





Citizens Advisory Council

Carbonate Geology and Sinkholes in Pennsylvania

Presented by: Louis F. Vittorio, Jr., P.G.

September 19, 2017

Today's Presenter

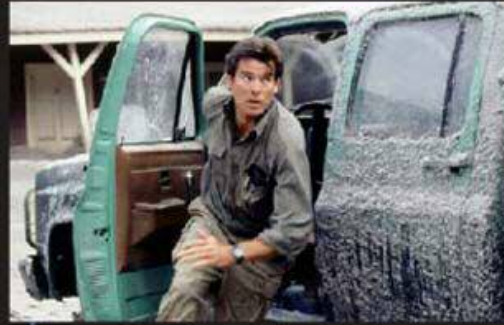


Louis F. Vittorio, Jr., P.G. - Mr. Vittorio is the V.P. and Principal Hydrogeologist at EarthRes in Pipersville, PA, and has over 30 years of experience hydrogeological investigation, in Pennsylvania. Mr. Vittorio received his BS Degree in Geology/Geophysics from the University of Pittsburgh in 1984 and his MS Degree in Geology from Lehigh University in 1988. Mr. Vittorio has organized and taught courses on hydrogeology, karst geology and ethics for [PCPG](#), having served as their President and long term board member. He has also provided talks on water resource development for regional water associations. Specialty areas include aquifer evaluation, dewatering analysis and modeling; water resource use planning, and permitting. He has been qualified as an expert at hearings related to water extraction and karst geology and has provided expert testimony for numerous groundwater related projects.

Today's Actual Presenter



What I think I do



What society thinks
I do



What my friends
think I do



What I actually do

Presentation Outline

- **Overview / Sources of Information**
- **Definition of Karst and Sinkholes**
- **Carbonate Geology of Pennsylvania**
- **Karst Formation (Millennia/Millions Yrs.)**
- **Sinkhole Formation and Triggers**
- **Climate Change / Storm Intensity**
- **Sinkhole Investigation and Remediation**
- **Sinkhole Prevention / Construction Practices**
- **Questions and Answers**



Primary Sources of Information

- **USGS** <https://water.usgs.gov/edu/sinkholes.html>
- **DCNR / Bureau of Topographic and Geologic Survey**
<http://www.dcnr.pa.gov/Geology/GeologicHazards/Sinkholes/Pages/default.aspx>
- **Sinkholes in Pennsylvania** ([DCNR ES-11](#), by William E. Kochanov)
- **PA DEP** <http://www.dep.pa.gov/Citizens/My-Water/Sinkholes/Pages/default.aspx>
- **Direct Project Experience Over 30 years**

Definition of Karst and Sinkholes

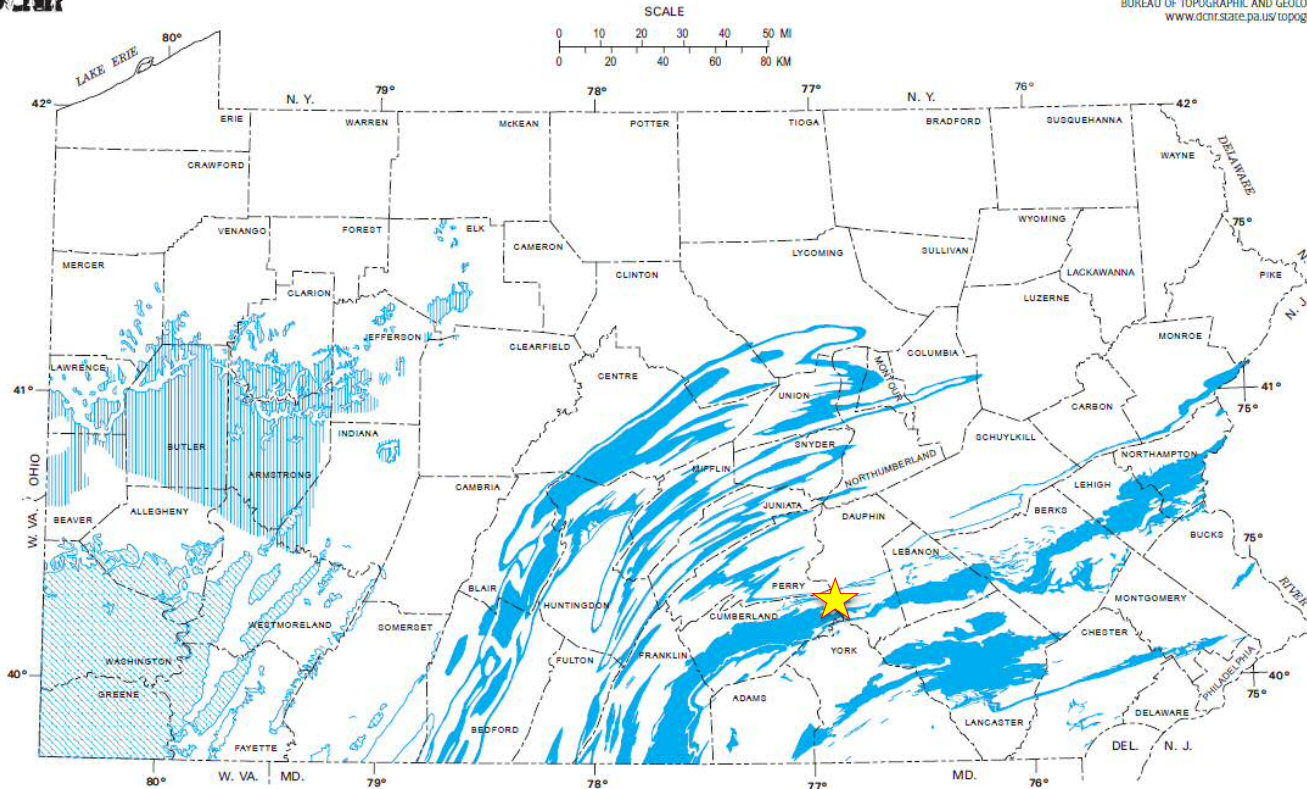
- **Sinkhole** - A hole or depression in the ground that results from surface material moving into subsurface pathways caused by the weathering process. A sinkhole occurs by either gradual subsidence to form a depression in the landscape or by collapse to form an abrupt break in the soil.
- **Karst** - Description of a landscape developed upon limestone or dolomite rock. Karst is characterized by sinkholes, caves and underground drainage of water due to the dissolution (dissolving) of the rock. Other features of a karst landscape may include rock pinnacles, uneven bedrock surface, rolling terrain, swallets (where stream flow is lost into a hole), large springs, and surface depressions that won't hold water.

Carbonate Geology and Karst In PA

MAP 15
DCNR

LIMESTONE AND DOLOMITE DISTRIBUTION IN PENNSYLVANIA

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF
CONSERVATION AND NATURAL RESOURCES
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
www.dcnr.state.pa.us/topogeo



EXPLANATION



Area underlain by flat-lying, generally thin, but locally thick, limestone beds, which are discontinuous in places and are commonly interbedded with shale.



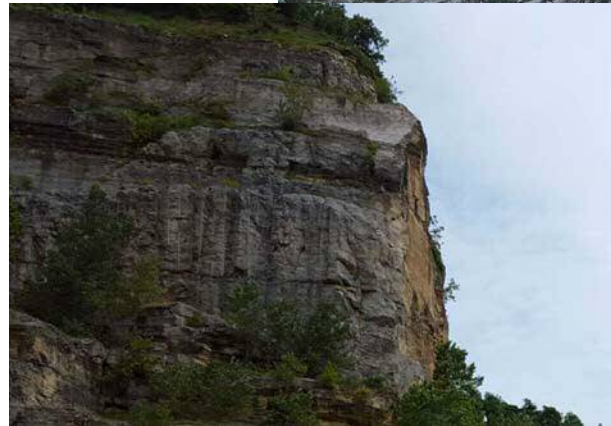
Area where limestone, dolomite, or both are at the surface. Layers are usually strongly folded and steeply dipping. Includes economically important high-calcium limestones of the Kinzers, Annville, Benner, and Keyser Formations and the Cocksவில் Marble, as well as the high-magnesian dolomites of the Ledger Formation and the Cocksவில் Marble. This area is most susceptible to sinkhole development.



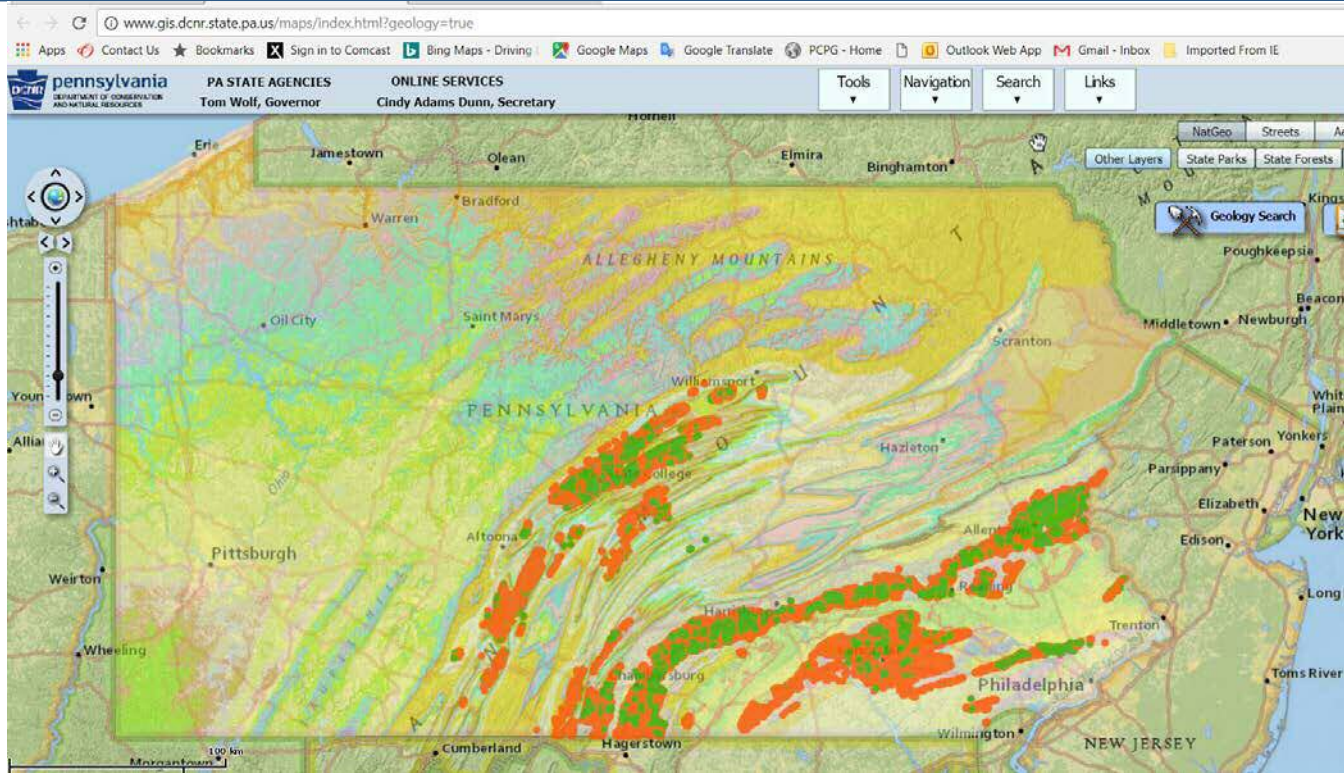
Area underlain by the generally flat-lying Pennsylvania Vanport Limestone, a high-calcium limestone. This limestone is generally overlain by less than 100 feet of sedimentary rocks, except in the southern part of the area.

Carbonate Geology and Karst In PA

Carbonate rocks are a class of sedimentary **rocks composed** primarily of **carbonate** minerals. The two major types are limestone, which is composed of calcite or aragonite (different crystal forms of CaCO_3) and dolostone, which is composed of the mineral dolomite ($\text{CaMg}(\text{CO}_3)_2$).



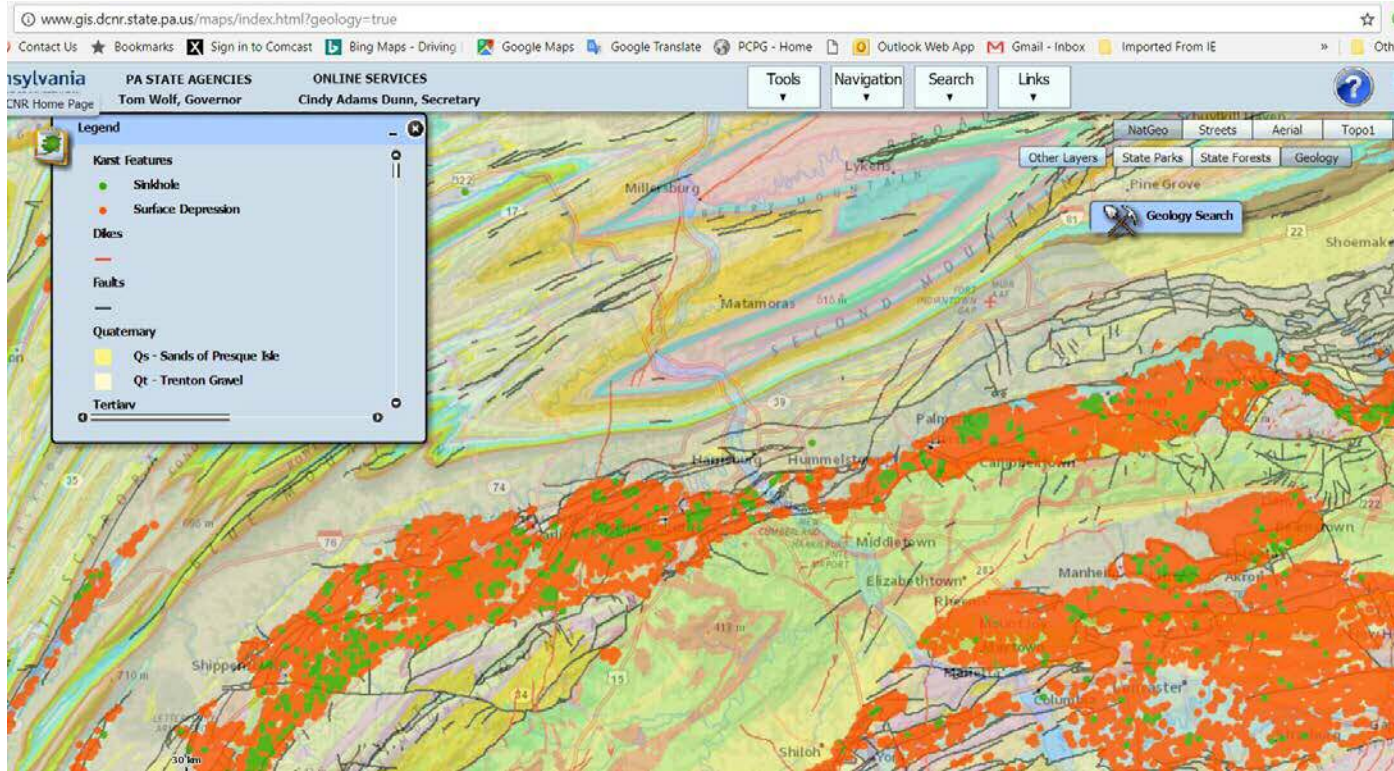
Carbonate Geology and Karst In PA



PaGEODE Mapping System

<http://www.gis.dcnr.state.pa.us/geology/index.html>

Carbonate Geology and Karst In PA



PaGEODE Mapping System

<http://www.gis.dcnr.state.pa.us/geology/index.html>

Karst Terrain Formation

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SINKHOLES IN PENNSYLVANIA

What makes rainwater acidic? Within the earth's atmosphere there is a small amount of carbon dioxide gas. The carbon dioxide gas reacts with water to form **carbonic acid** (Figure 3). Carbonic-acid production can increase as carbon dioxide gas that is also present in the soil reacts with infiltrating water. Carbonic acid is a weak acid and reacts with limestone and dolomite. In fact, it is the main acid that dissolves carbonate bedrock.

Source: PA DCNR
Publication: ES-11

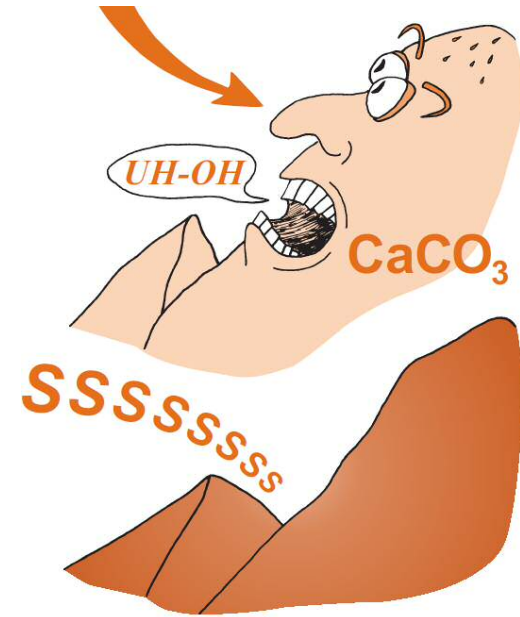
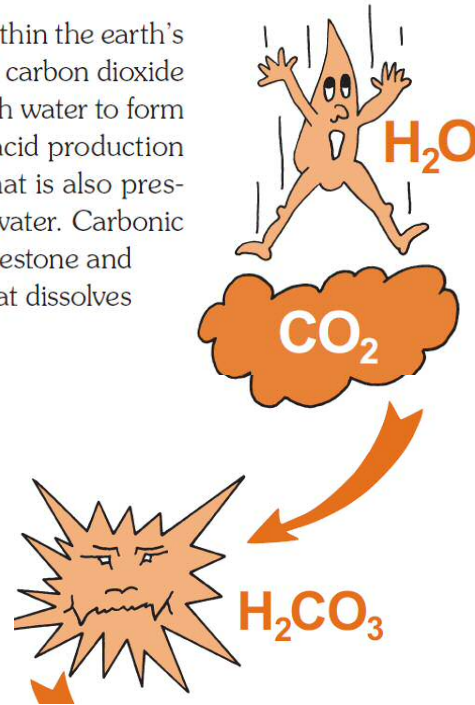


Figure 3. Water (H_2O) combines with carbon dioxide (CO_2) to form carbonic acid (H_2CO_3). This is the acid that dissolves limestone ($CaCO_3$).

Karst Terrain Formation

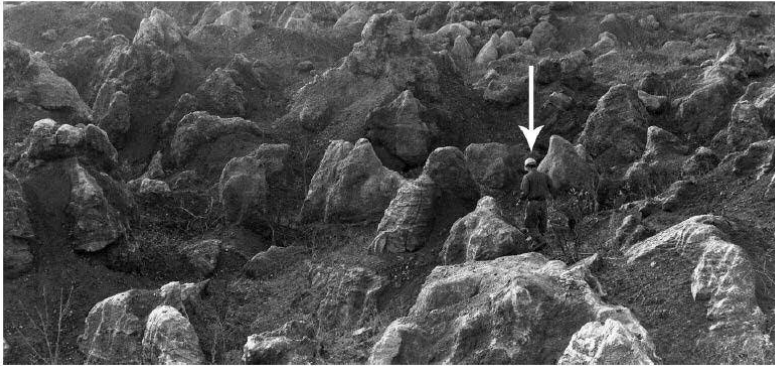


Figure 6. Pinnacles of limestone exposed on the property of the former J. E. Baker quarry in York County. Man (below arrow) is approximately 6 feet tall. Photograph by Helen Delano.

Source: PA DCNR
Publication: ES-11

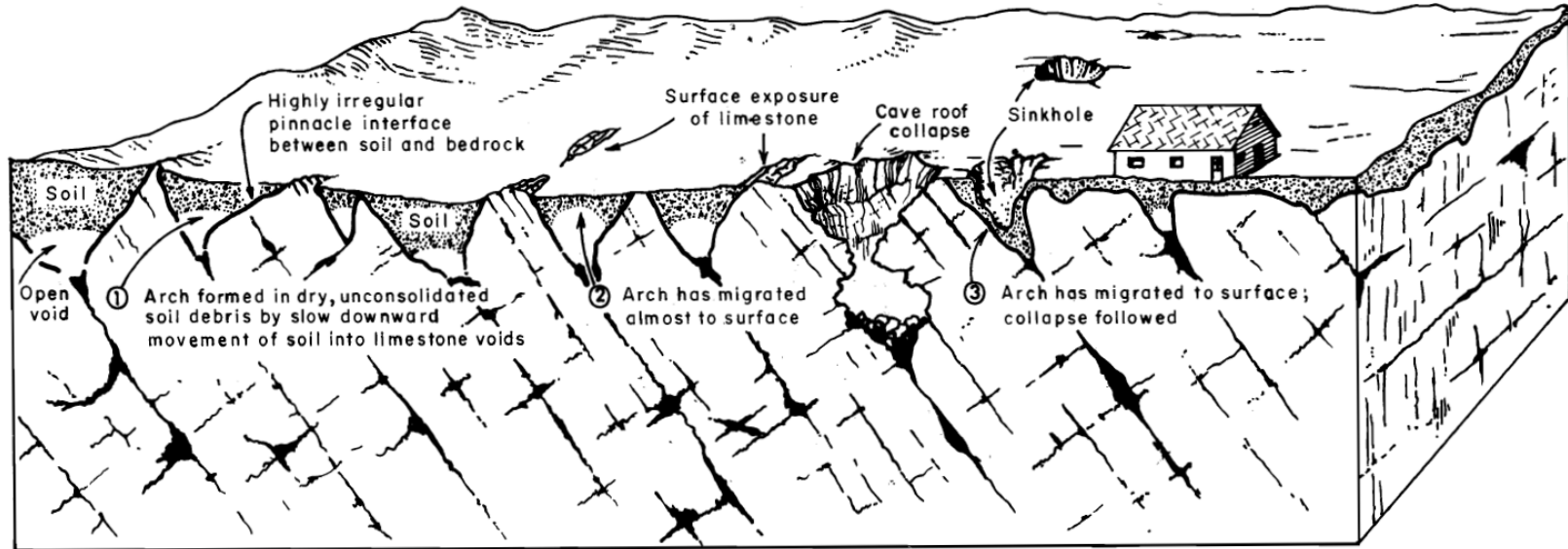


Oct 12, 2015 // At Kutztown University

Take A Tour Through Kutztown's Crystal Cave

<https://www.theodysseyonline.com/tour-kutztown-crystal-cave>

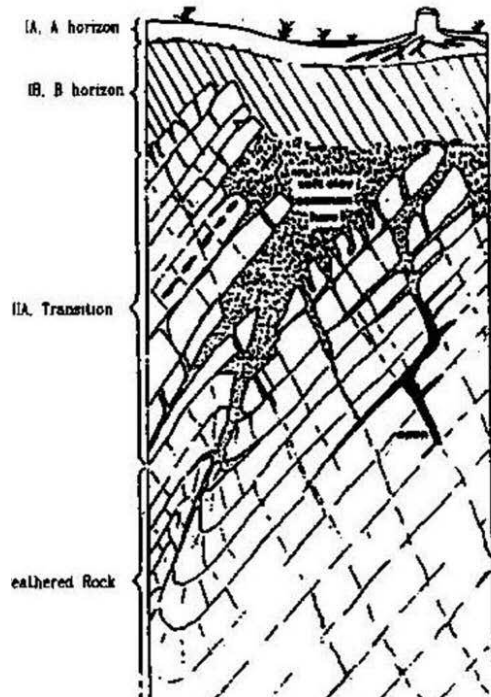
Karst Terrain Formation



[Engineering characteristics of the rocks of Pennsylvania](#)

Alan R. Geyer and J. Peter Wilshusen

Karst Terrain Formation



By Michael Perlow Jr., P.E. from PCPG Karst Seminar 2012

Karst Terrain Formation

- **What the USGS Says:** <https://water.usgs.gov/ogw/karst/pages/whatiskarst>
- Karst is a terrain with distinctive landforms and hydrology created from the **dissolution of soluble rocks, principally limestone and dolomite.**
- Karst terrain is characterized by **springs, caves, sinkholes**, and a unique hydrogeology that results in **aquifers that are highly productive but extremely vulnerable to contamination.** In the United States, **about 40% of the groundwater used for drinking comes from karst aquifers.**
- Some karst areas in the United States are famous, such as the [springs of Florida](#), [Carlsbad Caverns in New Mexico](#), and [Mammoth Cave in Kentucky](#), but in **fact about 20 percent of the land surface in the U.S. is classified as karst.** Other parts of the world with large areas of karst include China, Europe, the Caribbean, and Australia.

Karst Terrain Formation

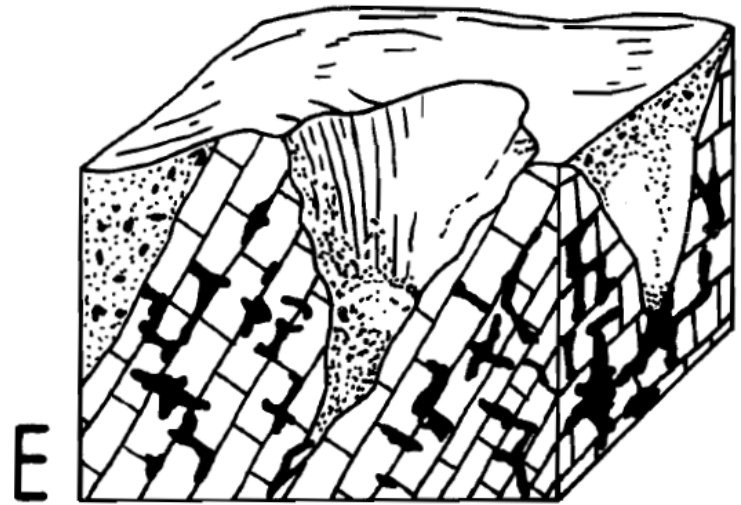
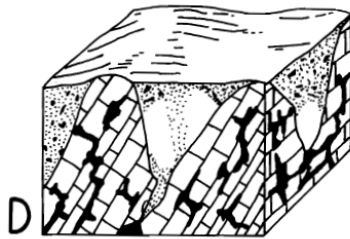
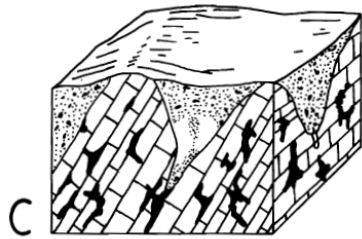
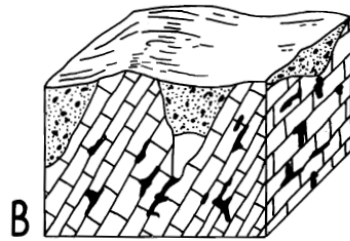
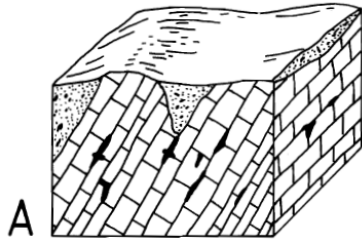
- **Dissolution of Carbonate Rocks occurs over Millennia to Millions of years: It is not happening in our lifetime**
- **Sinkholes and Caves are not forming due to current dissolution of limestone by carbonic acid.**
- **Sinkholes form in existing Karst Terrain**



How do sinkholes form?

[USGS Hydrologist Chuck Taylor](#)

Sinkhole Formation



Sinkhole Formation

SINKHOLE CHARACTERISTICS

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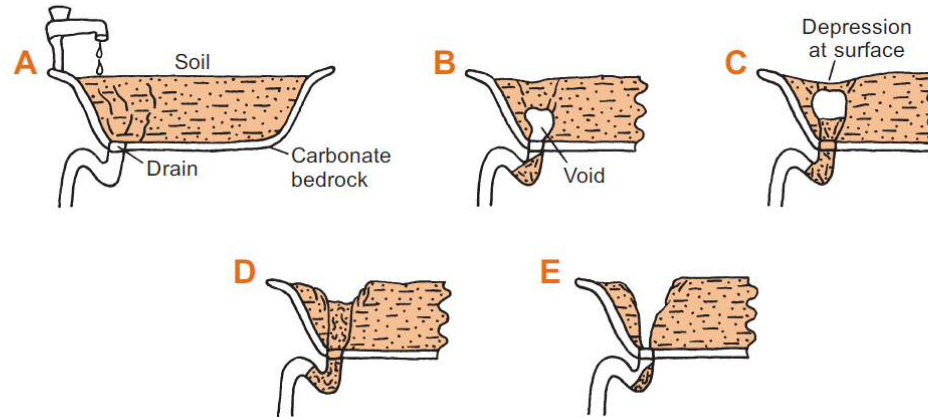
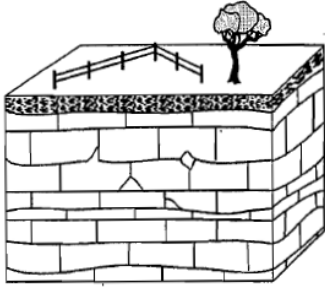


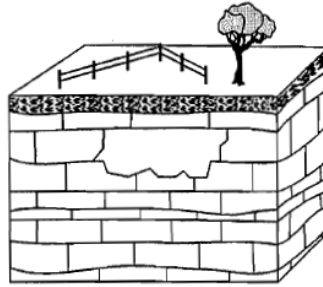
Figure 10. The bathtub model. A. Water infiltrates through the soil. B. As soil enters the drain, a void is left behind. C. Over time, the soil moves into the void, and the void “migrates” toward the surface. D. Support is removed and collapse occurs. E. If enough water is supplied, an open connection to the drain results.

Source: PA DCNR Publication: ES-11

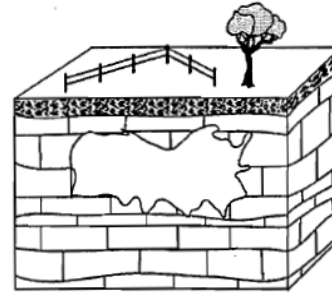
Sinkhole Formation



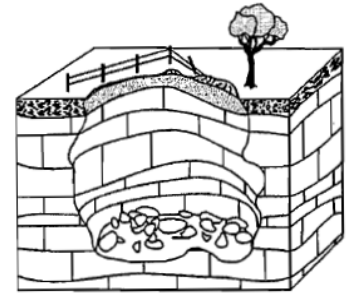
A. Solution of more soluble limestone strata.



B. Formation of cavern.



C. Enlargement of cavern and development of stalactites and stalagmites.



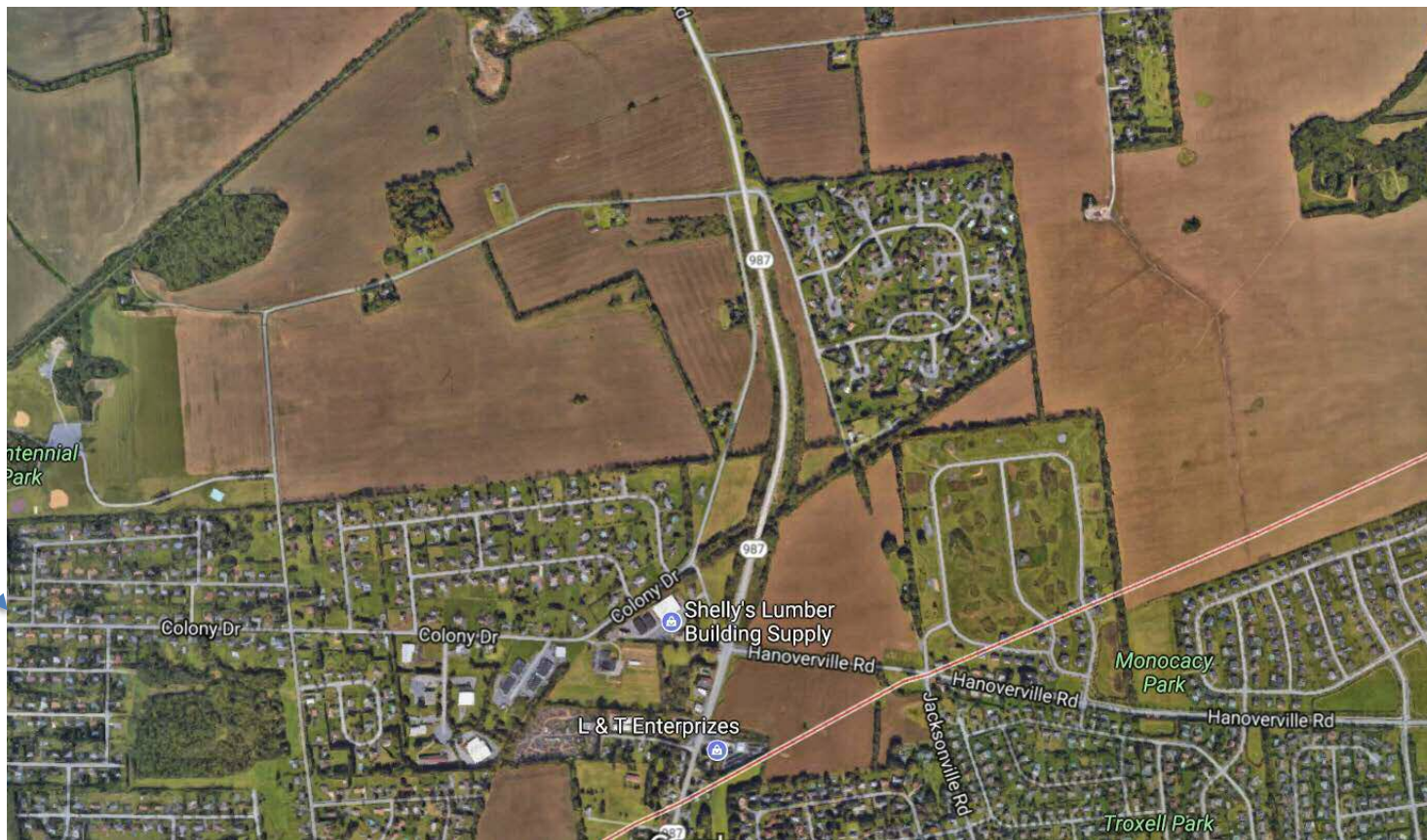
D. Collapse of cavern to form an irregular sink. Roof debris litters floor.

*Geotechnical Engineering Manual,
PENNDOT Publication 293*

Sinkhole Trigger Mechanisms

- **Naturally Occurring** - Runoff and Drainage caused from rain events and fluctuating surface and groundwater levels;
- **Construction Related** – Changes in drainage and grading (reason for construction related Karst ordinances);
- **Urban Land Related** – Underground utility leaks and breaks, concentration of runoff in basins, and unlined swales.
- **Geologic Structure Related** – Occurring at geologic faults, contacts, highly weathered zones;
- **Groundwater Lowering** - Due to pumping, mining, construction dewatering.
- **Climate Change** - Increased precipitation and storm intensity

Naturally Occurring



Construction Related



Construction Related



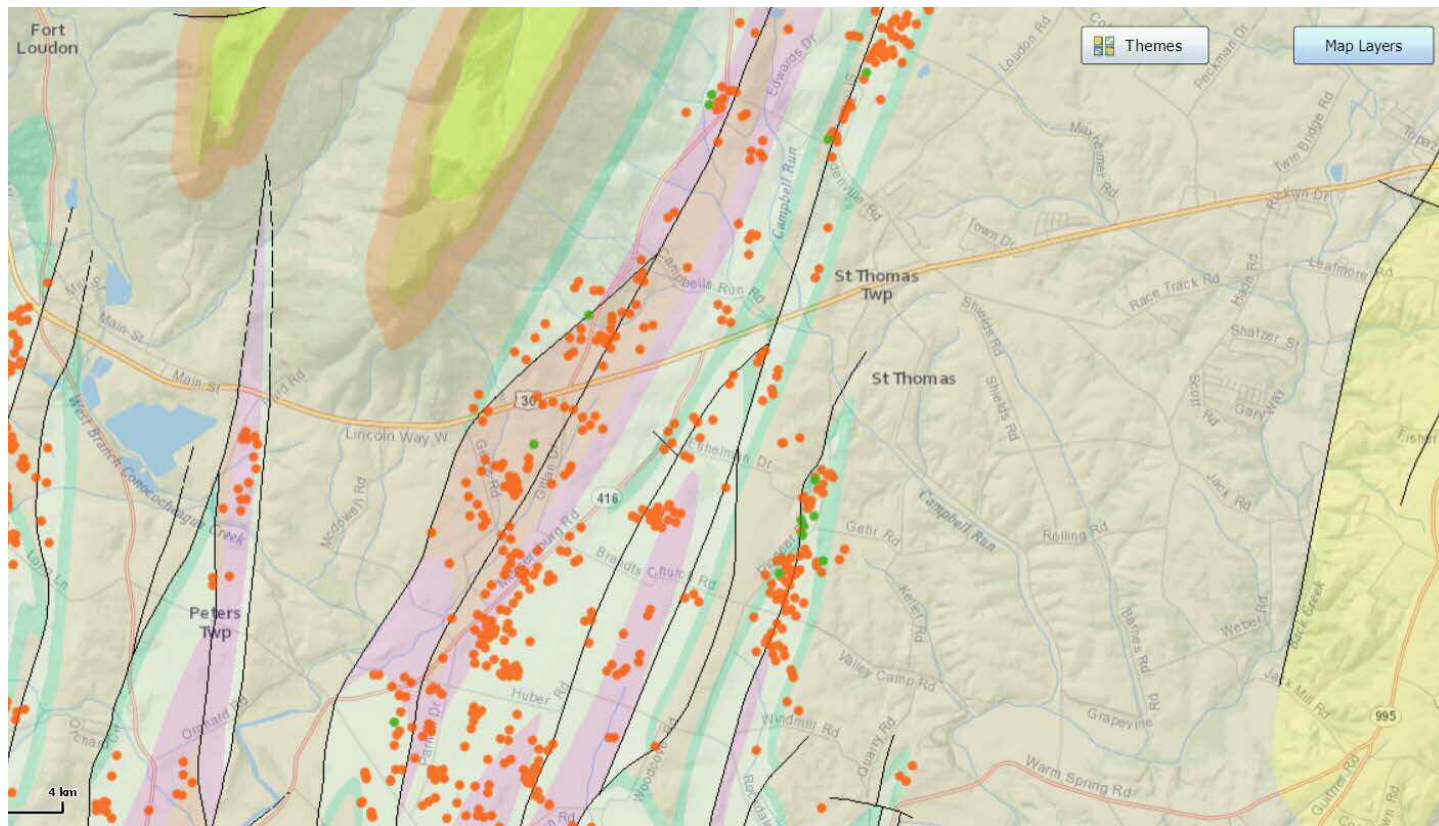
Urban Land Related



Urban Land Related



Geologic Structure Related



Groundwater Lowering Related




A sinkhole formed in NJZ's settling lagoon, which drained the lagoon into the Mine.

Friedensville Zinc Mines of Southern Lehigh County:
Geology, Industrial History, and Environmental Impact

Presented to the Harrisburg Area Geologic Survey, May 8, 2014, by Kent V. Littlefield, PG.



Groundwater Lowering Related?



Looking south at subsidence zone that formed on Camp Meeting Road. Mine buildings including main shaft and settling lagoon visible in background.

Friedensville Zinc Mines of Southern Lehigh County:
Geology, Industrial History, and Environmental Impact

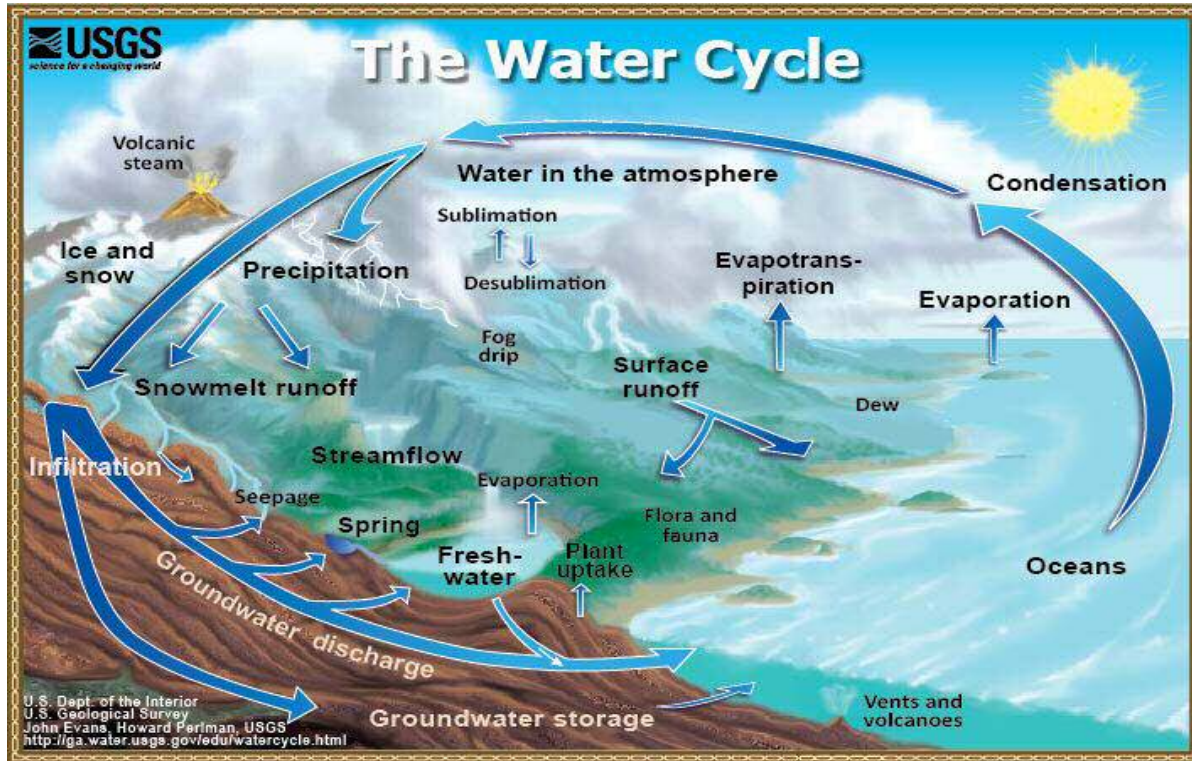
Presented to the Harrisburg Area Geologic Survey, May 8, 2014, by Kent V. Littlefield, PG.

Actually Mine
Subsidence:

A topic for
another day

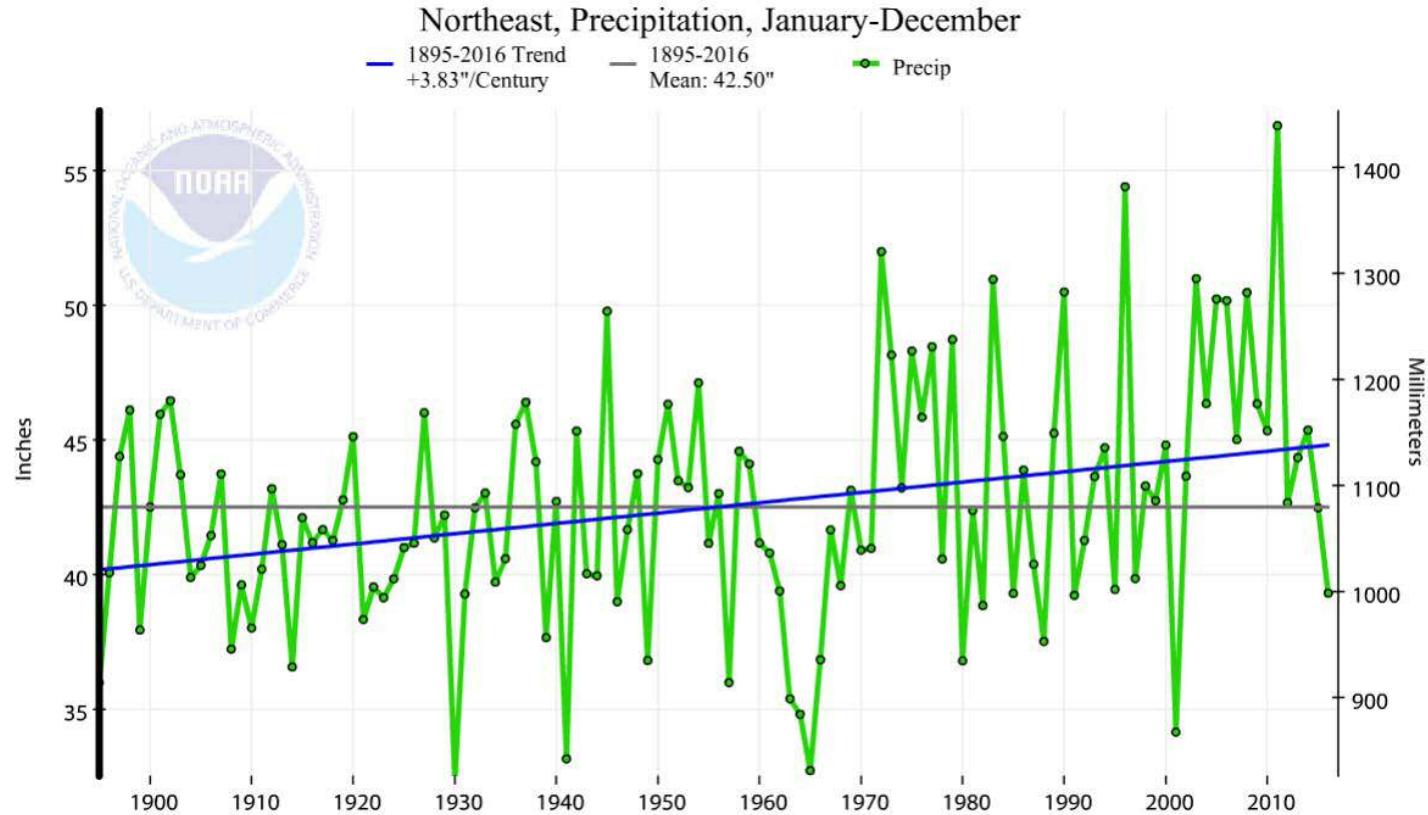
Some features
are generically
called
“Sinkholes”
but are not
karst related.

Climate & Climate Change



<http://ga.water.usgs.gov/edu/watercycle.html>

NOAA Precipitation Data



NOAA Precipitation Data

**Northeast US: Ten wettest years out of 122 years of record:
5 occurred since 2003!**

Year	Tot Precip.	Rank out of 122	Inches Above Normal
2011	56.67"	122	14.17"
1996	54.40"	121	11.90"
1971	51.99"	120	9.49"
2003	50.99"	119	8.49"
1983	50.96"	118	8.46"
1990	50.49"	117	7.99"
2008	50.47"	116	7.97"
2005	50.23"	115	7.73"
2006	50.17"	114	7.67"
1945	49.78"	113	7.28"

<http://www.ncdc.noaa.gov/cag/>

NOAA Precipitation Data

Hurricane Irene and TS Lee: Hershey Park September 8, 2011



Recent Droughts

Pennsylvania Department of Environmental Protection		
Berks County, PA		
Drought Declare Dates		Declared Drought Status
Start	End	
12/16/1999	5/5/2000	Watch
8/24/2001	12/5/2001	Watch
12/5/2001	2/12/2002	Watch
2/12/2002	11/7/2002	Emergency
11/7/2002	12/19/2002	Warning
12/19/2002	1/8/2003	Watch
4/11/2006	6/30/2006	Watch
9/16/2010	11/10/2010	Warning
8/5/2011	9/2/2011	Watch
3/24/2015	7/10/2015	Watch
8/2/2016	5/17/2017	Watch

Delaware River Basin Commission		
Berks County, PA		
Drought Declare Dates		Declared Drought Status
Start	End	
10/29/2001	11/3/2001	Drought Watch
11/4/2001	11/30/2001	Drought Warning
12/1/2001	12/17/2001	Drought
12/18/2001	11/25/2002	Drought Emergency
9/24/2010	10/31/2010	Drought Warning
8/2/2016	5/16/2017	Drought Watch

DRBC has updated its state-declared drought status

map: <http://www.nj.gov/drbc/library/documents/drought/map081117.pdf> .

<http://www.nj.gov/drbc/hydrological/drought/state-links.html>

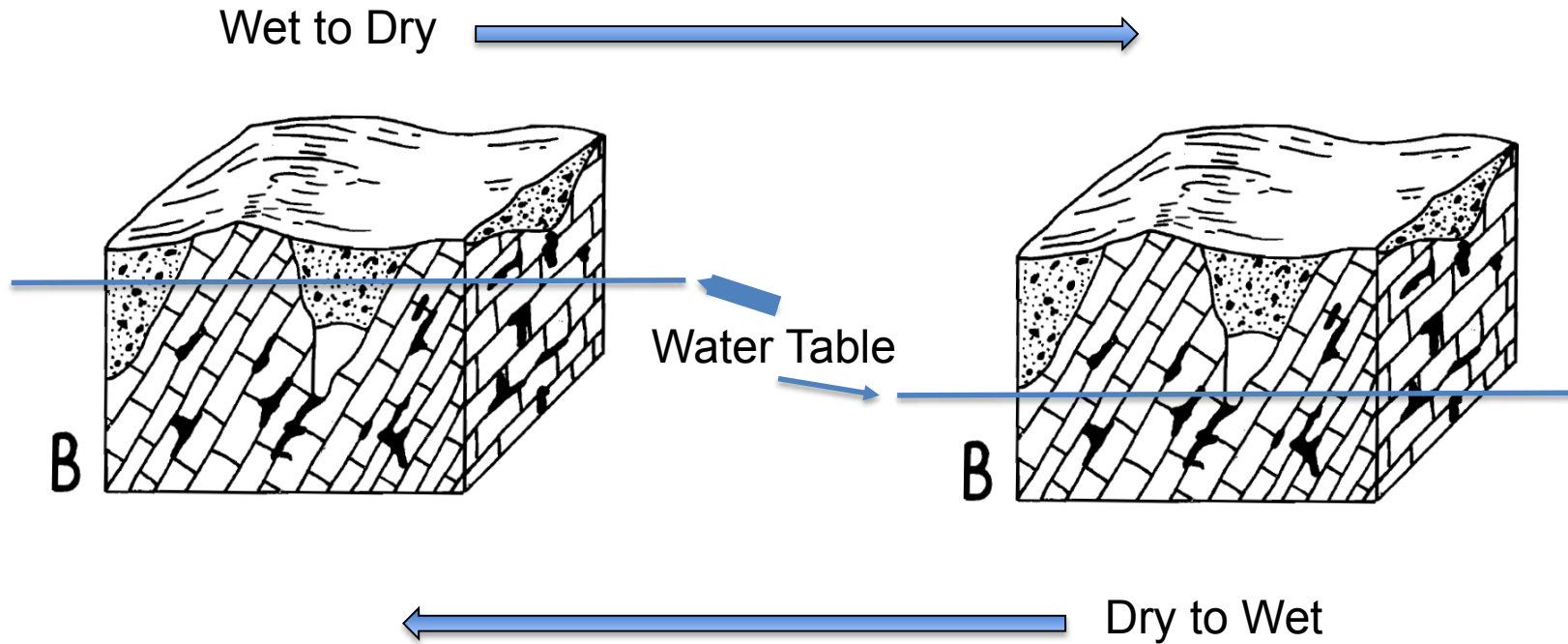
DRBC Drought Webpage: <http://www.nj.gov/drbc/hydrological/drought/>

PA: <http://www.dep.pa.gov/Business/Water/PlanningConservation/Drought/Pages/default.aspx>

Climate Change Observations

- Increasing Precipitation
- Frequent Droughts and Wet Weather Events
- Intensity of Storms is Increasing
- Observe Sinkholes with Storms of +/- 3 inches
- 2011 was a significant year for sinkholes: Drought followed by Hurricane Irene and TS Lee

Sinkhole Formation



Site Investigation

- Historical Information Review:
 - LiDAR, Aerial Photographs; Historical Topographic maps, Geologic Maps, Fracture Trace Assessments.
- Geophysical Surveys and Geotechnical Drilling
- Stormwater Surveys (Disappearing streams, Closed depressions, Ghost lakes)
- Karst Ordinances are developed in many areas, mandating similar steps to the above.

Site Investigation

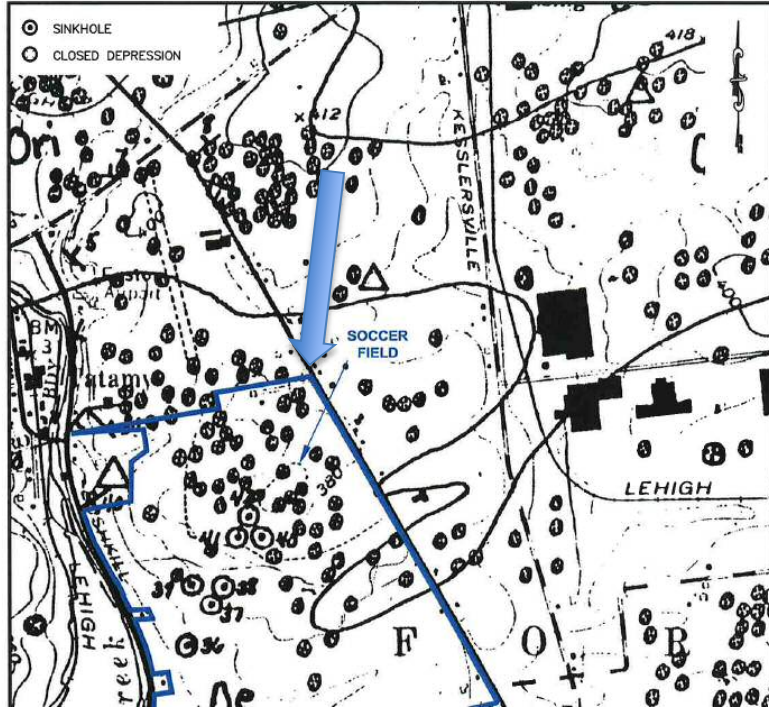


1938



1971

Site Investigation

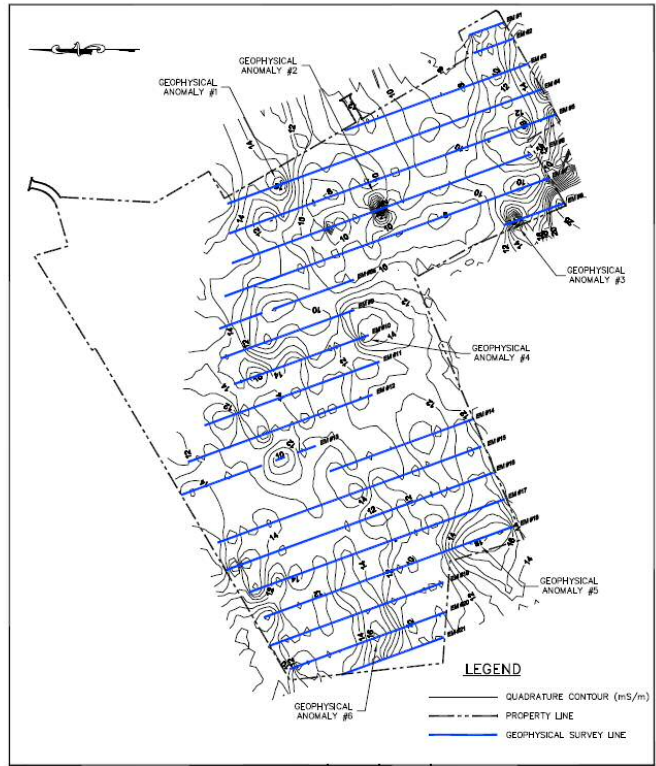


Sinkholes and karst-related features of Northampton County, Pennsylvania, William Kochanov PA DCNR OFR 87-02



Site Recon

Geophysical Surveys and Drilling



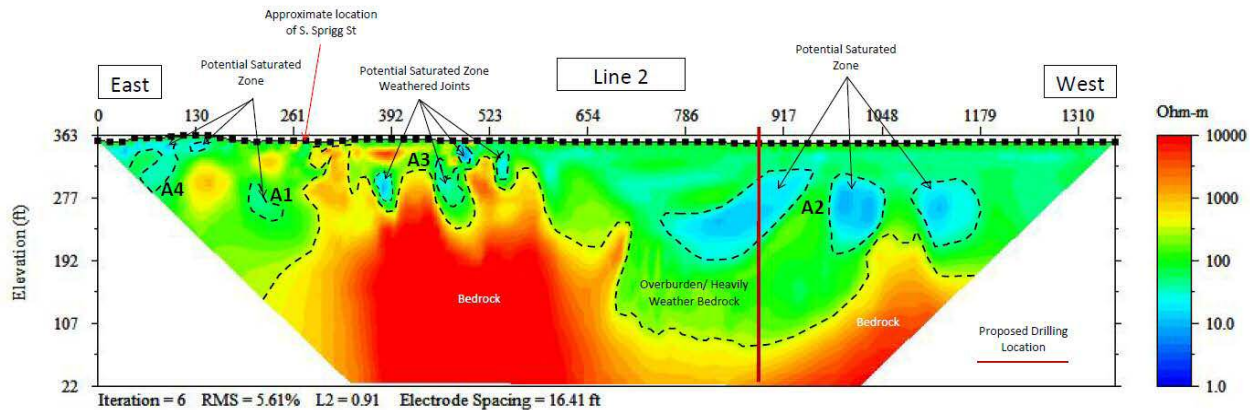
Geophysical Surveys: Conductivity, Resistivity and Ground Penetrating Radar are common



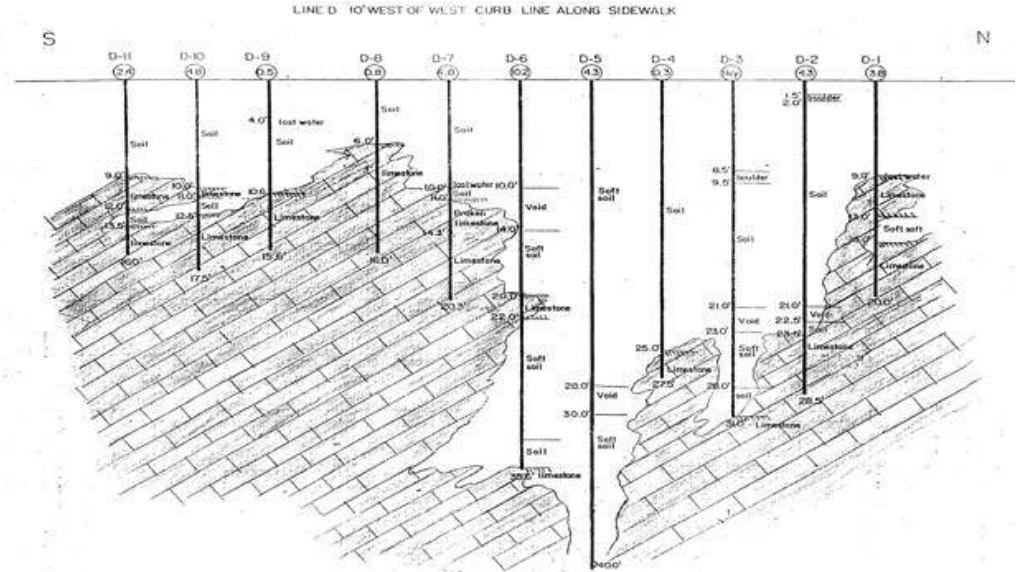
Geotechnical Drilling of Anomalies

Lou (circa 1985): I-78 Geophysical Surveys

ER Geophysical Surveys



Geophysical Surveys and Drilling



By Michael Perlow Jr., P.E. from PCPG Karst Seminar 2012

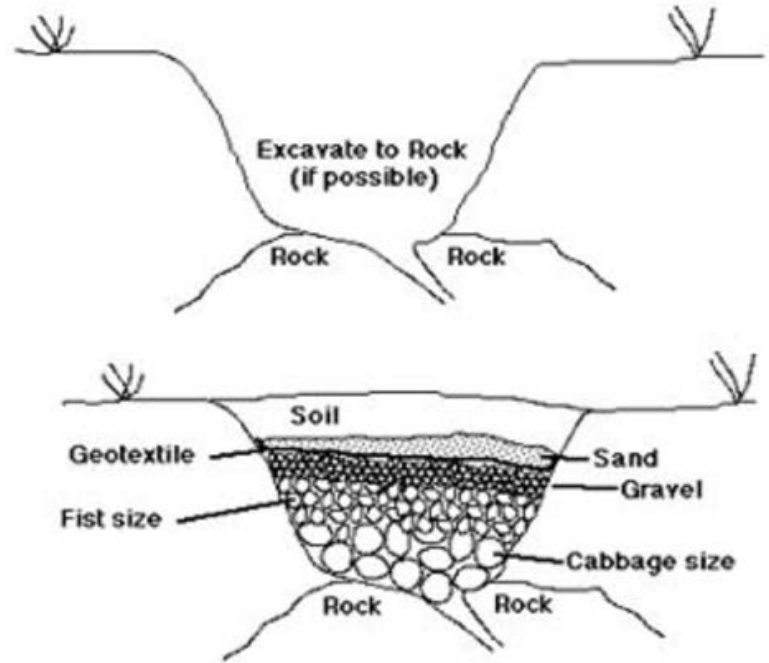
Sinkhole Repair

- **Graded Filter** (Clean stone, fabric and soil)
- **Impermeable non-filter fix** (flow-able fill, grout, impermeable soil, topsoil)
- **Subsurface grouting techniques: Many methods- Compaction, Cap grouting, Soil Amendments, etc.**
- **What Repair to use? Where to Use it?**
 - Depends on location: Open field, near a building, beneath roadway, etc. and engineering foundation requirements.

Sinkhole Repair: Graded Filter

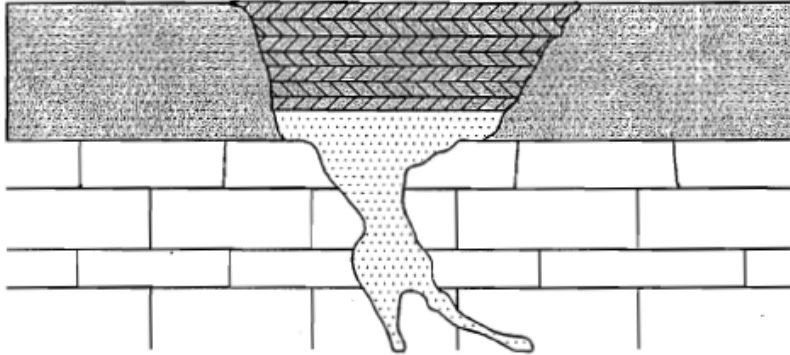
- Step 1: Excavate the sinkhole down to rock if possible.
- Step 2: Put a layer of large stones in the hole (cabbage size).
- Step 3: Put a layer of smaller stones on top (fist size).
- Step 4: Put a layer of gravel on top of the small stones.
- Step 5: Cover the gravel with a geotextile fabric. This prevents the next layer (sand) from being lost through the gravel.
- Step 6: Cover the geotextile fabric with a layer of coarse sand.
- Step 7: Fill the remainder of the hole with soil. This can be layered to match the existing soil profile.

....The objective is to provide an open path for percolating water so that it can't carry away soil and cause another sinkhole. The repair, as described, also provides good filtration of infiltrating water.....



<http://www.ei.lehigh.edu/envirosoci/enviroissue/sinkholes/repair.html>

Sinkhole Repair: Impermeable Filter



Plug swallow hole with type "C" concrete.
Backfill with impervious material and construct
Adequate surface drainage.

Figure 2.7.4.2.1 (F)

Correction of active sink-hole near surface.



Sinkhole Repair: Grouting



Sinkhole Prevention Recommendations

- Prudent Stormwater Management: Provide for positive surface water drainage away from building areas, excavations and exposed rock at all times before, during and after construction;
- Avoid the formation of depressions where ponding may occur;
- Swales and retention ponds should be lined to prevent infiltration;
- Deep excavations should be avoided to reduce erosional effects;
- If bedrock is encountered, excavation other than blasting should be used;
- Site preparation techniques should include proof-rolling and dynamic compaction methods;
- Excavations should be closed as soon as possible after exposure;
- Water utility trenches should be lined to prevent infiltration; and
- Underground piping should be leak-proof and utilize gasketed joints, etc.

Sinkhole Prevention Recommendations

Remediation techniques should be based on Site-specific sinkhole conditions and should be performed in accordance with accepted engineering practices recommended by a qualified professional.

Recommend that any proposed structures be located to avoid karst features or if such areas cannot be avoided, a qualified professional engineer should be retained to review the proposed structure(s) foundation and drainage design.

Prevention is much less costly than repair!

Questions and Discussion





Thank You!