Nitrogen (TN)	1.64	1.91	2.01	1.88	1.96	mg/L
Total Phosphorus (TP)	0.31	0.30	0.29	0.30	0.30	mg/L
Cadmium (Cd)	0.42	0.52	0.55	0.50	0.53	ug/L
Chromium (Cr)	5.60	6.04	6.19	5.98	6.10	ug/L
Copper (Cu)	11.7	15.4	16.8	14.9	16.0	ug/L
Lead (Pb)	11.1	13.3	14.1	13.0	13.6	ug/L
Zinc (Zn)	88.4	106.3	112.9	103.9	109.0	ug/L

Change in ambient water quality concentration:

	A-04	Area D	E-01 & -02	E-06	E-07 & -08
Total Suspended Solids (TSS)	7.3%	22.8%	28.5%	20.8%	25.2%
Total Nitrogen (TN)	8.6%	26.7%	33.4%	24.3%	29.5%
Total Phosphorus (TP)	-1.4%	-4.2%	-5.3%	-3.9%	-4.7%
Cadmium (Cd)	11.5%	35.8%	44.7%	32.5%	39.5%
Chromium (Cr)	3.8%	11.8%	14.7%	10.7%	13.0%
Copper (Cu)	17.4%	54.1%	67.6%	49.3%	59.8%
Lead (Pb)	10.6%	32.9%	41.1%	29.9%	36.3%
Zinc (Zn)	10.6%	32.9%	41.1%	29.9%	36.3%

IV. Construction Conditions

a. Pre-development land use:

	A-04	Area D	E-01 & -02	E-06	E-07 & -08	
Unimpacted Land Use	Pasture / grassland	Hardwood forest	Hardwood forest	Hardwood forest	Hardwood forest	
Area (A)	55.4	12.7	3.5	12.0	6.8	acres

b. Post-development land use:

Land Use	Pasture / grassland	Hardwood forest	Hardwood forest	Hardwood forest	Hardwood forest	
Area (A)	46.8	3.5	0.5	5.1	1.6	acres

Land Use	Dirt Road	Dirt Road	Dirt Road	Dirt Road	Dirt Road	
Area (A)	8.6	9.2	3.0	6.9	5.2	acres
	15.5%	72.4%	85.7%	57.5%	76.5%	

c. Equivalent runoff coefficient:

$$S = \frac{1000}{CN} - 10$$

[eq. 2-4][A]

$$C = 1 - \frac{S}{P_t}\left(1.2 - \left(\frac{S}{P_t + 0.8S}\right)\right)$$

U= unimpacted, I=impacted
[normalized based on Pt, eq. 2-3][A]

24 hour return period rainfall amount (Pt)	2.49	2.49	2.49	2.49	2.49	inches/yr[B]
Unimpacted land use:						
Unimpacted (CN, weighted)	79	76	73	73	73	(Table 2-2c[A])
Soil storage (S) =	2.66	3.16	3.70	3.70	3.70	inches
Equivalent runoff coefficient (C_U) =	0.33	0.28	0.23	0.23	0.23	
Impacted land use:						
Unimpacted (CN, weighted)	89	89	89	89	89	(Table 2-2a[A])
Soil storage (S) =	1.24	1.24	1.24	1.24	1.24	inches
Equivalent runoff coefficient (C_I) =	0.58	0.58	0.58	0.58	0.58	

d. Calculate annual runoff volume:

$$Rv = A \cdot P_t \cdot C \left(\frac{1\ ft}{12\ in}\right)$$

U= unimpacted, I=impacted, T=total [Eq 1]

Pre-development land use:	U= unimpacted, I=impacted, T=total					**(from I.d.)**
Total Annual generated runoff volume (Rv_T) =	3.84	0.73	0.16	0.56	0.32	ac-ft/yr
Construction land use:						
Annual generated runoff (Pt * C_U) =	0.83	0.69	0.56	0.56	0.56	inches
Annual generated runoff volume (Rv_U) =	3.24	0.20	0.02	0.24	0.07	ac-ft/yr (**from II.d**)
Annual generated runoff (Pt * C_I) =	1.45	1.45	1.45	1.45	1.45	inches
Annual generated runoff volume (Rv_I) =	1.04	1.11	0.36	0.83	0.63	ac-ft/yr
Total Annual generated runoff volume (Rv_T) =	4.28	1.31	0.38	1.07	0.70	ac-ft/yr

e. Event mean concentration (EMC):

Total suspended solids (TSS, mg/L)					
	(from **Table 8** for Pasture and Wooded[D])				
EMC from unimpacted land use	84	84	113	113	113
	(from **Table 8** for Construction-II[D])				
EMC from construction	985	985	985	985	985

f. Calculate change in loading:

Change in pollutant load (L_T) by pollutant parameter per land use:

$$L = Rv \cdot EMC = \left(Rv, \frac{ac-ft}{yr}\right)\cdot\left(\frac{43{,}560\,ft^2}{ac}\right)\cdot\left(\frac{7.48gal}{ft^3}\right)\cdot\left(\frac{3.785liter}{gal}\right)\cdot\left(EMC, \frac{mg}{liter}\right)\cdot\left(\frac{1kg}{10^6\,mg}\right)$$ [eq. 2 for kg/year]

$$L = Rv \cdot EMC = \left(Rv, \frac{ac-ft}{yr}\right)\cdot\left(\frac{43{,}560\,ft^2}{ac}\right)\cdot\left(\frac{7.48gal}{ft^3}\right)\cdot\left(\frac{3.785liter}{gal}\right)\cdot\left(EMC, \frac{mg}{liter}\right)\cdot\left(\frac{1g}{10^6\,\mu g}\right)$$ [eq. 3 for g/year]

$$L_T = L_U + L_I = Rv_U \cdot EMC_U + Rv_I \cdot EMC_I$$ U= unimpacted, I=impacted, T=total

Pre-development	397.3	75.5	22.9	78.3	44.4	kg/yr
During Construction	1594	1367	442	1043	772	kg/yr
Change in Annual Load:	301%	1712%	1836%	1232%	1638%	

g. Calculate composite ambient water quality concentrations (AC):

AC by constituent parameter per land use:

$$AC = L_T / Rv_T = \frac{(L_T, kg \text{ or } g)\cdot\left(\frac{10^6\,mg}{1kg} \text{ or } \frac{10^6\,\mu g}{1g}\right)}{\left(Rv_T, \frac{ac-ft}{yr}\right)\cdot\left(\frac{43{,}560\,ft^2}{ac}\right)\cdot\left(\frac{7.48gal}{ft^3}\right)\cdot\left(\frac{3.785liter}{gal}\right)}$$

Pre-development	84	84	113	113	113	mg/L
During Construction	302	847	932	790	892	mg/L
Pre-development	260%	908%	725%	599%	689%	

[A] SCS TR55, Urban Hydrology for Small Watershed
[B] NOAA/NWS/OHD/HPSC Created: Aug 24, 2013
[C] USEPA, The National Stormwater Quality Database, Version 1.1, September 4, 2005
[D] ERDC TN-WRAP 04-3, 2004