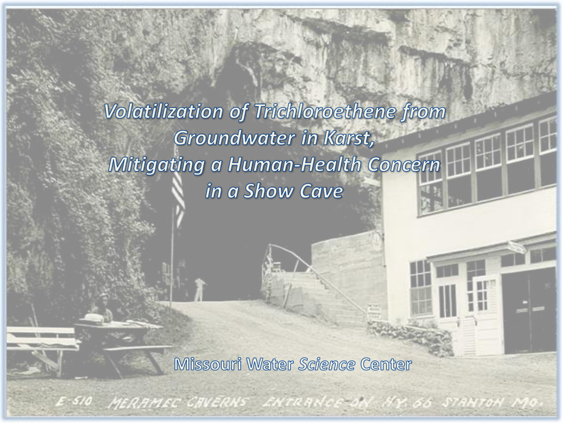
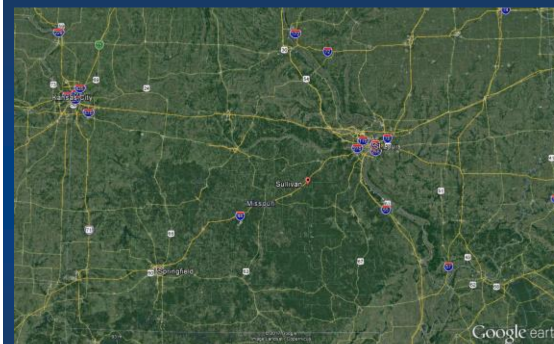




USGS science for a changing world

TCE - widely in use for nearly 100 years

- 1860s- first prepared in Germany
- 1920-30s- initial degreasing use in USA
- 1940-60s- Widespread use in industry (metal cleaning, electronics, dry cleaning de-caffeinated coffee, anesthetic)
- 1970s- health concerns emerge, use decreases
- 1972, Woburn, Mass. drinking water wells closed. 1982 Superfund, "A civil Action"
- 1-11-2017 EPA proposed ban for use as commercial vapor degreaser


When I had my baby
I gave myself the
ANESTHETIC
A mother's own story of what happened when she took a new drug to ease her labor pains
BY JOAN L. MILES

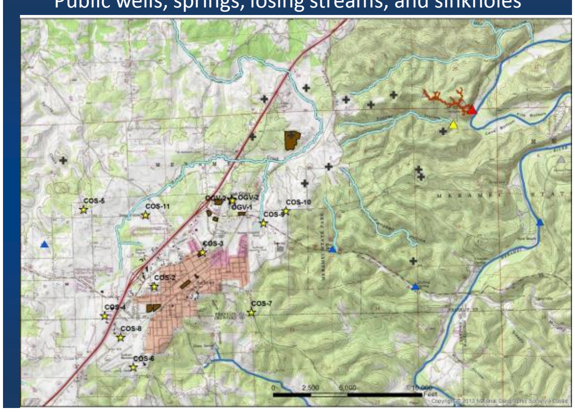
Oak Grove Village Site History

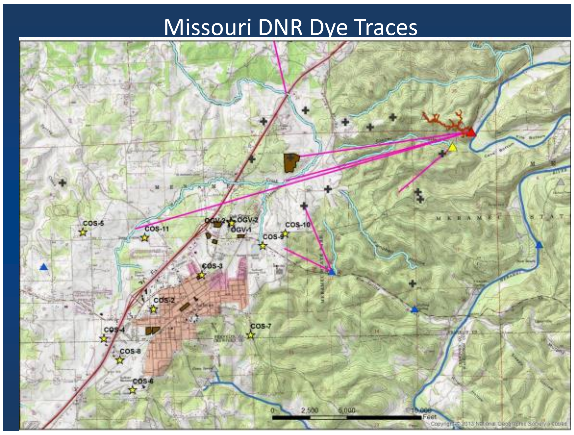
- 1986 TCE detected at 6 ug/L (MCL=5) in Oak Grove Village well
  - Follow-up sampling confirmed detections
  - Late 1980s also found in several Sullivan wells below MCL
- Two known sources of TCE to GW identified:
  - Ramsey Plant
  - City landfill
- 1946 Ramsey Corporation started in City auditorium
  - 1950-83, Main plant operated piston rings, etc.
  - **EPA compliance report 8,300 kg spent TCE waste/year**
    - (~1,500 gal/yr * 33 years = 49,500 gallons ~900 drums or ~27-30/year)
  - 1985 Several sludge lagoons closed (8,400 tons sludge/soil removed)
  - 1992 RCRA Facility Assessment 1993 Consent Order with EPA RFI
    - 5 waste units (sludge lagoon, drum storage, Cr plating area, burn areas)
- 1970 City Landfill opened

Sullivan City Landfill

- 1970-83 Municipal landfill
- 1970-74 ravine fill in south landfill
- 1974 permitted by MDNR
- 1980s small drum "cell" constructed for ~ 200 drums industrial waste
- 1990-91 USGS sampling seeps, nearby wells, springs
- 1991 MDNR Dye tracing from sinkhole (Meramec caverns)
- 1992 Initial monitoring wells installed, drums removed from cell
- 1994-95 Cap and leachate collection system installed
- 2009-12 Additional characterization required by EPA

Public wells, springs, losing streams, and sinkholes

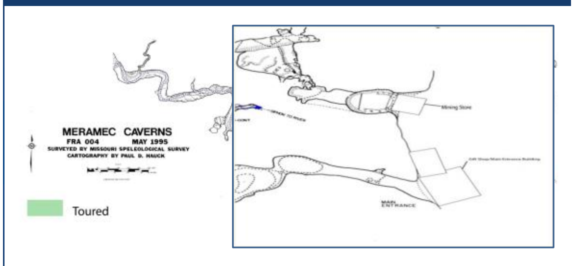


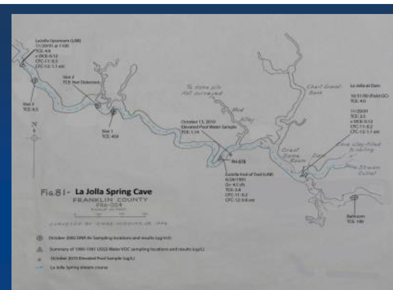

Missouri DNR Dye Traces


E-510 MERAMEC CAVERNS ENTRANCE ON HY. 66 STANTON MO.


RAMEC CAVERNS


MERAMEC CAVERNS
JESSE JAMES HIDEOUT
Stanton Missouri

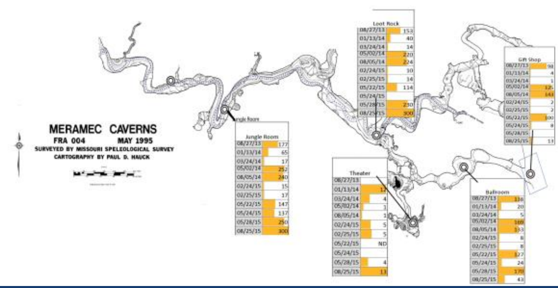




- 1991: USGS measured low levels of trichloroethylene (TCE) in La Jolla spring
- Oct 2002: MDNR measured 450 ug/m3 TCE in cave air

USGS sampling

- Between 2002 and 2007, MDNR sampled MC for TCE in air several times, detecting levels up to 1700 ug/m3
- USEPA requested that USGS perform quarterly air sampling for TCE between March 2013 through the summer of 2015
- TCE concentrations generally increase as the sampled location moves further up cave (Jungle Room is typically the highest).
- Seasonal variability in TCE concentrations seemed to relate to outdoor air temperature



TCE Loading/Flushing

In-cave airflow monitoring

- In April 2014, a 2-dimensional ultra sonic anemometer (Gill Windsonic) was placed near the Jungle Room to record air velocity and direction
- Cross-sectional air velocity measurements taken with handheld hotwire anemometer
- Dimensional measurements taken with photogrammetric "Structure from Motion" techniques

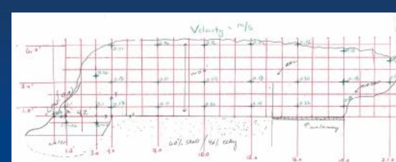
Continuous airflow logging

- Continuous logging anemometer should be mounted at or near a location which represents average cross sectional velocity
- Extremely sensitive to disturbances. Close proximity to walking paths or heat will cause noisy measurements
- Does not like RH near 100%. Condensation causes failed readings

Manual airflow measurements

- Hotwire (manual) anemometer must have minimum threshold of 0.01 m/s (Kanomax Climomaster)
- It is recommended that measurements are not made "by hand." Microphone stands work well.
- Using manual hotwire measurements, determine the relationship between average cross-sectional air velocity and actual measurement of ultrasonic anemometer

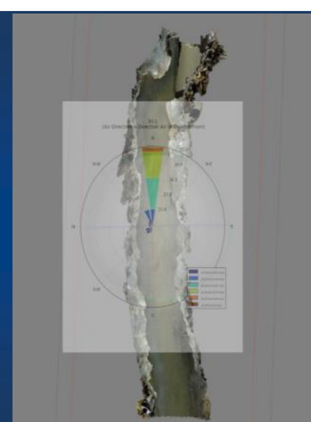
Manual Airflow measurements

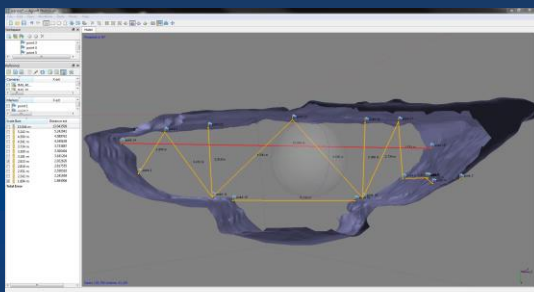


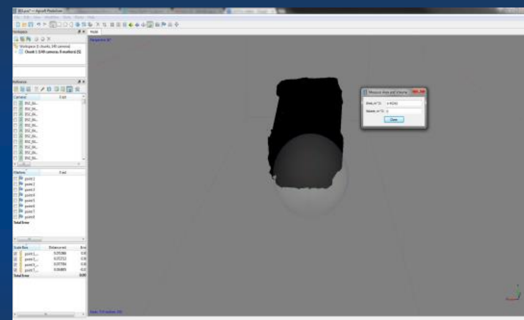
- Take manual air velocity measurements in a cross-sectional grid (every 2-3 ft)
- Use measurement to calculate the average cross-sectional velocity and "rate" the continuous logging anemometer.

Photogrammetric Modeling

- Easily attain dimensional measurements in difficult passages (water filled, muddy, too delicate) where terrestrial LIDAR would be risky
- Requires little equipment (inexpensive camera, tripod)
- High accuracy is achievable with good dataset
- Caves lend themselves to photogrammetric modeling

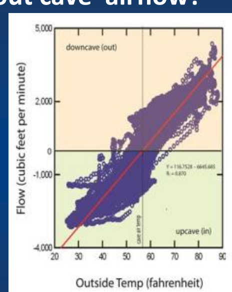




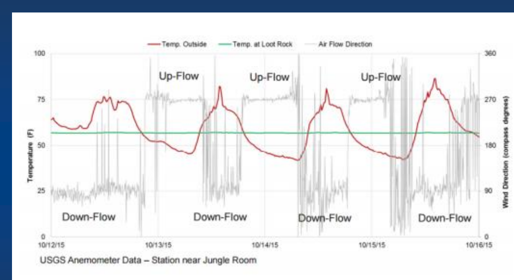


What did we learn about cave airflow?

- When outside temperatures less than cave temperature = up-cave (in) flow
- When outside temperatures more than cave temperature = down-cave (out) flow
- As outside air temperature approaches cave air temperature, airflow decreases (stagnant condition)
- Lower velocity flows increase frequency of direction changes

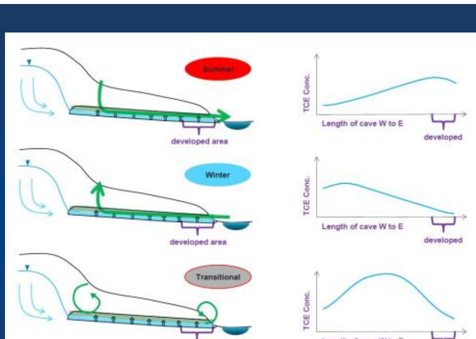


USGS science for a changing world



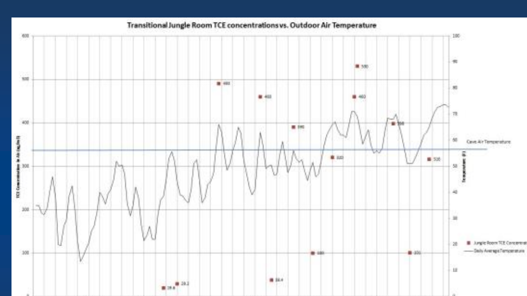
Graphic credit: Arcadis "Phase Two Work Plan" https://semspub.epa.gov/work/07/30286188.pdf

USGS science for a changing world

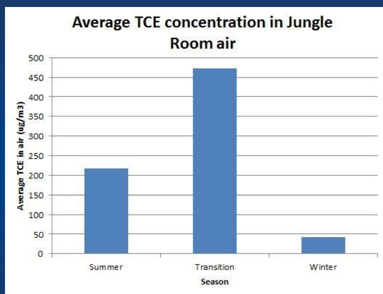


USGS science for a changing world

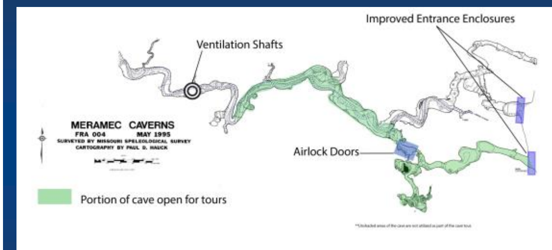
Graphic credit: Arcadis "Phase Two Work Plan" https://semspub.epa.gov/work/07/30286188.pdf



USGS science for a changing world

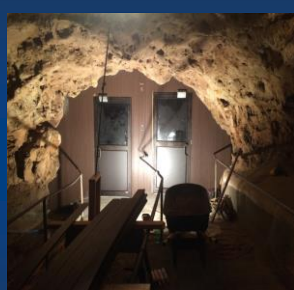


Remediation approach



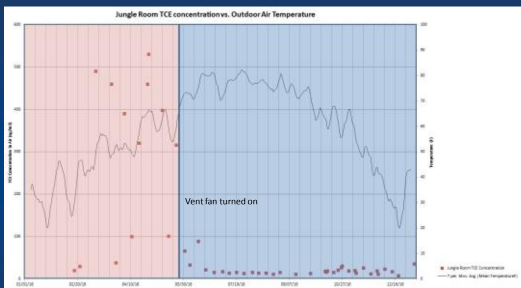
Airlock Doors

- In cave "airlock" installed at the original "dip"
- Two doors, approximately 100 ft apart, as well sealed as possible
- Concept is to keep TCE laden air from entering "front" section of cave during down cave (out) flow
- Completed June 2015



Ventilation Shafts

- Two 12" boreholes
- 6500 CFM design capacity
- Forced ventilation
- Completed May 2016



Future Challenges

- Secondary effects
  - Humidity/Fog
  - Mold
  - Speleothem damage
- Seasonal ventilation plan
- Additional flooding
  - Cave was inundated twice in two years by severe floods
- Additional sources of stored TCE
- Other caves?