Class V, Gravity-Fed Injection Well Applications in Karst Limestone Terrain

KCF Groundwater, Inc.

Mid-Atlantic Quality Assurance Workshop

Hershey, Pennsylvania

February 7-9, 2017
"Celebrating 50 Years"

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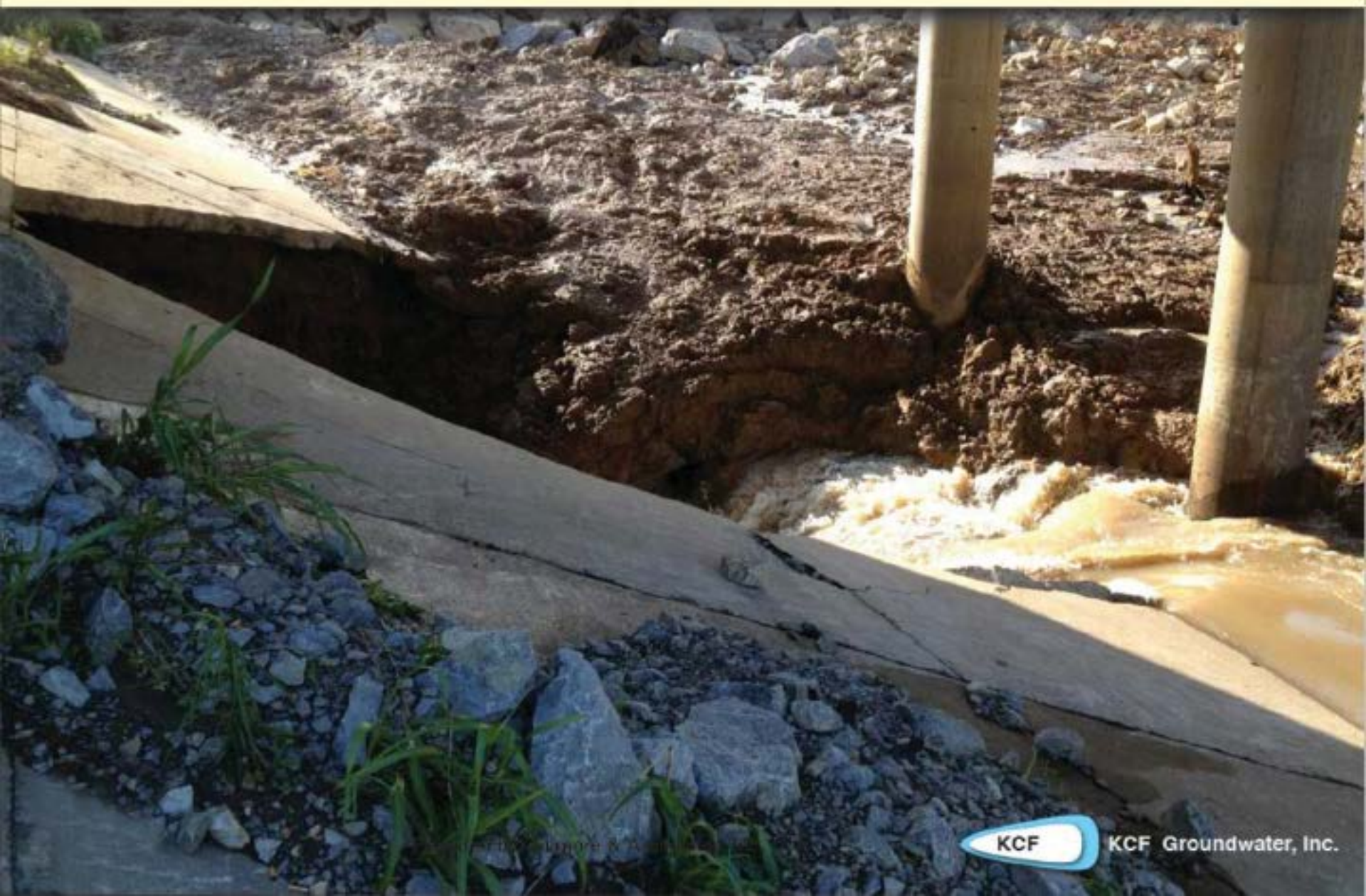
Uncontrolled Recharge



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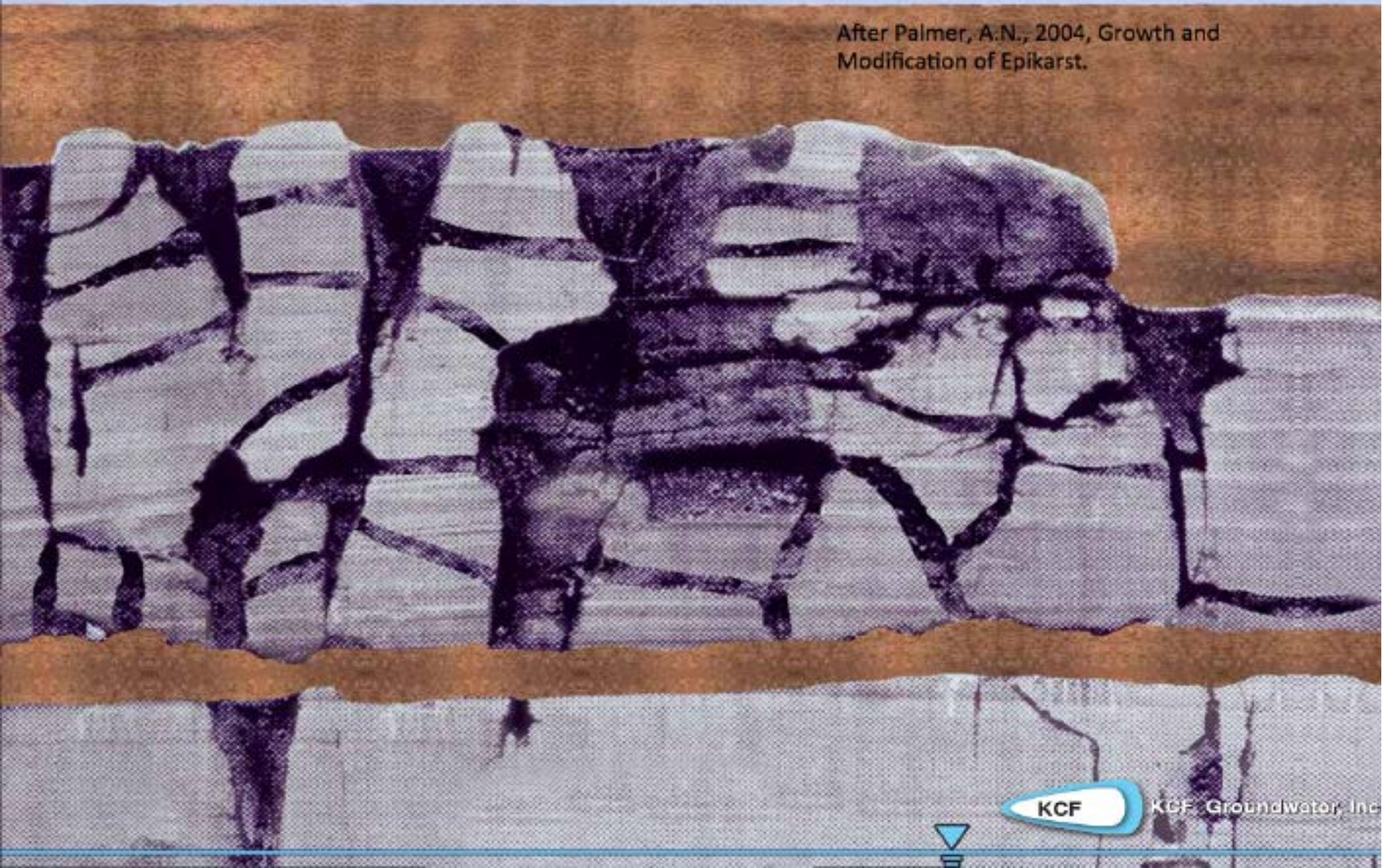
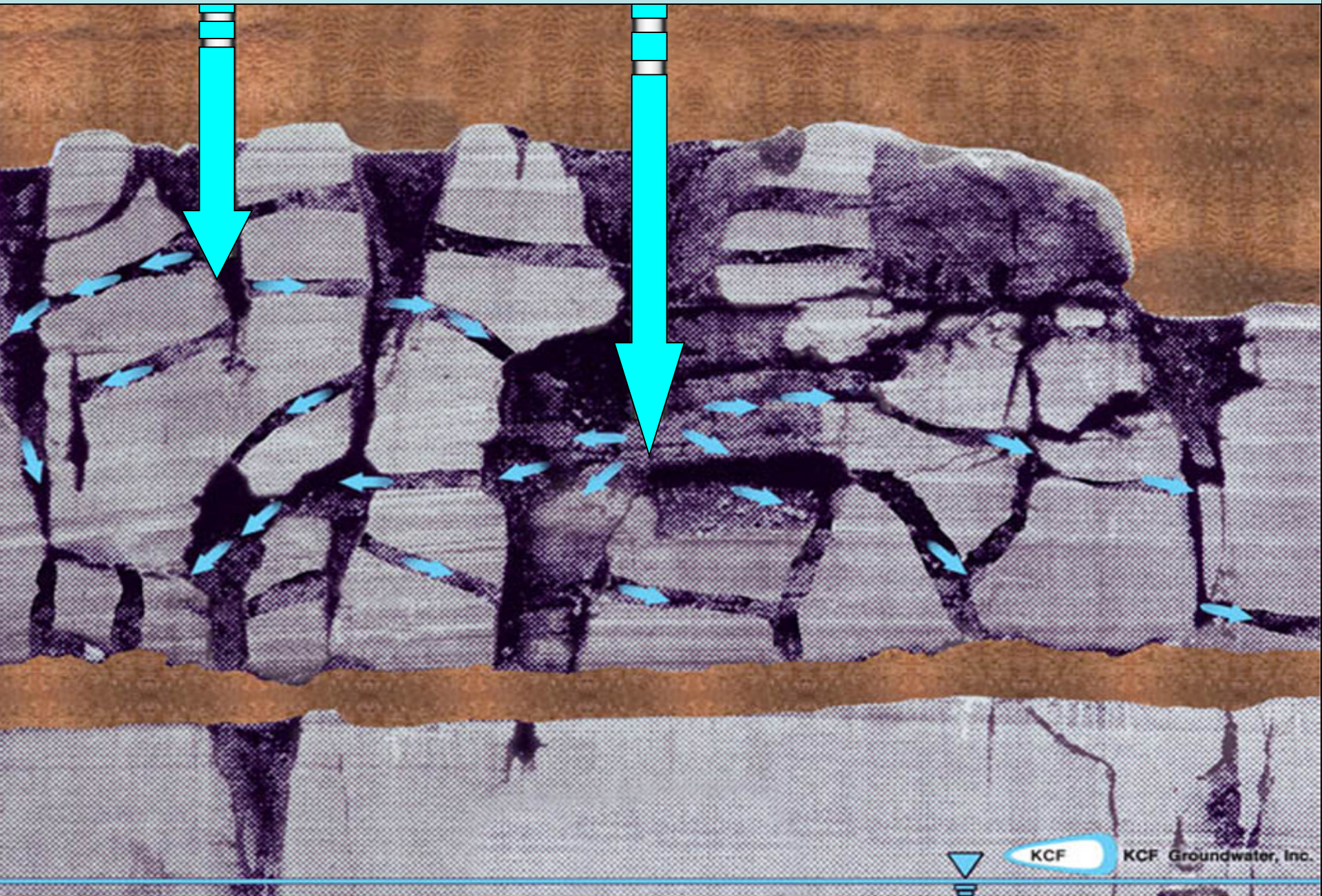
Buried Epikarst Bedrock

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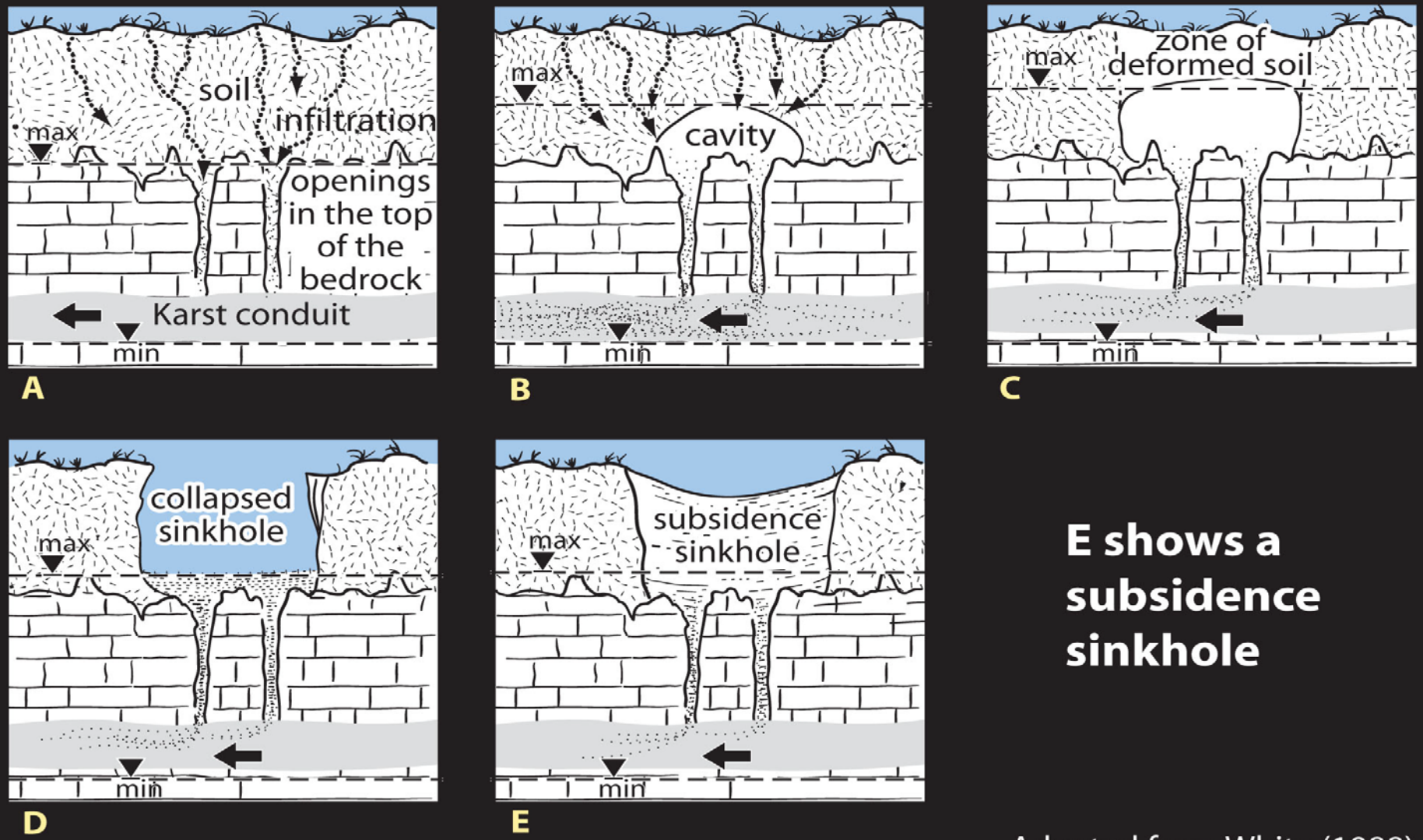
Two Types of Sinkholes

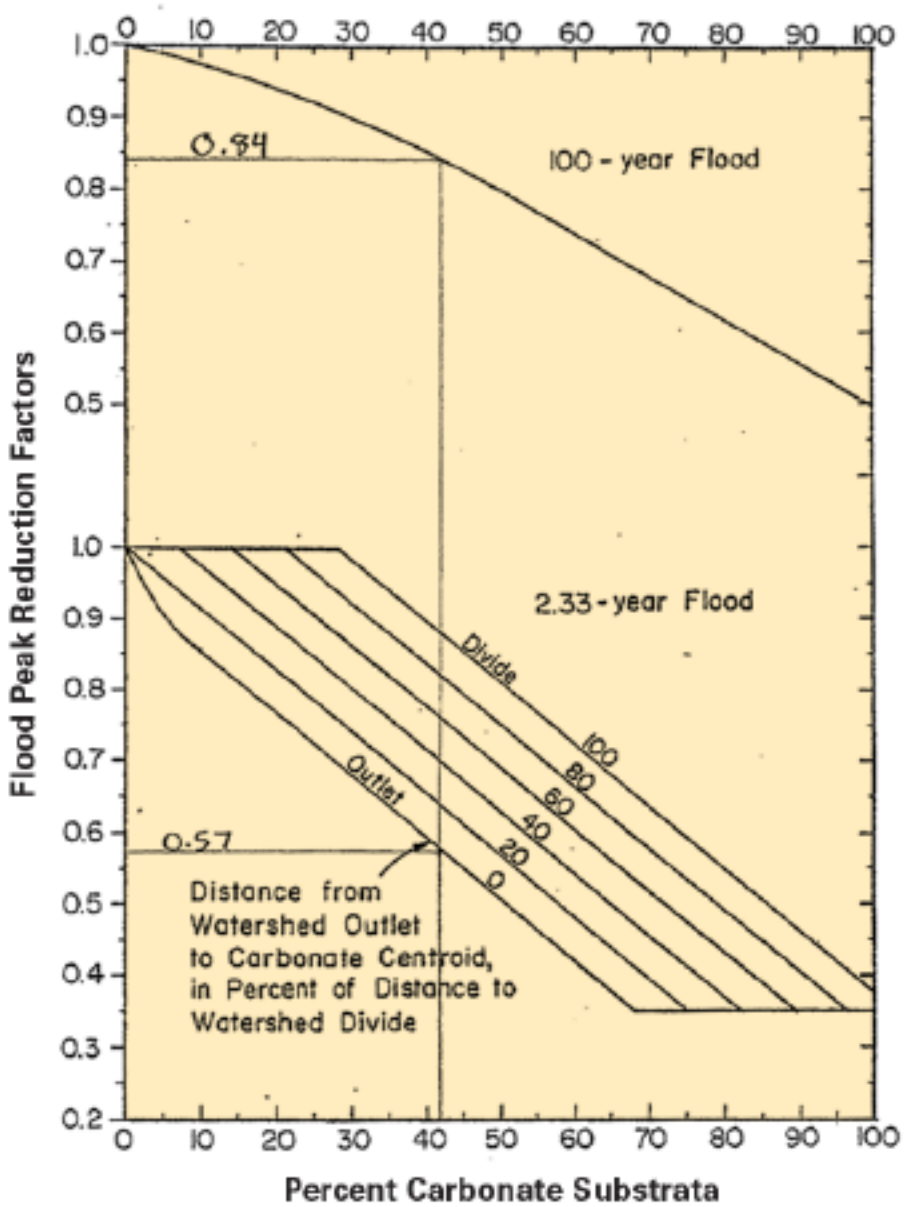
A through D show the formation of a ground collapse sinkhole



E shows a subsidence sinkhole

Adapted from White (1988)

Fig. 4.2. Flood Peak Reduction Factors for Carbonate Rocks

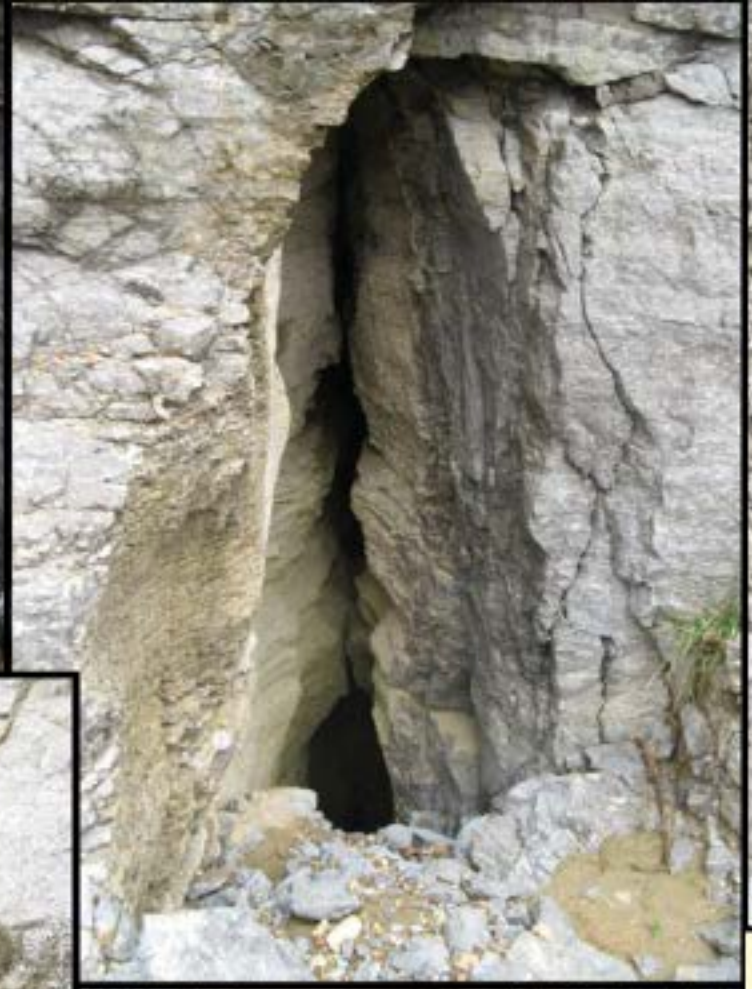


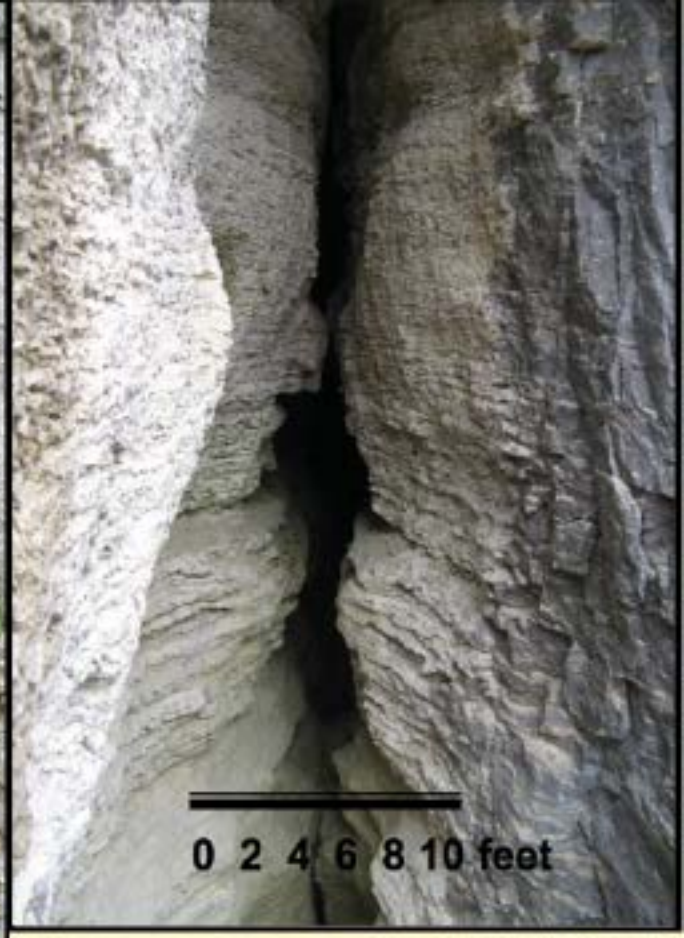
$Q_2 = 150cfs$ $Q_{2r} = 0.57Q_2 = 85.5cfs$

$Q_{100} = 565cfs$ $Q_{100r} = 0.84Q_{100} = 474.6cfs$

A Karstic Flow Conduit in Fractured Dolomite

Massive-Scale Epikarstic Openings





Karstic Flow Channels

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Pop Quiz #1 Geology and Hydrogeology

What is the correct name for stormwater recharging into the underlying epikarst bedrock through swallets or karstic openings?

a. **Sink-point loss?**

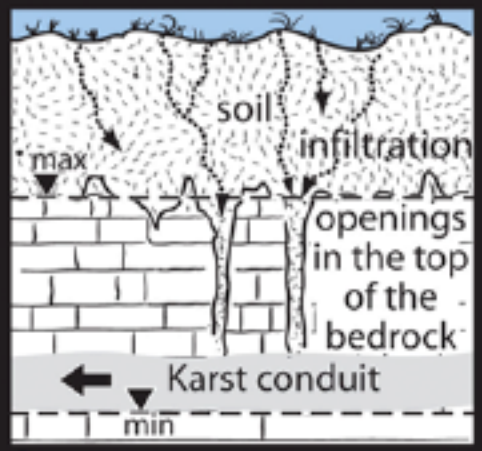
b. **Stormwater infiltration?**

c. **Karst-loss?**

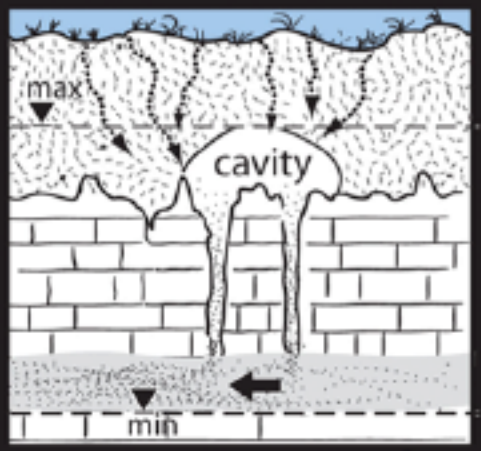
d. **All of the above?**

The Causes of Sinkholes

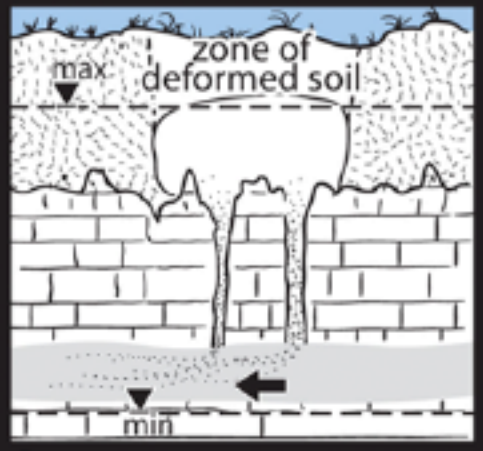
A through D show the formation of a ground collapse sinkhole



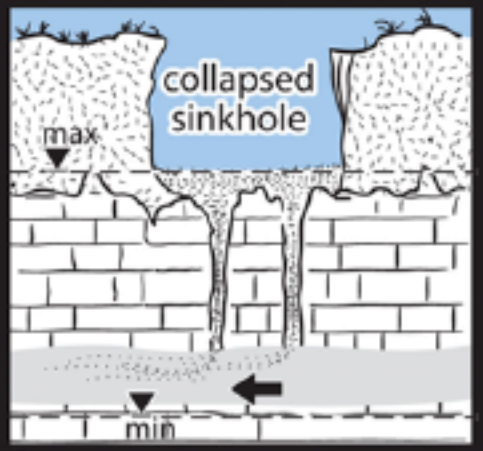
A



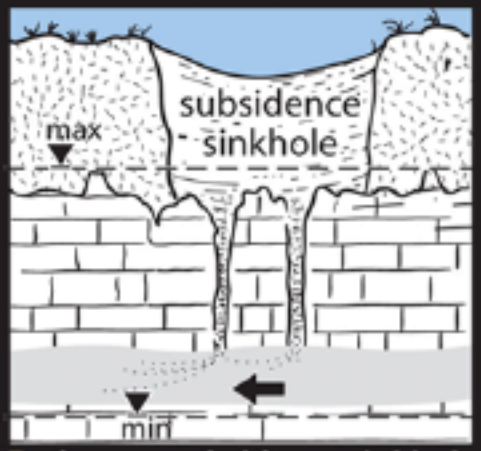
B



C



D



E-shows a subsidence sinkhole

Adapted from White (1988)

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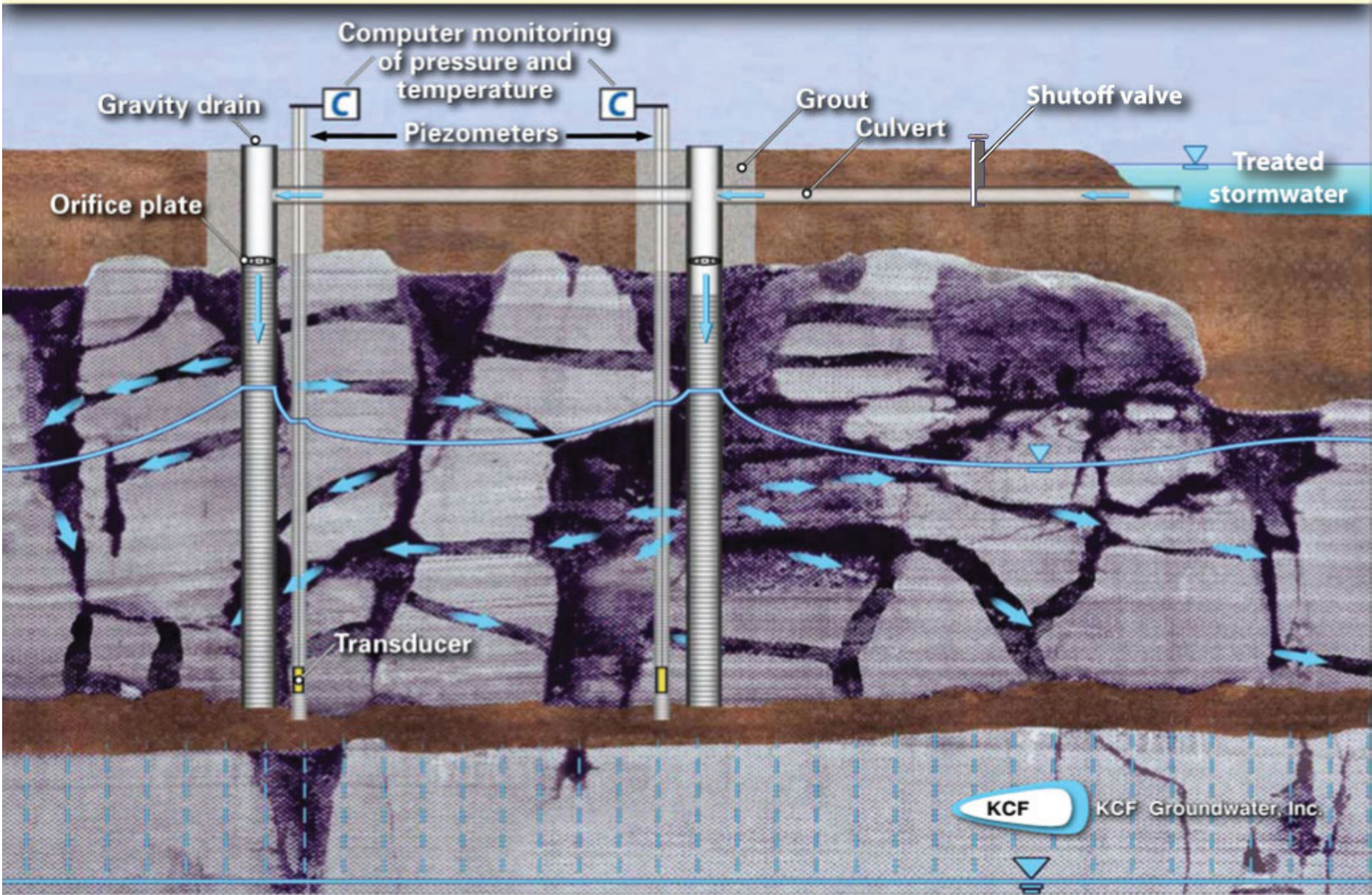
Gravity Drain Approach



Geotechnical Considerations

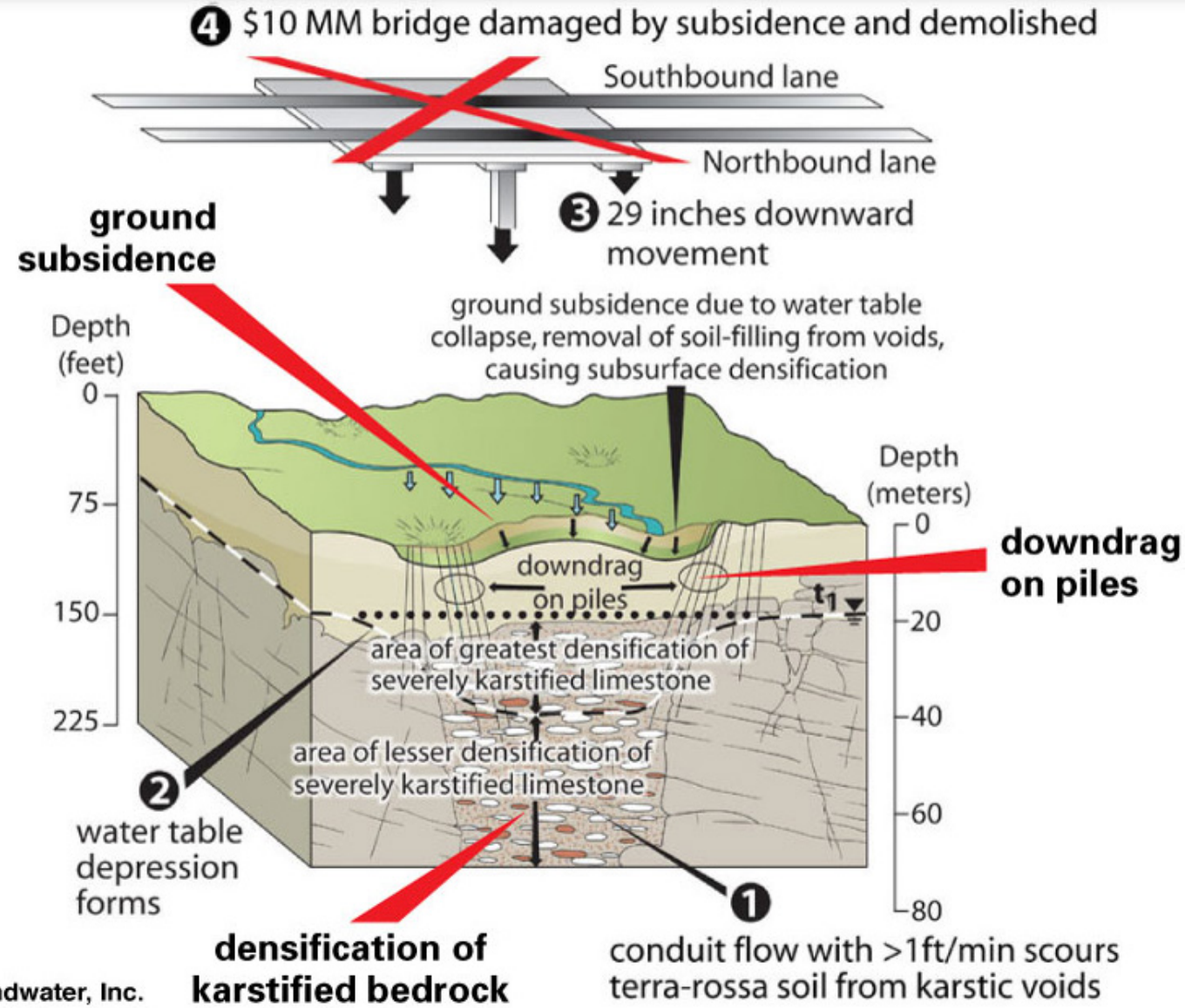
Pilot Hole Program

- Evaluate epikarst quality and capacity
  - Minimum ratio of rock skeleton to void space from drilling logs
  - Sufficient void space to accept drainage
  - Erosion of overburden soils (groundwater levels during water capacity testing)

Geotechnical Considerations (Cont'd)

- Ground stability is a key consideration in managing the hydrogeologic environment
- The epikarstic bedrock, which hosts conduit flow, must also support building foundations
- Pilot holes are drilled through the soil and epikarstic bedrock to test existing conditions
- A Guideline Ratio for epikarstic bedrock is about 70 % rock skeleton to 30 % void space

Geotechnical Considerations



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Site Suitability Assessment

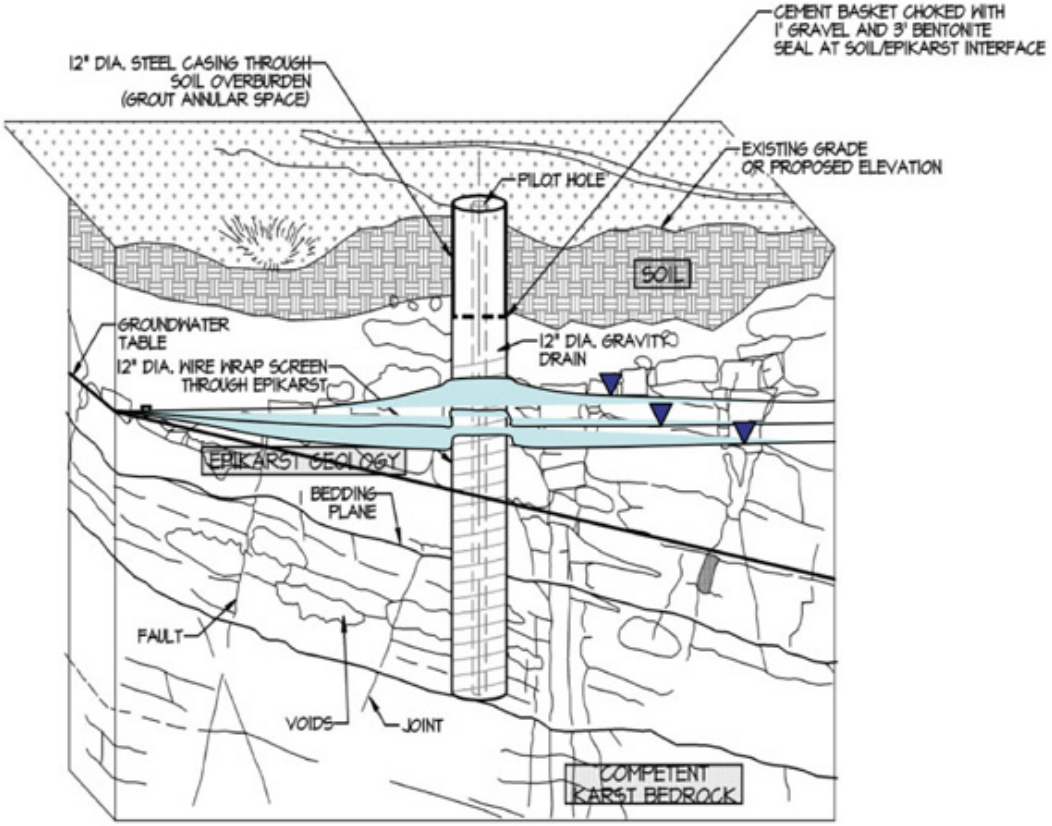
- Review of site geology, hydrogeology, and geotechnical literature
- Mapping of bedrock exposures, sinkholes, and artesian springs
- Water-injection testing of sinkholes, springs
- Photo-lineament ID of possible conduits
- Spontaneous Potential geophysical surveying
- Drilling and water-injection testing of flow rate

Summary and Perspective

- The *drain system* consists of:
  - A distributed array of stormwater gravity drains, grouted in place, at locations of large karstic permeability
  - Automated continuous monitoring of the water table
  - An option for mechanical adjustment of flow rates to prevent epikarstic flooding
  - Contingency planning for sinkhole repair, and maintenance of water quality

Injection Well Capacity Testing

- Step-injection testing of each well with potable water
- Step increases in injection rate to a pre-selected maximum water level
- Individual ratings are 170 gpm (1), 700-900 gpm (5), 1000-1500 gpm (7), 1500-2000 gpm (5), 2300 gpm (1)



GRAVITY DRAIN

NOT TO SCALE

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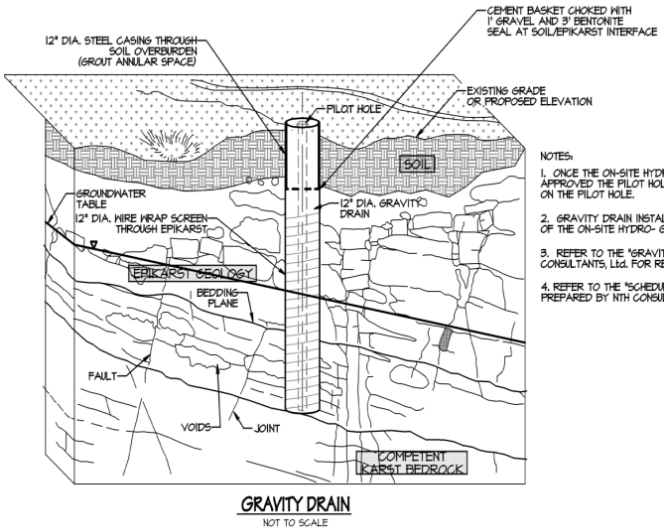
Injection Capacity Testing

Gravity Drain Design & Installation



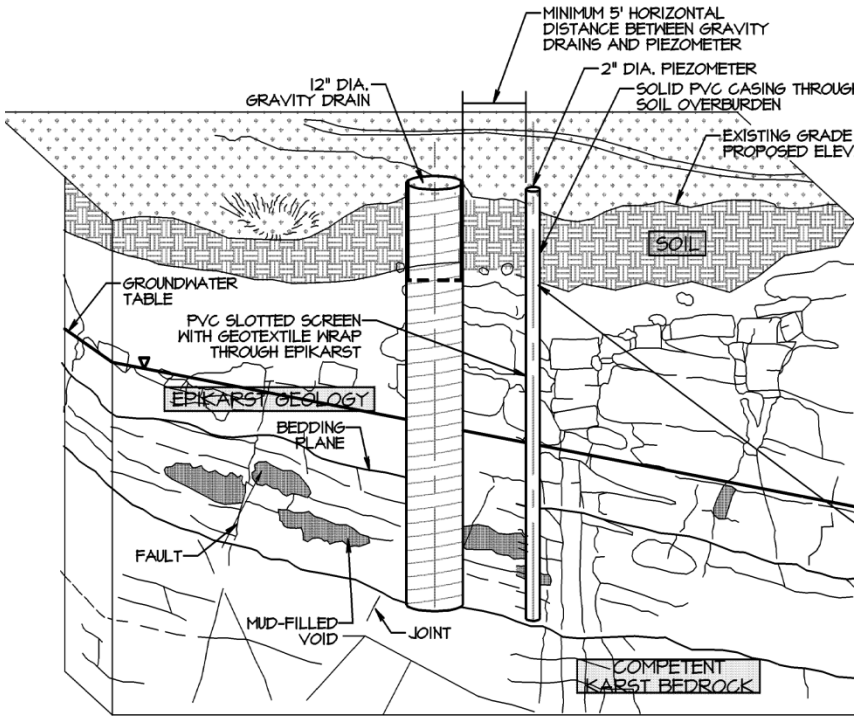
GRAVITY DRAIN
NOT TO SCALE

- Gravity Drain System Components
  - 12-inch blank casing through overburden
  - Mechanical seal at manhole
  - Grout seal through overburden
  - Cement basket
  - Stainless steel well screen through epikarst
  - Piezometer adjacent to drain
- System Goals
  - Limit vertical infiltration
  - Limit overburden scouring/piping

Construction Details and Specifications

Piezometer Construction

- Temporary casing installation
- 2-inch PVC blank and slotted sections
- Shale trap and bentonite seal
- Annular space grouting



PIEZOMETER
NOT TO SCALE

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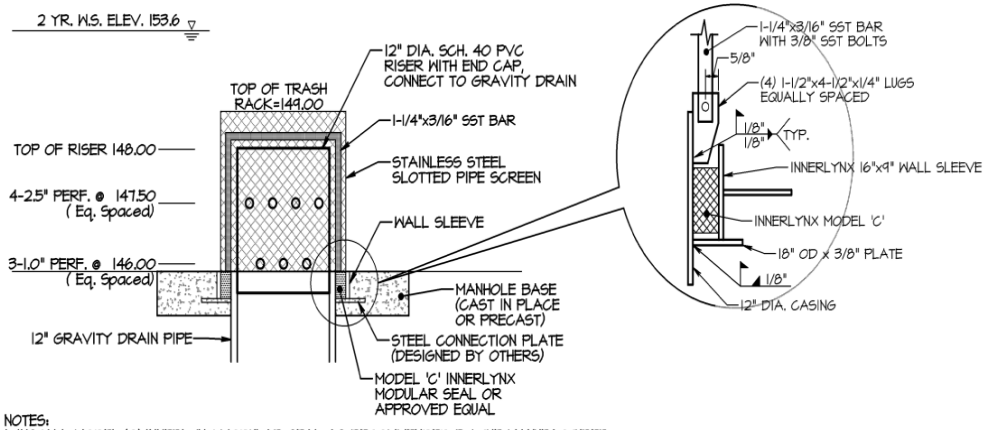
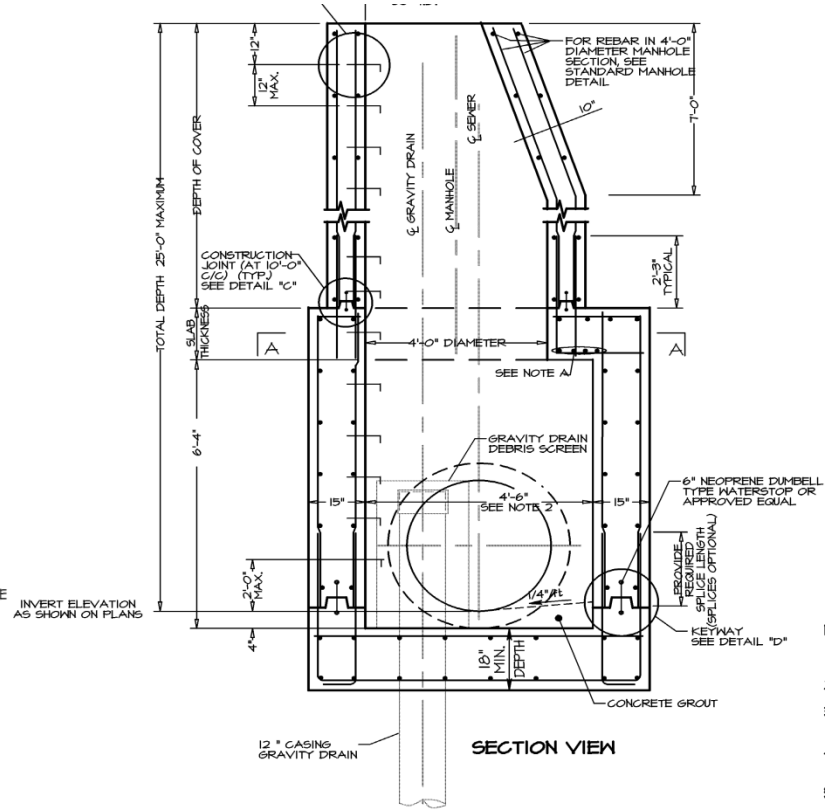
Construction Details and Specifications

Manhole Construction And Injection Well Head Design

- Water tight joints
- Rigid connection
- CIP manhole base
- Backfill requirements





NOTES:
1. INSTALL MODEL 'C' INNERLYNX MODULAR SEAL AS RECOMMENDED BY THE MANUFACTURER.
2. WALL SLEEVE AS PROVIDED BY INNERLYNX TO MATCH OPENING SIZE.
3. STEEL CONNECTION PLATE SIZE AND WELD CONNECTION TO BE DESIGNED BY OTHERS.
4. IF MANHOLE BASE IS PRECAST, THE PRECASTER SHALL DESIGN THE APPROPRIATE INNERLYNX CONNECTION AND CONNECTION TO SUPPORT GRAVITY DRAIN CASING.
5. PROVIDE MIN. 12" CLAY LINER BEDDING (NATIVE SOIL MIXED WITH DRY BENTONITE) UNDER MANHOLE BASE.

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Pop Quiz #2 The Main Causes of Sinkholes in Karst Terrain

What are the 5 main factors causing sinkholes? (according to Newton/USGS)

a. **Collapsing limestone, gravity, rainfall, leaking pipes, thin soil**
b. **Conduit flow, karst openings, karst loss, soil piping, water table fluctuation**
c. **Rodent holes, rainstorms, cracked pavement, torn liners, quarries**
d. **All of the above**

Gravity Drain Components and Installation

Injection Well Manhole - Interior Detail

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Water Quality Monitoring Well Design & Installation

- Water Quality Monitoring Well Location Selection
  - Representative groundwater inflow and outflow
- Well Construction
  - Low flow sampling (less sediment disturbance)
  - Pump positioning (dedicated equipment)

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Pre-Treatment of Injected Water

- Operations and Maintenance
  - Street Sweeping
  - Spill Control
- Pre-recharge Treatment
  - Vortech units
  - Settling basin
  - Gravity drain riser/screen

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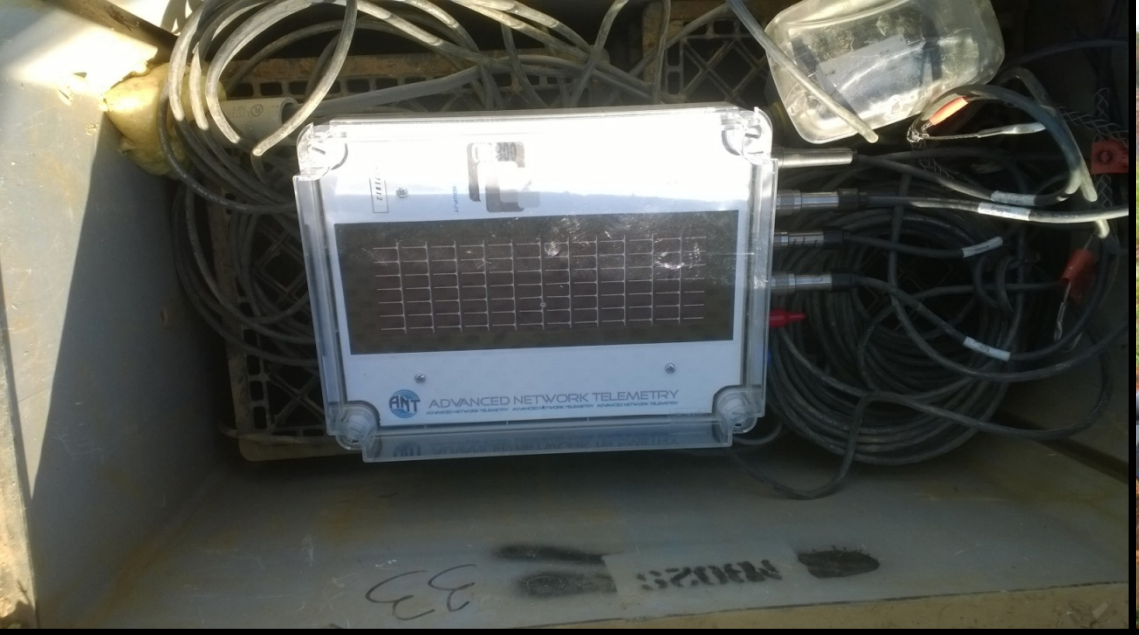

Automated Remote Monitoring Hardware

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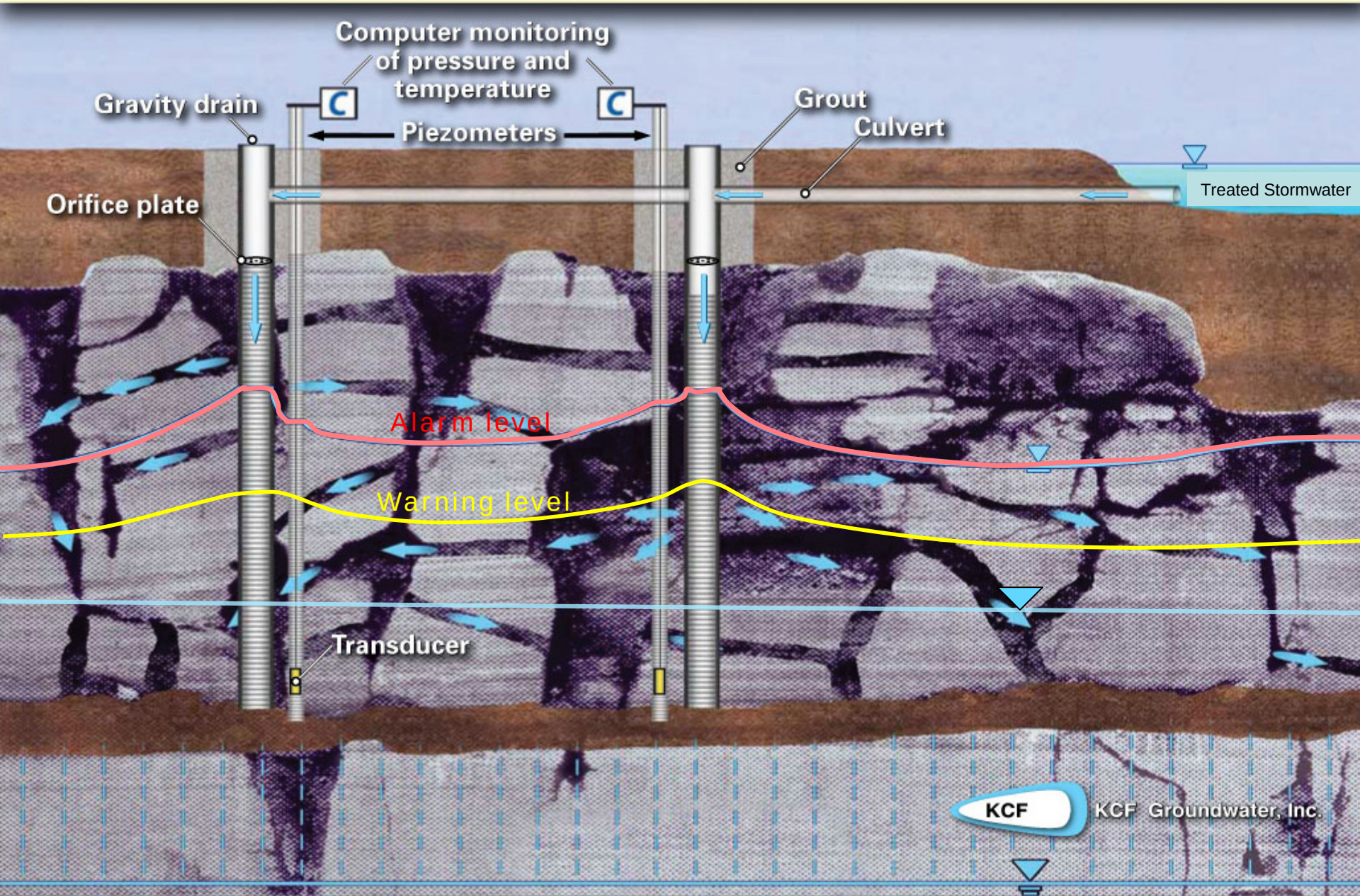
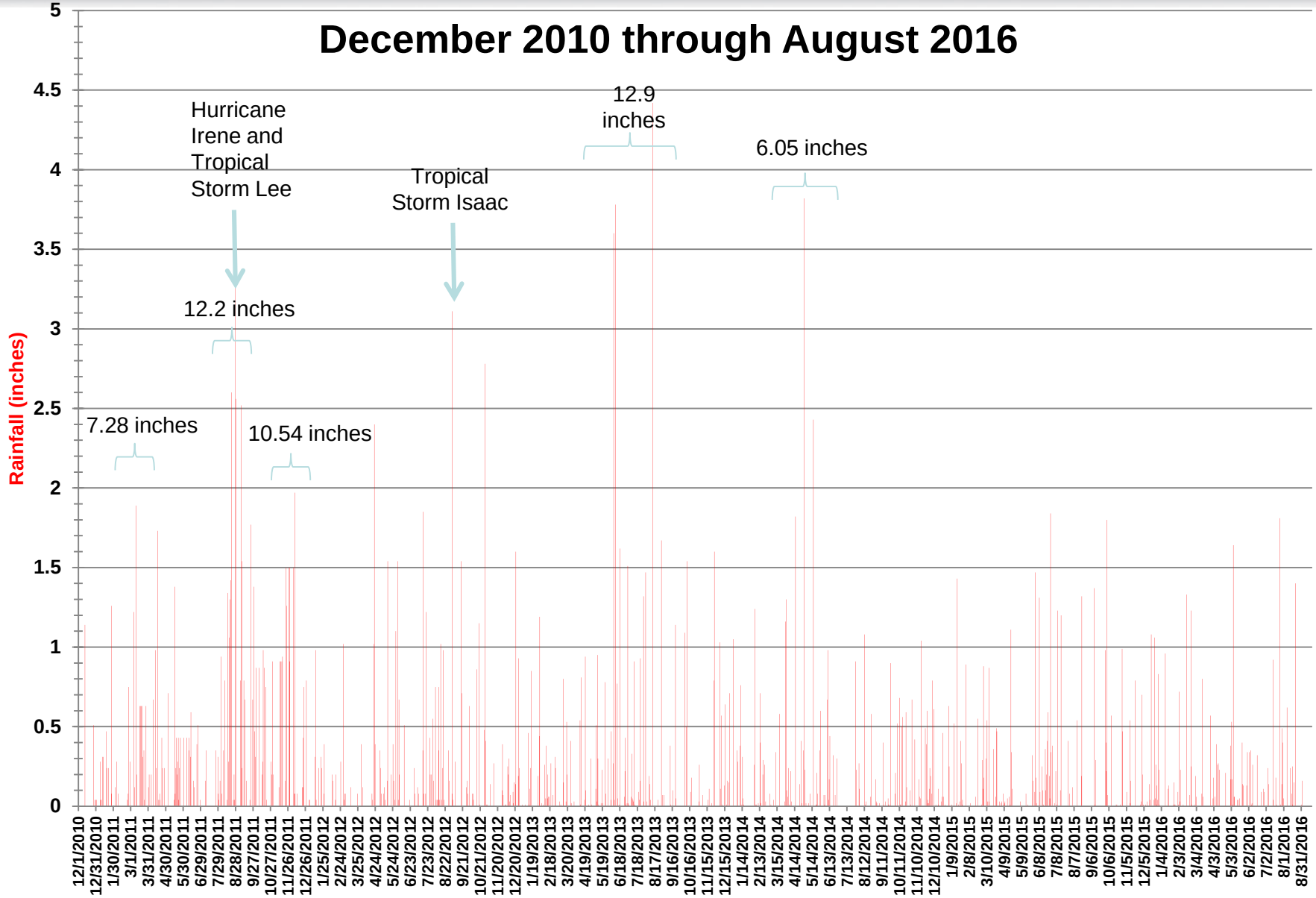
Gravity Drain Approach

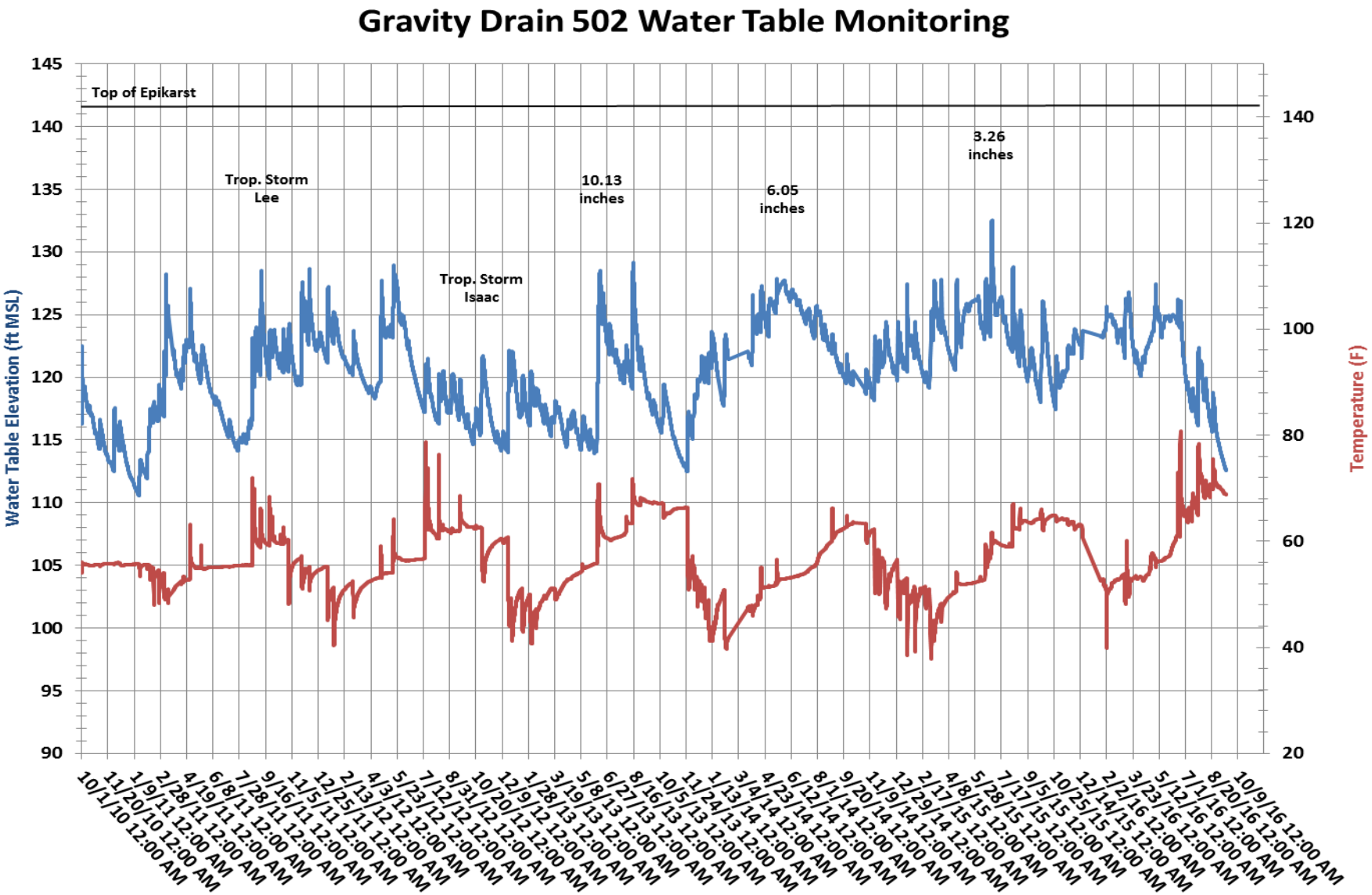


Periodic Inspection and Maintenance

Rainfall Summary



Hydrogeologic Response



Summary and Perspective

- A very successful 6 years
- About 300 million gallons disposed of; ~ 920 acre-feet, with no sinkholes having formed
- Injection capacity continues undiminished
- Injection wells, with stainless screens, continue to perform as designed; occasional cleanout required
- Injection rate maximum 10,100 gpm; typical 1,600 gpm injection rate
- Automated remote monitoring system for water table level and flow-rate to the injection well field has enabled maximum injection rate while controlling the water table level, and sinkhole risk

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Pop Quiz #3 Class V Injection Well Permitting

What are the main steps towards permitting of Class V injection wells in PA?

a. **Township and PADEP application-only**
b. **NPDES application with PADEP, and USEPA notification and registration**
c. **USEPA permitting only, because PA is not a Primacy State and therefore has no authority**
d. **None of the above**

Compatibility of Deep Class V Injection Well Use with Geotechnical Construction and Land Development in Karst Limestone Terrain

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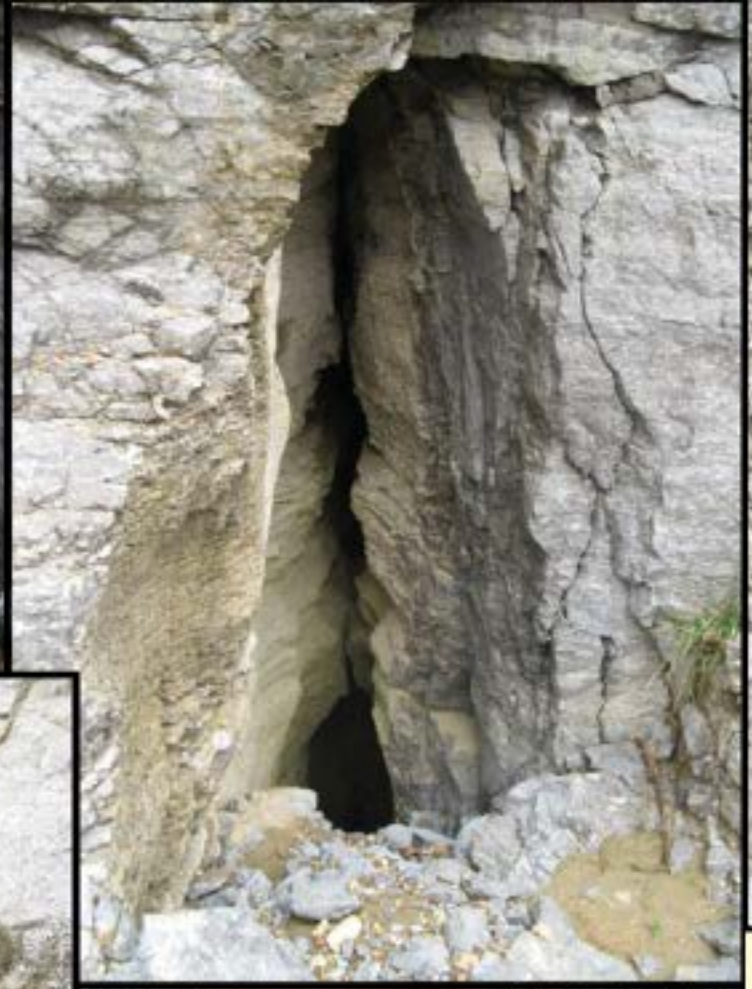
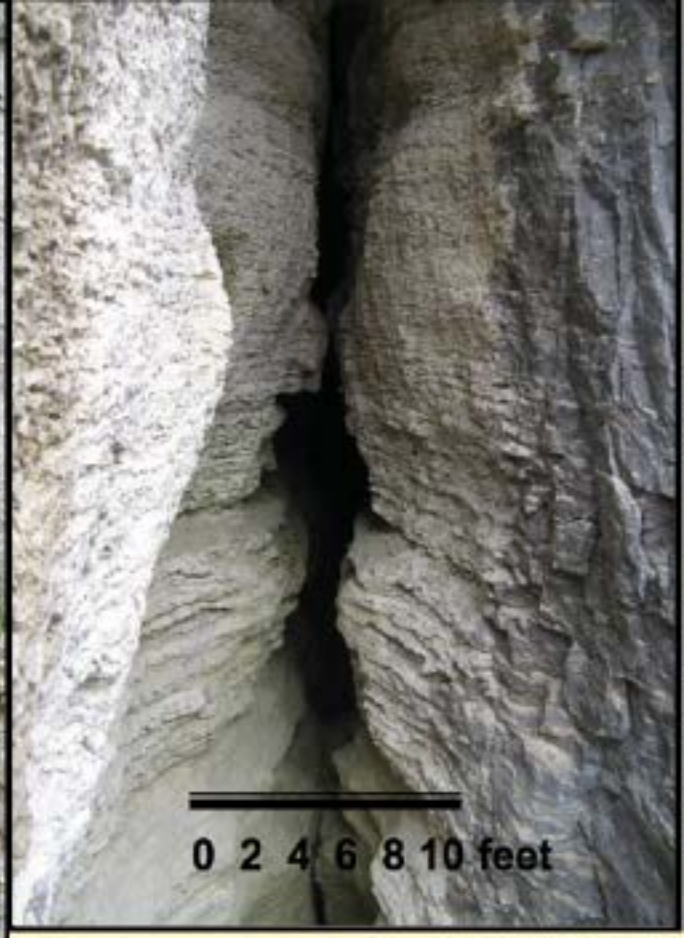
27th Central Pennsylvania Geotechnical Conference, Hershey, Pennsylvania, April 23-25, 2014





Karstic Flow Channels

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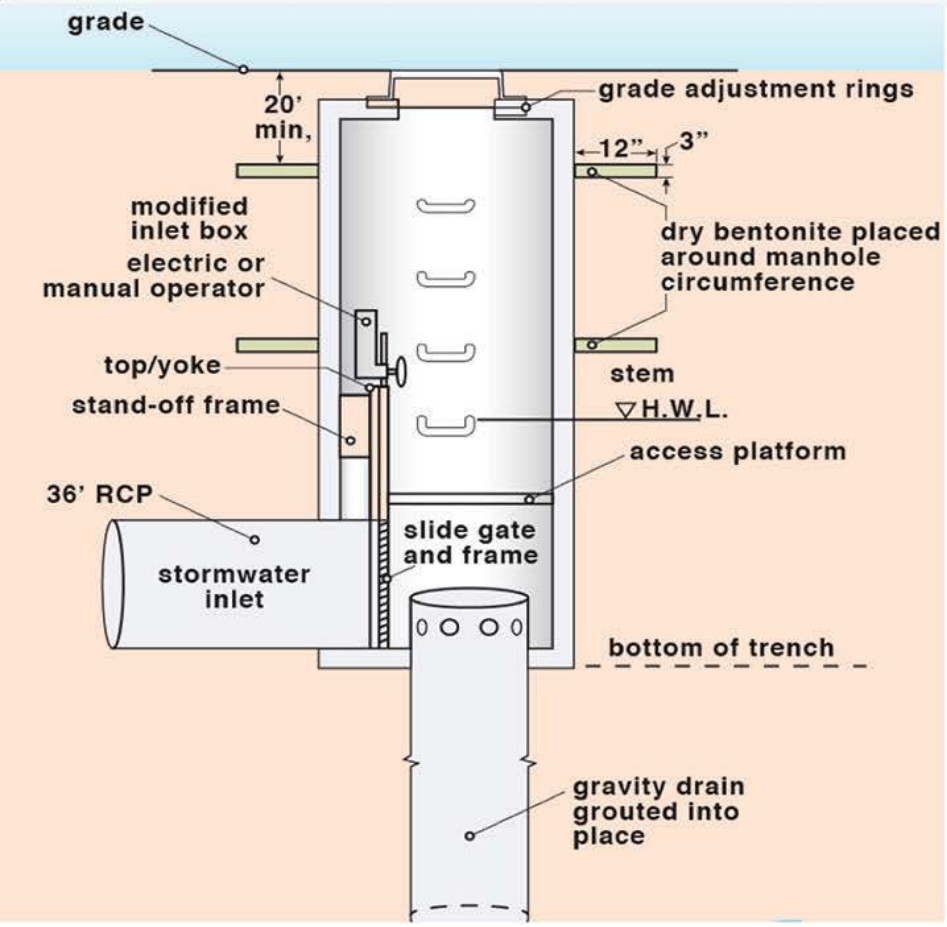
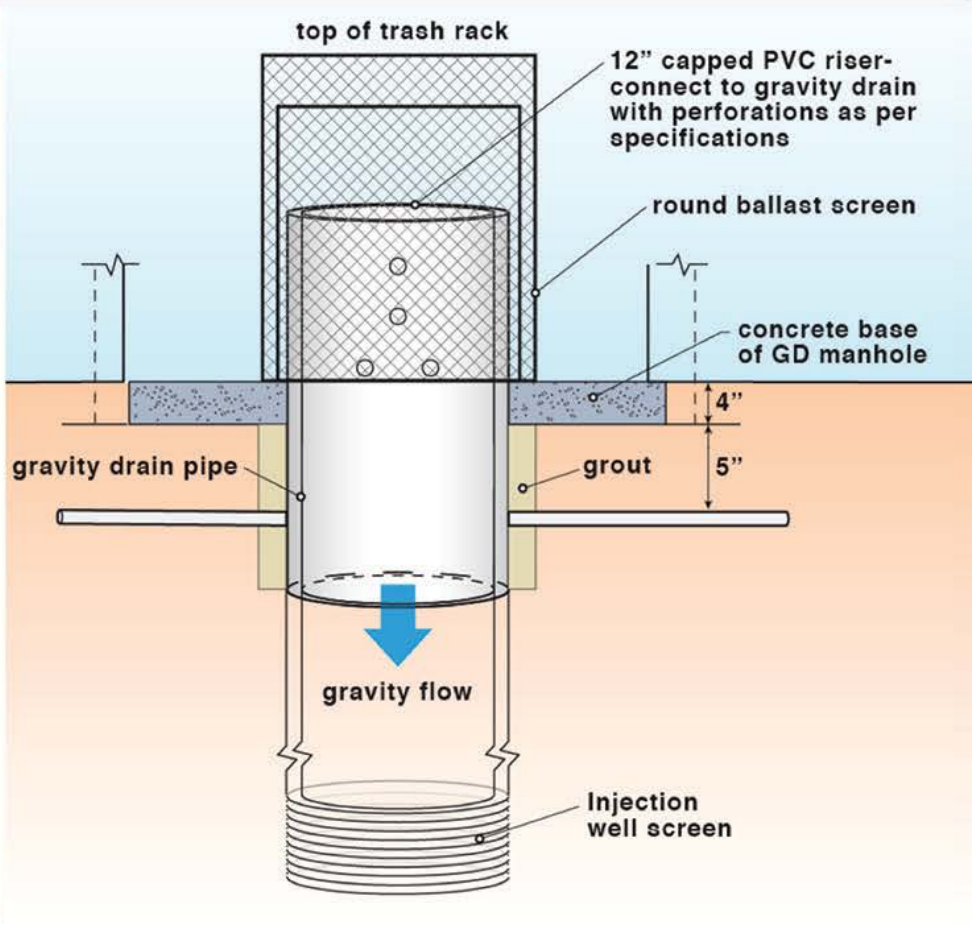
A Roadbed Stabilization Application For Karst Terrain



Injection well manhole design



Gravity drain flow resistor

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Publications and Guidance

2008. Gravity Drainage of Large Stormwater Volumes into Epikarstic Bedrock. *GeoCongress 2008: Geosustainability and Geohazard Mitigation*; ASCE Geotechnical Special Publication No. 178, pp. 1113-1120.

2011. Hydrogeologic Testing, Engineering, and Start-up of a Gravity Drain System. Proceedings of the 2011 Pennsylvania Sustainability and LID Symposium, Philadelphia, Pennsylvania.

2013. Proven Viability of a Multi-Well Gravity Drain System During 3 Years of Stormwater Injection. VUSP Stormwater Management Symposium, Villanova University, Pennsylvania.

2014. Demonstrated and Conceptual Compatibility of Deep Stormwater Injection Well Use with Geotechnical Construction and Land Development Practices in Karst Limestone Terrain. 27th Central Pennsylvania Geotechnical Conference, Hershey, Pennsylvania.

2016. Six Years of Stormwater Injection Well Use in King of Prussia, PA. PSPE Annual Meeting, King of Prussia, PA.

Remote Detection of Deep Conduit Flow by Brine-enhanced Electrical Resistivity Surveying

James Lolcama - KCF Groundwater, Inc.

James Stuby - Earth Resources Technology, Inc.

Presented at Dam Safety 2015
Annual Conference of the Association
Of State Dam Safety Officials

New Orleans, Louisiana September 14, 2015

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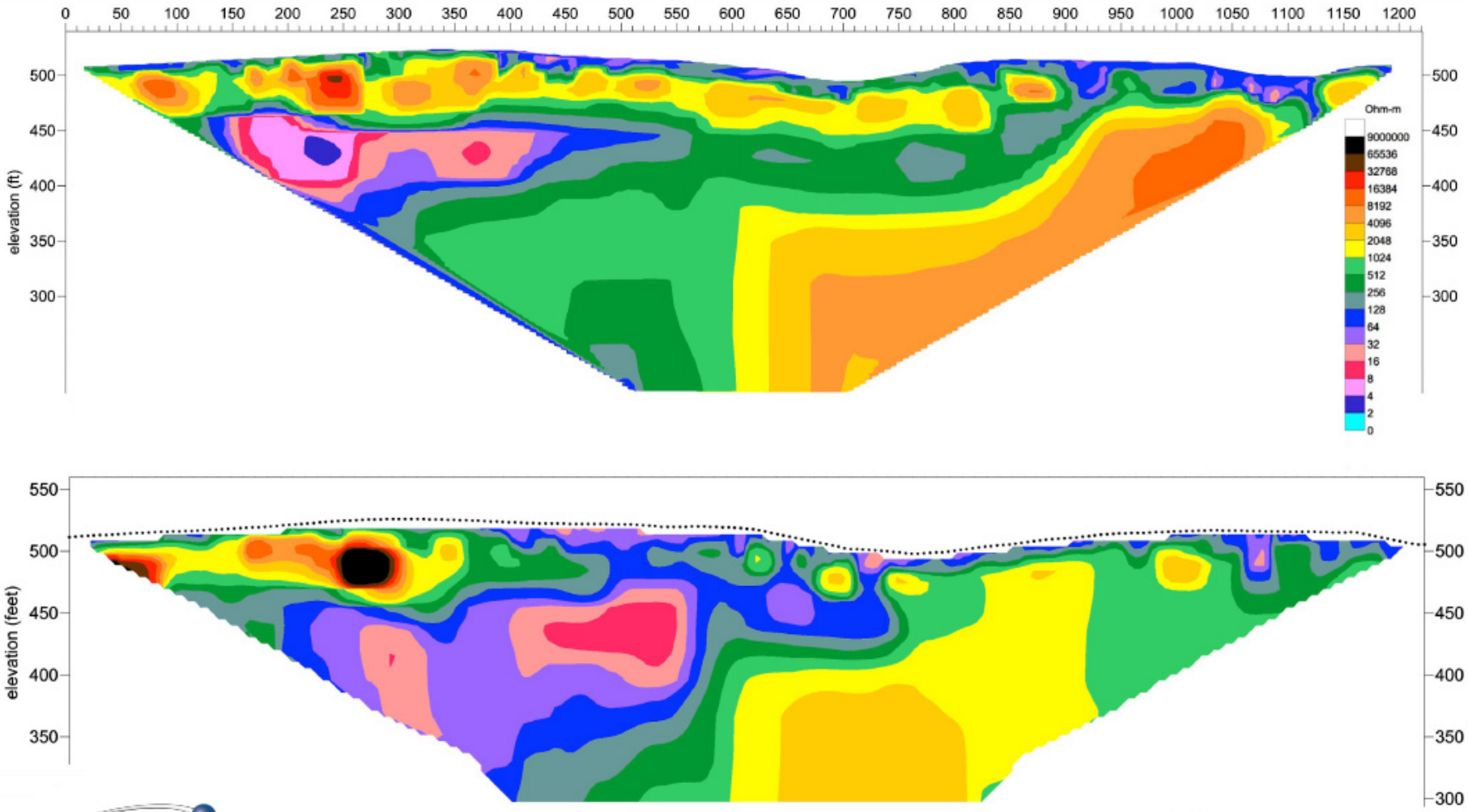
Shortcomings of Off-the-Shelf Geophysical Methods (Continued)



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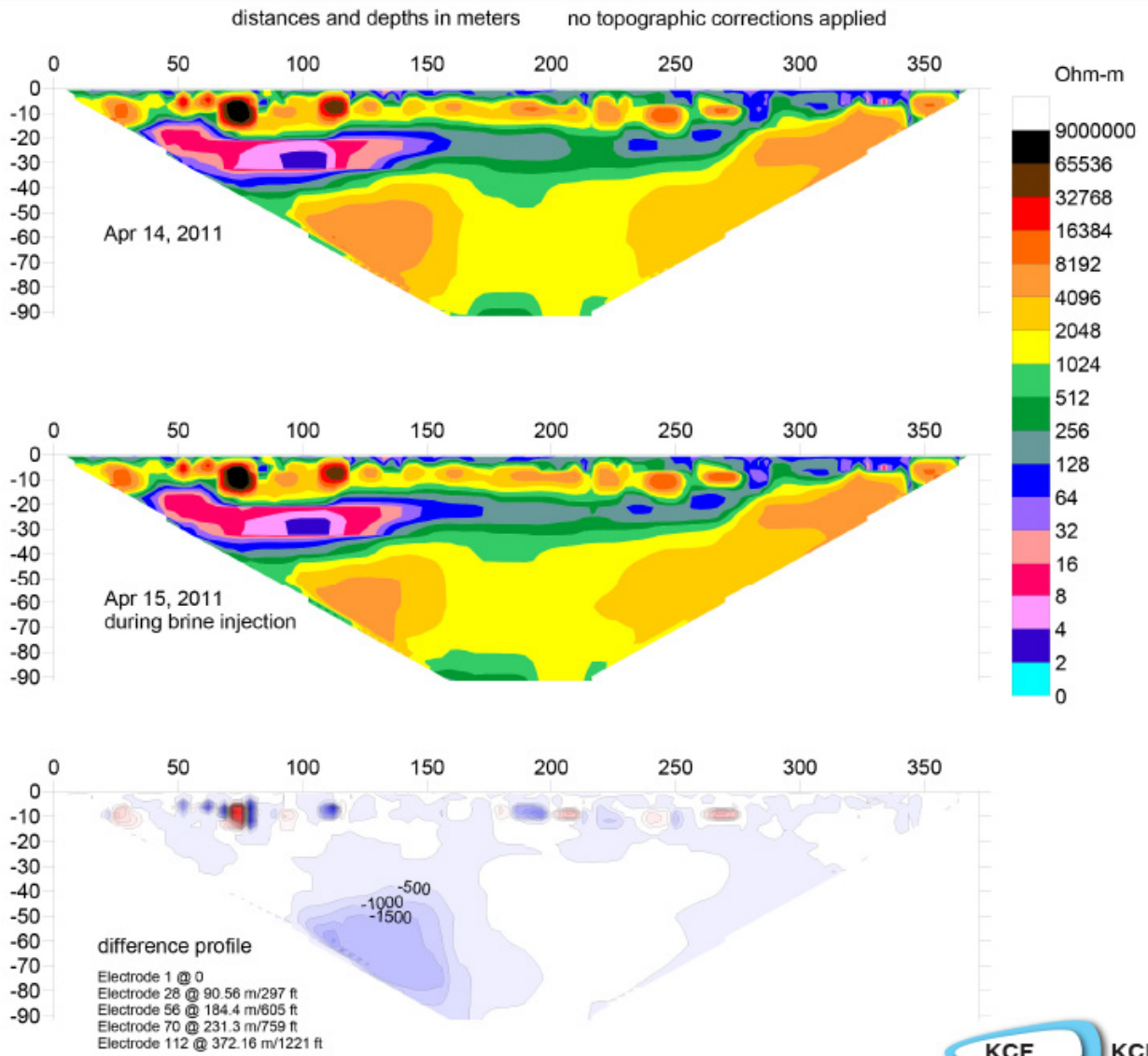
Anomaly in the Non-grouted Bedrock



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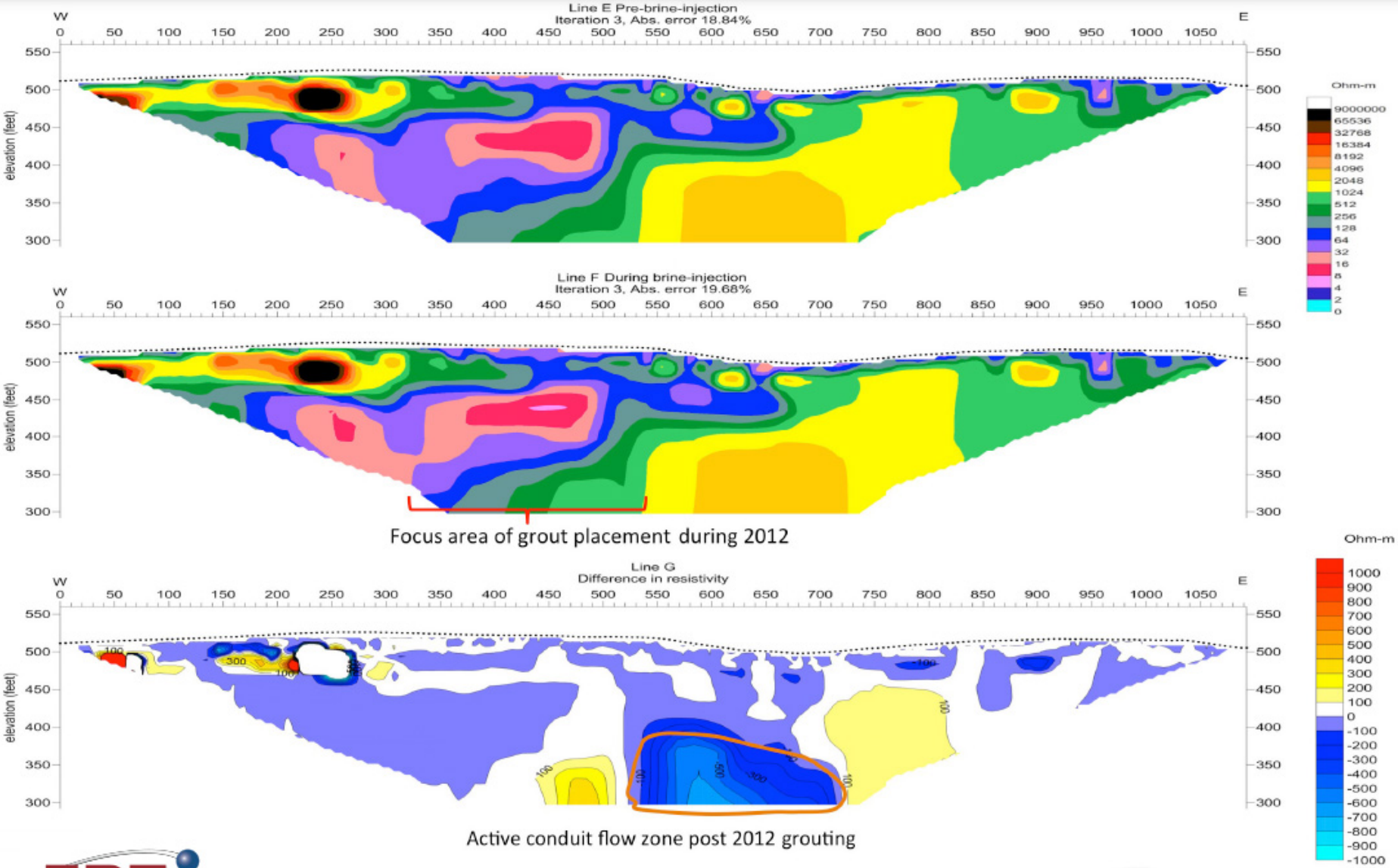
Geophysical Data Analysis



Focus area of grout placement during 2012

Active conduit flow zone post 2012 grouting

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THANK YOU

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Questions?
Thoughts?