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DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
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KARST FLOODING IN BELLEVUE, OHIO, AND VICINITY—2008

by
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MAP EG-5
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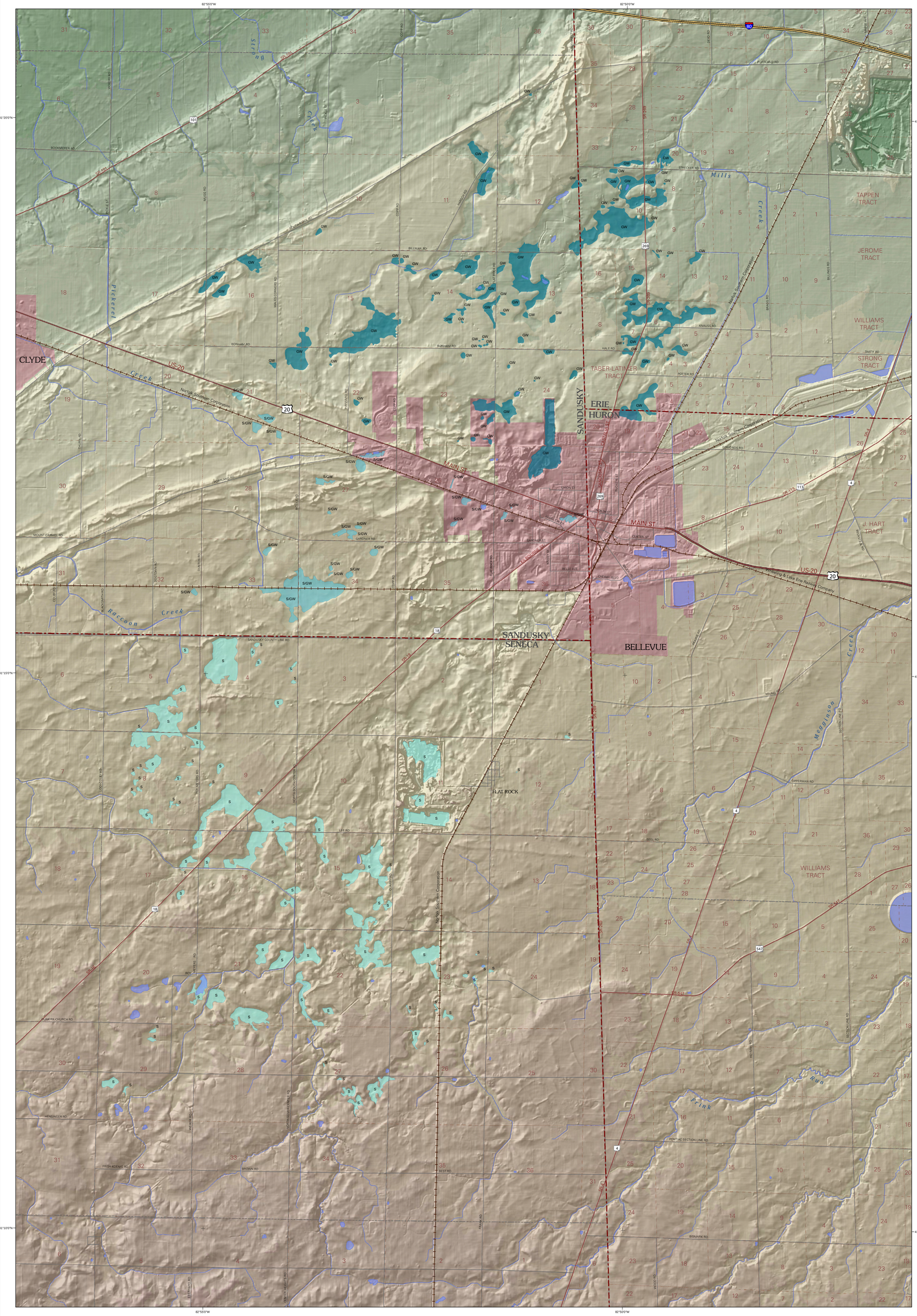

INTRODUCTION

On March 18, 2008, ground-water levels rose to a 30-year high in the vicinity of Bellevue, Ohio. Sinkholes that typically accept surface water were acting as springs. Aerial photography revealed extensive flooding of fields, roadways, and residences, caused by a lack of surface drainage (fig. 1). Surface and near-surface geologic conditions coupled with unique increases in precipitation created a situation where ground water rose to the surface, flowed from existing sinkholes, filled existing closed basins and sinkholes, caverns, and underground drainage (collectively called *karst*), and drained slowly over the course of months.

The Ohio Department of Natural Resources (ODNR), Division of Geological Survey, along with the ODNR Division of Water and the ODNR Division of Soil and Water, were tasked by the ODNR Director's Office to help investigate the extent and causes of the flooding. The purpose of this publication is to provide a detailed map of the flood area; to explain the background geology and review the nature of the flooding experienced in the vicinity of Bellevue, Ohio, in 2008; and to provide map documentation of the flooded area for future land-use planning by citizens and government.

HYDROLOGIC CONDITIONS CAUSING THE FLOODING

During the spring and summer of 2008, unusual severe flooding occurred in Bellevue and surrounding areas, whereby excessive ground water welled up through near-surface openings in the underlying limestone bedrock—a phenomenon common to the north of this area as represented by the perpetual flow from "blue holes," a term locally applied to a number of very wide-mouthed springs in the Castalia area. To the observer these springs appear bottomless and the clear water reflects the sky, leading to the term *blue holes*. These springs continually flow a high volume of water. The source of this flow of water comes from the large recharge area comprised of the sinkholes and karst terrain in the vicinity of Bellevue and Flat Rock. This type of flooding has happened in the Bellevue area approximately six times since 1800. The most recent occurrences were in 1937 and 1969. Like those two flood events, the 2008 flood was in response to heavy precipitation events.

Rain and snow fall from November through April provides fresh ground-water supplies during a period known as the *ground-water recharge season*. Much of Ohio experienced record and near-record amounts of rain during the 2008 recharge season. In the north-central climatic region of Ohio, the Division of Water calculated that cumulative precipitation from October 2007 through March 2008 totaled a record 23.55 inches—9.14 inches above normal—easily surpassing the 1898 record of 21.56 inches. The month of March averaged a near-record 5.41 inches for the north-central region, the third wettest March in the past 114 years. Much of the precipitation fell as snow and did not melt until mid-month, when it combined with additional rain and resulted in rivers and streams running at four times the normal March flow. The karst geology in this area allowed much of this surface water to quickly become ground water, forcing ground-water levels to rise.

GEOLOGY OF THE BELLEVUE AREA

The Bellevue area features unique surface and near-subsurface geology and causes karst flooding to occur in a localized area. Beneath the city of Bellevue and areas north and south of the city is a six-mile wide band of limestone bedrock, the Delaware and Columbus Formations, which tilt gently to the east (fig. 2) and trend in a north-south direction from Lake Erie through Central Ohio. The younger Olentangy Shale and Ohio Shale formations overlay the Delaware Limestone to the east; the older Salina Dolomite underlies the Columbus Limestone and is present at the surface to the west (fig. 2). Contacts between the bedrock units generally run north and south because of the eastward tilting of the bedrock units as they descend into the Appalachian Basin to the east.

The Columbus Limestone and, to a lesser extent, the Delaware Limestone are prone to karst formation because of the ease of dissolution of the high-calcium, generally coarse crystalline nature of the rock. Slightly acidic ground water flowing through pore and fracture spaces in these formations dissolve the limestone and result in numerous karst features in the localized area. Collapse of more competent limestone above the solutioned zones has formed some of the caves and caverns in the north-central Ohio area. Seneca Caverns, the largest cavern in northern Ohio, was formed in this manner. The Plum Brook Shale, Olentangy Shale, and Ohio Shale to the east are not prone to the formation of karst. The Prout Limestone member is a very thin unit and contains some shaley zones; it is also not prone to karst formation. Thus karst features abruptly stop near the interpreted contact with the Delaware Limestone and the overlying Olentangy/Ohio Shale. To the west, the Salina Dolomite is near the surface, but dolomite (chemical composition of $CaMg(CO_3)_2$) is less prone to dissolution than limestone (chemical composition of $CaCO_3$) and therefore, karst formation is less frequent or developed. Probable karst areas (fig. 3) represent areas underlain by carbonate bedrock and lying within a half mile of a known karst feature (Pavey and others, 1999; Pavey and others, 2005).

The glacial geology of the Bellevue area also contributes to karst development. Ice Age glaciers covered north-central Ohio on several occasions and commonly deposited 50 or more feet of clayrich glacial till. However, in the Bellevue area the glacial drift is commonly less than 20 feet thick or not present at all. Lack of glacial till allows direct contact between surface water and the underlying limestone, providing more opportunity for dissolution. The drift thickness map (fig. 4) shows the approximate areas of less than 20 feet of glacial drift. Karst is generally best developed where thin drift overlies the Delaware and Columbus Limestones. One potential reason for the thinner glacial drift in the vicinity of Bellevue is that the Columbus Limestone was resistant to erosion and formed a ridge that impeded glacial erosion and minimized deposition. Another possible cause is that waters of ancestral lakes, such as Lake Maumee, inundated the Bellevue area and wave erosion from these lakes stripped away much of the previously deposited drift. Prominent sandy beach ridges associated with these ancestral lakes are visible just to the west of Bellevue and Castalia. The Columbus and Delaware Limestones are subject to dissolution where the highly permeable, sandy beach ridges overlie these units and thick clay deposits are absent. Thicker drift deposits covering the Delaware and Columbus Limestones probably protected the units from contact with amounts of surface water significant enough to initiate large dissolution features. Other regions of the state that possess well-developed karst features, such as areas along the Scioto River in Delaware and Franklin Counties and portions of Highland and Adams Counties, occur in limestone and dolomite units in areas of thin glacial drift or areas in which glacial drift is absent.

Joints (breaks in rock along which no movement has occurred) are found throughout the local bedrock formations. Regionally, the joints in bedrock generally trend NE-SW and NW-SE and are natural pathways for ground water to flow within the rock formations. These narrow joints are widened through the dissolution of the limestone by the surface and ground water that flow through them, leading to the eventual widening of the joints to a pathway. The NE-SW trending joints play an especially important role in the travel of ground water in the Bellevue area and are of particular importance to understanding karst flooding along the trend.

The relationship between these joint patterns and sinkholes is complex and variable. Water will preferentially flow along certain joint patterns. Because two adjacent sinkholes may or may not be interconnected by joints, a particular sinkhole may discharge water more readily and flood an area, unlike an adjacent sinkhole that may not pose a flooding threat.

MAPPING THE EXTENT OF THE FLOODING

On May 30, 2008, the Ohio Department of Transportation (ODOT) collected high-resolution aerial photography and LiDAR elevation data for the flooded region. To interpret and map the flooded areas, the Division of Geological Survey used the aerial photos and available 12.5-ft-resolution LiDAR elevation data, compiled by the Ohio Environmental Protection Agency. Time and resource constraints have precluded processing of the ODOT LiDAR data at this time.

The areas shown on the large format map (at left) represent the interpreted apparent high-water levels for 179 separate flooded sinkhole basins. There were two causes of the flooding experienced in these 179 basins: (1) surficial flooding resulting from the plugging of the sinkholes with sediment and vegetation and (2) ground-water flooding resulting from the upwelling of water out of the ground-water aquifers.

The sinkhole basins labeled **S** were flooded because of surface water flowing into the closed depressions, which were plugged or blocked by vegetation that impeded the drainage. These sinkholes lie predominantly in the southern portion of the affected area in Thompson Township, Seneca County.

The sinkhole basins labeled **GW** were flooded because of an upwelling of ground water into the northernmost basins. This local upwelling of water was caused by excessive precipitation, resulting in the local water table rising much higher than normal for the area proximal to Bellevue. Farther north of the Bellevue area, the land surface is intersected by the water table, as represented by the perpetual flow from the blue holes.

The sinkhole basins labeled **S/GW** are located between the surficial flooded area (**S** on the map) and the ground-water flooded area (**GW** on the map). In these areas, flooding could have been caused by either surficial or ground-water flooding. Visual verification at the time of flooding would have been necessary to determine the cause of flooding in these sinkhole basins.

Because of the time lapse from the maximum flood levels to the date of photography, all areas that were flooded may not be captured on this map. In particular, basins in the higher-elevation area south of Bellevue were the first to drain, and flood evidence may have been obscured by subsequent cultivation. Known flood areas within the city of Bellevue are also obscured by the density of urban detail.

CONCLUSIONS

The extent and duration of flooding in and around Bellevue during the spring and summer of 2008 was not typical, sporadic surface flooding of a few sinkhole basins. The flooding during this time period was a result of ground-water levels rising above ground elevation in many sinkhole basins. Record October 2007–March 2008 precipitation levels, culminating with 5.41 inches of rain in March, added billions of gallons of water into the aquifer.

The Columbus Limestone and Delaware Limestone formations present in this area favor karst development. These limestones outcrop in a six-mile-wide band that trends almost north–south. The thin to absent glacial drift over these limestones makes the Bellevue area a prime candidate for karst development.

The presence of over 1,000 sinkholes in the Bellevue area allows surface water to rapidly flow directly into the ground-water system. Ground-water levels were not measured in the Bellevue area prior to the flooding; however, ground-water levels measured in a previous study show that these levels can rise up to 50 feet over a brief (few days) period but take weeks to return to pre-flood conditions. The U.S. Geological Survey Ohio Water Science Center maintains a water well that continuously monitors the elevation of the water table northeast of Bellevue, just off State Route 269. Information on the local water level as observed by this well is provided at the following URL: **http://waterdata.usgs.gov/nwis/uv/?site_no=411819082493900**

The main objective of the large map is to help document the areas impacted by the spring 2008 flooding. While the Division of Geological Survey was unable to map all flood areas in the Bellevue vicinity because of conditions discussed in the previous section, this map highlights areas of extensive flooding and represents the unusual nature of the event. The map also offers information that will be valuable to local planners, officials, and decision makers for future land usage and zoning decisions. It is impossible to predict when or how often the next phase of similar hydrologic conditions will occur. Also, unlike typical flooding associated with rivers overflowing their banks, predicting the extent and nature of karst-related flooding is very difficult; and the engineering means to prevent or mitigate the effects of karst-related flooding is technically very difficult and cost-prohibitive. Wise land-use planning is encouraged for areas that are most likely to be flooded upon the return of this pattern of climatic and hydrologic conditions.

ACKNOWLEDGMENTS

Several figures and portions of the map text have been taken from Raab and others (2009). The report is the result of a joint effort by the ODNR Division of Water and the ODNR Division of Geological Survey to document a study of the Bellevue flood. Written by staff of both divisions, it provides a detailed analysis of ground water and geologic conditions and a discussion of the hydrologic and meteorologic conditions associated with the Bellevue flood.

The Division of Geological Survey is grateful to the Ohio Department of Transportation for providing aerial photography; to Eric Dodrill of the Erie County Soil and Water Conservation District for providing field locations of flooded areas; and to the Ohio Environmental Protection Agency for providing invaluable LiDAR elevation data of the Bellevue, Ohio, area.

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EXPLANATION

Elevation, ft

- 600–625
- 626–650
- 651–675
- 676–700
- 701–725
- 726–750
- 751–775
- 776–800
- 801–825
- 826–850
- 851–875
- 876–900

High water level flood types

- GW — Ground water
- S/GW — Surface and ground water mix
- S — Surface water
- Ponds, lakes, and reservoirs

N

0.5 0.25 0 0.5 1 miles

0.5 0.25 0 0.5 1 1.5 kilometers

Scale 1:24,000

Base map derived from Ohio Department of Transportation data sets.
Projection is Ohio state plane coordinate system, south zone North American Datum, 1983.

INDEX MAP

FIGURE 1.—Aerial photograph of the Bellevue area, looking north, showing State Route 269 flooded and closed. Photo courtesy of Ohio Department of Transportation District 3.

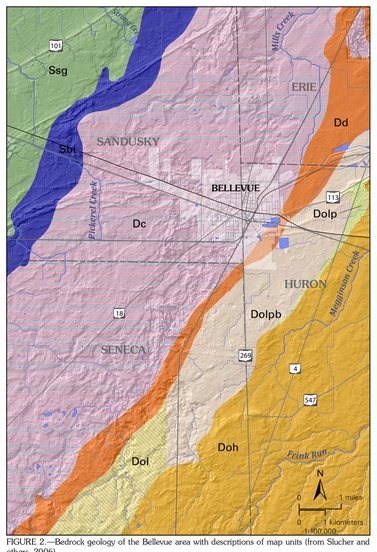

FIGURE 2.—Bedrock geology of the Bellevue area with descriptions of map units (from Slucher and others, 2006).

Bedrock geology units

- Ssg - Salina group
- Sbi - Bass Islands Dolomite
- Dc - Columbus Limestone
- Dd - Delaware Limestone
- Dolp - Prout Limestone member
- Dolpb - Plum Brook Shale
- Dol - Olentangy Shale
- Doh - Ohio Shale

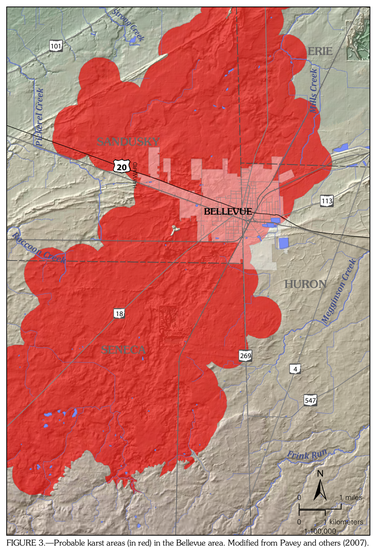

FIGURE 3.—Probable karst areas (in red) in the Bellevue area. Modified from Pavey and others (2007).

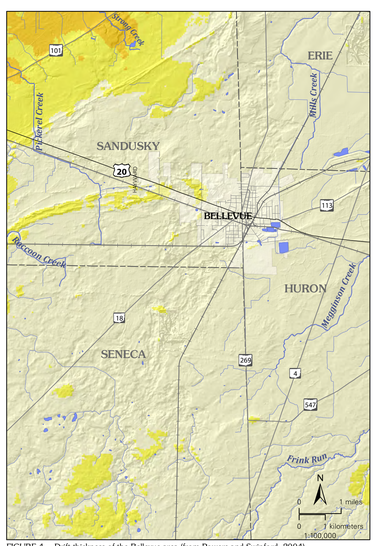

FIGURE 4.—Drift thickness of the Bellevue area (from Powers and Swinford, 2004).

Thickness in feet

- 0–30
- 30–60
- 60–90

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