Gas Migration at Karst Landfills

2016 Environmental Show of the South

Presented by
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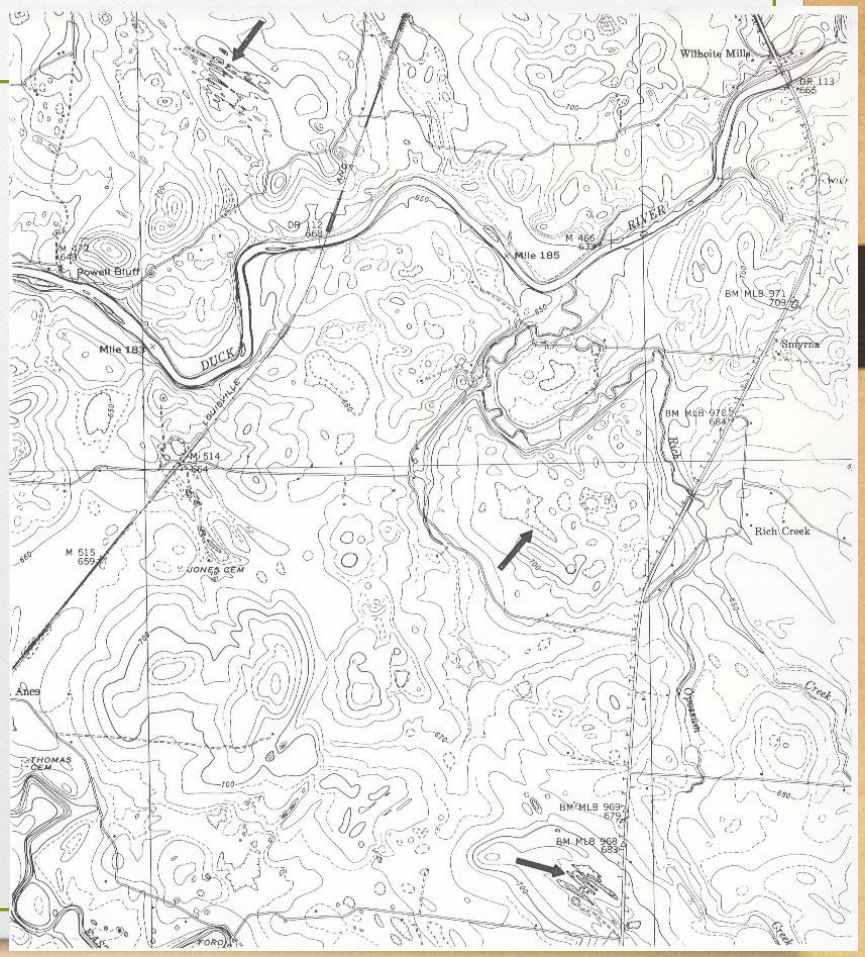
Geologic Evaluation of Sanitary Landfill Sites

Environmental Geology Series No. 1 (TDEC Div. Of Geology, 1972)

KARST TERRIAN - This type of topography is characterized by sinkholes, caves, and similar solutional openings ... Such areas offer poor sites for landfills and should be avoided.



New York Times – March 15, 2013

Lewis Land, an organizer of the 2013 Annual Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst is quoted:

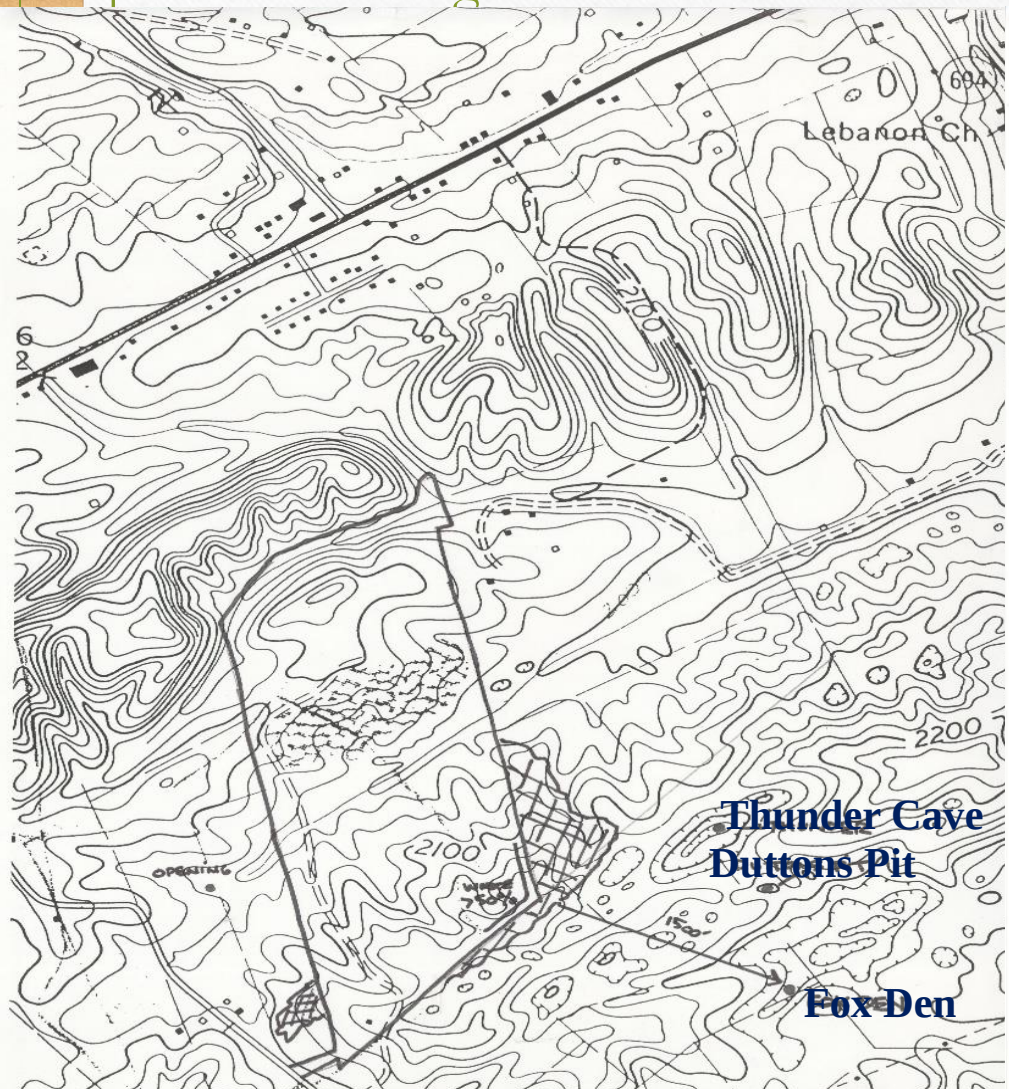
"A sinkhole on a farmer's property is almost like God has gifted him with a naturally occurring landfill."

Landfill Gas Monitoring and Mitigation

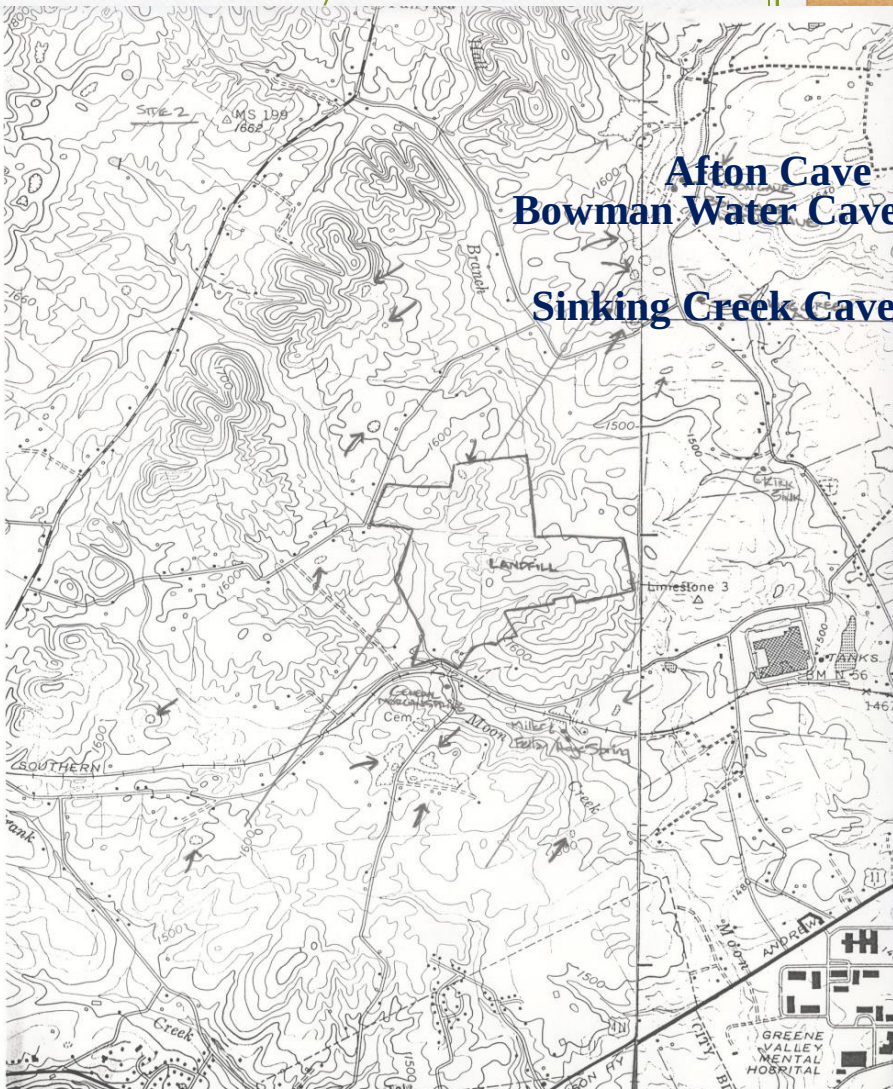
The Technical Section, Tennessee Division of Solid Waste Management (March 3, 1999)

Migration of Landfill Gas "Once landfill gas has exited the cell limits, there are numerous natural and man-made mechanisms for promoting further gas migration including, but not limited to: the presence of … (caves) in the vicinity of the cell.

Washington Co. VA



Greeneville/Greene Co. TN



Tennessee Landfills Situated in Karst

- Many older, closed unlined disposal areas in eastern Tennessee are underlain by limestones and dolomites, where erosion has produced a karst topography.
- Solution cavities and solution opened ground fissures are common to this terrain.
- Unique challenges are encountered when characterizing gas migration at older unlined landfills located above karst.

Regulation of gas migration at old, unlined landfills situated in karst

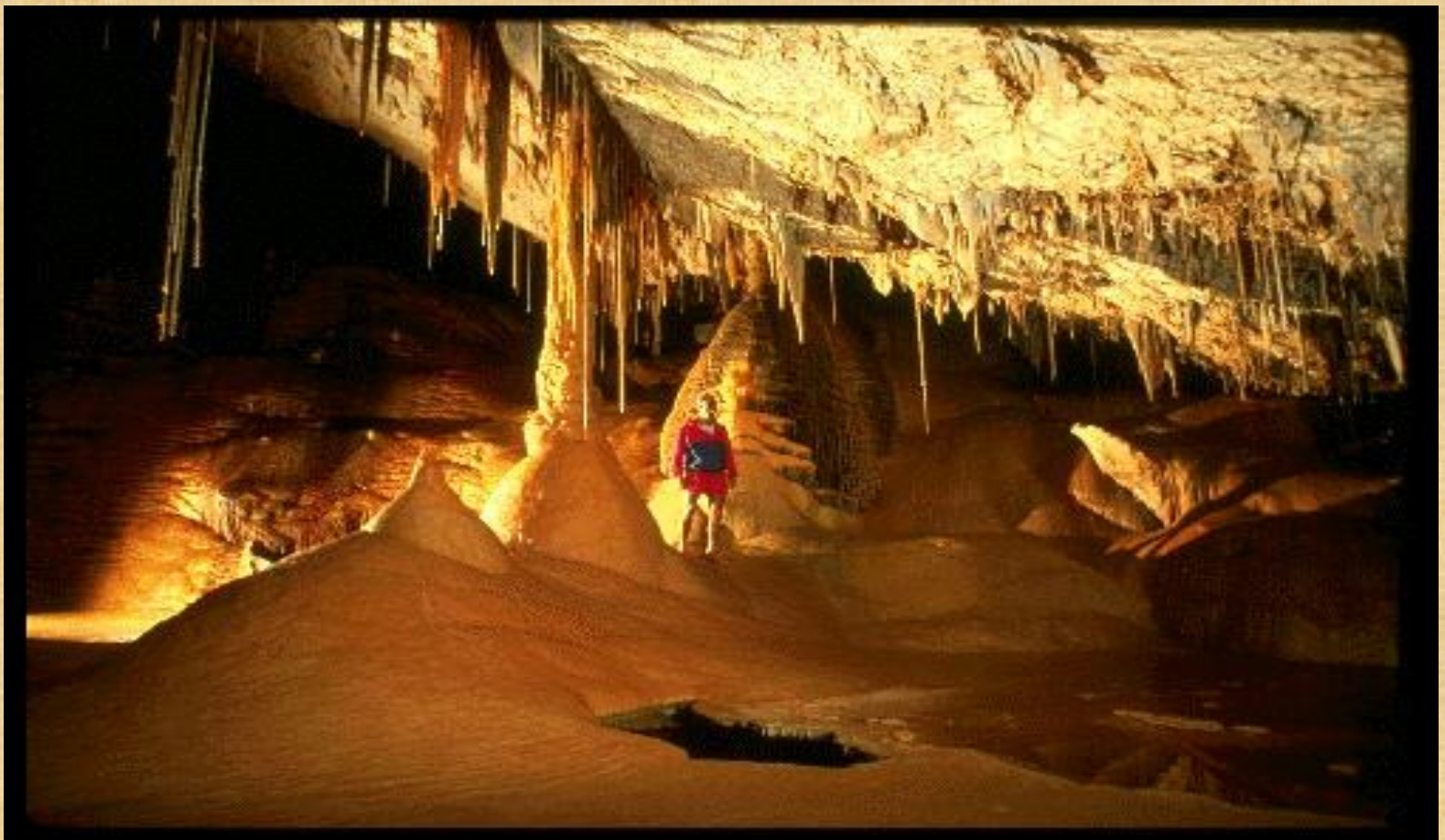
- Regulations require that

1) facilities control landfill gases and
2) monitoring networks be designed to ensure detection of gases migrating beyond the facility boundary, including accounting for local soil and rock conditions.

- Few facilities account for landfill gas transport via the karst void network.

Karst Landfill Gas Migration

Deep conduit flow patterns followed by gas migration in karst require that a different approach be taken when investigating the nature and extent and designing appropriate remedial responses.



Gas characterization issues at old, unlined landfills situated in karst

- Ample opportunity for gases trapped beneath the cap of unlined disposal areas to have found their way to this karst void network.

✓ The uppermost water table is often deep beneath these karst disposal areas, leaving plenty of space for gas to be transported offsite via karst cavities and open fissures.

✓ These voids offer the path of least resistance for gas transport, favored over transport in surficial clays.

- Once in the voids, the geometry and orientation of the void network govern the extent of gas migration.

Gas monitoring & migration issues at old, unlined landfills situated in karst

- Monitoring networks are typically installed in shallow soils (not greater than 30 ft below ground surface).
- ✓ Landfill gas residing in the deeper karst bedrock voids is not being monitored.
- ✓ Neglects deeper gas transport pathways existing in karst bedrock void network.
- ✓ Void transport pathways are favored migration routes.
- ✓ Most likely to take gas offsite to neighboring properties.

Post-closure remedial issues for gas at old, unlined landfills situated in karst

- Remedial responses typically involve traditional approaches (additional waste gas vents, dewatering existing gas vents, soil trenches/vents, air injection, etc).

✓ Traditional approaches focus on shallow soil gas migration.

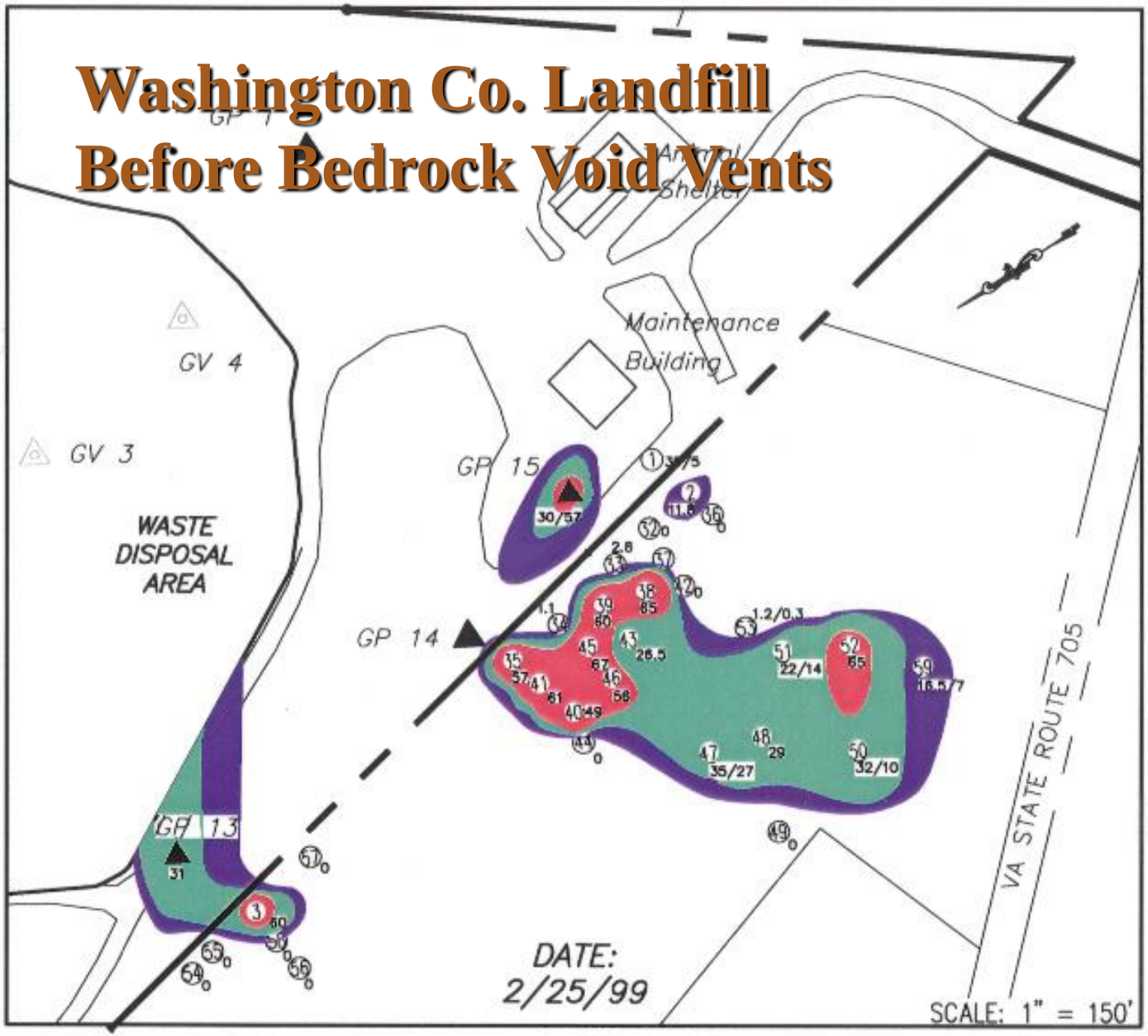
✓ Ineffective at remediating deeper karst transport.

✓ Neglect favored karst void gas migration routes most likely to take gas offsite to neighboring properties.

Characterizing and Remediating Landfill Gas Transport via the Karst Void Network

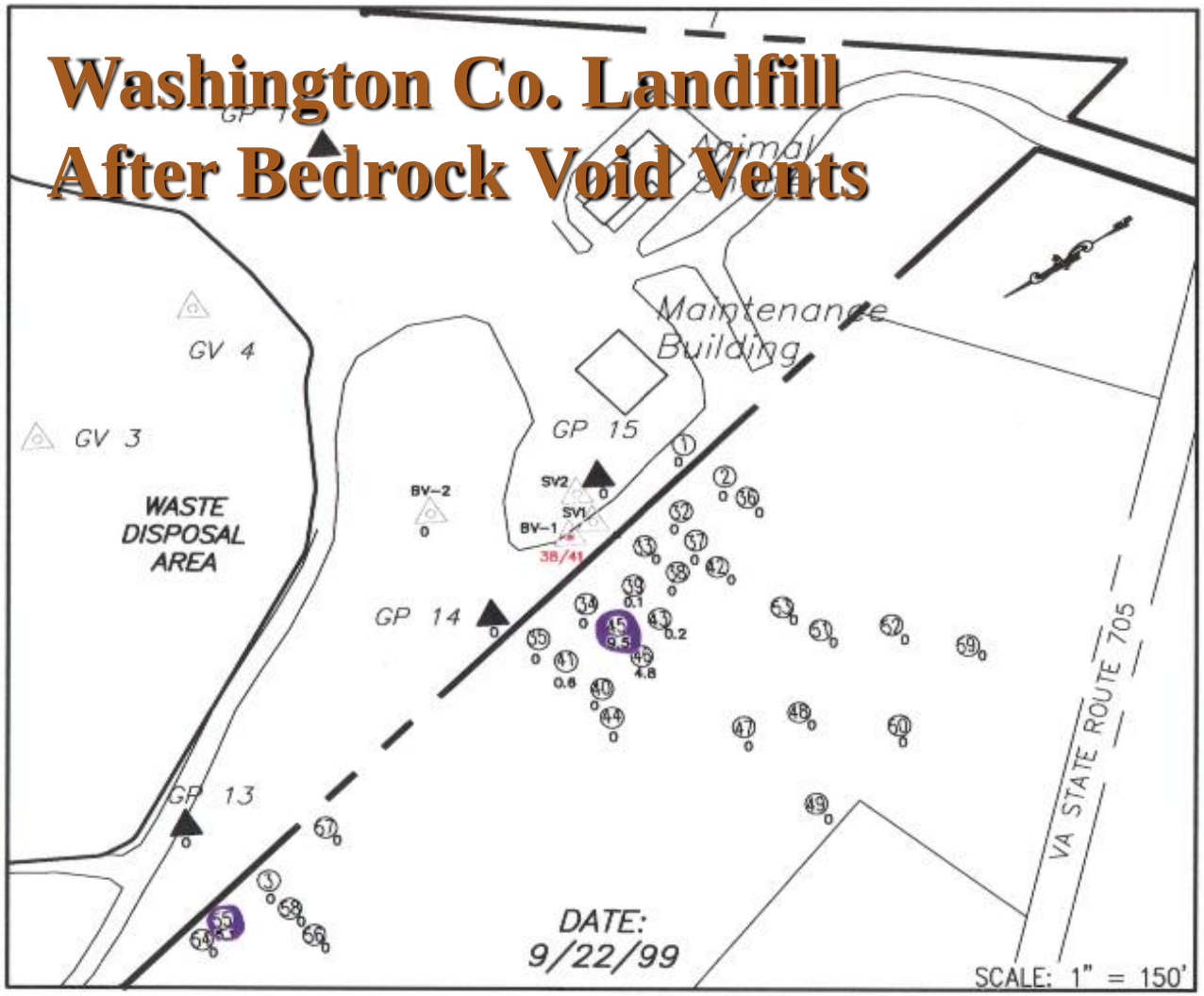
- Direct-push gas monitoring techniques actively map and track the distribution and migration of landfill gas in the soil overburden.
- Characterizing the extent of offsite impact in the soil overburden reveals gas transport mechanisms and flow paths existing deep within karst voids in the bedrock.
- Offsite gas impacts are remediated by accessing the bedrock voids and venting the gas to the surface at the property line.
- First introduced at the 1999 NGWA AGWSE Technical Education Program in Nashville & 2000 TDEC Environmental Conference.
- Published in Geotechnical and Environmental Applications of Karst Geology and Hydrology, Beck & Herring (eds) © 2001 Swets & Zeitlijger, ISBN 90-5809-190-2.
- Presented at the Eighth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karsts in 2001.

Washington Co. Landfill
Before Bedrock Void Vents



FEBRUARY

Washington Co. Landfill
After Bedrock Void Vents

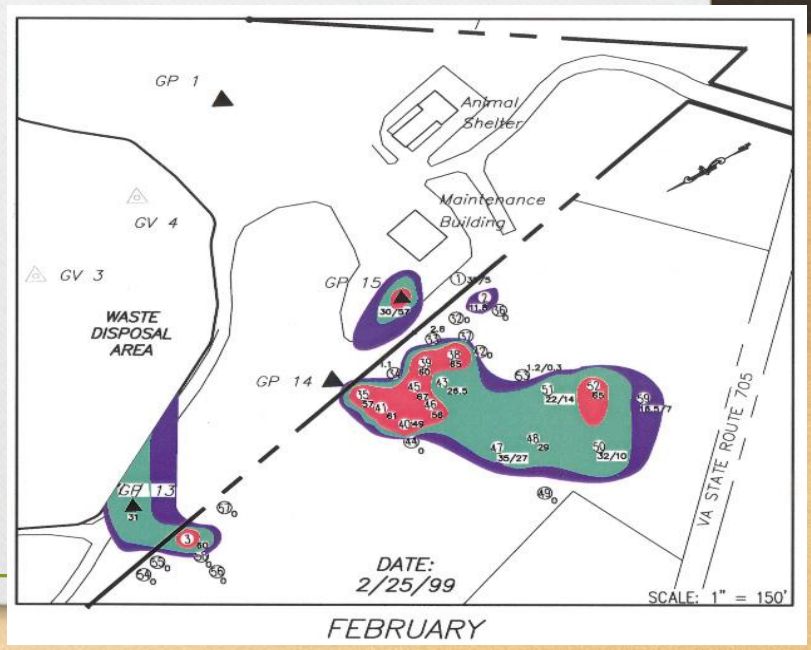


SEPTEMBER

(AFTER THE PASSING BY OF TROPICAL STORMS DENNIS AND FLOYD)

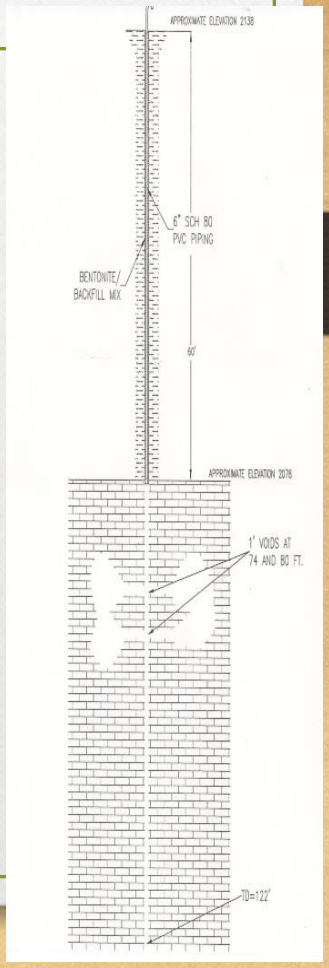
How did you know?

- Offsite probes indicated that concentrations of methane in the soil overburden (upper 30 feet) *increased* away from the source.
- If the soil was the transport mechanism, methane would be expected to decrease away from the source.



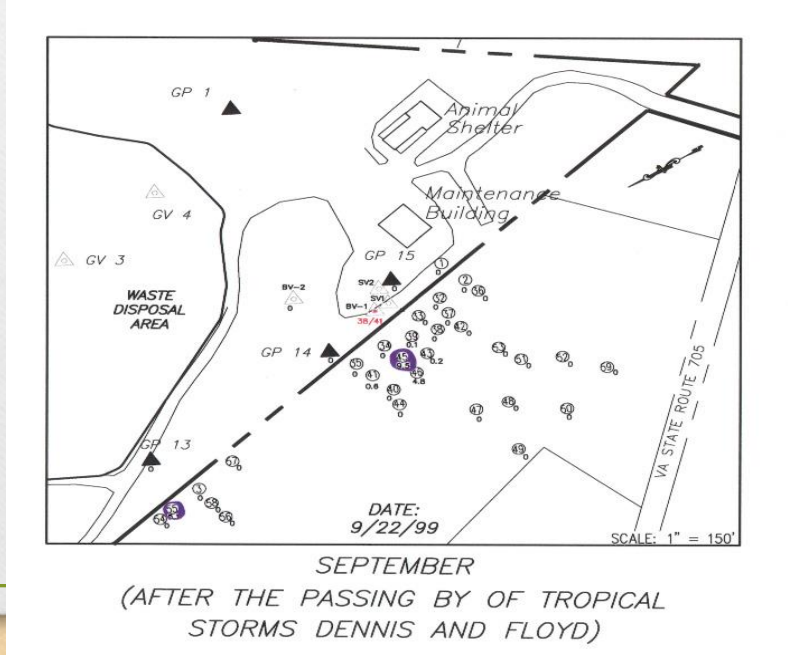
What did you do?

- 3 vents were drilled into bedrock voids at 'non-impacted' locations at the landfill property boundary.
  - 1 to 5 foot dia. voids,
  - 60 to 80 feet deep.
- First vent installed consistently vented methane at > 50% by volume. Second two vents periodically vented methane from 5% to 55% by volume.



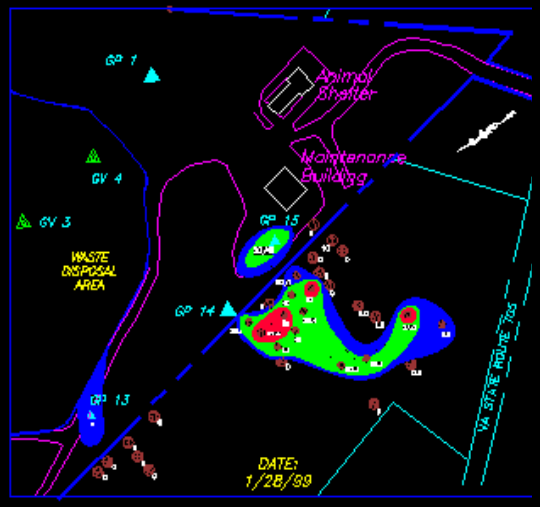
And what did that do?

- Soon after the bedrock vents were installed, offsite gas concentrations dropped and the extent of impact diminished.
- In September 1999, after tropical storms Dennis and Floyd, even concentrations at the property boundary dropped dramatically.

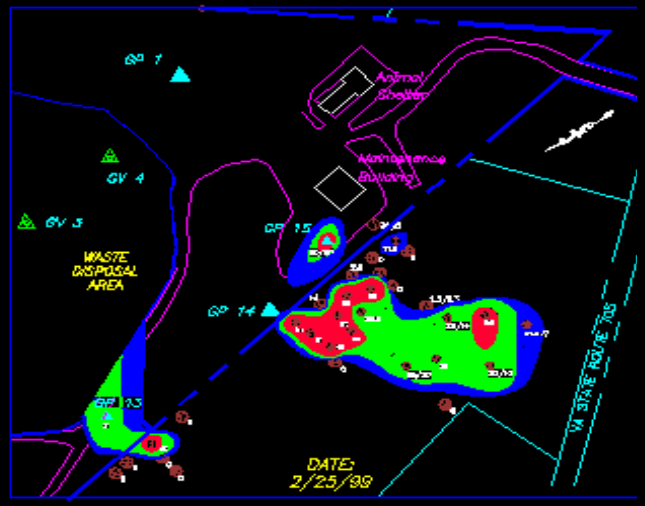


SEPTEMBER
(AFTER THE PASSING BY OF TROPICAL STORMS DENNIS AND FLOYD)

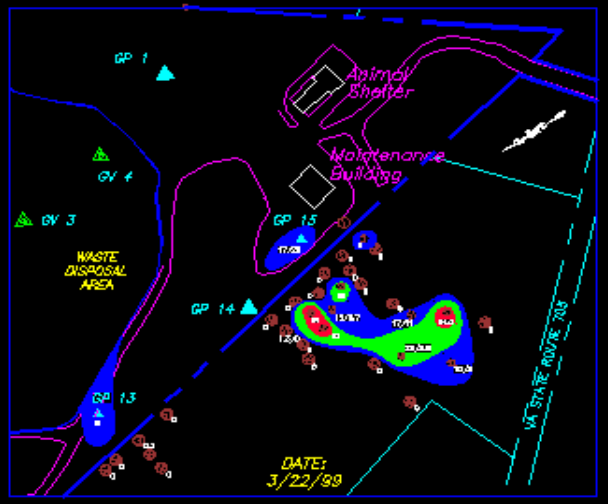
BEFORE VOID VENTS



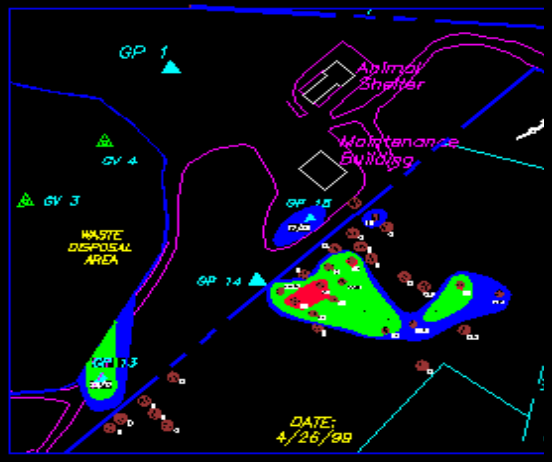
JANUARY



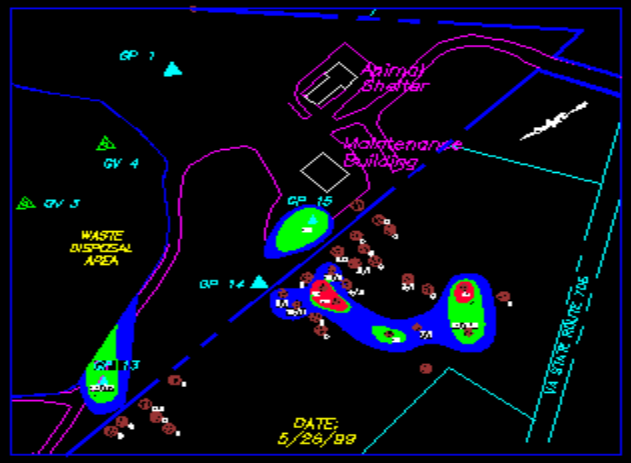
FEBRUARY



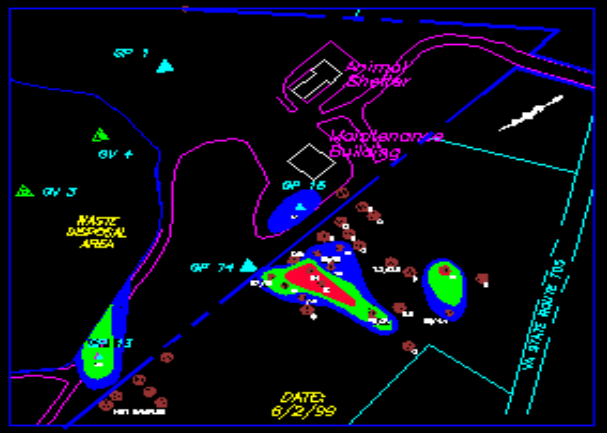
MARCH



APRIL

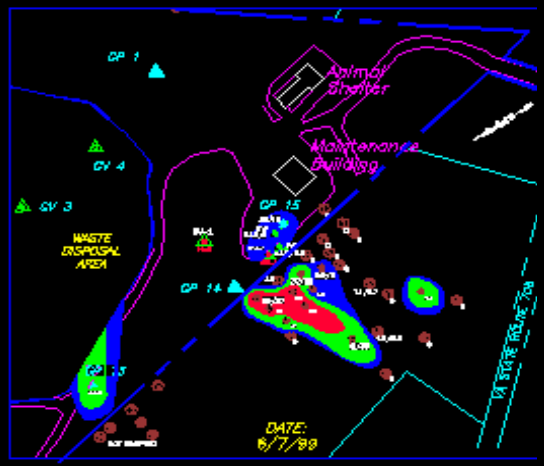


MAY

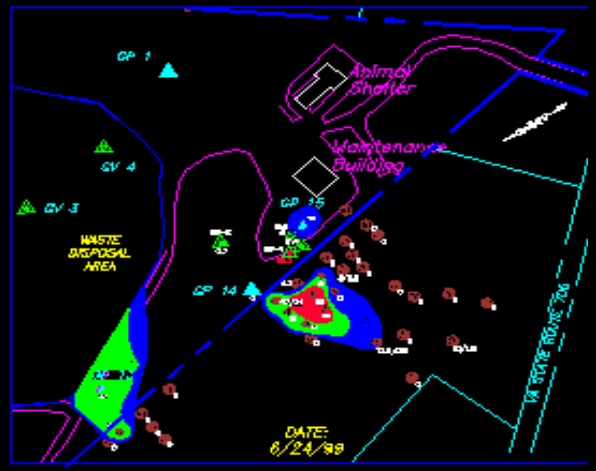


JUNE
(MORNING PRIOR TO VENT INSTALLATION)

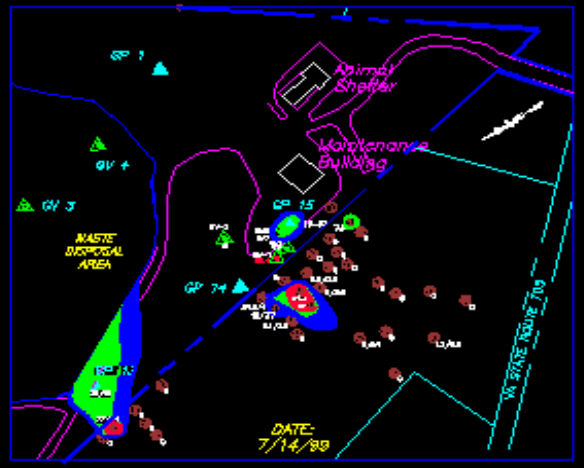
AFTER VOID VENTS



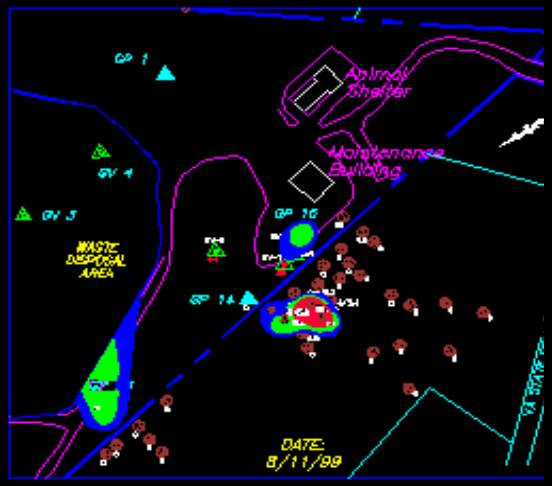
JUNE
(3 DAYS AFTER VENT INSTALLATION)



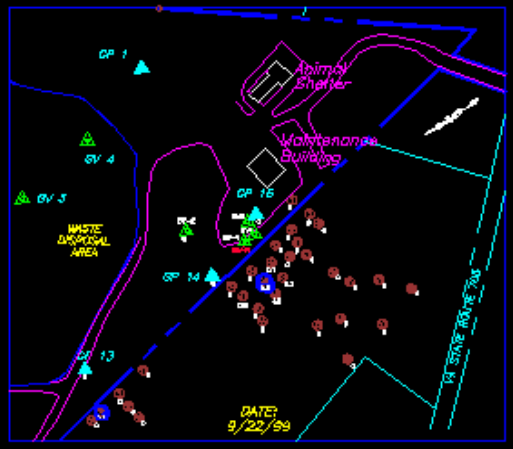
JUNE
(3 WEEKS AFTER VENT INSTALLATION)



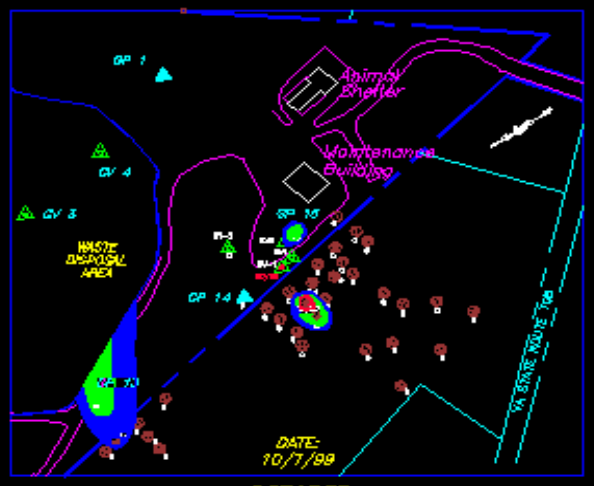
JUNE
(6 WEEKS AFTER VENT INSTALLATION)



AUGUST



SEPTEMBER
(AFTER THE PASSING BY OF TROPICAL STORMS DENNIS AND FLOYD)

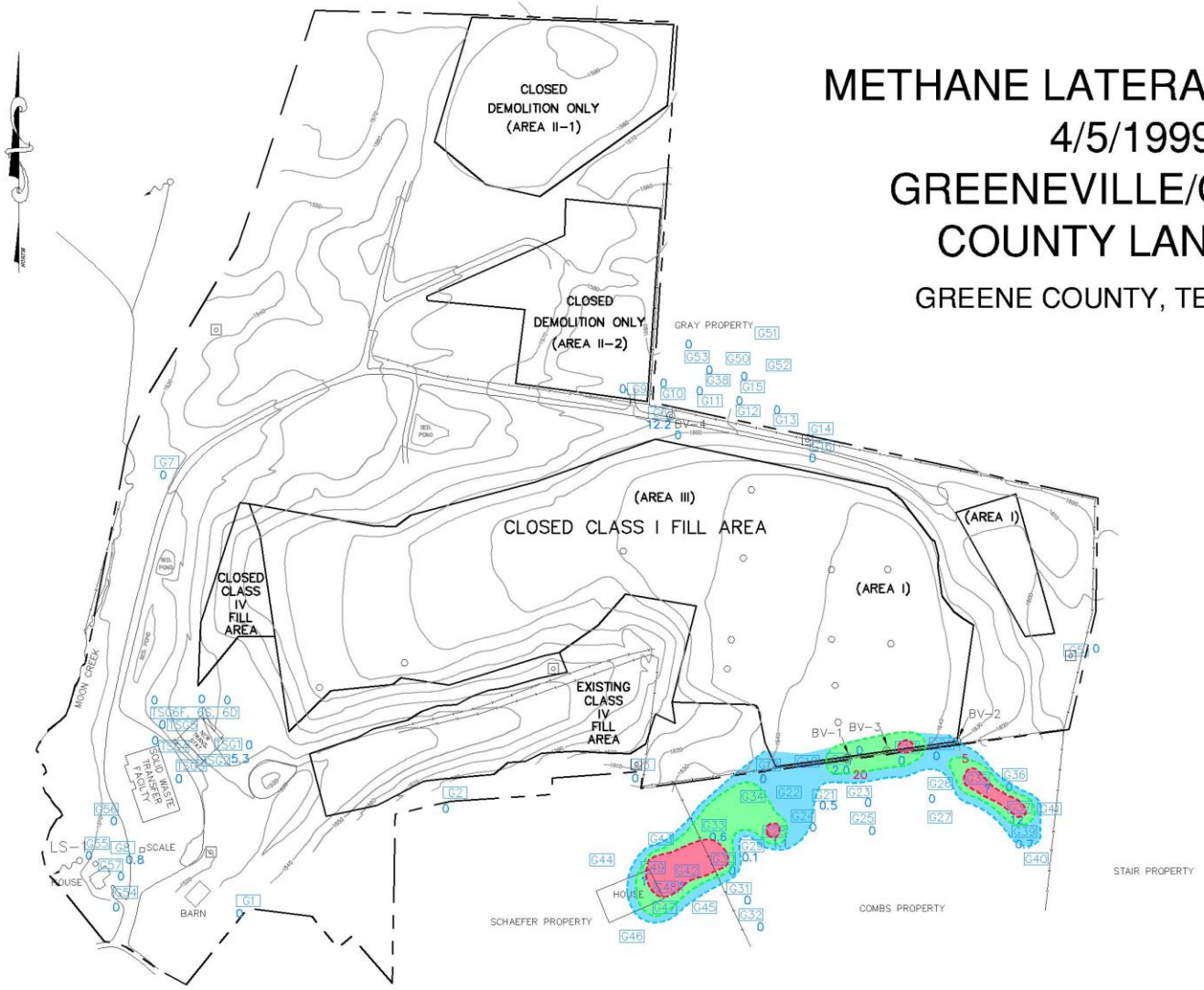


OCTOBER

Greeneville/Greene County Landfill Gas Remediation

- Offsite lf gas migration detected in 1998.
- Successfully remediated in 1999 via venting of Karst bedrock voids.

Greeneville Greene Co :Before Bedrock Void Vents



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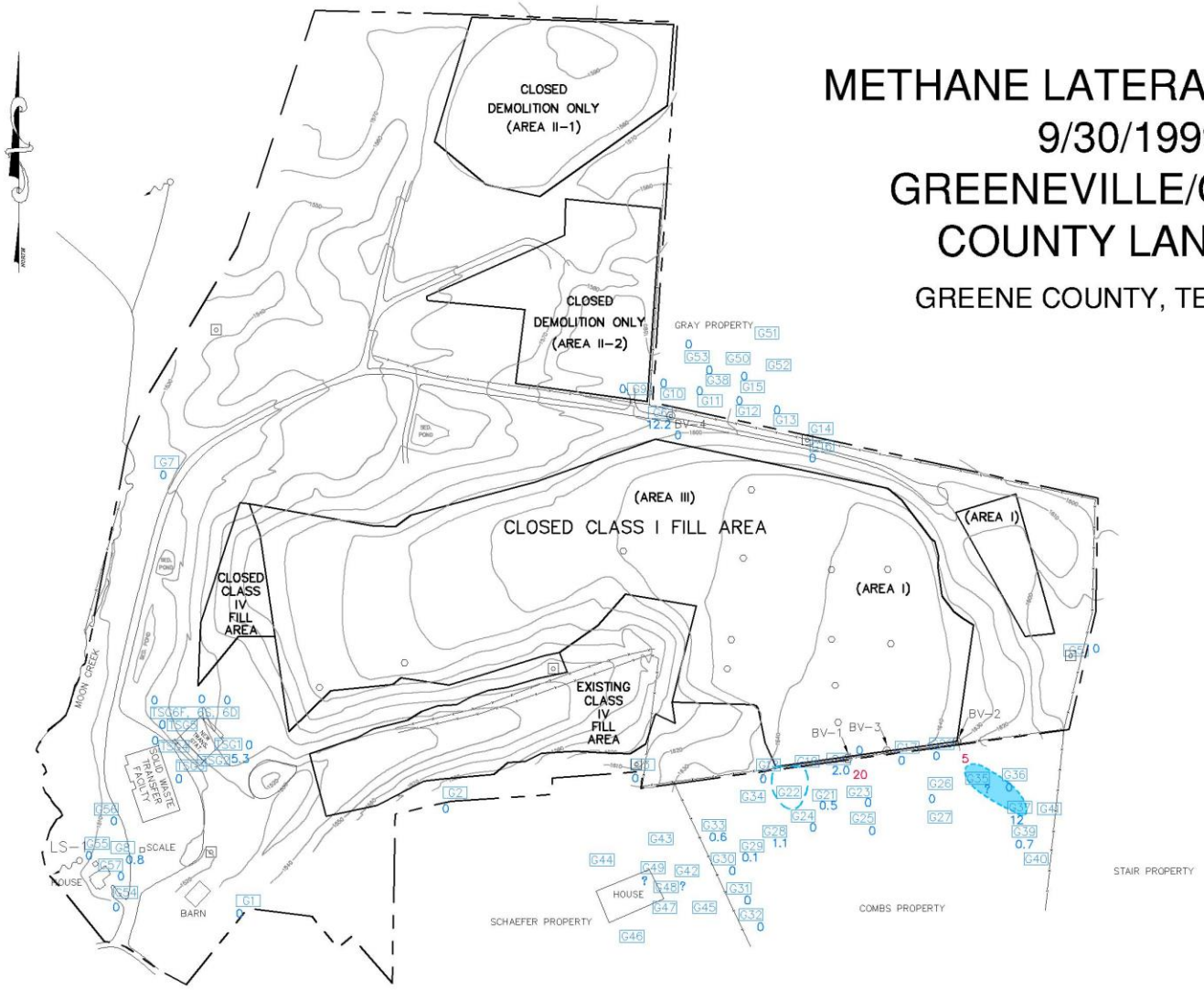
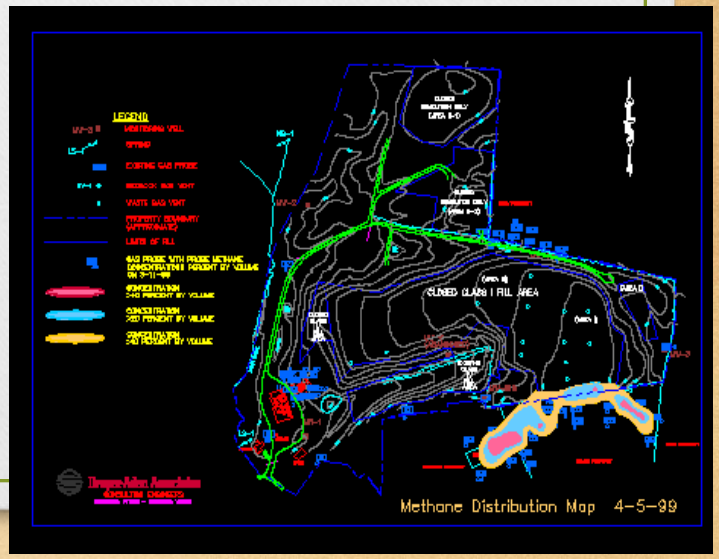


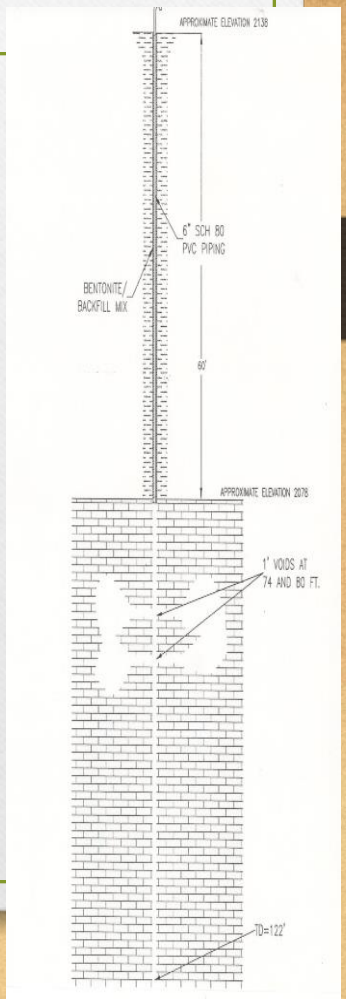
How did you know?

- Again, offsite probes indicated that concentrations of methane in the soil overburden (upper 30 feet) increased with increasing distance from the source.
- If the soil was the primary transport mechanism, methane should decrease away from the source.

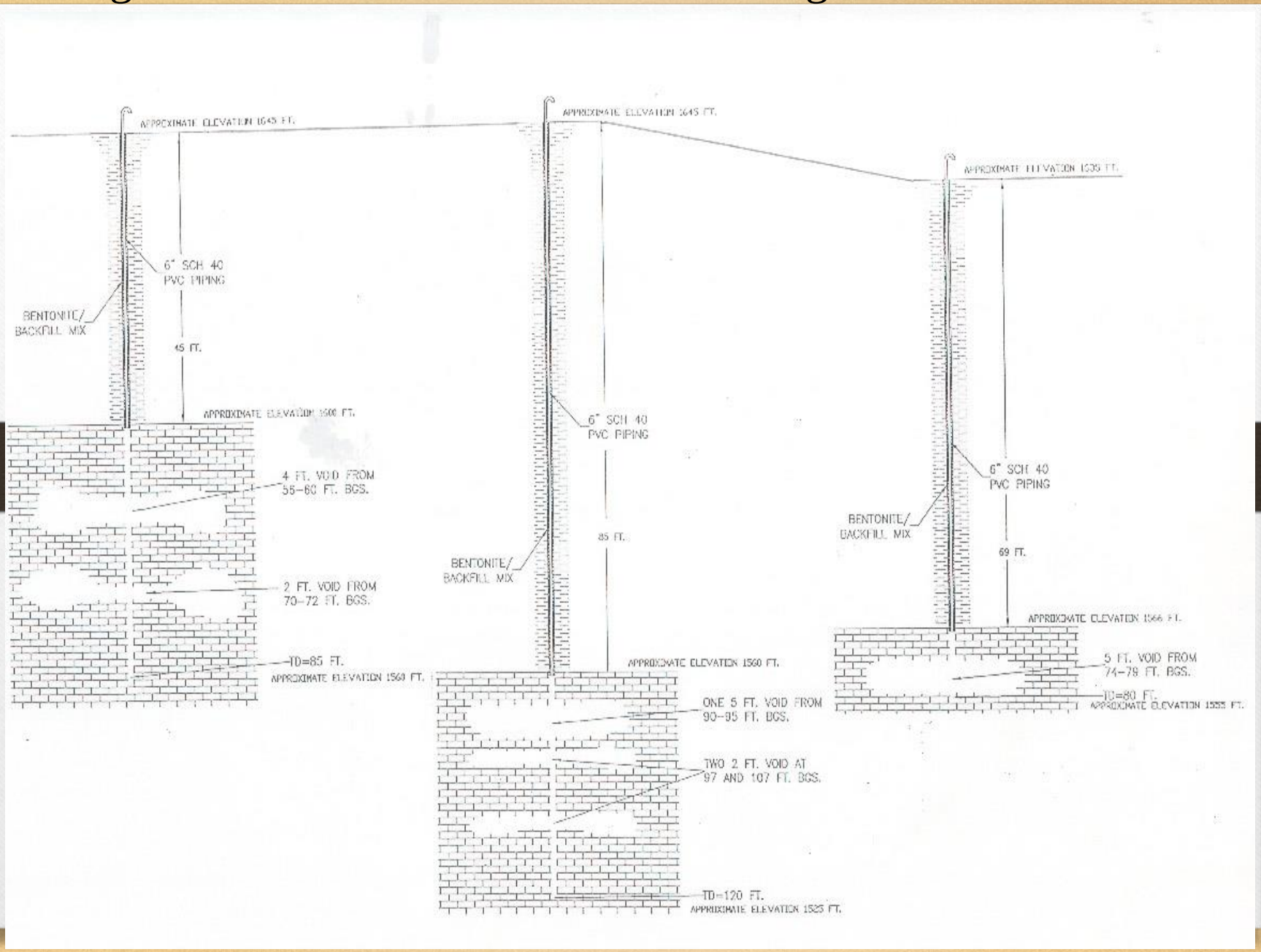


What did you do?

- Installed 3 vents into bedrock voids at a ‘non-impacted’ location at the landfill property boundary.
  - First two, 4 to 5 ft dia. voids ~ 70 ft deep.
  - Third vent, 10 ft of voids ~ 100 ft. deep.
- First two vents periodically vented methane at concentrations varying from 5% to 55% by volume. The third vent never vented methane passively.



- Original three Greeneville bedrock void gas vents



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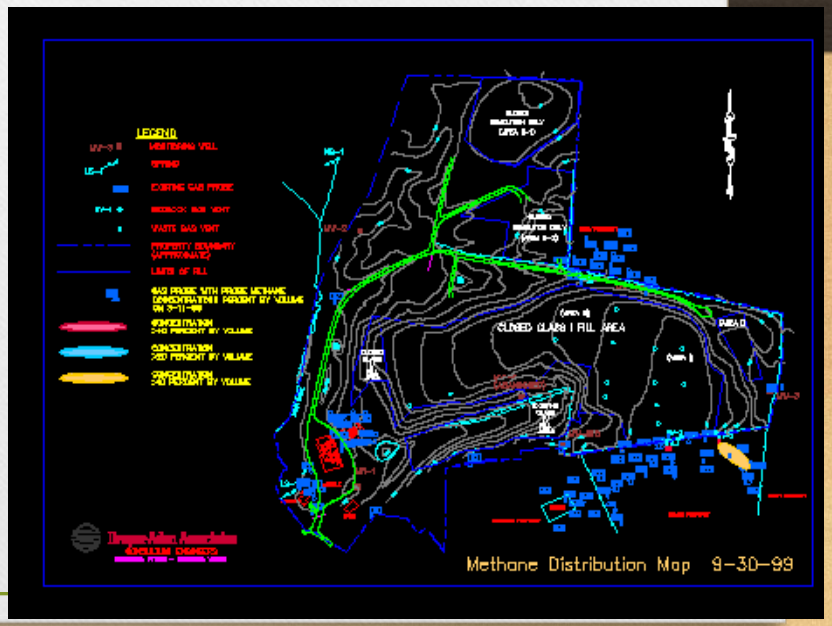
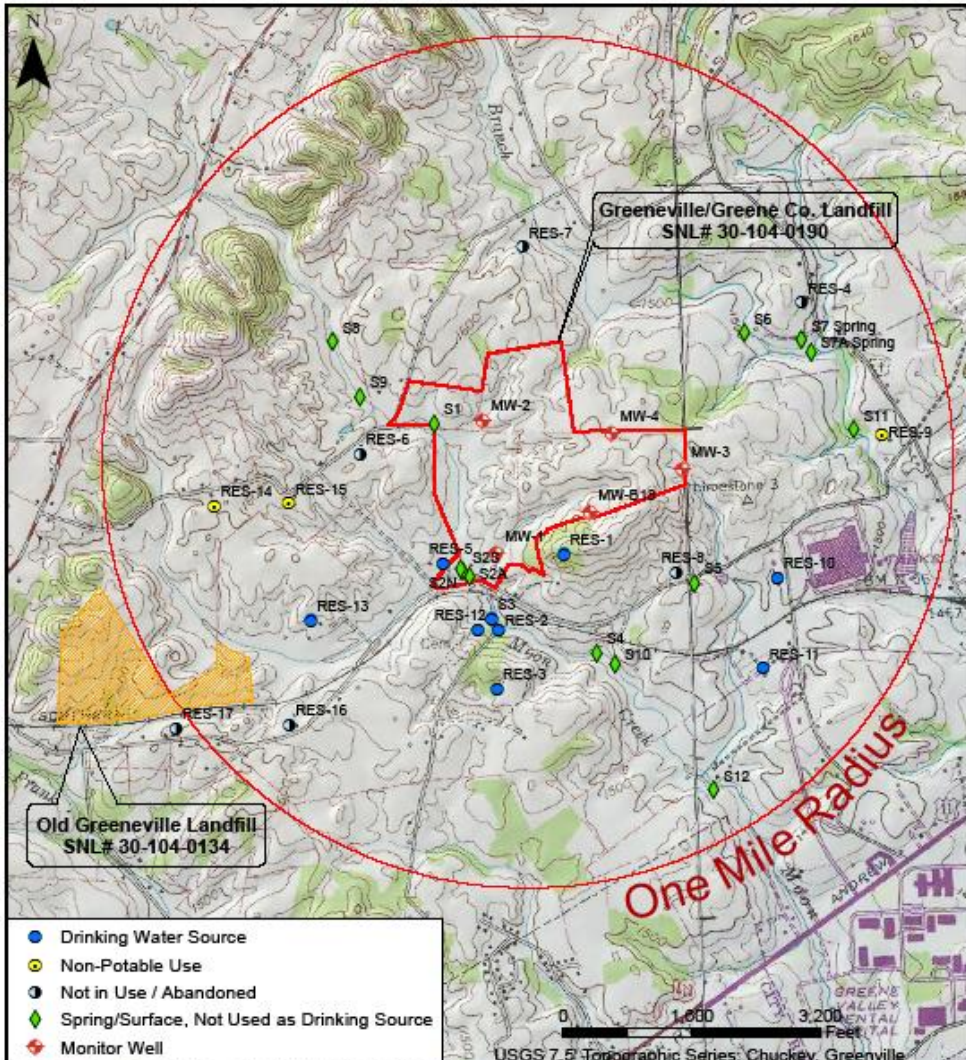


OLD Greeneville Landfill

Closed in 1992

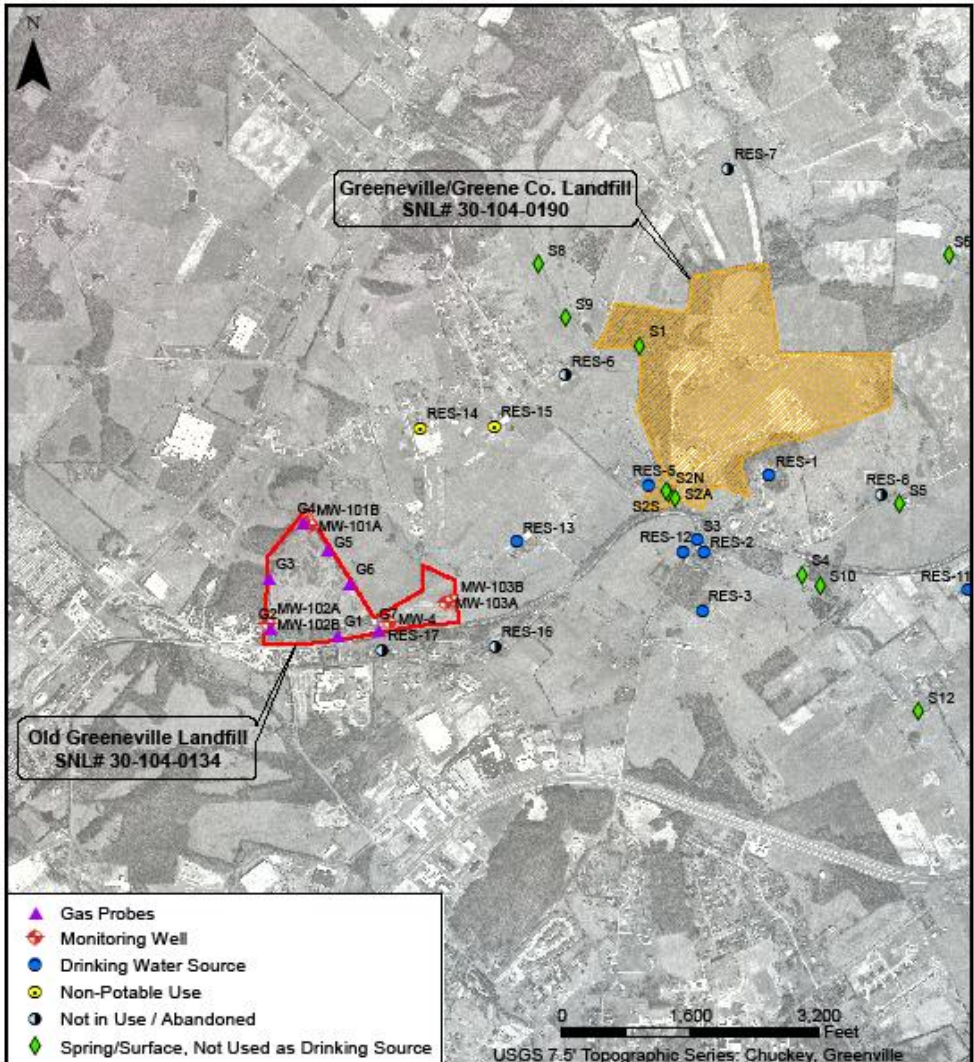
Re-evaluated in 2006 for Corrective Measures Assessment for the Greeneville/Greene County Landfill located within a mile-radius.



OLD
Greeneville Landfill

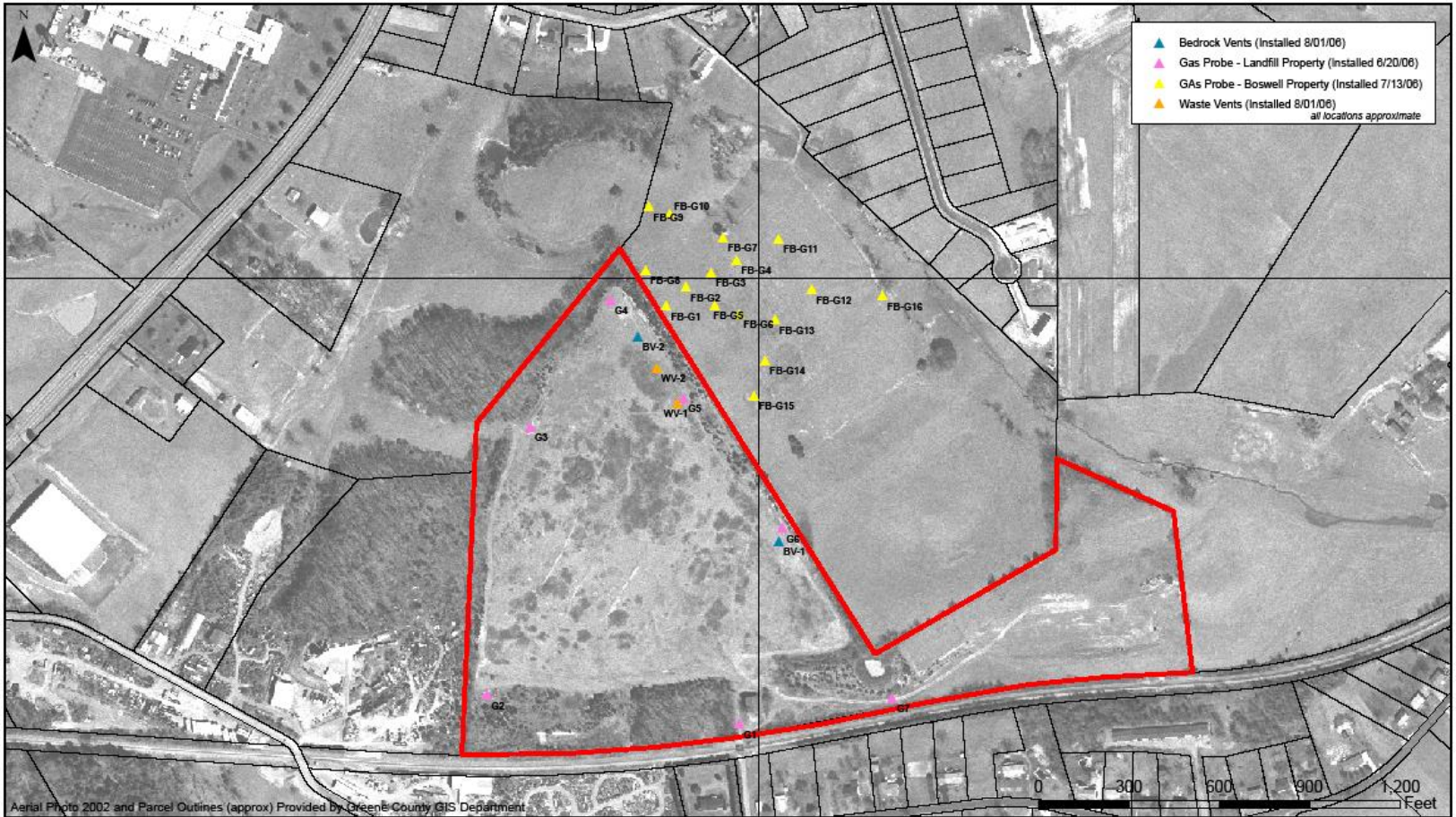
Installed seven direct-push Property Boundary Gas Probes

Gas Probes indicated Methane concentrations above the LEL at NW property boundary.



Old Greeneville Landfill

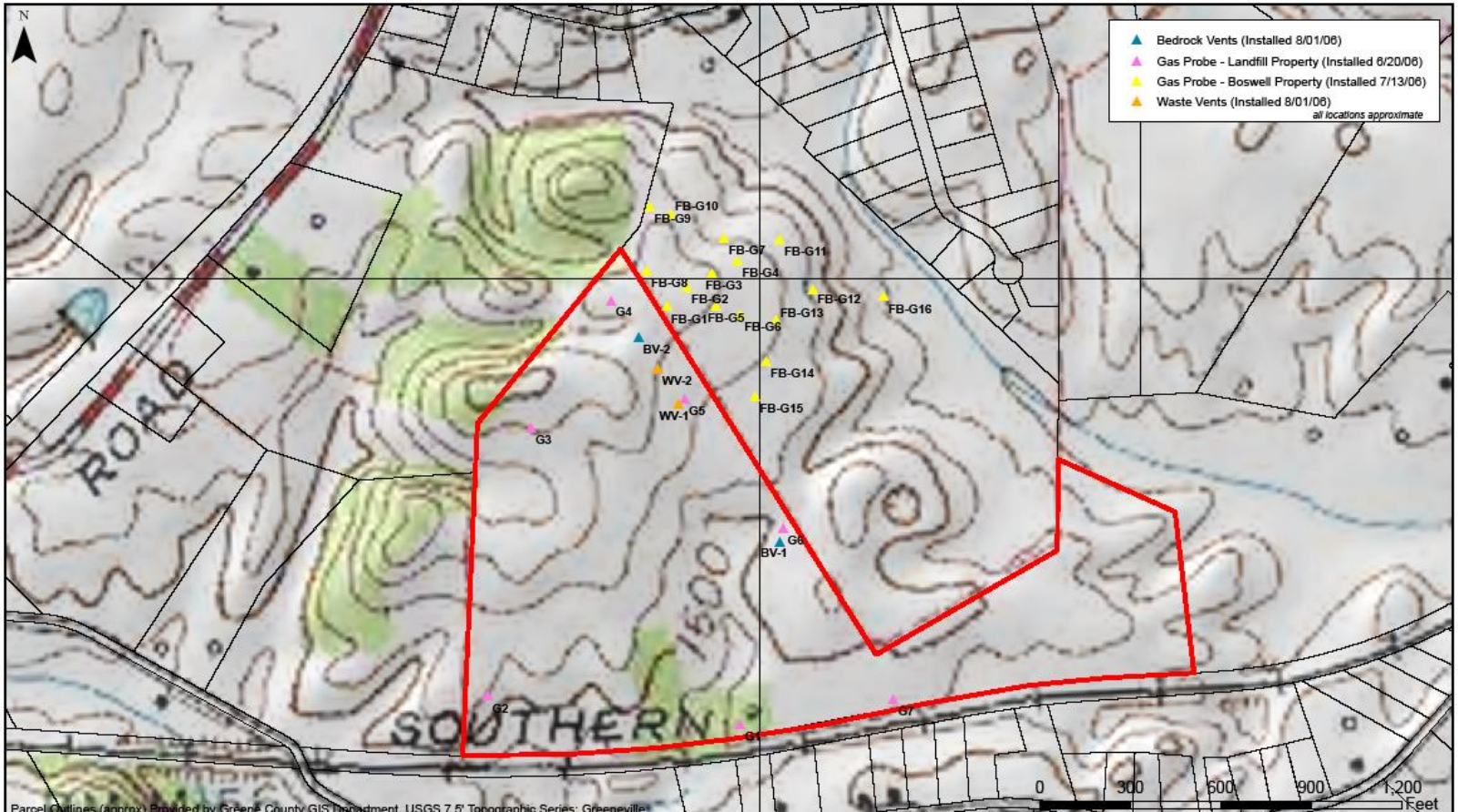
Installed sixteen direct-push Property Boundary Gas Probes offsite in cow pasture between the landfill and a new twenty-two lot subdivision.
Offsite gas Probes indicated Methane concentrations above the LEL at several offsite locations.



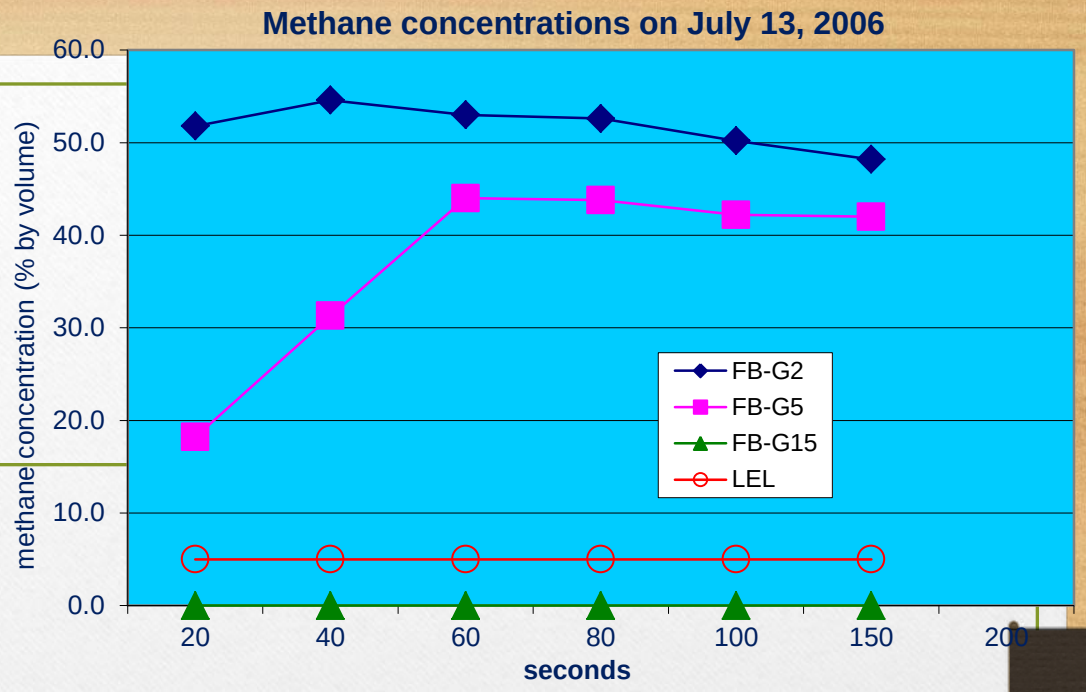
Old Greeneville Landfill

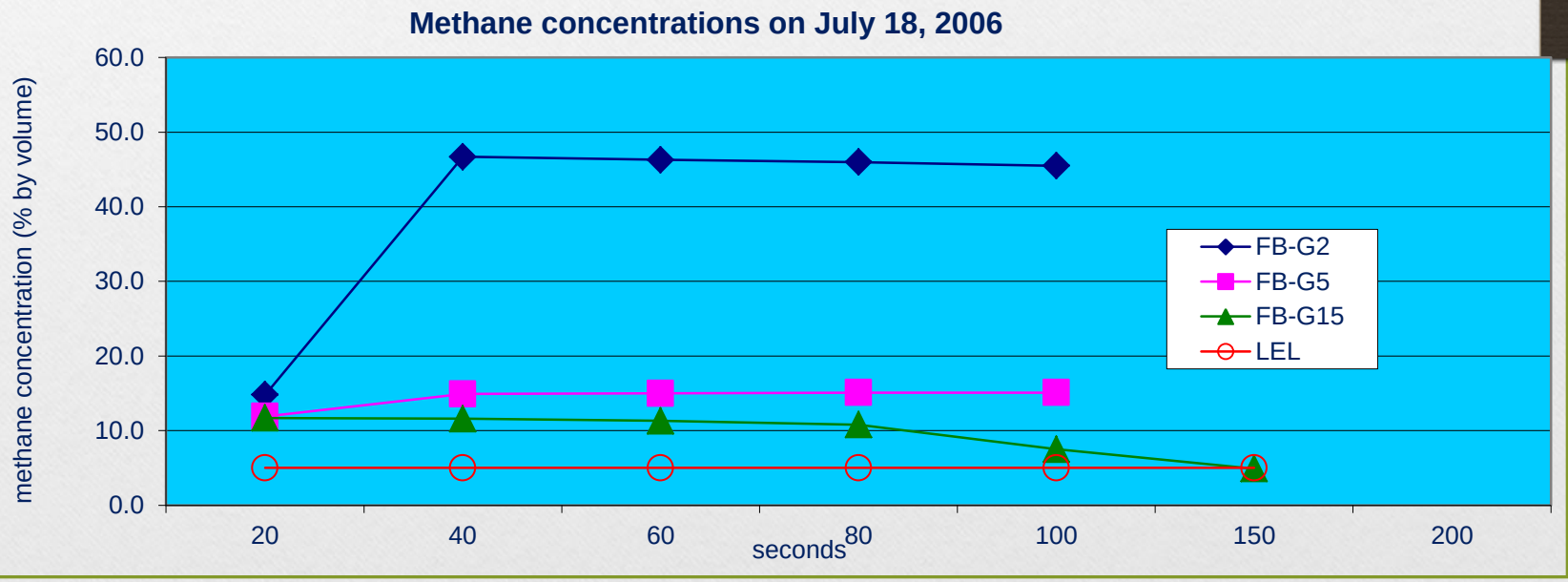
Installed two bedrock void vents at Property Boundary adjacent to cow pasture.

Connected Solar Powered Exhaust Fan to Bedrock Void Vent BV-2.

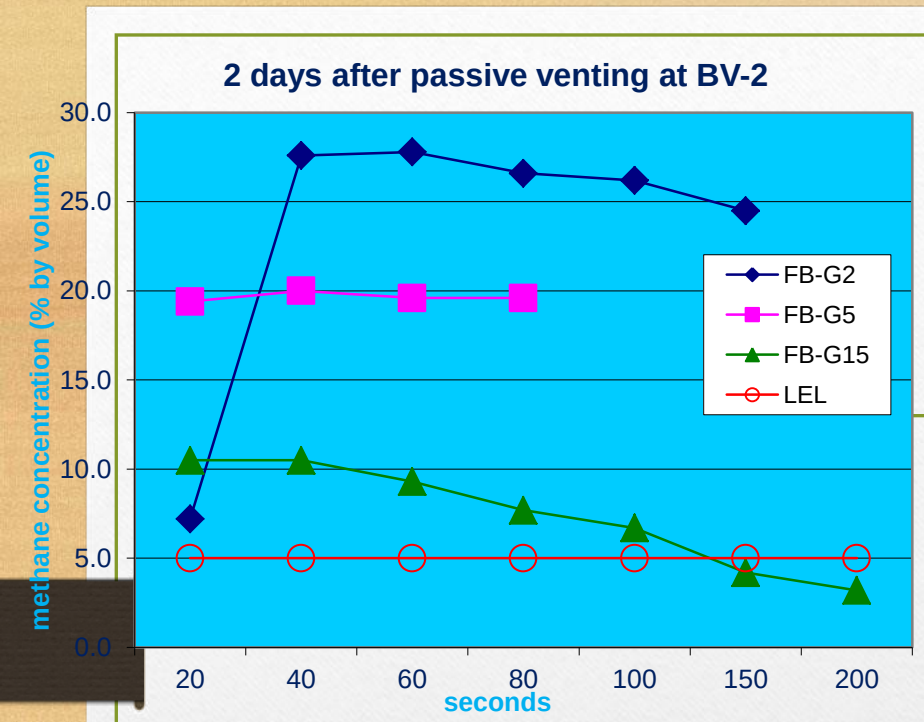


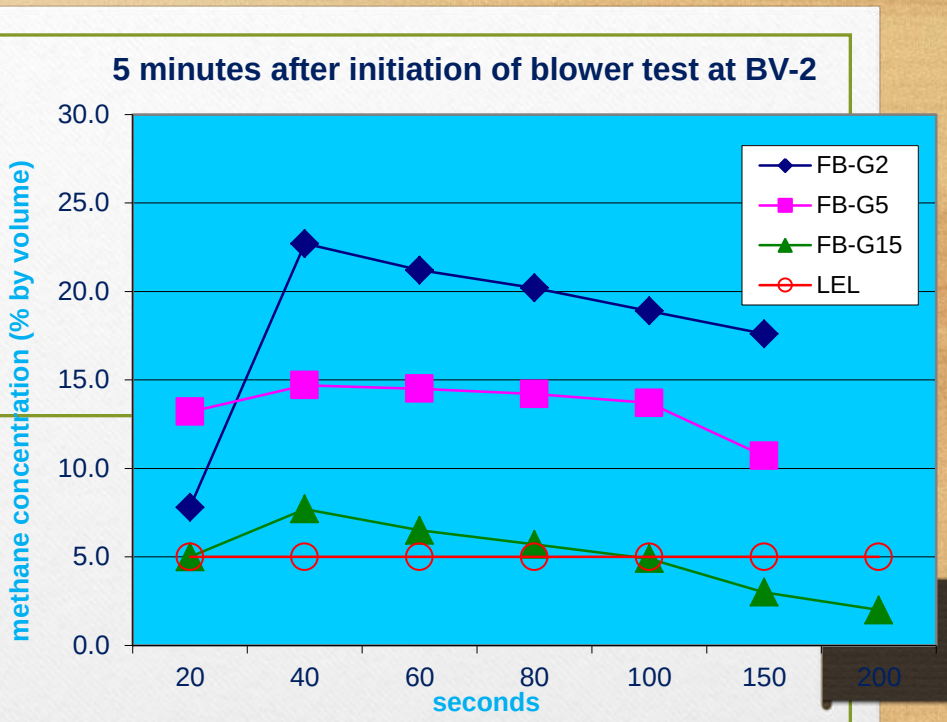
Methane concentrations before installation of Bedrock void vent

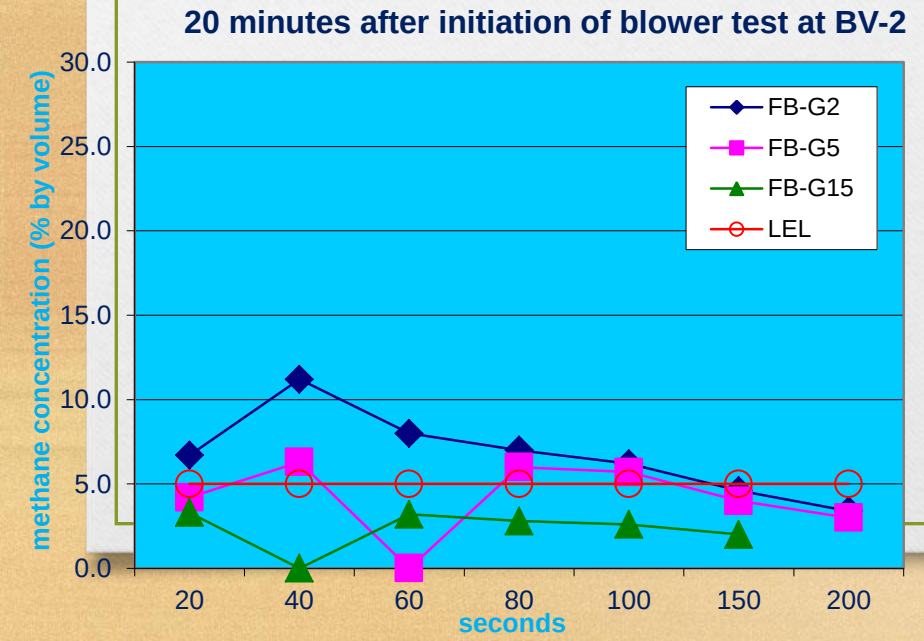


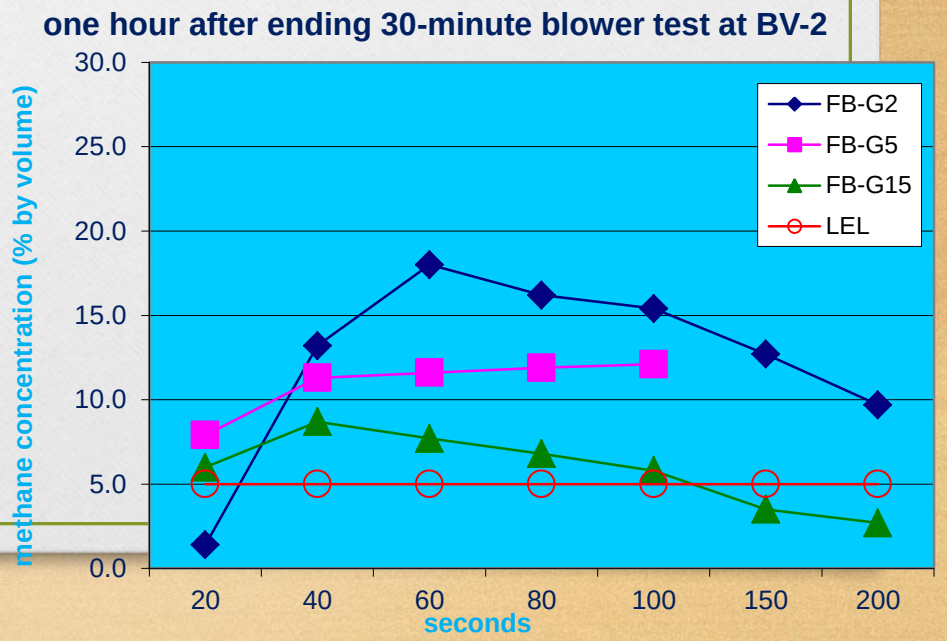


Methane concentrations after installation of Bedrock void vent

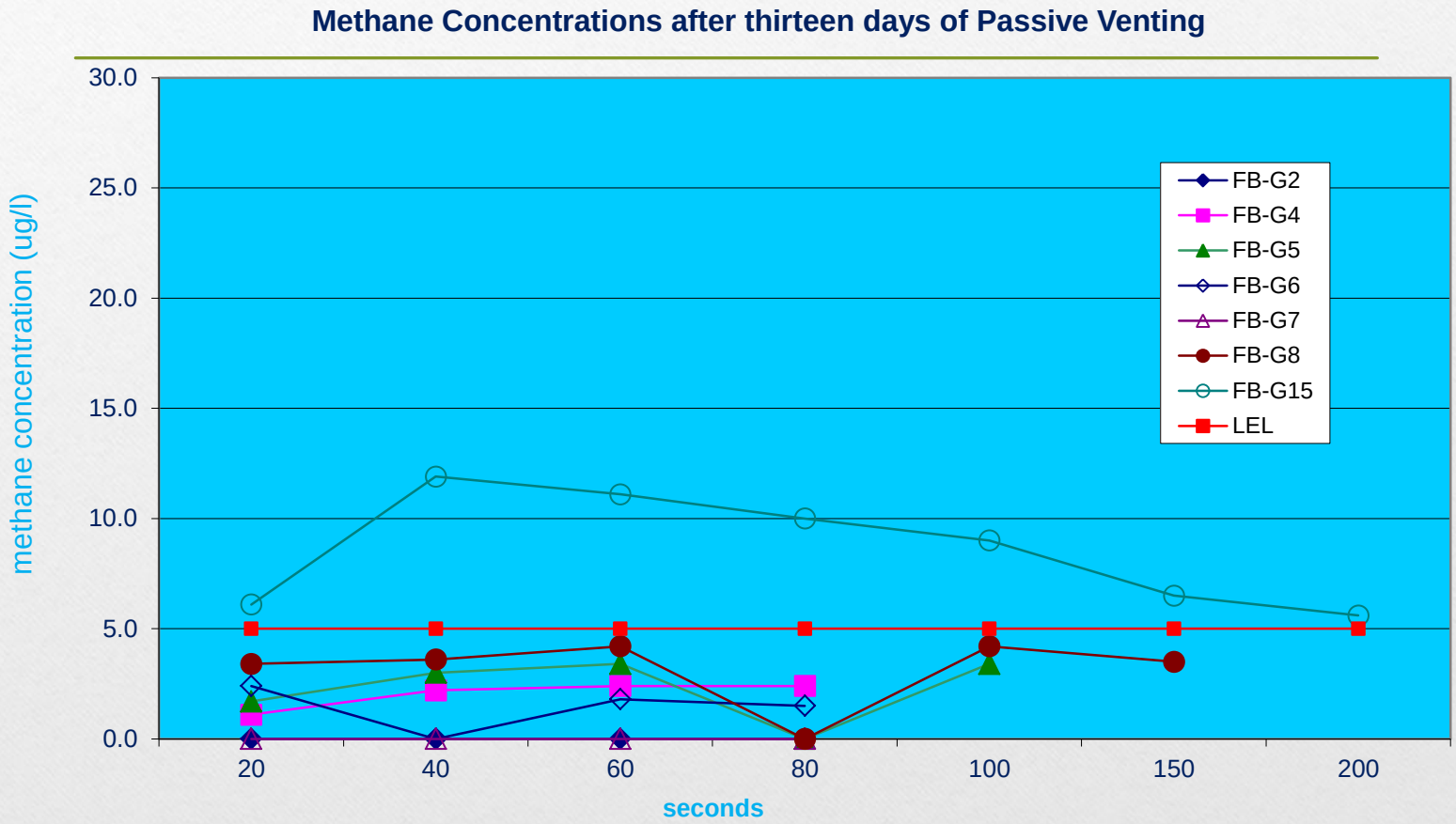




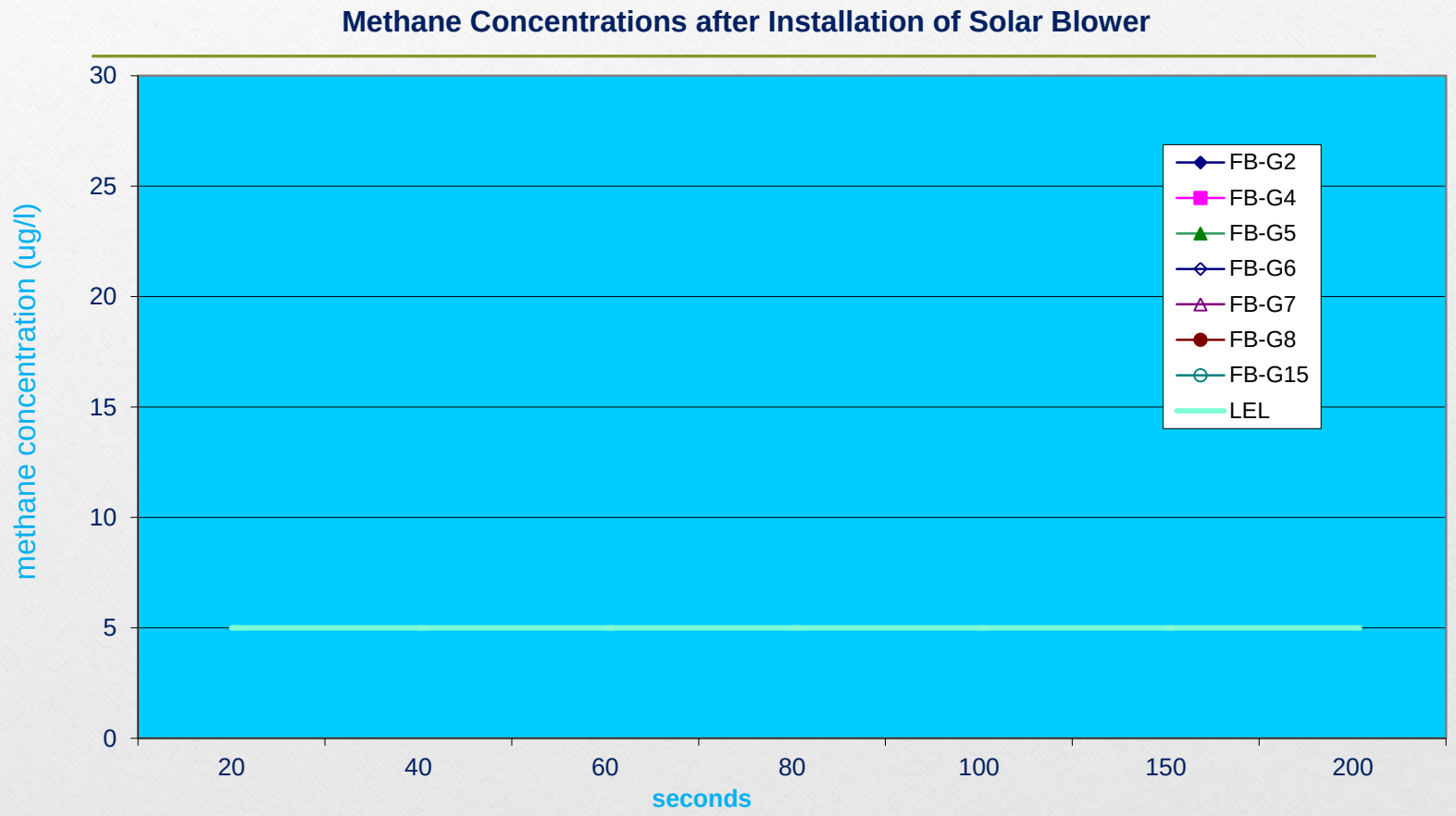




Methane concentrations prior to installation of solar blower.

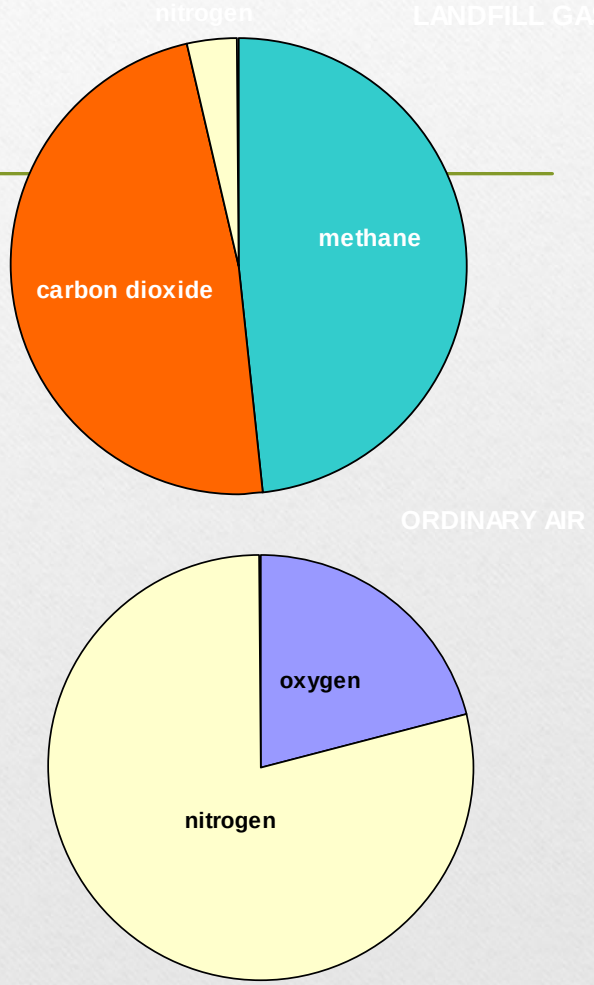


Methane concentrations after installation of solar blower.



Basic Elements

- Primary components of landfill gas are
  - methane (40-60%),
  - carbon dioxide (40-60%) and
  - nitrogen (2-5%)
- Primary components of ordinary air are
  - oxygen (21%) and
  - nitrogen (78%)

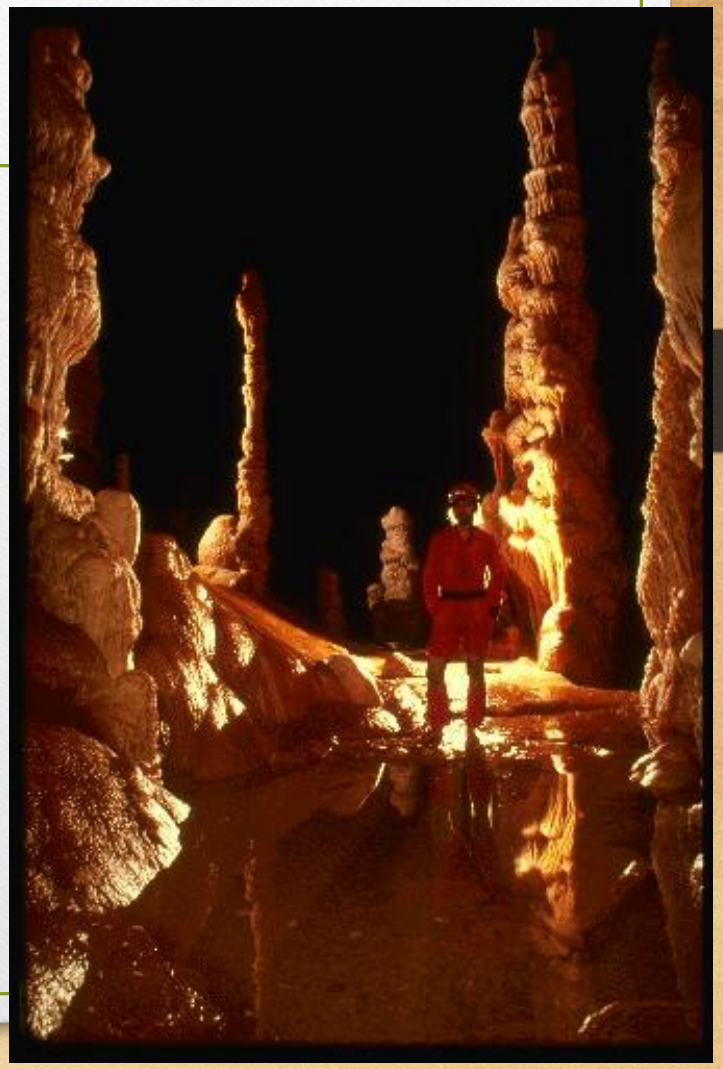


Basic Physics

- Landfill gas and ordinary air are mechanical (not chemical) mixtures. Mixture density is related to the proportion of components present.
- Since methane is less dense (.55x), and carbon dioxide is more dense (1.5x) than ordinary air, methane-rich landfill gas mixtures, where $CH_4/CO_2 > 1$, will be less dense than air.

How does this influence Landfill Gas Transport in Karst?

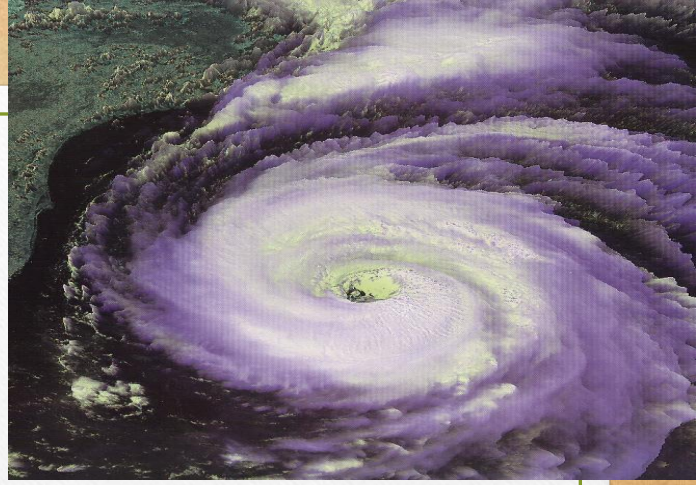
- Once gas has seeped into the subsurface, methane's lighter density relative to air promotes transport of methane rich gas mixtures to high points in the void network.
- A porous connection with the soil overburden at these high points can result in surface impacts observed some distance from the source.



How do you know?

- Monitoring networks, installed in the soil overburden, provide the data that demonstrate offsite gas distributions and the effectiveness of the bedrock void gas vents.
- Monitoring has shown that accessing the voids and venting gas to the surface can short-circuit the migration mechanism and remediate offsite impacts.

Like a Hurricane!



- As the previous case studies illustrated, the passing of tropical storms Dennis and Floyd in September 1999 coincided with a drastic off-gassing of the bedrock vents and subsequent reduction of gas levels observed in the near subsurface.
- These significant barometric pressure drops resulted in corresponding increases in the volume of the gas in the voids. Vents installed during the summer of 1999, promoted mobilization and enabled the release of this increased gas volume.

What's the weather like down there?

- Atmospheric barometric pressure increases result in volume decreases in pockets of landfill gas in karst voids (Boyle and Mariotte's Law, i.e., air and all gases are compressible).
- Conversely, barometric pressure decreases results in volume increases.

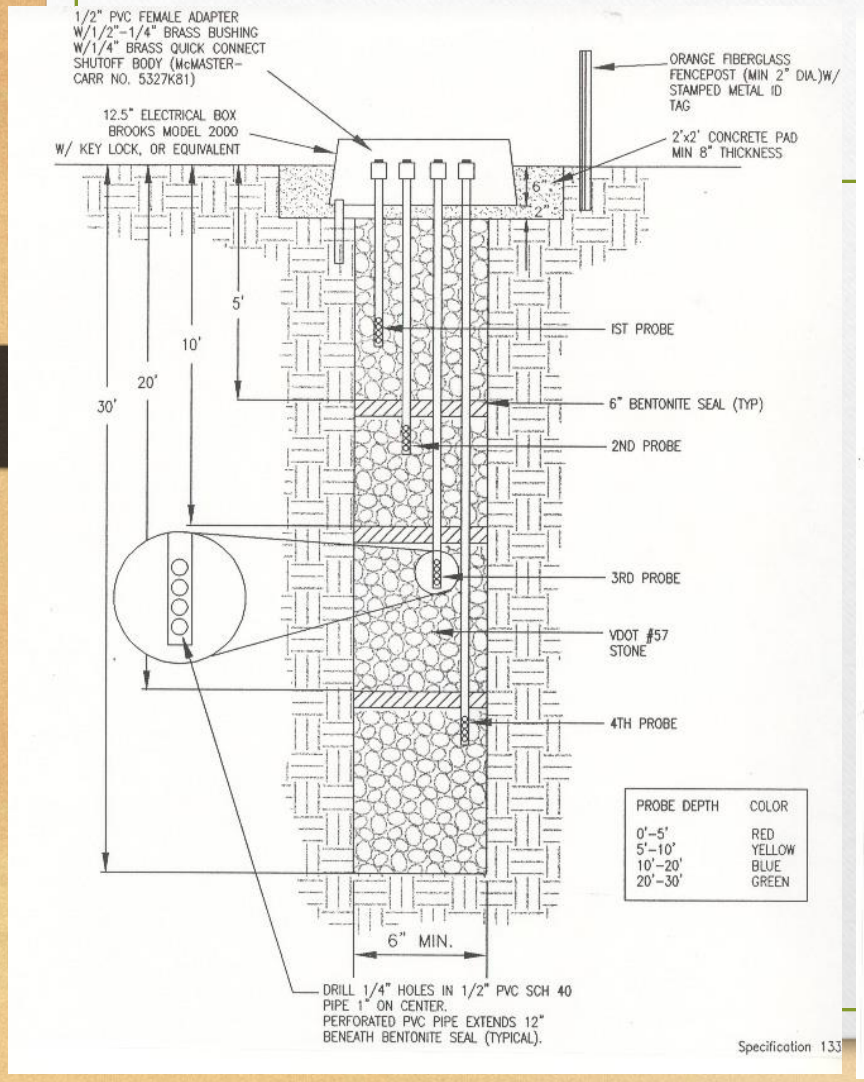
What remains after the storm?

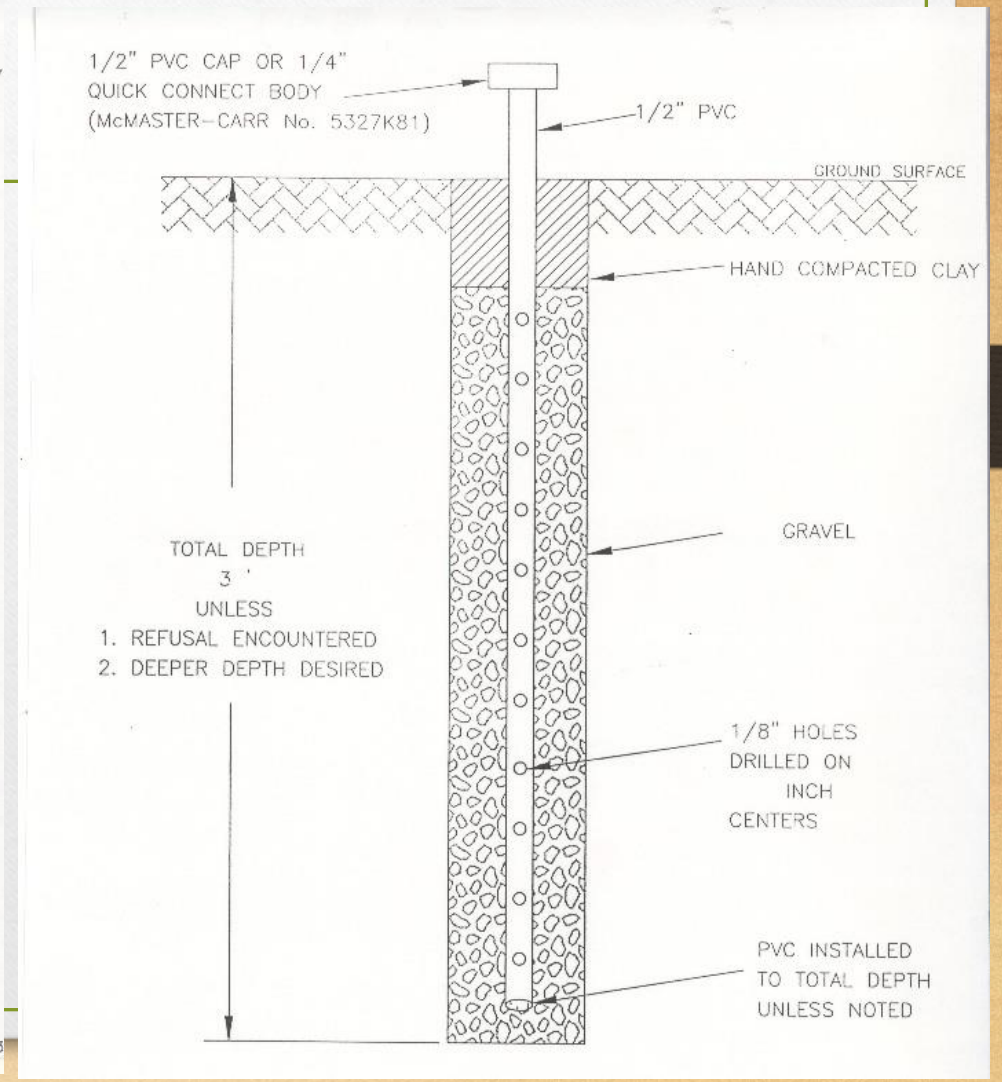
- Although the success of the passive bedrock void vents was remarkable, offsite landfill gas impact remained at several locations.
- As observed prior to bedrock void vent installation, methane levels remaining in the soil overburden appeared to vary with the passing of each pressure system.

Isolated zones?

- Electric and solar power blowers subsequently installed at each bedrock vent were successful at remediating remaining impacts.
- *Important note:* Offsite gas existing in the karst soil overburden is not remediated by the venting of gas directly from the soil to the ground surface, but rather by the influx of fresh air in from the surface.

Nested & direct-push probes





Direct-push gas probe

System Installation Costs

Washington Co LF

- 1994 - 15 nested wells installed at property boundary - $15,000.
- 1998 - 31 probes offsite - $3800.
- 1999 - 28 probes offsite - $2600.
- 1999 - 4 bedrock void vents - $8800.
- SITE 1 TOTAL = $30,2000

Greeneville/Greene Co LF

- 1998 - 16 probes installed on property - $1200.
- 1999 - 50 probes offsite in 4 phases - $8000.
- 1999 - 4 bedrock void vents - $7800.
- SITE 2 TOTAL = $17,000

Old Greeneville LF

- June 2006 - 7 probes installed on property - $2000.
- July 2006 - 16 probes offsite - $2000.
- August 2006 - 2 bedrock void vents - $7200.
- SITE 3 TOTAL = $11,200

Identifying and venting landfill gas that has migrated into open cavity and fissure networks situated beneath karst landfills is an easy remedial response to help facilities control landfill gases.

Controlling landfill gas that has migrated into open cavity and fissure networks situated beneath karst landfills can also be an easy remedial response to help facilities control low level organic groundwater impacts.

ASTM WK9184*

New Guide for Identifying Landfill Gas Impacts to Groundwater at MSW Landfill Facilities

*** Work item under development (initiated in 2005).**

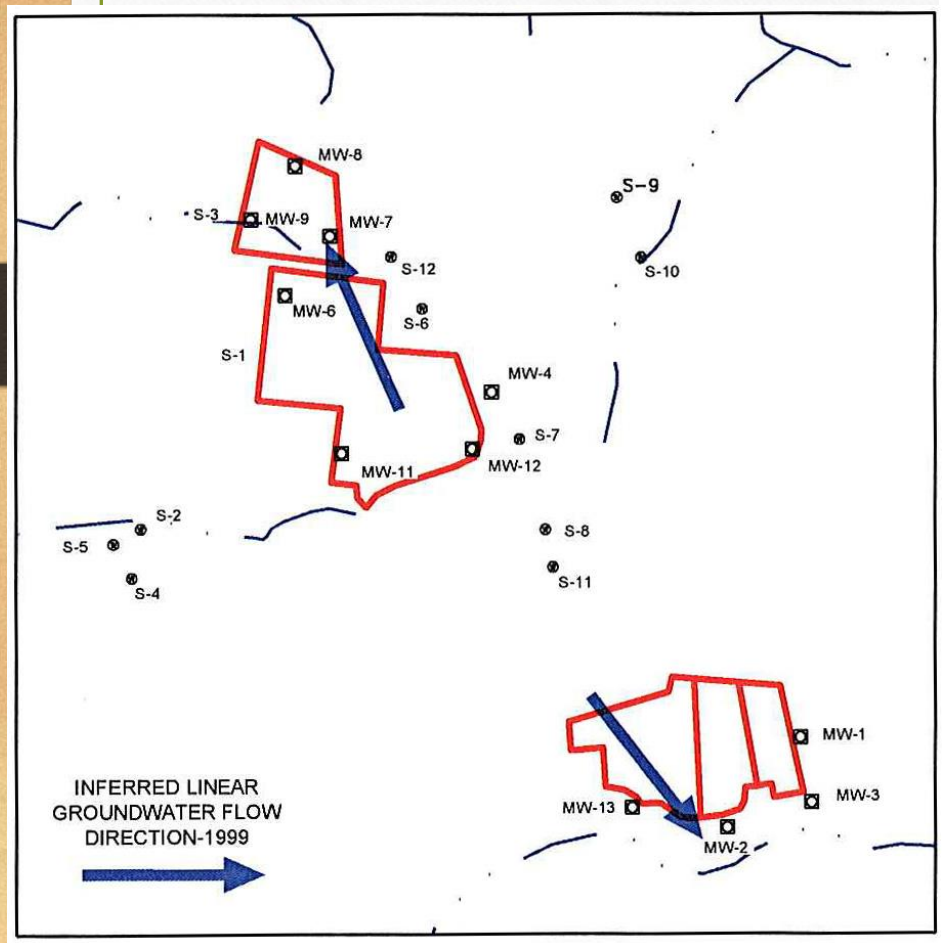
Offsite Karst Transport Gas and Groundwater

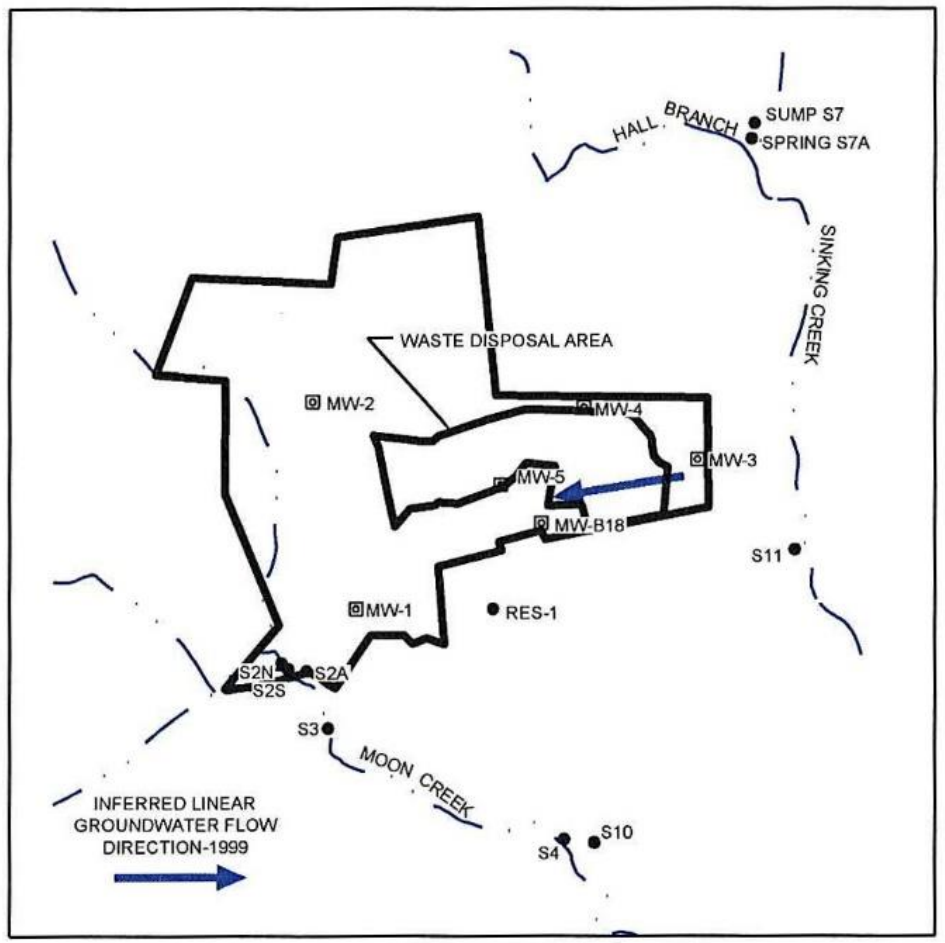
- Three prior gas migration case studies show offsite impacts resulting from landfill gas transport via the karst void network and remediation via void vents.
- The following groundwater case studies show offsite impacts resulting from complex radial groundwater flow from karst landfills, an often shared phenomena with karst void gas transport sites.

Radial groundwater flow from karst landfills

- Misinterpretations of groundwater flow directions and contaminant transport often result from information that is confined to the landfill property. Monitoring techniques utilizing existing offsite spring and well networks enable a better understanding of the distribution and migration of landfill groundwater impacts.
- Topic previously presented at the 2005 TDEC Environmental Conf. & 2006 NGWA AGWSE Conference in San Antonio.
- Published in Sinkholes and the Engineering and Environmental Impacts of Karst, Beck (ed) © 2005 ASCE. Geotechnical Special Publication No. 144, ISBN 0-7844-0796-7.
- Presented at the Tenth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karsts in 2005.

Linear Flow Interpretations

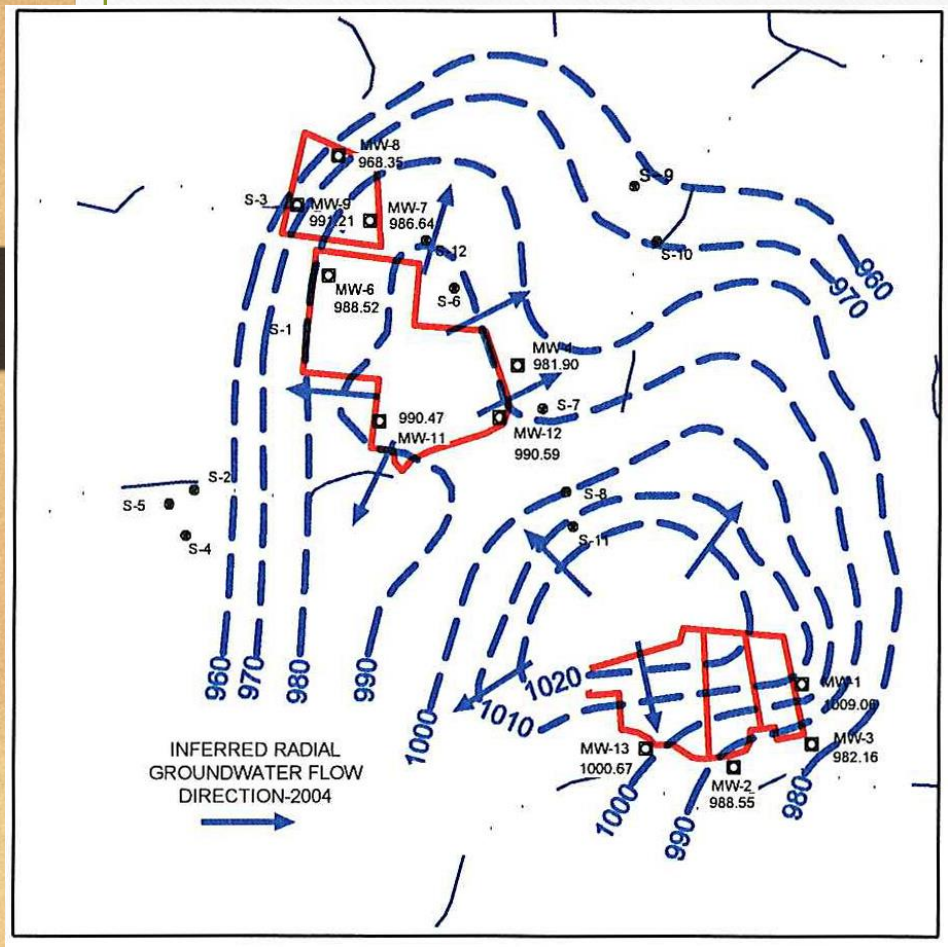


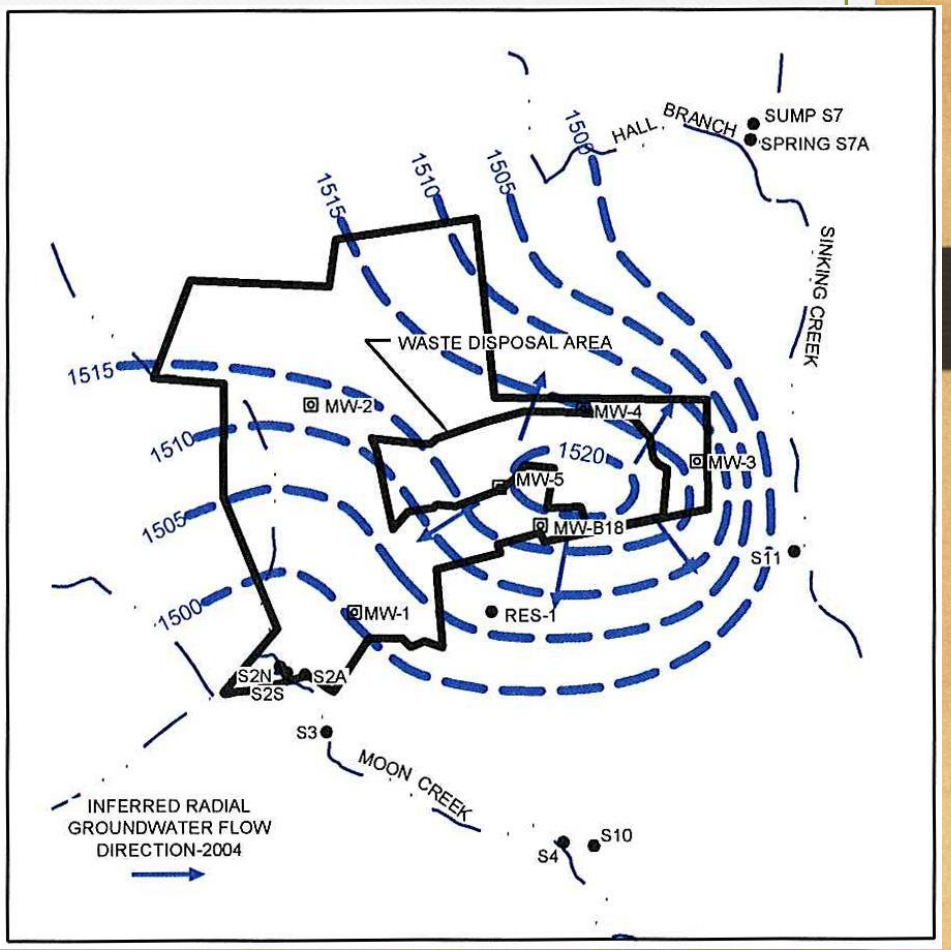


SEVIER

GREENEVILLE

Radial Flow Interpretations





SEVIER

GREENEVILLE

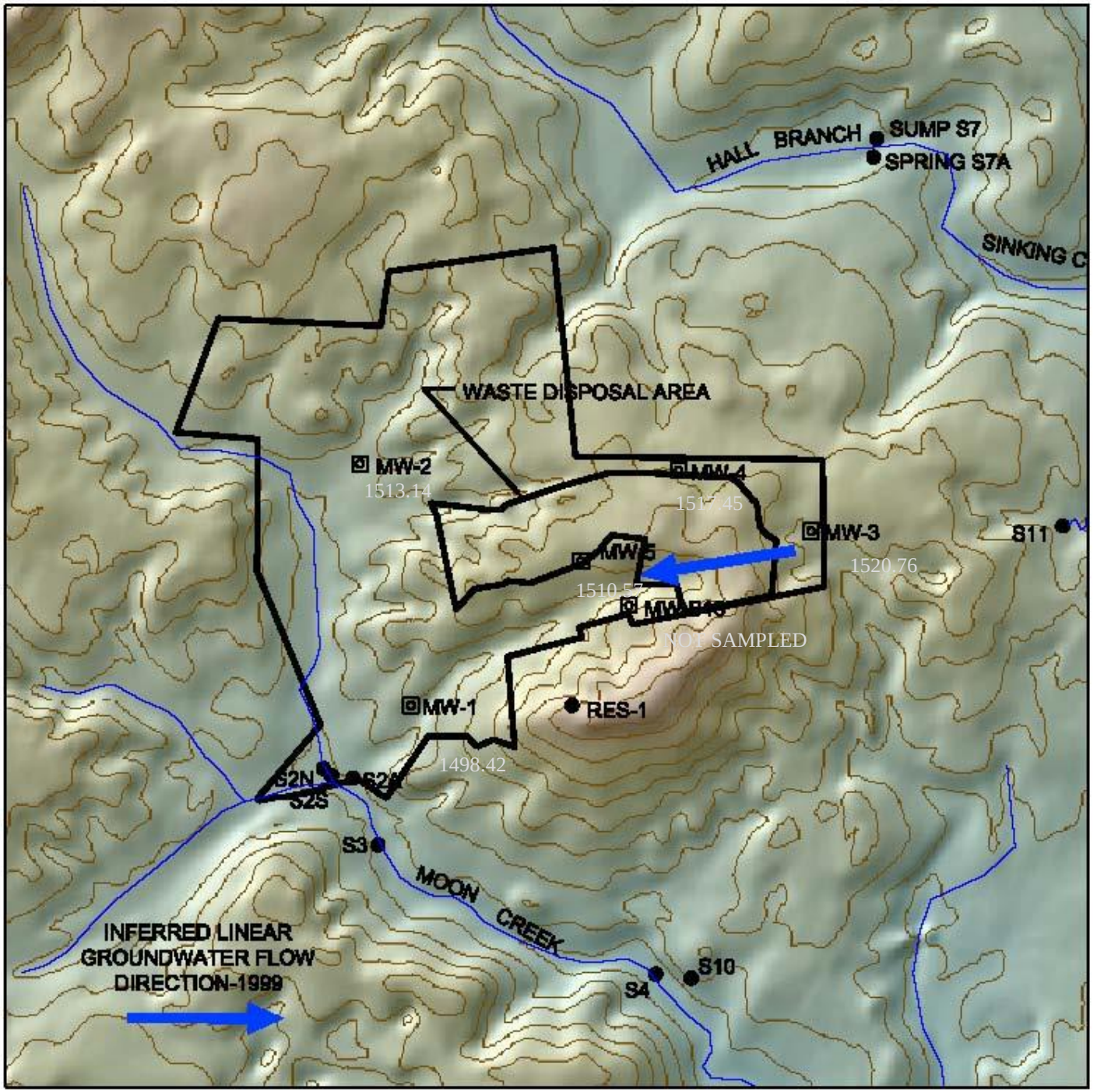
Greeneville/Greene County Landfill

Located in eastern Tennessee, west of the Blue Ridge and north of the Smokey's, with Greene Mountain & Appalachian Trail visible from the site, looking south across the Nolichucky River valley.

Greeneville
Linear flow

Upgradient well
MW-3
most impacted
Why?

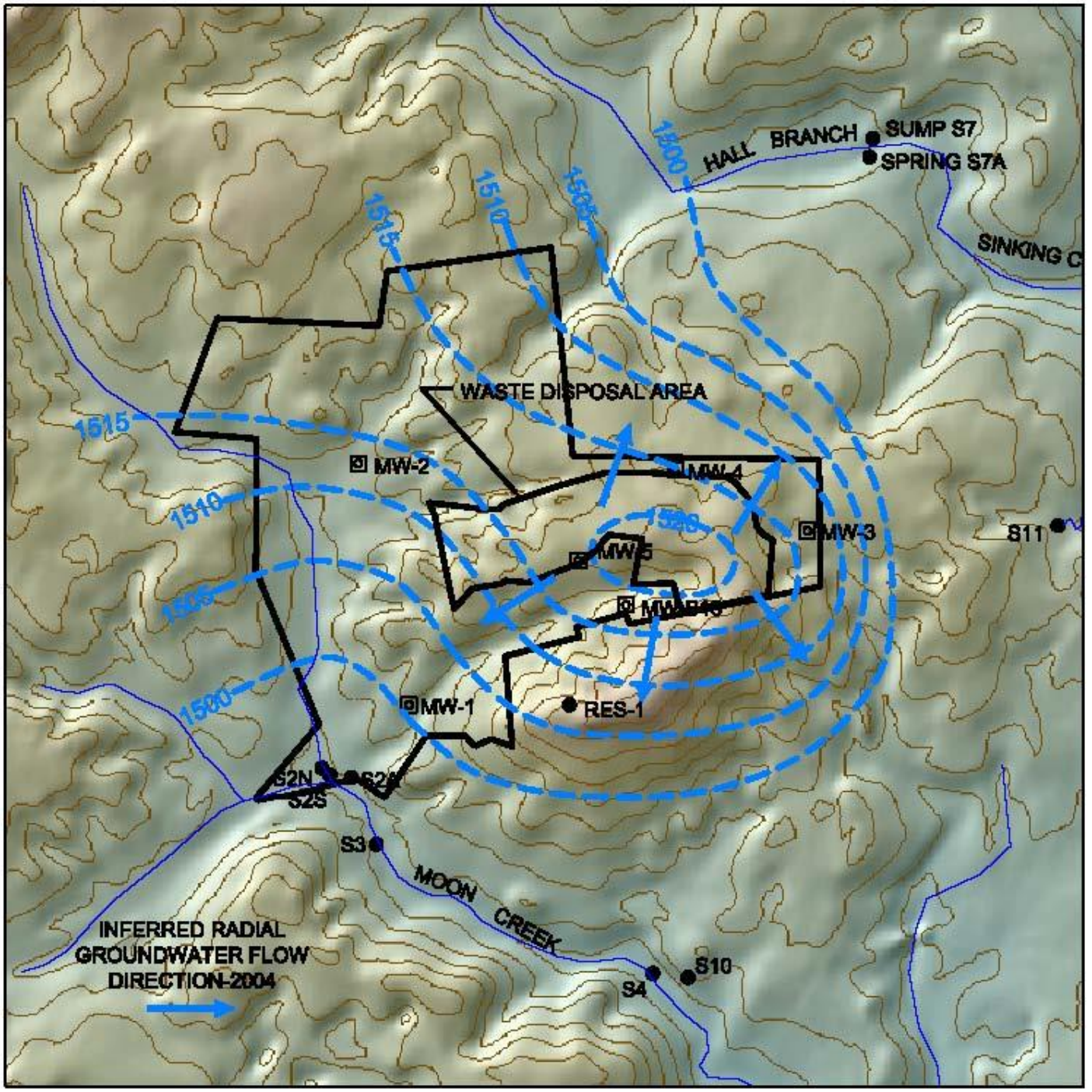
Radial flow

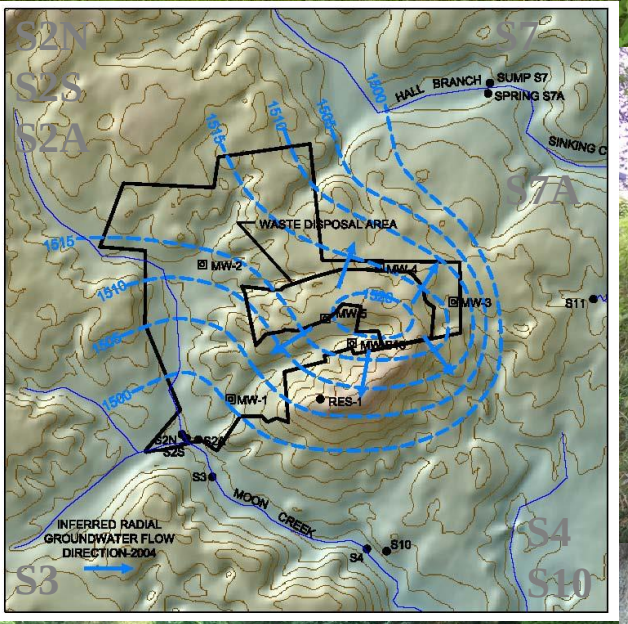


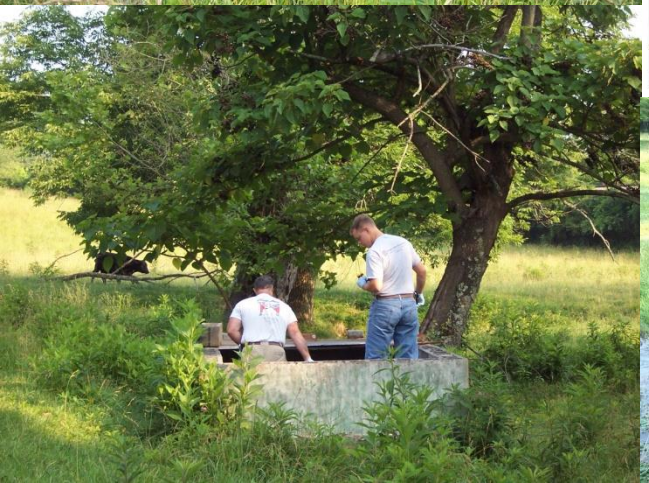
Greeneville Radial flow

Confirmed with Nine Impacted Springs:

S2N
S2S
S2A
S3
S4
S10
S11
S7
S7A



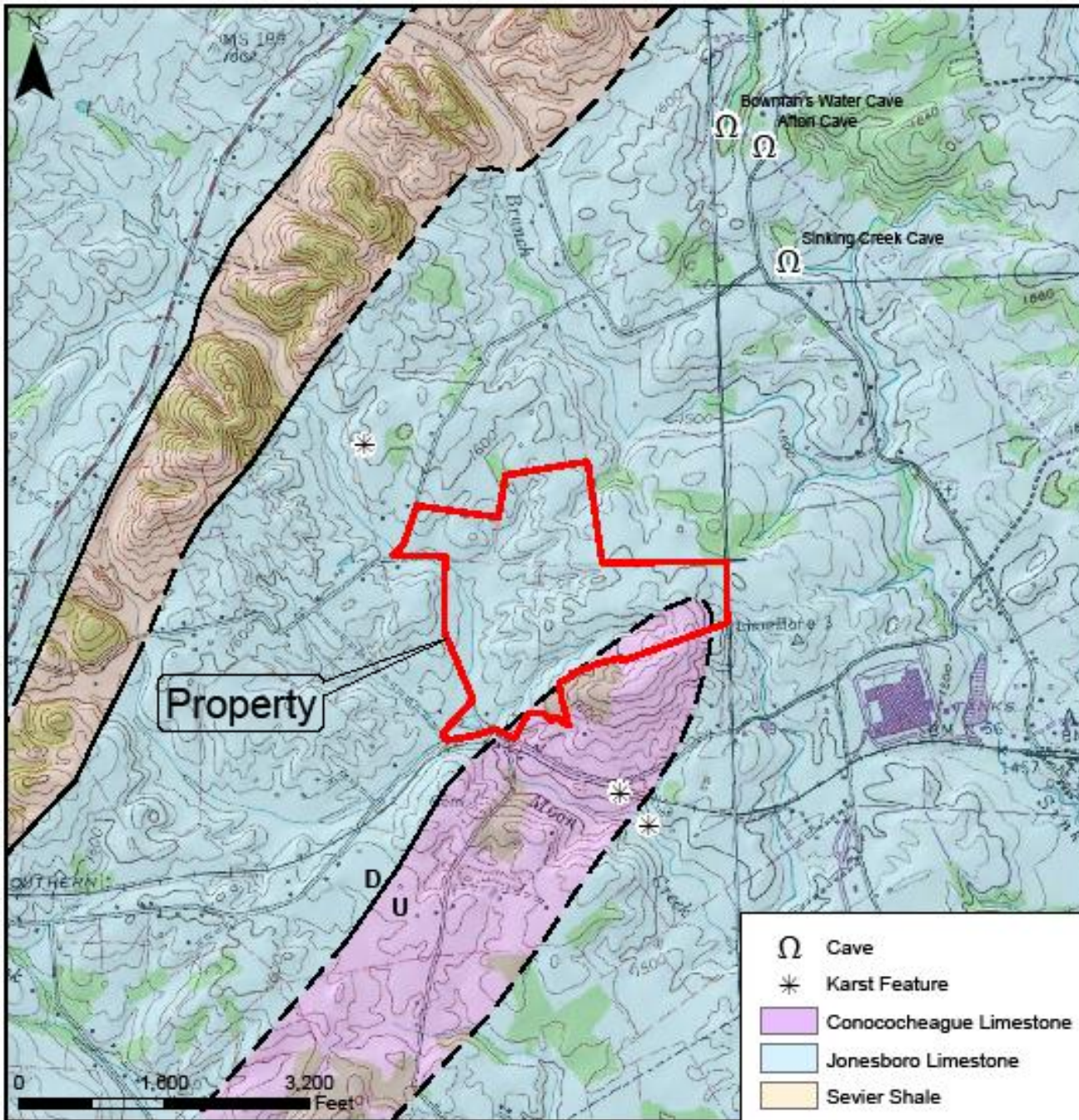

S2N
S2S
S2A
S7
S7A
S4
S10
S3
HALL BRANCH
SUMP S7
SPRING S7A
SINKING C
WASTE DISPOSAL AREA
MW-2
MW-4
MW-3
MW-5
MW-6
MW-1
RES-1
S11
S2N
S2S
S2A
S3
MOON CREEK
S4
S10
INFERRED RADIAL
GROUNDWATER FLOW
DIRECTION-2004
1515
1510
1505
1500
1520
1525



Greeneville Geology

Jonesboro and Conococheague Limestones

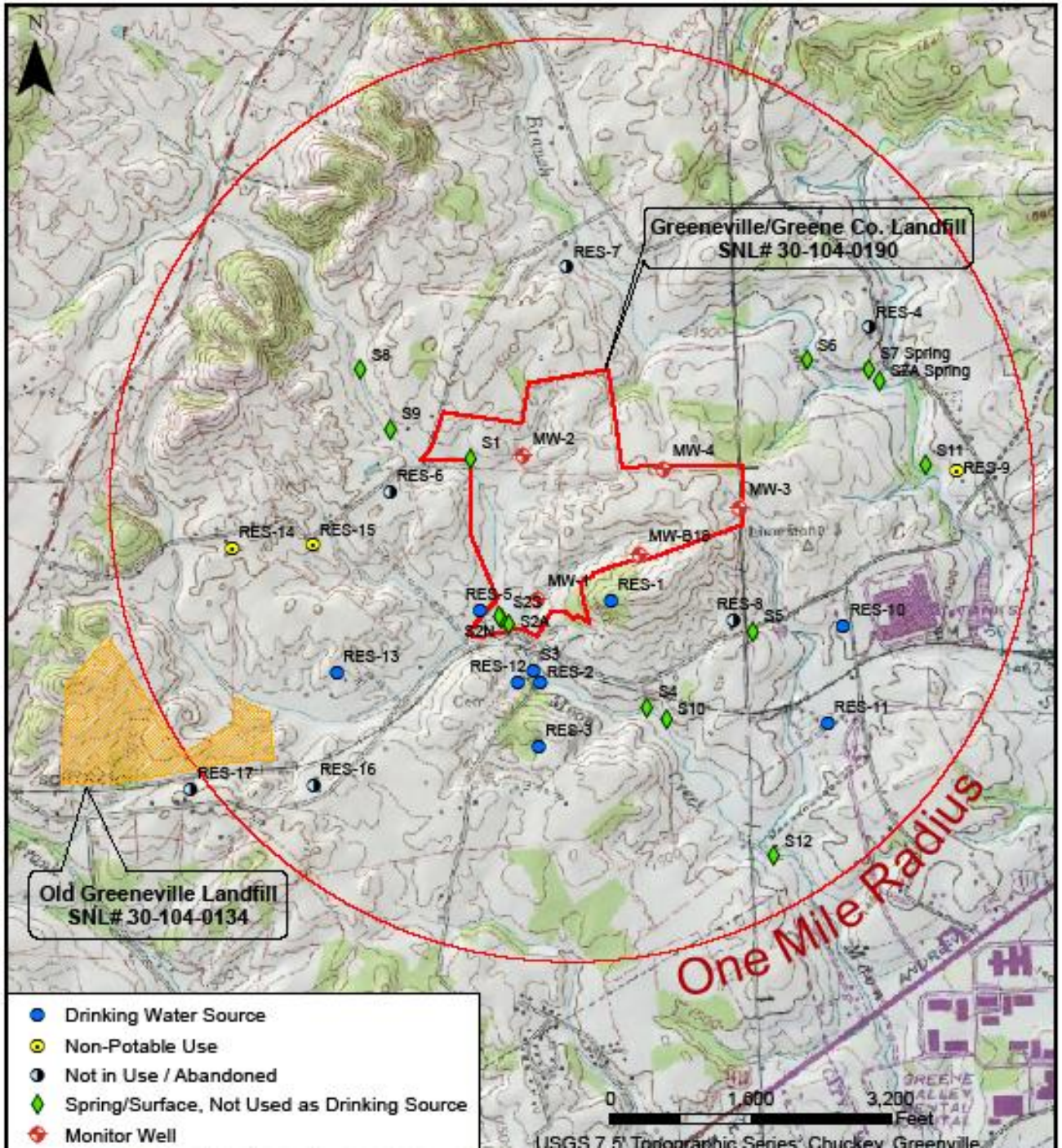
Northeast plunging anticline



Greeneville LF

2006 Mile Radius Drinking Water Well and Spring User Survey

18 private wells
9 potable use,
3 non-potable use,
6 abandoned
(not in use).



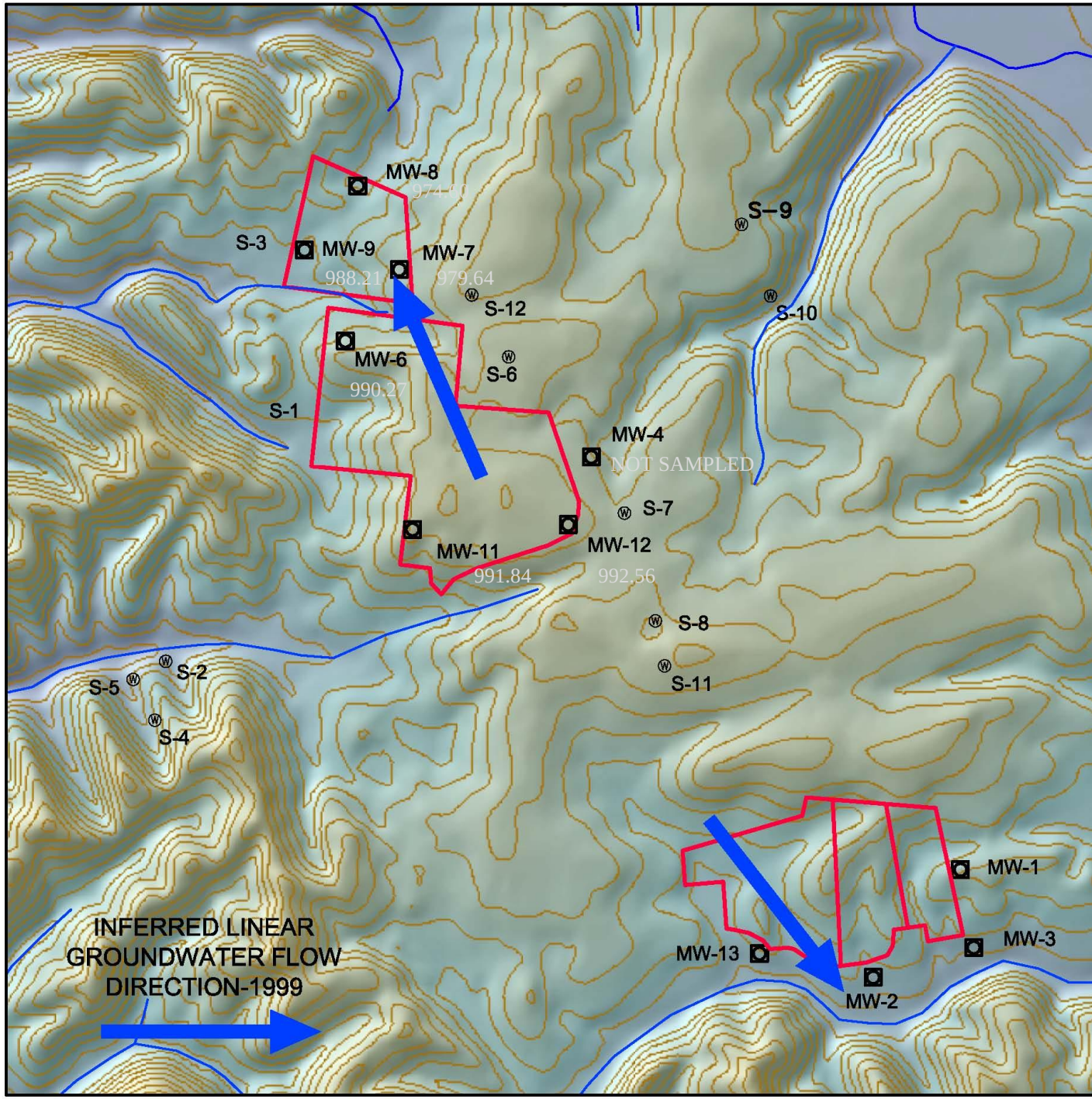
Sevier Solid Waste Landfill

Located in eastern Tennessee, west of the Smokey's, with Mt LeConte & Appalachian Trail visible from the site, looking west towards Gatlinburg.

Sevier
Linear flow

Upgradient well MW-11, impacted. Replaced by MW-12, impacted. Why?

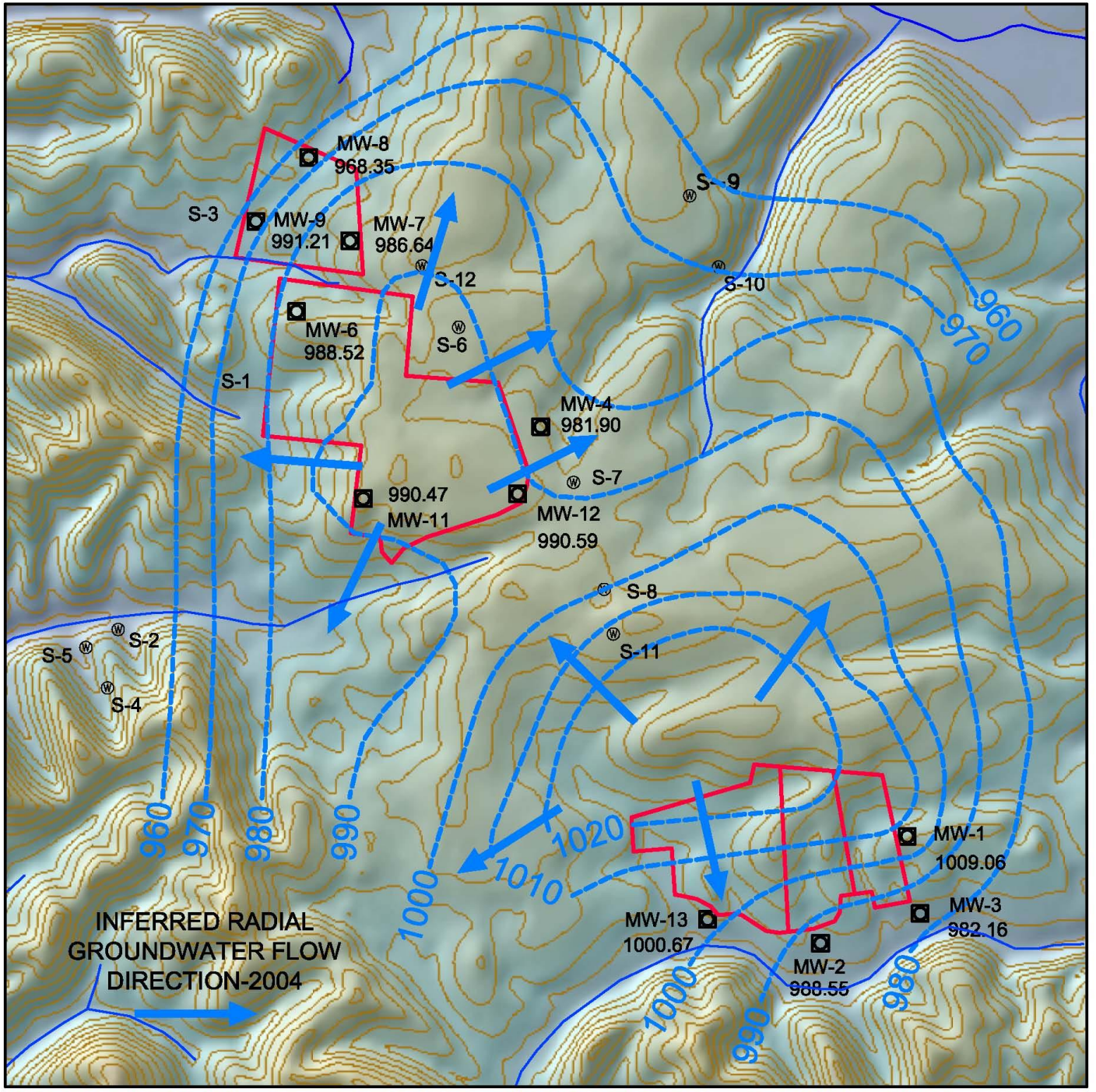
Radial flow



Sevier
Radial flow

Confirmed with five impacted offsite locations:

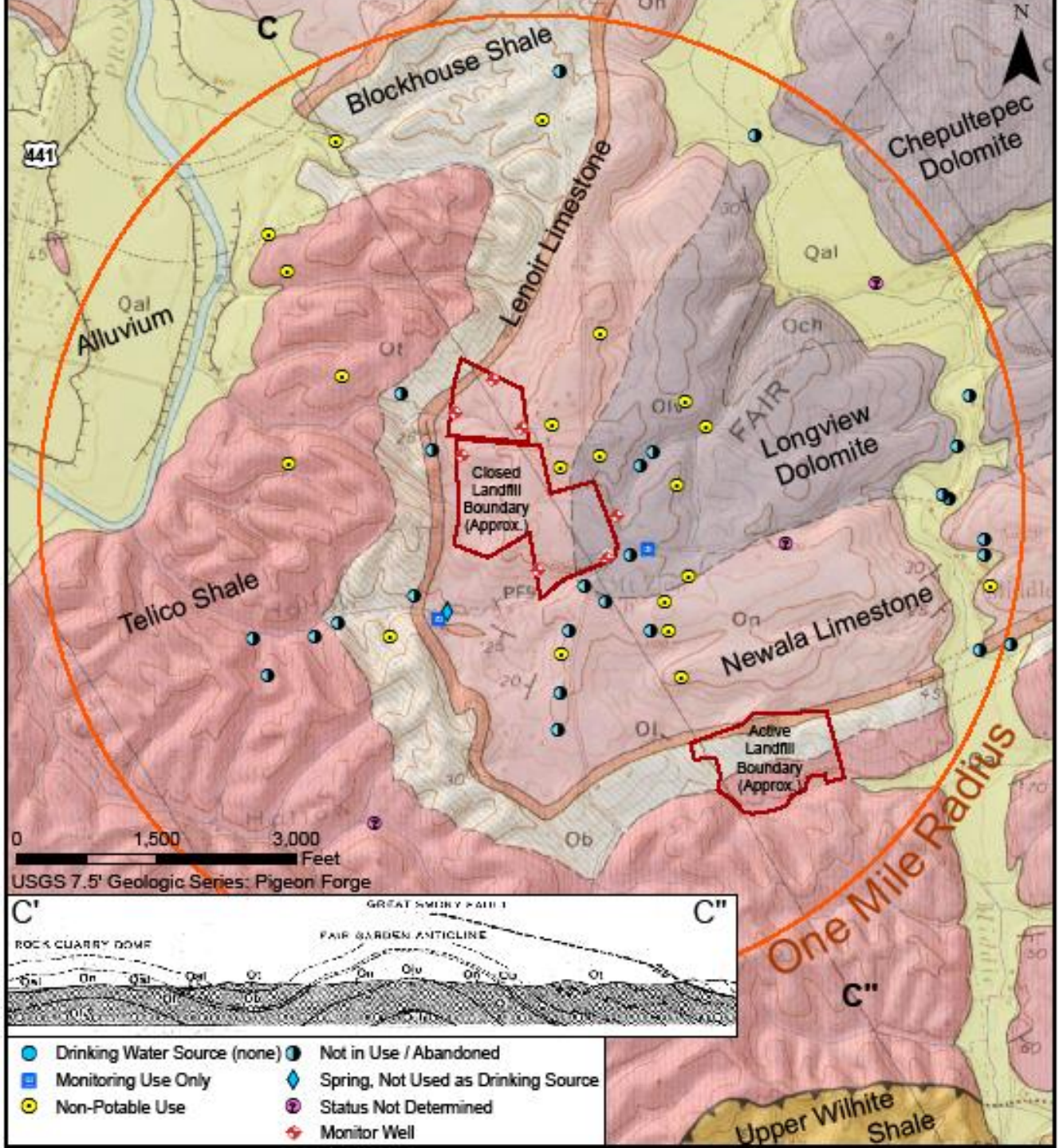
S-2
S-5
S-6
S-10
S-12



Sevier Geology

Lenoir and Newala Limestones

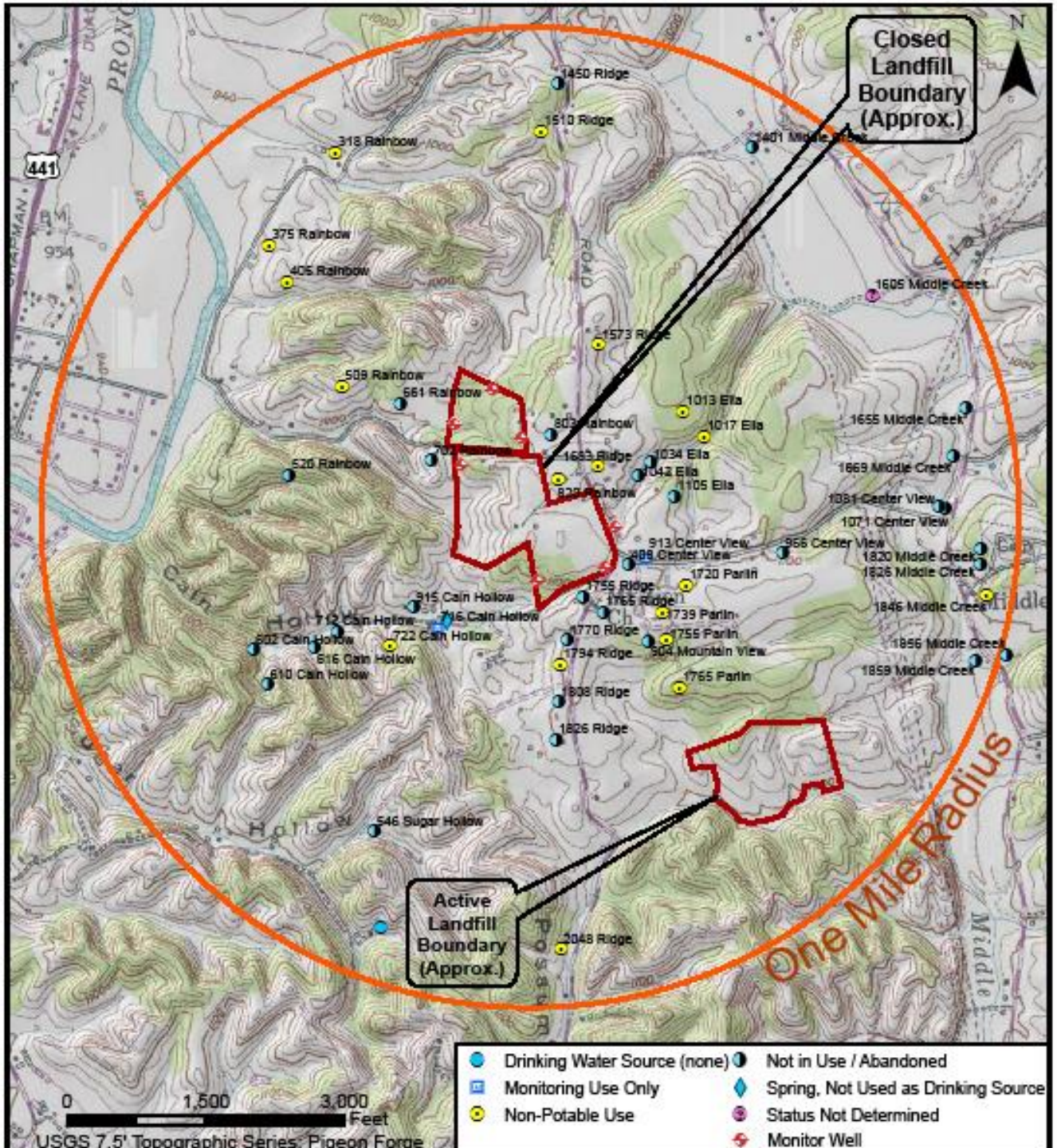
Southwest plunging Fair Garden Anticline

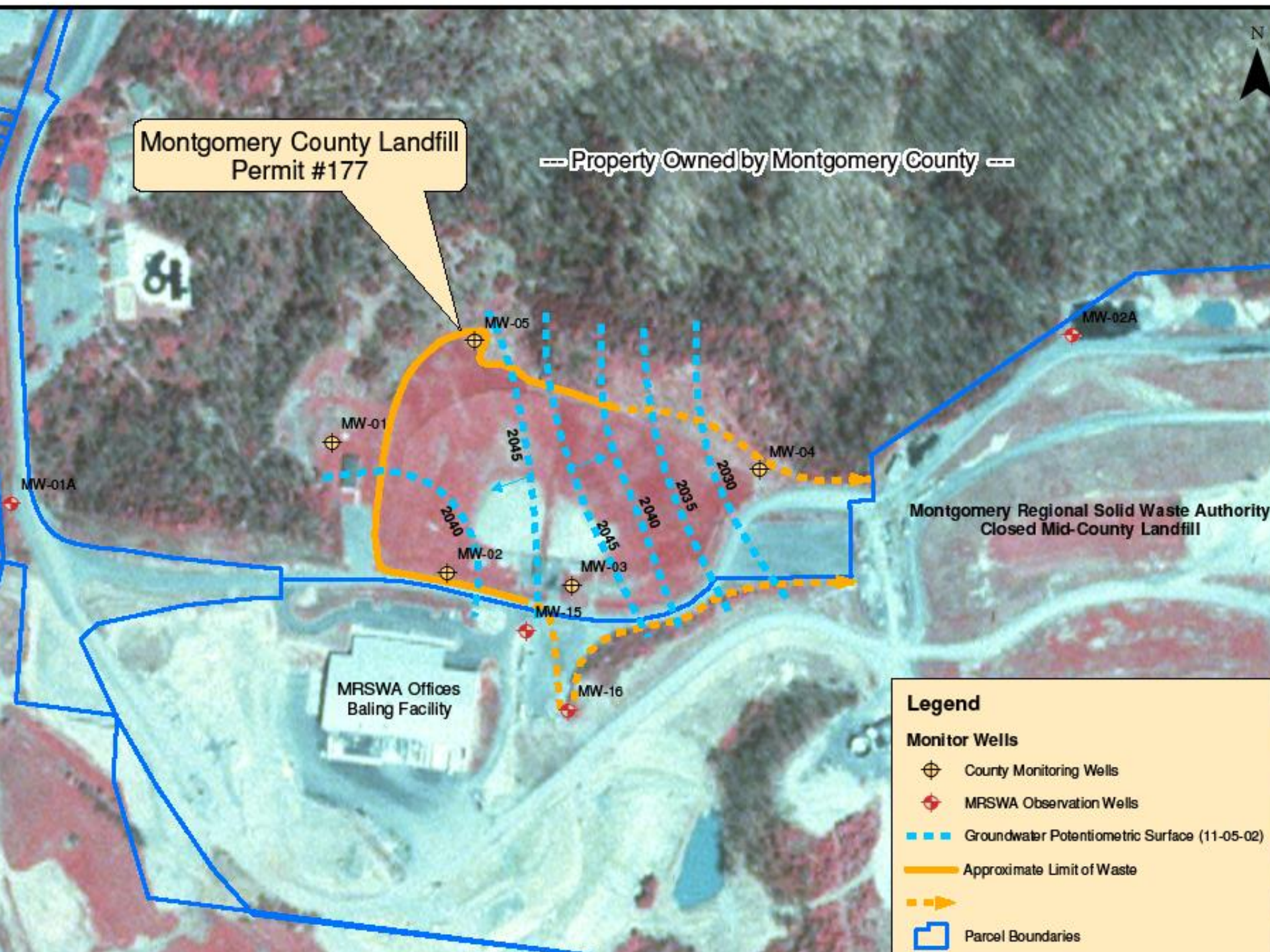


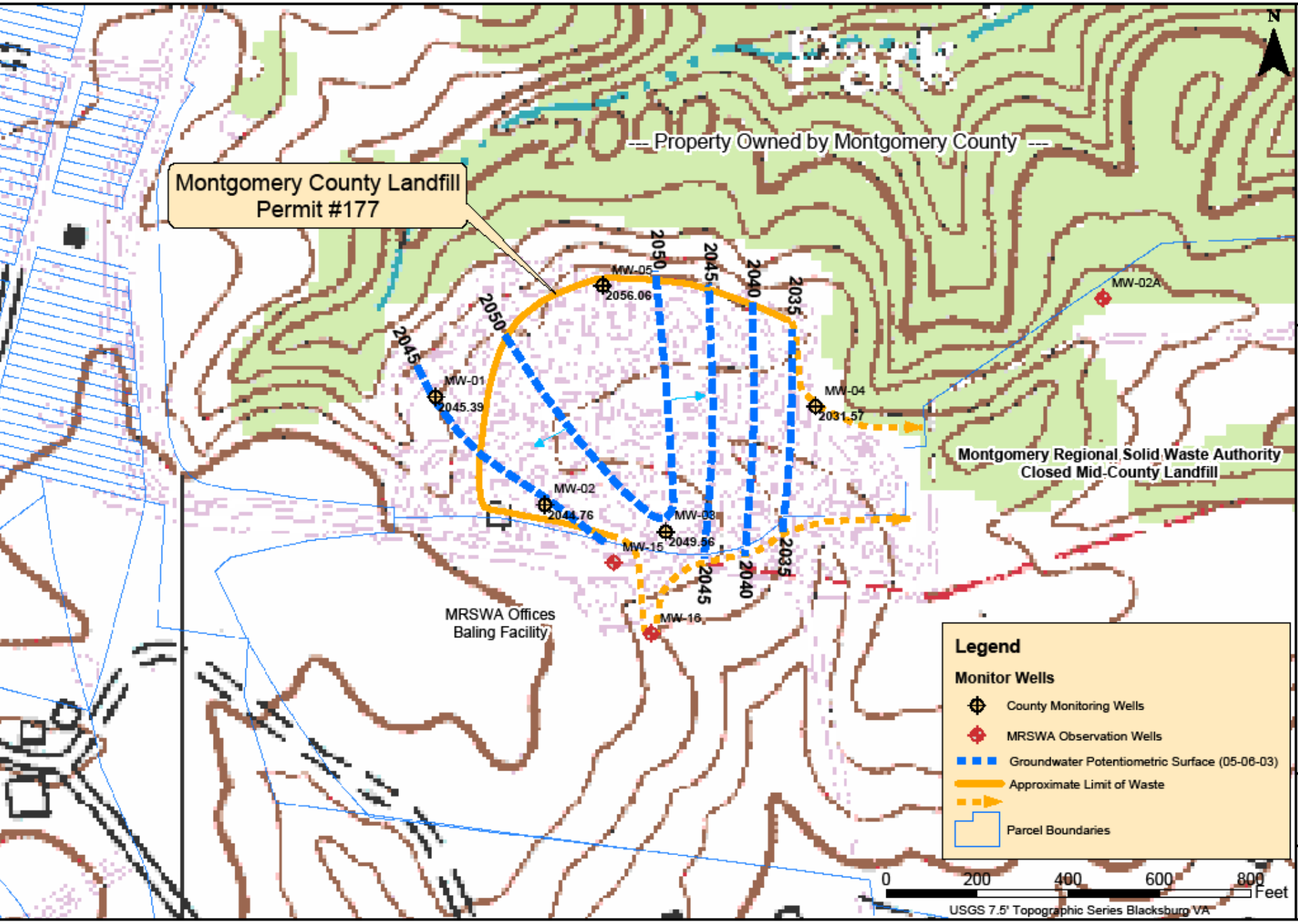
Sevier LF

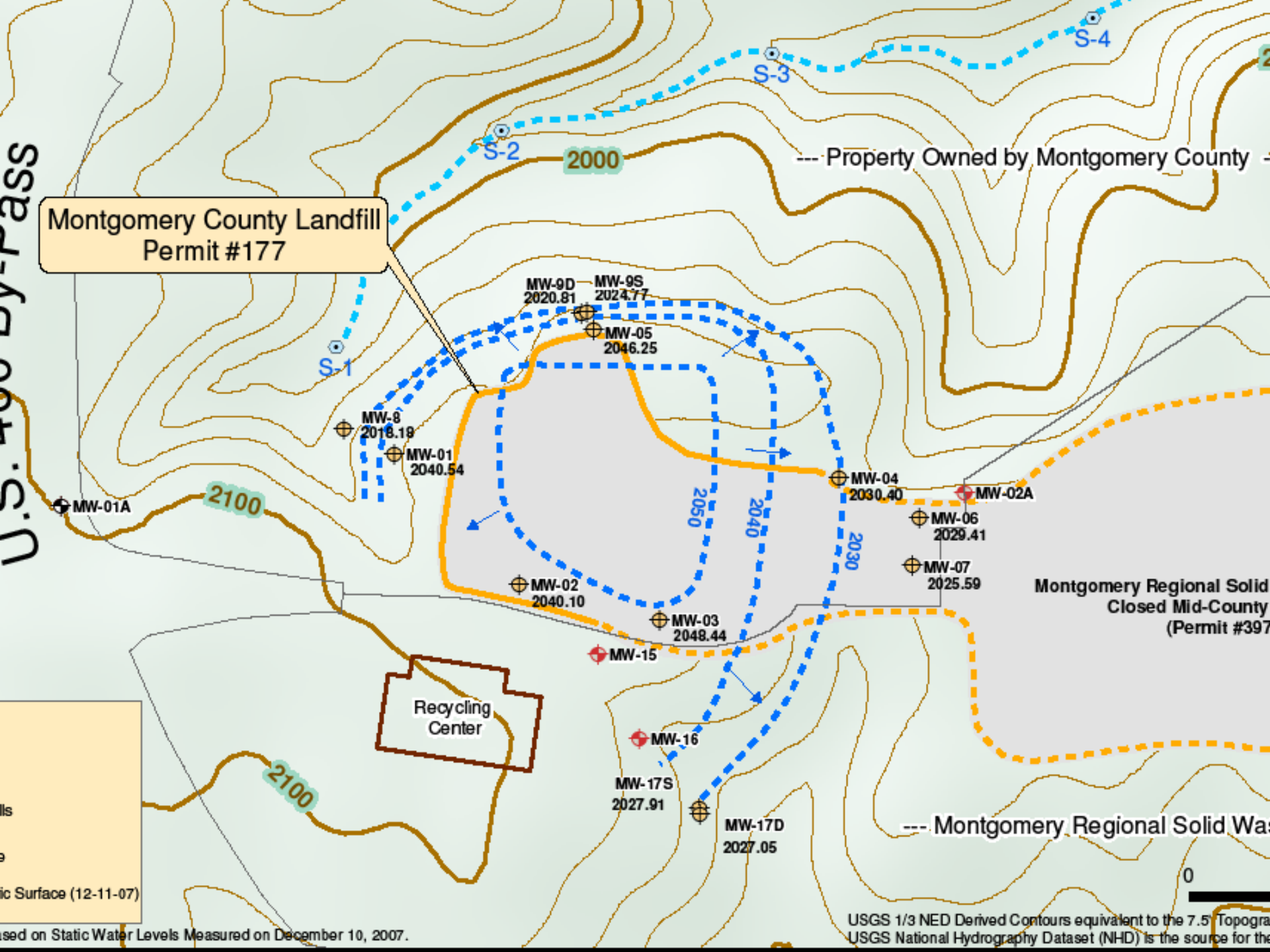
2007 Mile Radius Drinking Water Well and Spring User Survey

~40 private wells
18 non-potable use
>30 abandoned (not in use), only 1 potable use.




Montgomery County Landfill
Permit #177
--- Property Owned by Montgomery County ---
N
MW-05
MW-01
MW-01A
MW-02
MW-03
MW-04
MW-02A
MW-15
MW-16
2045
2040
2045
2040
2035
2030
Montgomery Regional Solid Waste Authority
Closed Mid-County Landfill
MRSWA Offices
Baling Facility
Legend
Monitor Wells
County Monitoring Wells
MRSWA Observation Wells
Groundwater Potentiometric Surface (11-05-02)
Approximate Limit of Waste
Parcel Boundaries


N
--- Property Owned by Montgomery County ---
Montgomery County Landfill
Permit #177
2050
2045
2040
2035
MW-05
2056.06
MW-02A
MW-01
2045.39
MW-04
2031.57
Montgomery Regional Solid Waste Authority
Closed Mid-County Landfill
MW-02
2044.76
MW-03
2049.56
MW-15
MW-16
MRSWA Offices
Baling Facility
Legend
Monitor Wells
County Monitoring Wells
MRSWA Observation Wells
Groundwater Potentiometric Surface (05-06-03)
Approximate Limit of Waste
Parcel Boundaries
0
200
400
600
800
Feet
USGS 7.5' Topographic Series Blacksburg VA


Montgomery County Landfill
Permit #177
--- Property Owned by Montgomery County
U.S. 40 By-Pass
S-1
S-2
S-3
S-4
2000
2100
2100
2050
2040
2030
MW-9D
2020.81
MW-9S
2024.77
MW-05
2046.25
MW-8
2018.19
MW-01
2040.54
MW-01A
MW-04
2030.40
MW-02A
MW-06
2029.41
MW-07
2025.59
MW-02
2040.10
MW-03
2048.44
MW-15
MW-16
MW-17S
2027.91
MW-17D
2027.05
Recycling
Center
Montgomery Regional Solid
Closed Mid-County
(Permit #397
--- Montgomery Regional Solid Was
ic Surface (12-11-07)
ased on Static Water Levels Measured on December 10, 2007.
0
USGS 1/3 NED Derived Contours equivalent to the 7.5' Topogra
USGS National Hydrography Dataset (NHD) is the source for the

Thank You – Enjoy the rest of the Conference

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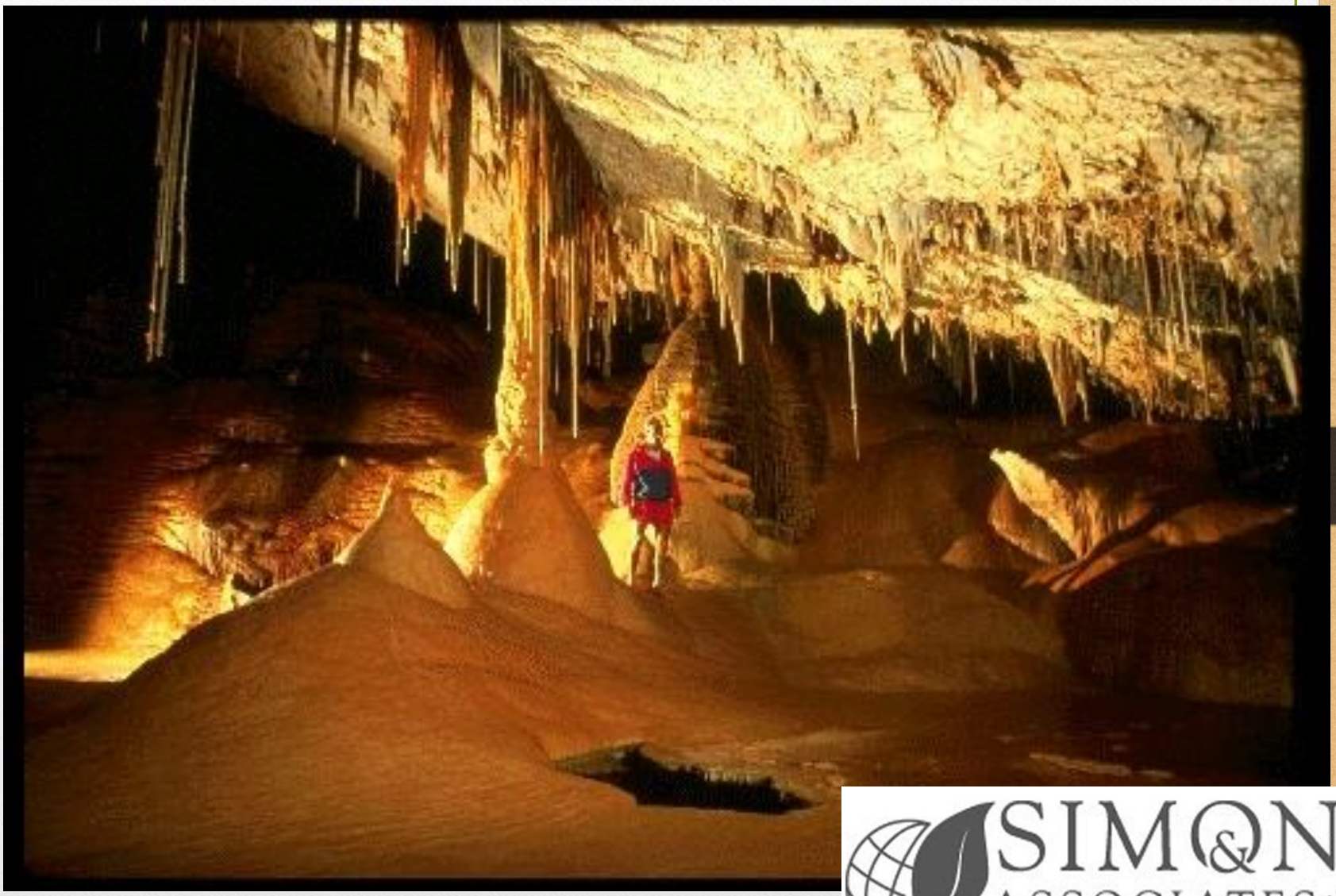

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