Remediating and Managing Karst Sites

12th Annual Groundwater Conference, June 6, 2012

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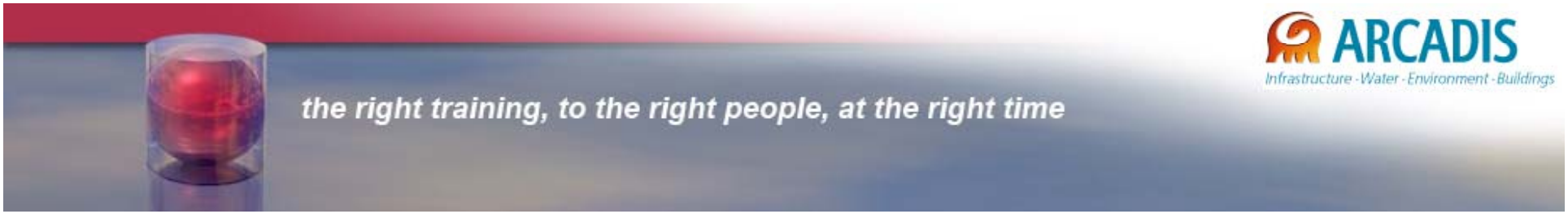


Outline

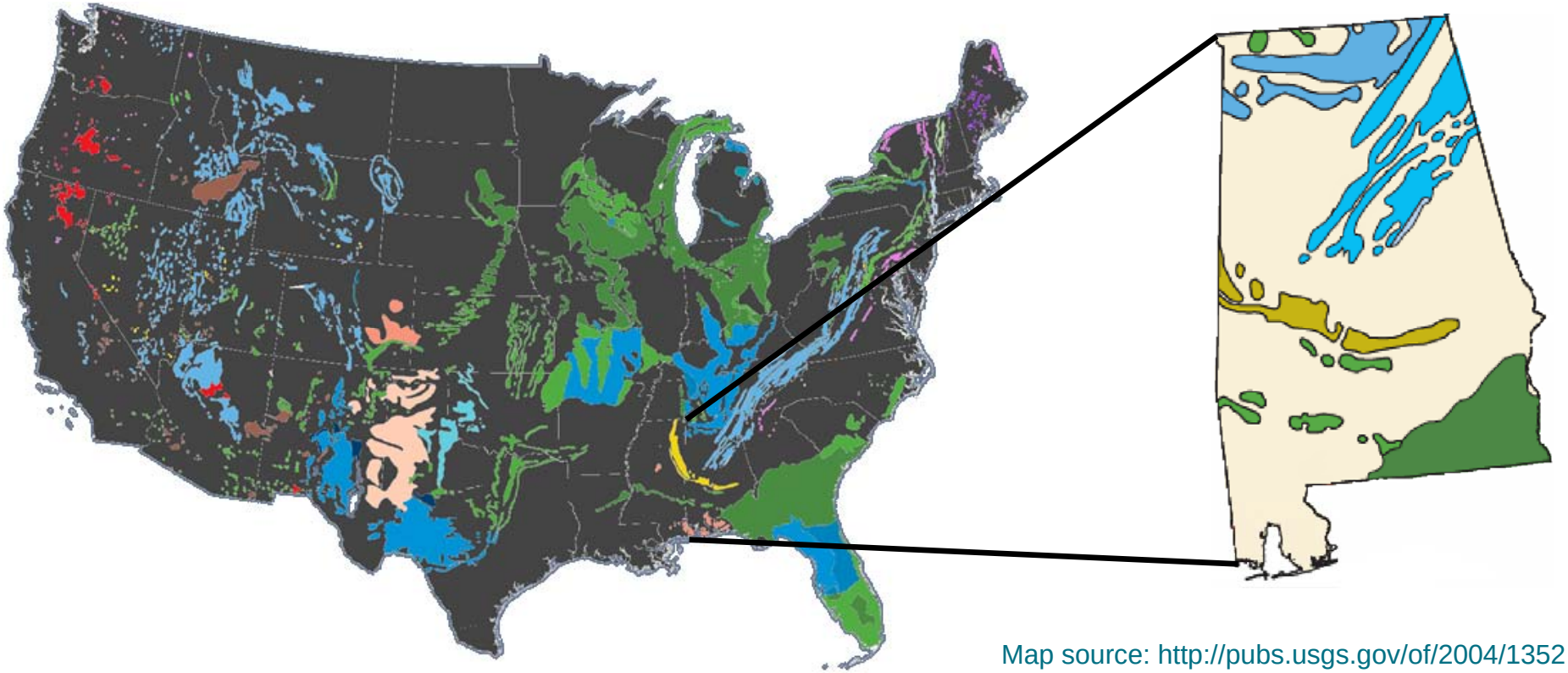
- Karst Hydrogeology 101
- CERCLA Remedies at Karst Sites
- Remedial Techniques and Strategies
- Performance Monitoring

Karst Hydrogeology 101

Why Karst Matters

Karst aquifers store a substantial portion of the world's supply of fresh water

- Karst aquifers are present on all continents and crop out on more than 20% of the earth's land surface
- At least 20% of the world's population is partly or entirely dependent on water derived from karst aquifers

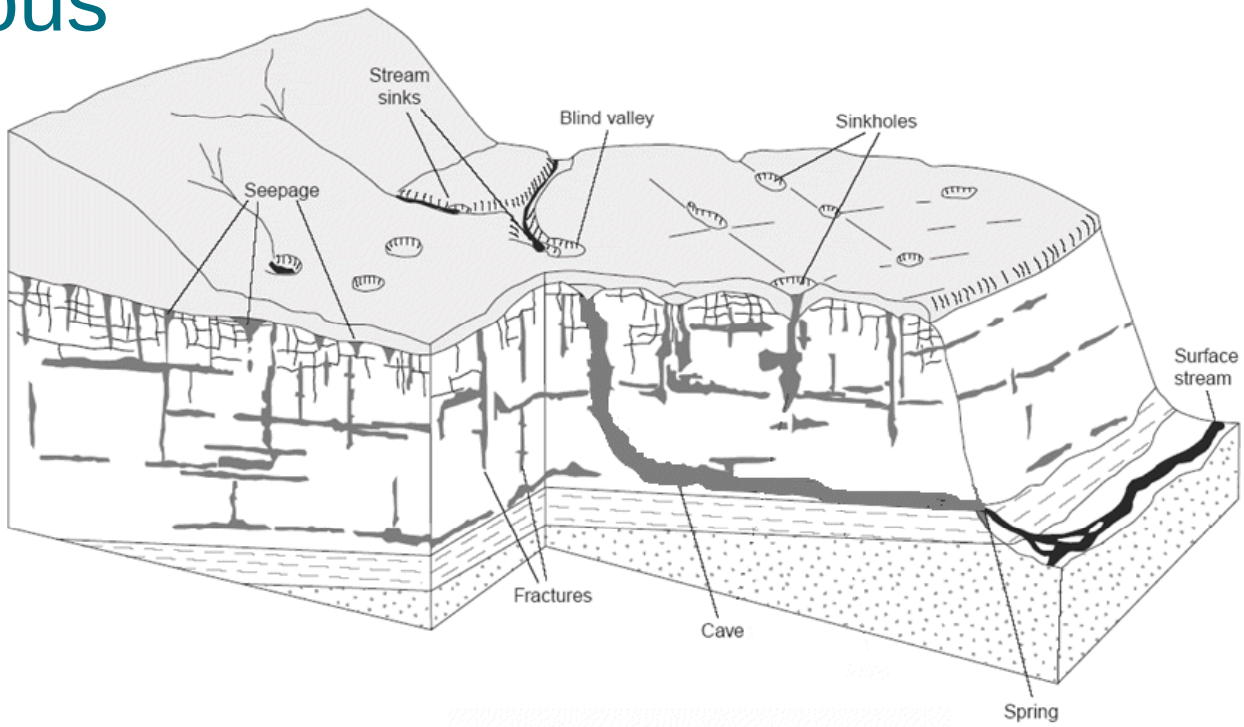


Map source: http://pubs.usgs.gov/of/2004/1352

Permeability Structure of Karst

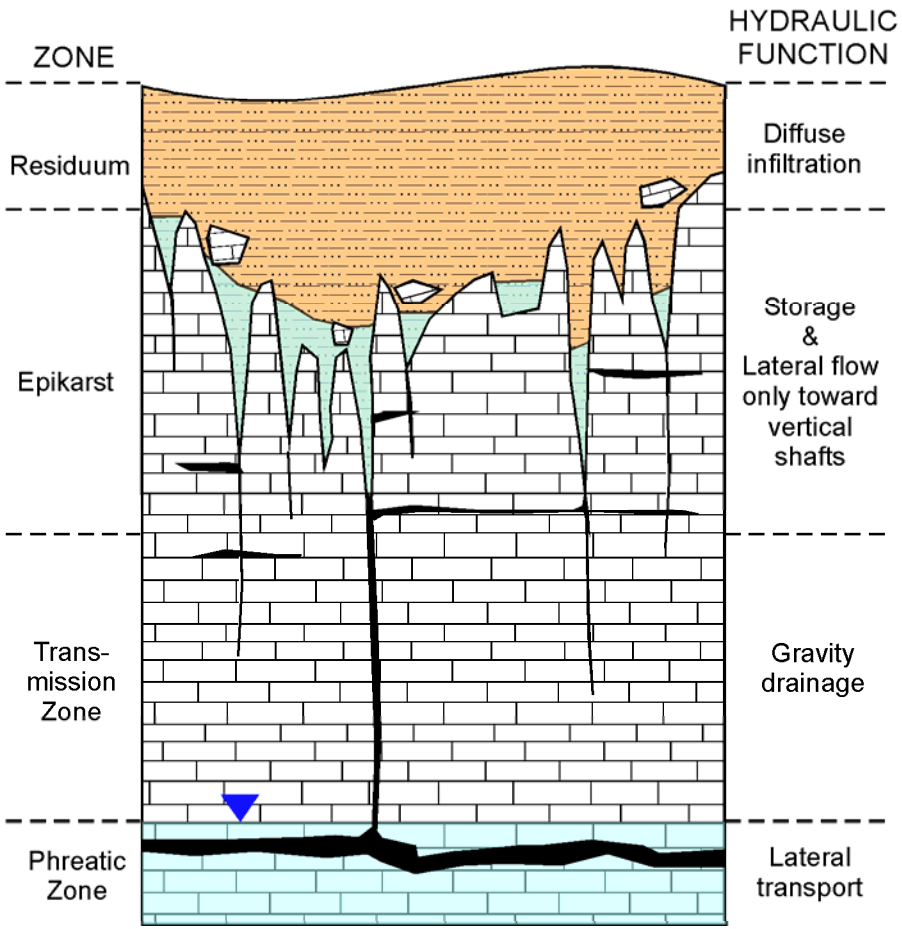
Three important zones:

- Overburden
- Epikarst (a.k.a. “subcutaneous zone”)
- Bedrock



Epikarst

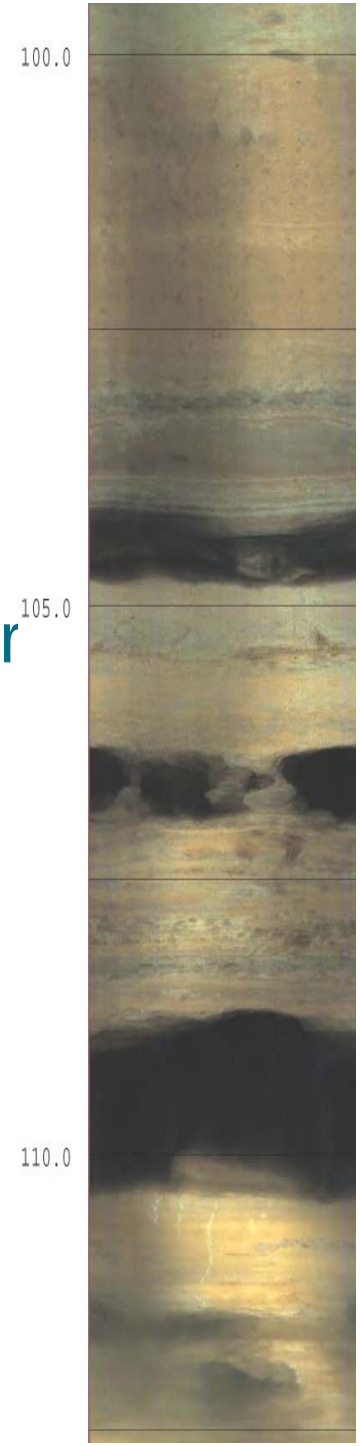
- A zone in the uppermost portion of the bedrock
- Typically a few tens of feet in thickness; but can be in excess of 100 feet
- A veritable “swiss cheese” of voids
- The voids are often sediment filled
- The voids are complexly interconnected to each other
- Connected to the deeper bedrock at discrete points



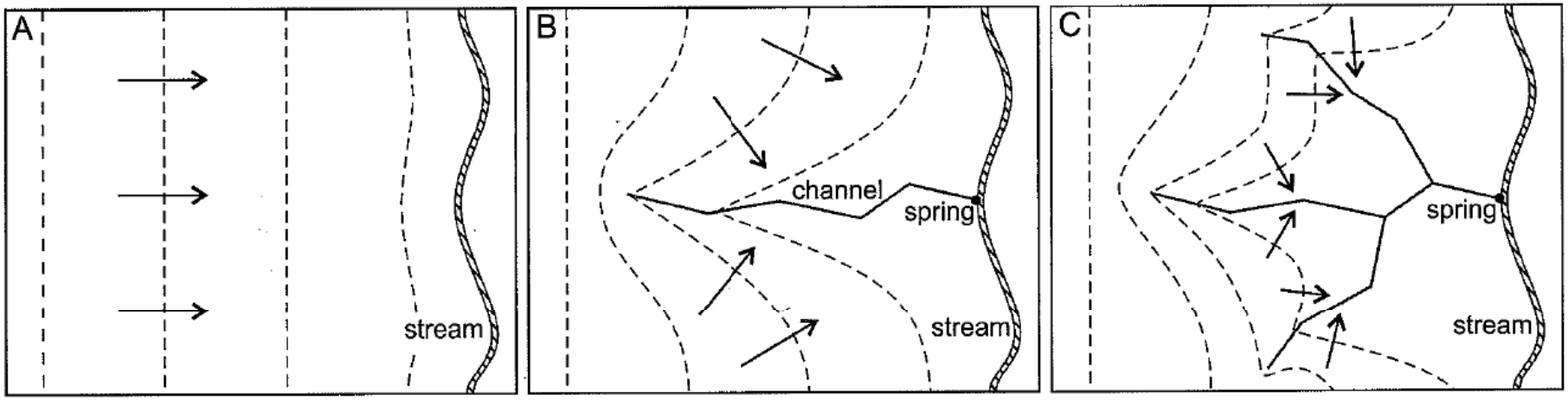
Epikarst

Bedrock

- Often represents a “triple-porosity” medium
- Usually drained by a network of conduits (a.k.a. “channels”)
- Conduits may vary in size from a centimeter or less to tens of meters
- Conduits are capable of turbulent velocities
- Conduits typically contain sediments
- The conduit networks are *convergent*; permeability is “self-organized”



Self-Organized Permeability



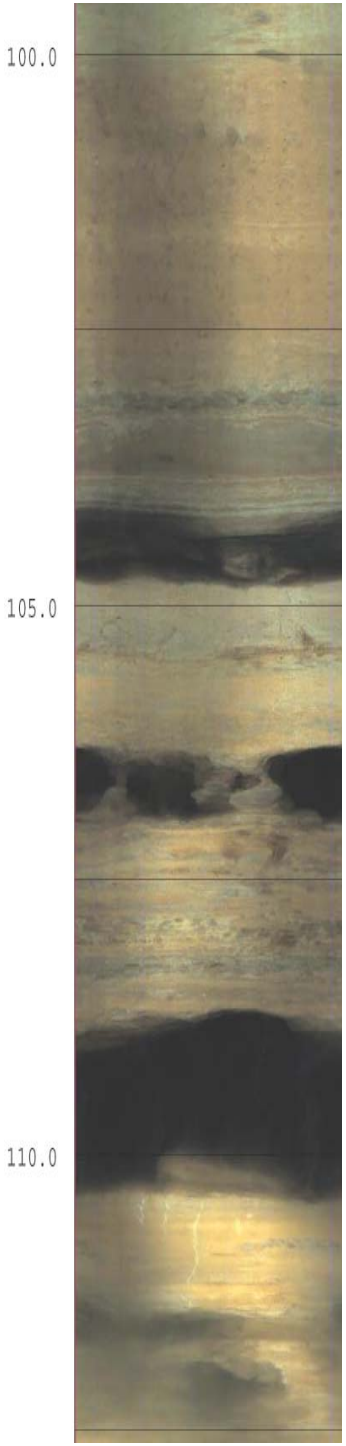
Worthington and Ford (2009)

- A=initial flow field, B=after one conduit achieves breakthrough, C=after tributary conduits achieve breakthrough

Arrows represent flow lines (except in conduits); dashed lines represent equipotentials

Site Characterization Tips

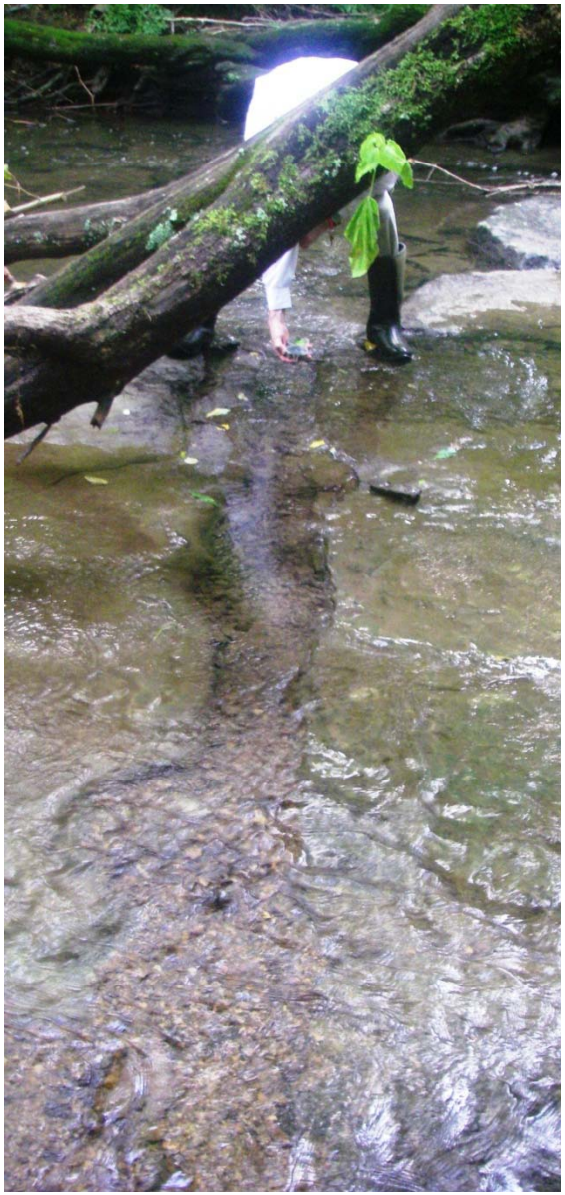
- A karst-specific CSM is critical; project teams must include someone with karst knowledge and experience
- While springs are not relevant at all karst sites, where they are, they should be included in the characterization
- While tracer studies are not required at all karst sites, in many cases tracer studies are needed to supplement information obtained from monitoring wells
- Extents and levels of contamination cannot be determined as precisely as at non-karst sites



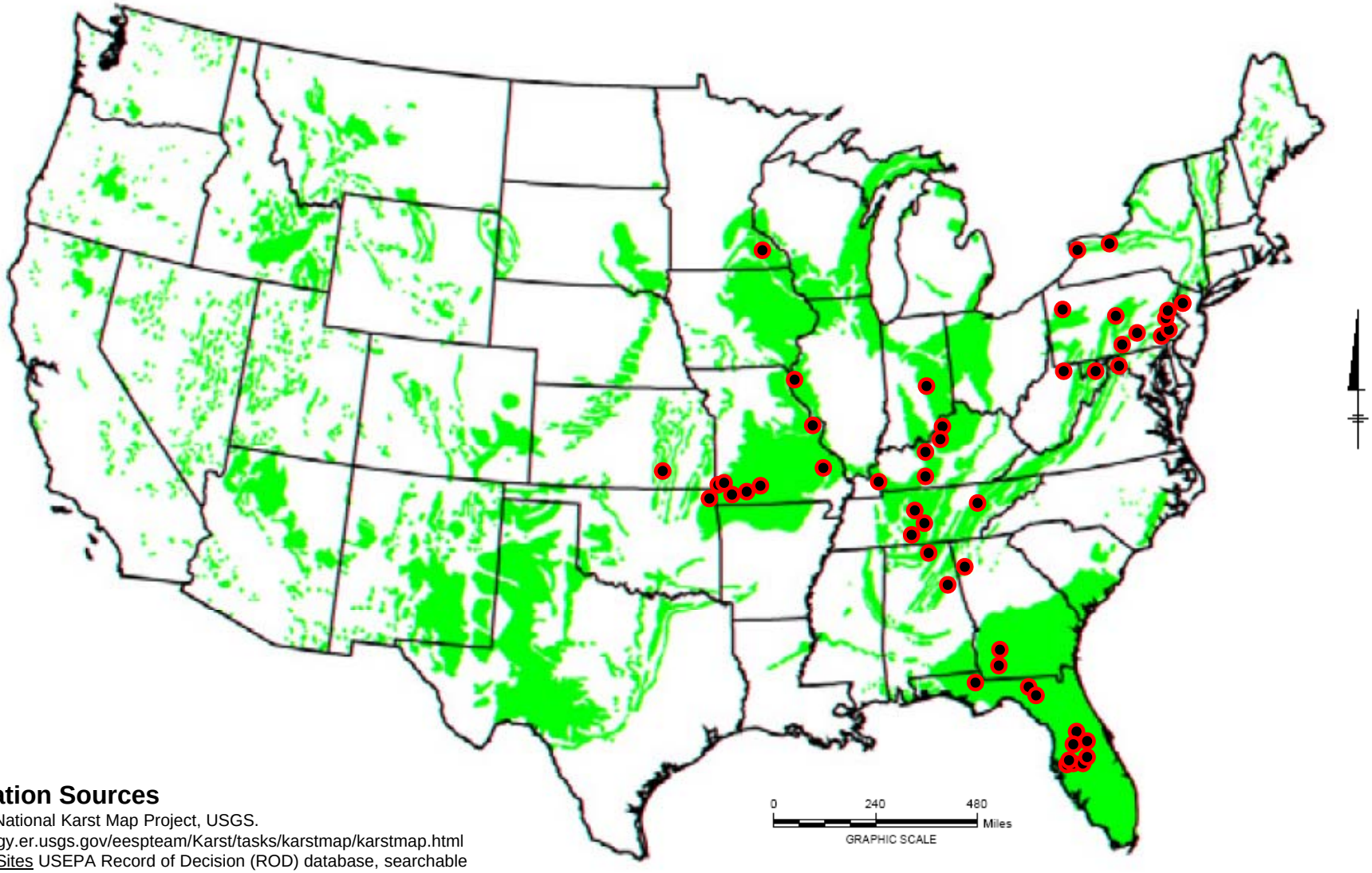
CERCLA Remedies at Karst Sites

Review of RODs for USEPA Karst Sites

- Developing a database summarizing information contained in USEPA RODs for karst sites (work-in-progress)
- Reviewed 161 RODs for 71 karst sites
- Looked at types of remedial elements and associated monitoring required



USEPA Superfund Sites* in Karst Terranes

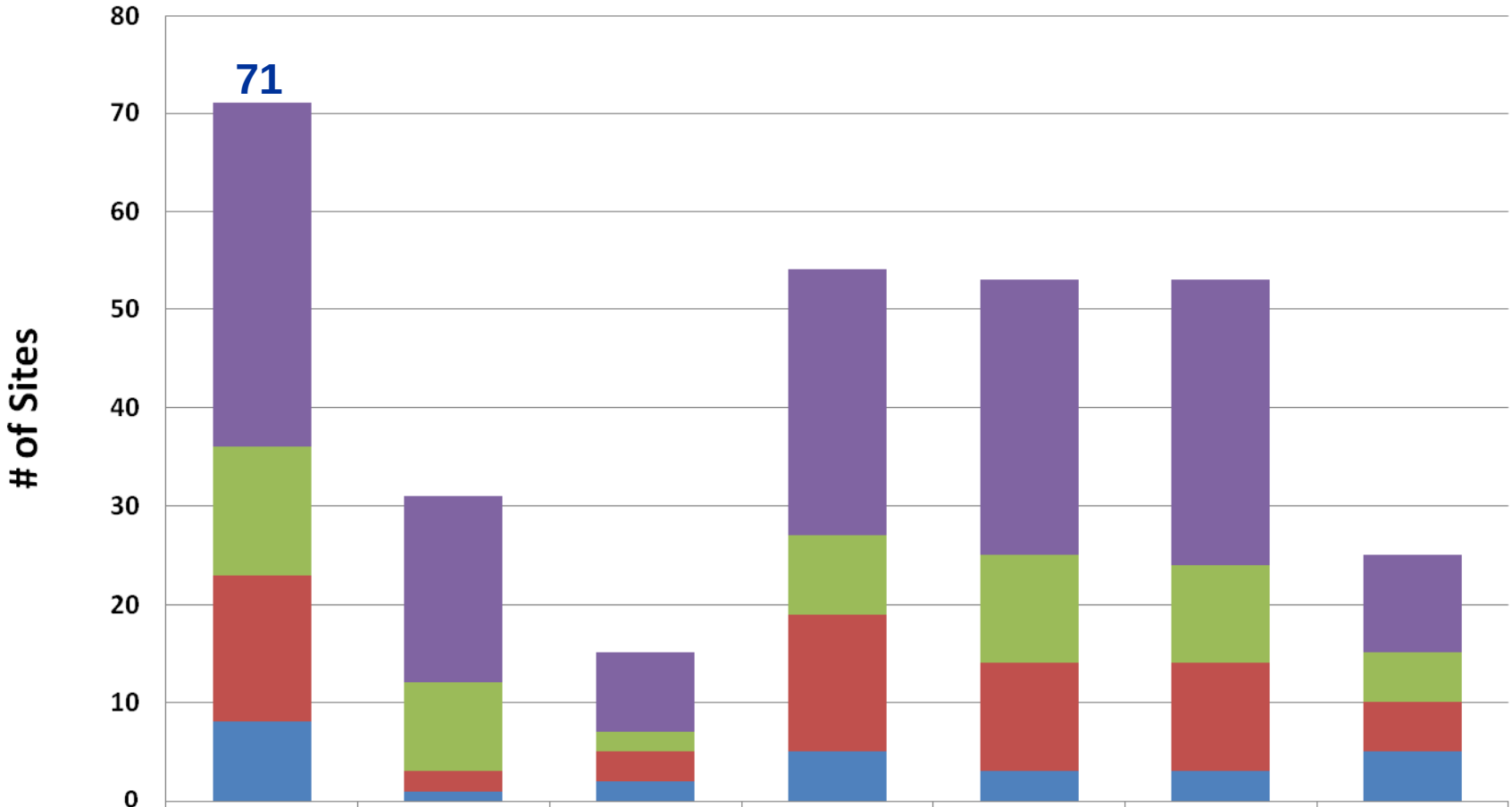


Information Sources

Base Map National Karst Map Project, USGS.
http://geology.er.usgs.gov/eespteam/Karst/tasks/karstmap/karstmap.html
Superfund Sites USEPA Record of Decision (ROD) database, searchable via: http://www.epa.gov/superfund/sites/rods/index.htm

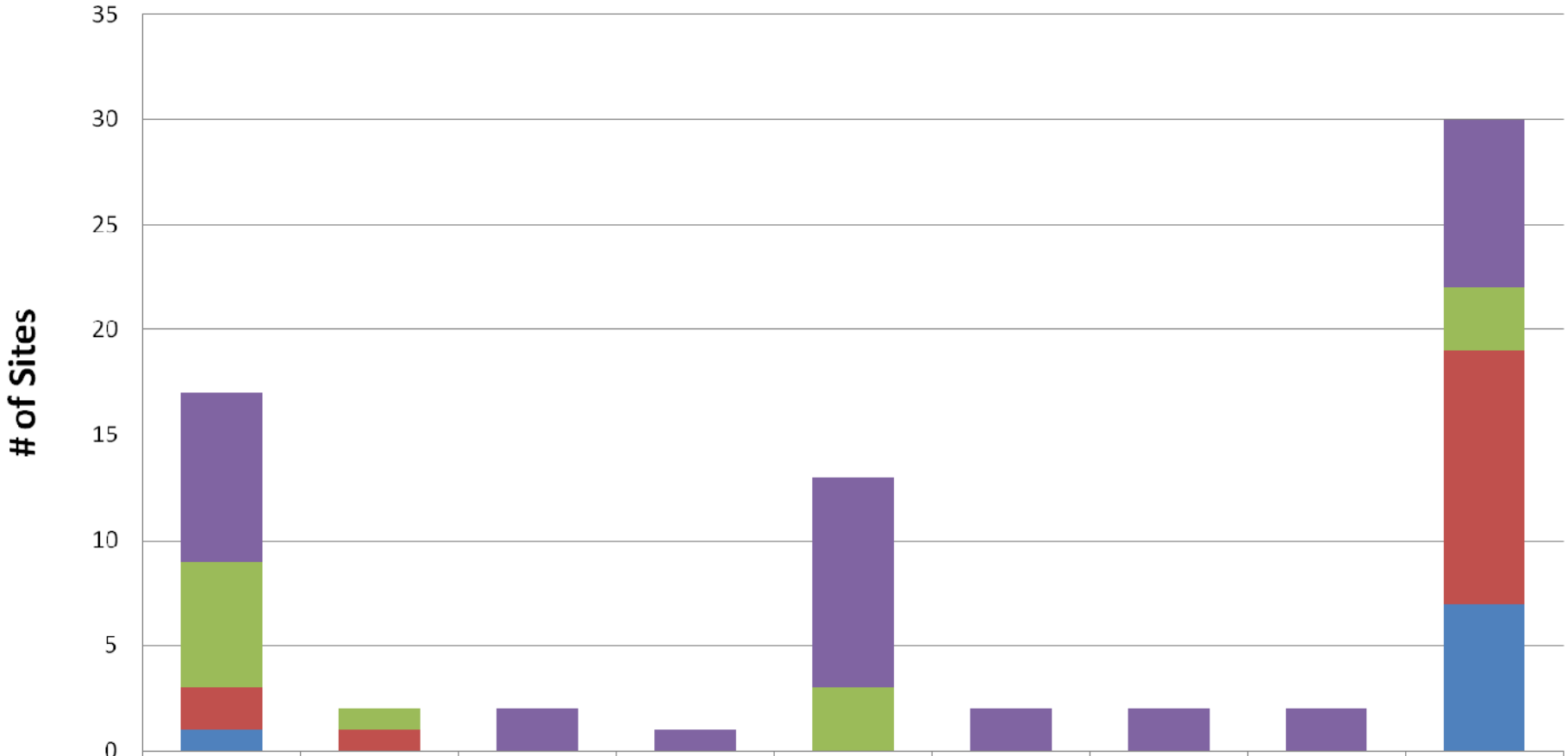
* Sites in the continental U.S. that have reached the ROD stage

Remediation and Monitoring Categories – Karst Superfund Sites



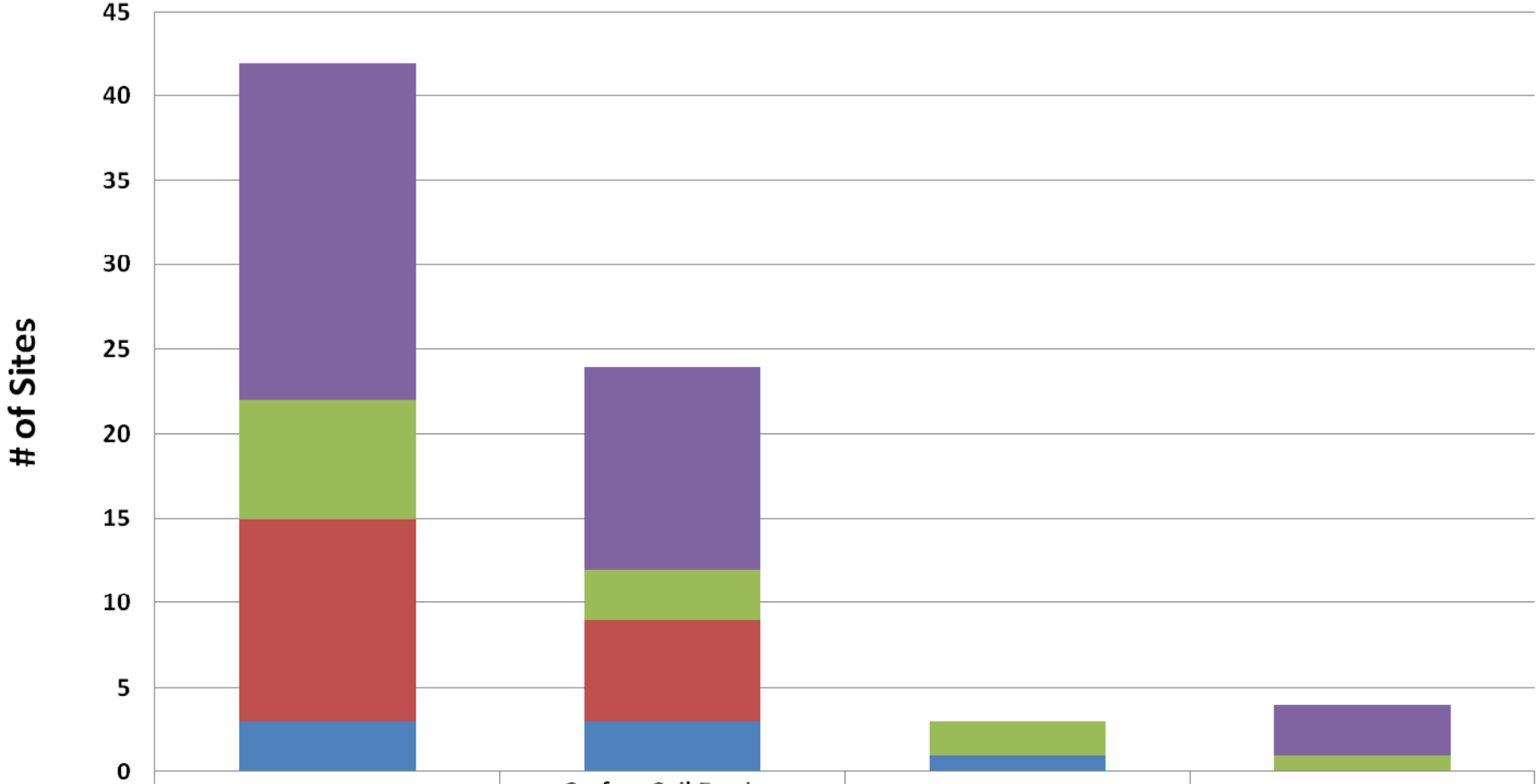
	Number Karst Groundwater Sites	Groundwater Remediation	Surface Water Remediation	Soil Remediation	Monitoring Strategies	Institutional Controls	Other
Southeast	35	19	8	27	28	29	10
Northeast	13	9	2	8	11	10	5
Midwest	15	2	3	14	11	11	5
Caribbean	8	1	2	5	3	3	5

Active Groundwater Remediation Strategies Used at Karst Superfund Sites



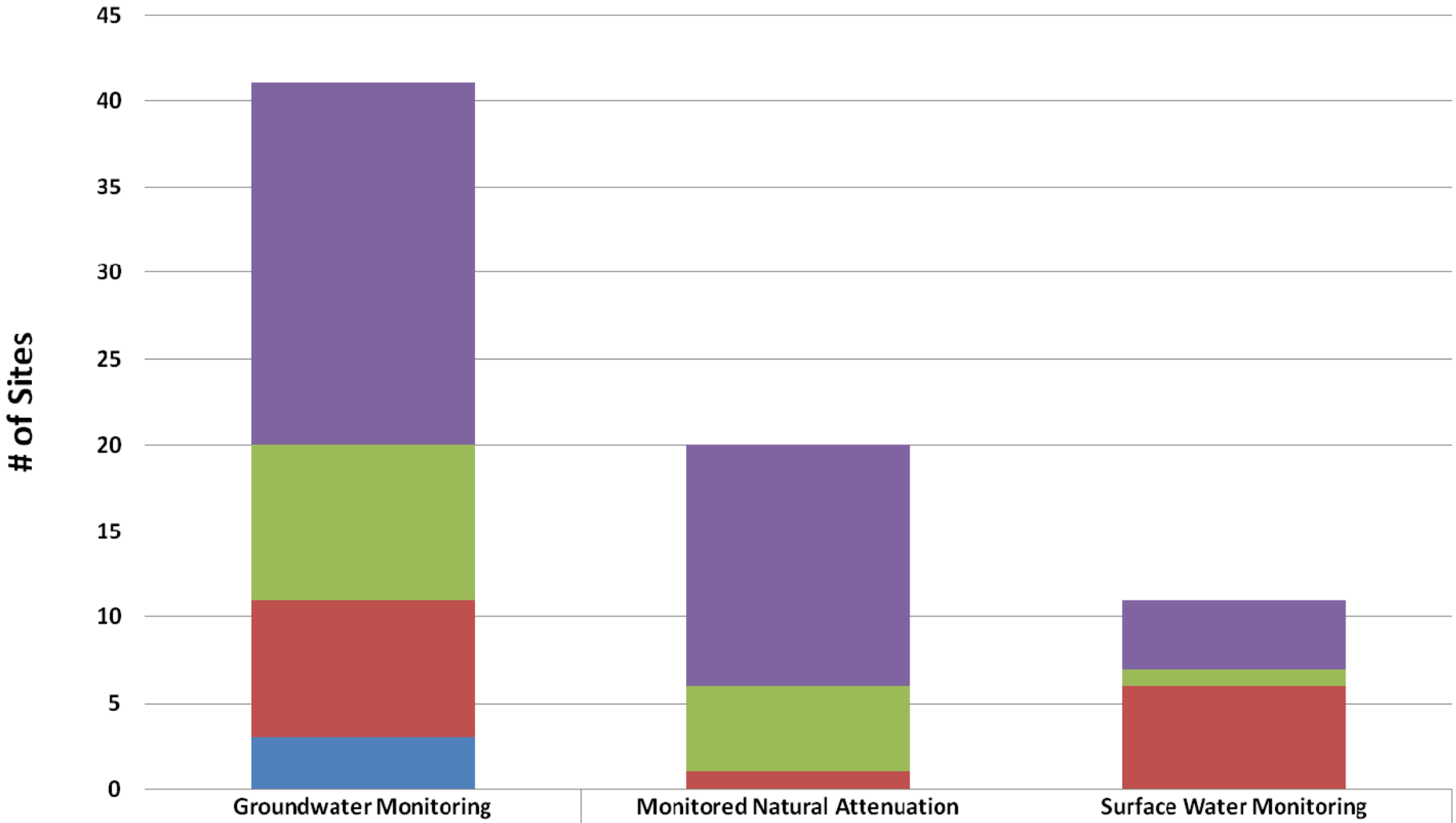
	Groundwater Extraction and Treatment	Hydraulic Containment	Vertical Barrier Wall/GW Diversion Trench	Compression/ Jet Grouting to Seal Karst Features	In Situ Groundwater Treatment	Permeable Reactive Barrier	Evapotrans./ Phyto	NAPL Collection/ Removal	No Active Groundwater Remediation
Southeast	8	0	2	1	10	2	2	2	8
Northeast	6	1	0	0	3	0	0	0	3
Midwest	2	1	0	0	0	0	0	0	12
Caribbean	1	0	0	0	0	0	0	0	7

Soil/Sediment Remediation Strategies Used at Karst Superfund Sites



	Removal of Soils/Sediments/Debris	Surface Soil Erosion Controls/Infiltration Controls/Soil Capping	SVE/Enhanced SVE	In Situ Treatment/ Stabilization
Southeast	20	12	0	3
Northeast	7	3	2	1
Midwest	12	6	0	0
Caribbean	3	3	1	0

Types of Monitoring Performed at Karst Superfund Sites



	Groundwater Monitoring	Monitored Natural Attenuation	Surface Water Monitoring
Southeast	21	14	4
Northeast	9	5	1
Midwest	8	1	6
Caribbean	3	0	0

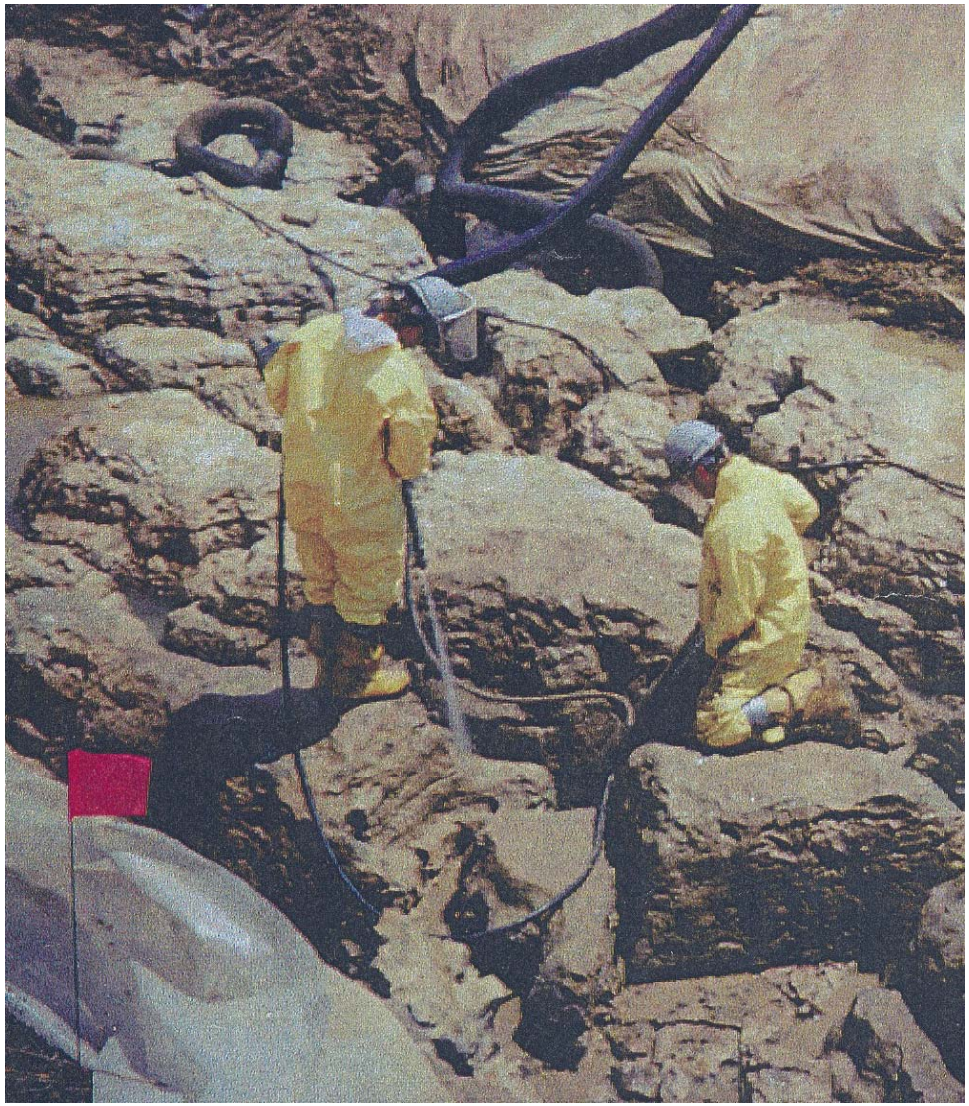
Remedial Techniques and Strategies

Overall Strategy

- Address source areas to the extent practicable
- “Treating at the tap” can be more relevant than at non-karst sites
- Recognize limits of current remedial techniques
- Focus on risk reduction
- Conduct karst-appropriate performance monitoring of groundwater

1. Address Source Zones

- Excavation/capping
- In-situ mass destruction
- Mass reduction via removal
- Physical, chemical, or hydraulic containment



1. Address Source Zones

- <u>Mass removal via excavation or mass-flux reduction via capping</u>
  - most-commonly performed (93% of USEPA karst RODs)
  - Caveat:
    - Much of the mass may reside in the epikarst or underlying bedrock and be inaccessible to excavation or may render the benefits of capping negligible

1. Address Source Zones

- <u>In-situ mass destruction (e.g., chemical oxidation, thermal treatment)</u>
  - Not aware of proven success stories in epikarst and bedrock
  - Difficulties include:
    - Locating complexly-distributed sources and getting reagents in contact with them
    - Controlling injected fluids; can potentially move fast and far
    - Rapid flux of groundwater in conduits could preclude sufficient heating and control of adverse migration

1. Address Source Zones

3. <u>Mass reduction via removal</u>
   - Commonly employed at sites with pooled NAPL
     - Typically use the same suite of technologies employed at non-karst sites
     - Volumes of pooled NAPL may be large due to the high porosity of the epikarst
     - Accumulation may be more episodic than continual

1. Address Source Zones

- <u>Mass reduction via removal (continued)</u>
  - "EVE" (Epikarst Vapor Extraction)
    - Air-filled, interconnected nature of many epikarsts lends itself to this technology
    - Limited to volatile compounds
    - Used successfully to mitigate gasoline vapors in the basements of residential homes

1. Address Source Zones

4. Physical and chemical containment (e.g. barrier walls, permeable-reactive barriers)
   - Often technically or cost prohibitive (only 6% of USEPA karst RODs)
   - Main obstacles include:
     - Excessive grout loss during pressure grouting
     - Costs to excavate rock to the base of impacts and collect/treat water generated often cost-prohibitive
     - For PRBs, quantifying and addressing sedimentation can be a significant issue

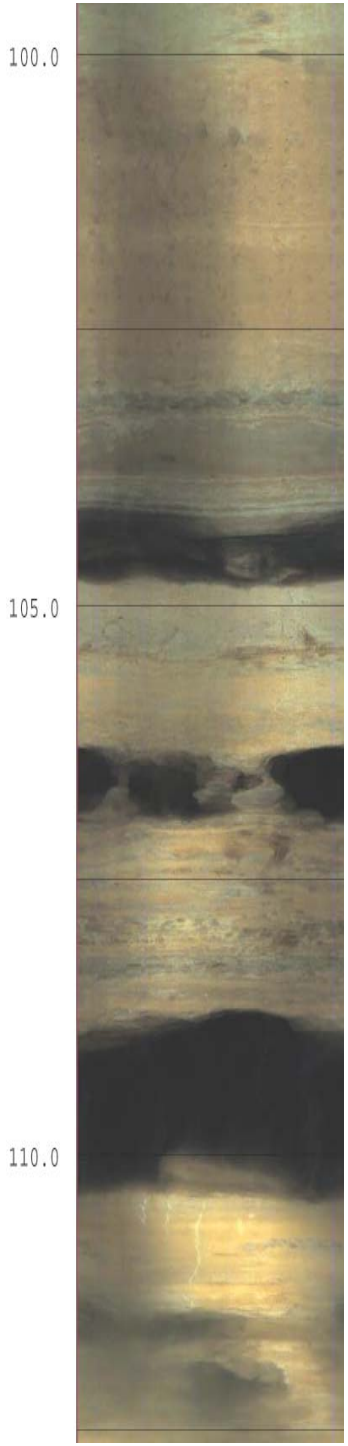
1. Address Source Zones

4. <u>Hydraulic containment</u>
   - Pump & treat/hydraulic containment (26% of USEPA karst RODs)
     - System design is challenging; cannot rely on standard (Darcian) methods and models
     - Low-likelihood of pumping wells intercepting important elements of the permeability structure (e.g., conduits)

2. Manage Impacted Groundwater

Enhanced bioremediation

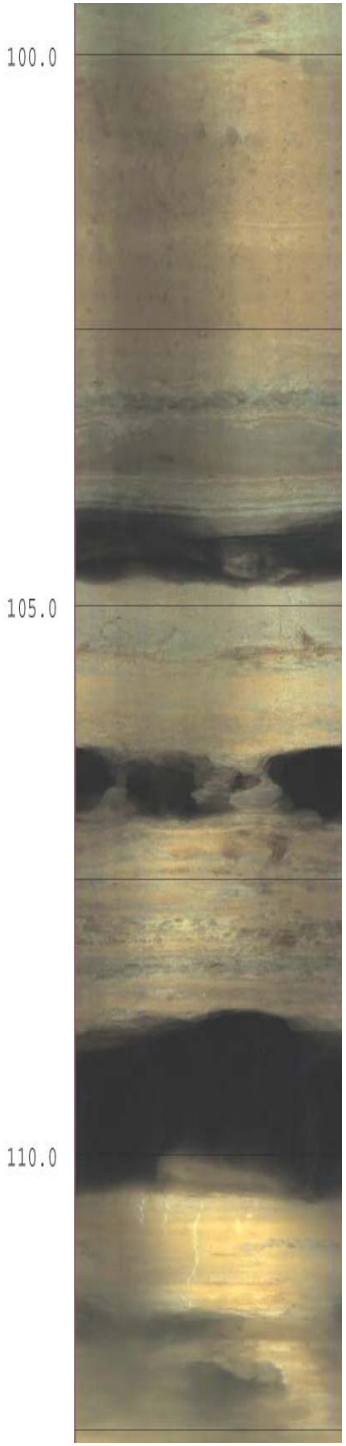
- May be viable; though more research is needed
- Has been attempted; but peer-reviewed performance evaluations are lacking
- Delivery of nutrients to where they are needed is a key challenge



2. Manage Impacted Groundwater

Monitored Natural Attenuation

- Regulators and consultants seem to like it
  - Included as a remedial component in 27% of USEPA karst RODs
- May be viable; though more research is needed in our opinion
- Clearly, an appropriate monitoring approach and high-quality monitoring data are critical to evaluate effectiveness



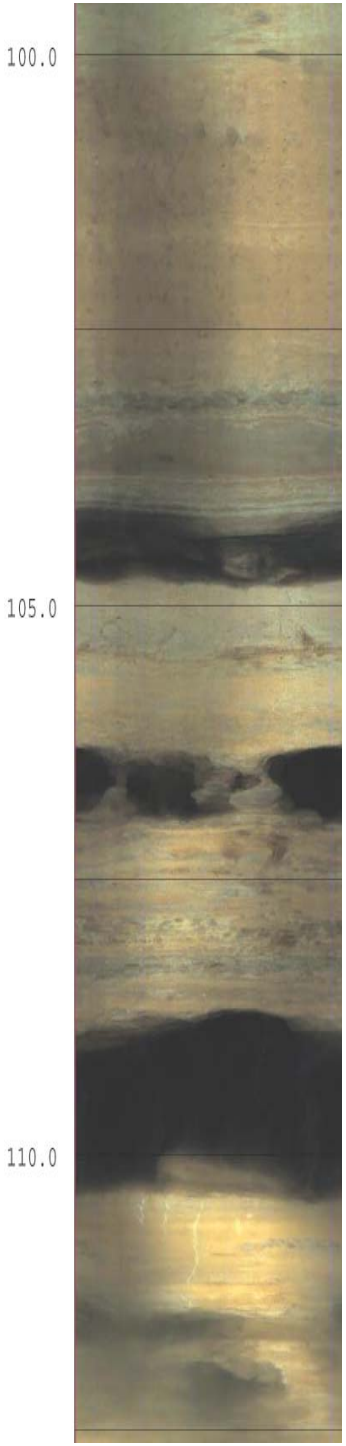
3. Eliminate Exposure Pathways

"Treating at the Tap" – Perhaps the most useful active remedial component in karst

1. <u>Treating or Replacing Potable Water Supplies</u>
   - Commonly employed in karst (and non-karst) sites
   - Long-term O&M costs

3. Eliminate Exposure Pathways

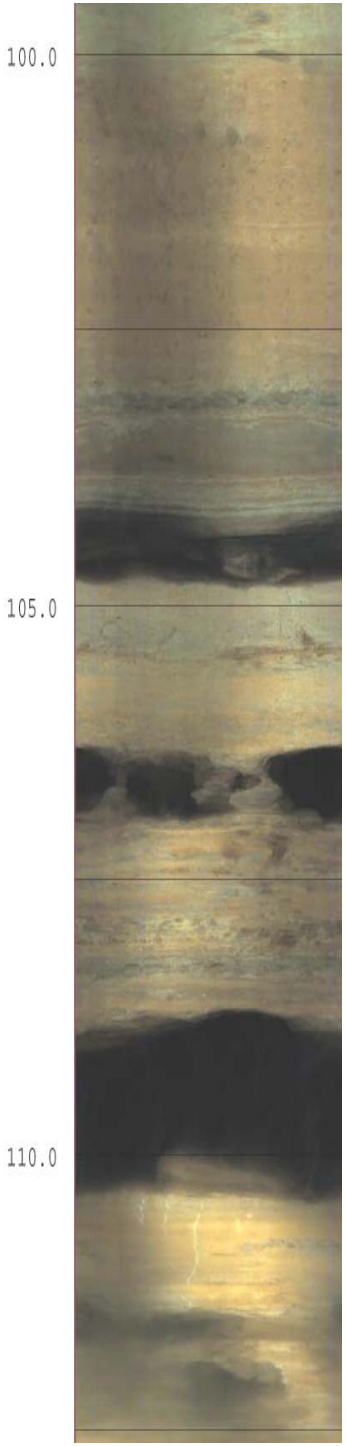
2. <u>Treating Spring Water</u>
   - Capturing and treating spring flow
     - Has been successfully performed using caissons and other means to isolate and collect flow for treatment
     - Is underutilized – selected as a remedial component at only 3 of 71 CERCLA karst sites
     - Spring biota will likely be affected



4. Impose Institutional Controls

Common component of many remedies (64% of USEPA karst RODs)

- Given the complexity of karst aquifers and difficulties with pinpointing the exact limits of impacts, ICs are arguably more important in terms of mitigating exposure risk at karst sites than at other sites

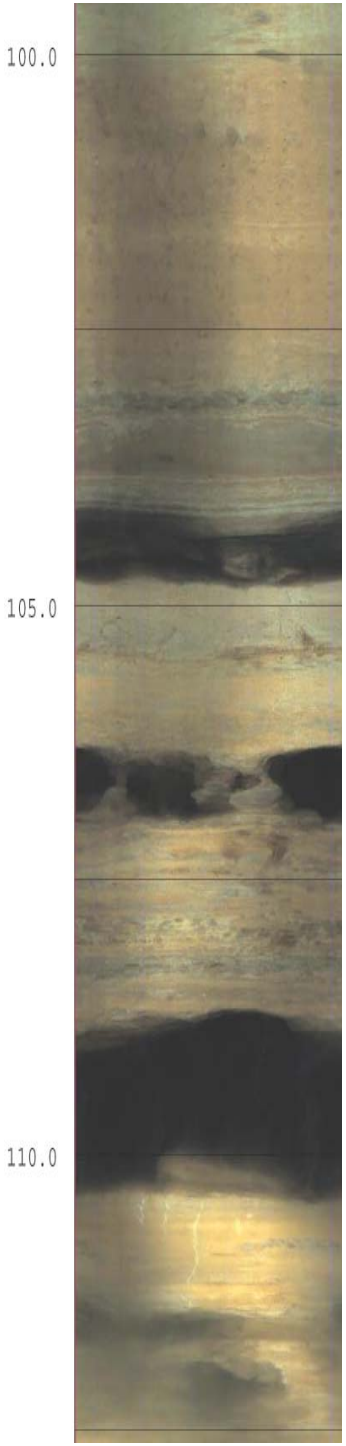


Performance Monitoring

Performance Monitoring

Remedial components that are designed to affect groundwater movement or quality often require karst-specific methods

- For *groundwater movement*, tracer tests should be included to assess performance
  - Tracer monitoring should focus on springs, streams, extraction systems (if any), and monitoring wells previously shown by tracing to be relevant



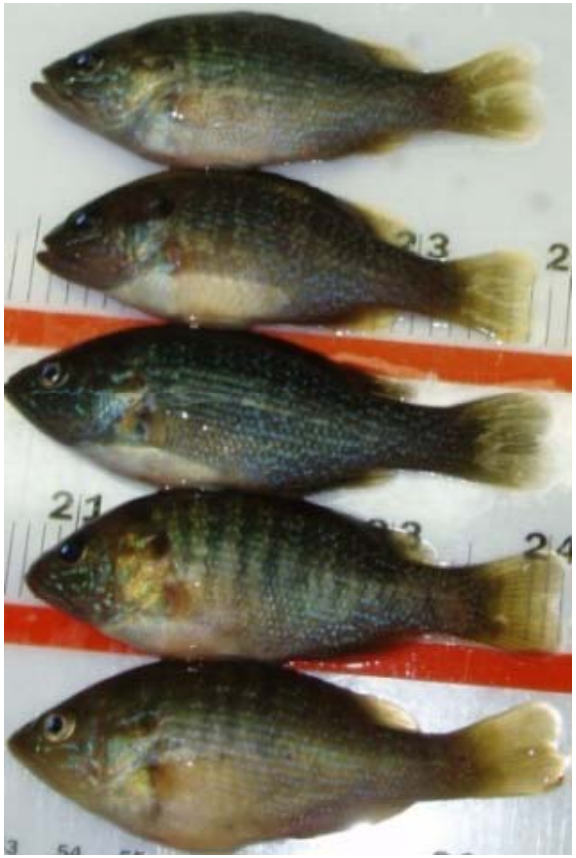
Performance Monitoring

For *groundwater quality monitoring:*

- Often the best places to monitor are springs, streams and, in some cases, extraction systems
- Water-quality sampling often needs to be “event-based”

Performance Monitoring

- Consider including evaluation of biota
- In some cases may be a better means of assessing the quality of emerging groundwater than analysis of periodic water samples
  - The science is well-developed for surface water; however, springs/cave streams have lower biodiversity. More research may be needed on using these biota for assessing water quality



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Imagine the result