Designing for a Zero-Leak Containment Facility

Instructors:
Parts 1&3: Abigail Gilson, M.S., P.E., TRI Environmental, Inc.
Part 2: Jeff Blum, Weaver Consultants Group

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Short Course Timeline

- Part 1: 1:00-2:30 pm CST
- 10-Minute Break
- Part 2: 2:40-3:40 pm CST
- 10-Minute Break
- Part 3: 3:50-4:50 pm CST

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Designing for a Zero-Leak Containment Facility

- The zero-leakage goal is extremely unlikely without Electrical Leak Location (ELL)
- ELL will locate actual leaks at the time of the test
  - almost always after construction and before service life
- Leaks can still develop in time
- Some facilities impossible to effectively test using ELL after they are put into service
- Zero-leakage goal must incorporate:
  - Specifying ELL for short term leakage (Part 1)
  - Good CQA practices for long-term leakage (Jeff Blum, Part 2)
- Part 3: Designing for a target leakage rate (zero?)

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Part One: The Physics of Electrical Leak Location (ELL) Testing Methods

And How to Maximize Method Effectiveness

Presented By:
Abigail Gilson, M.S., P.E.

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Significance of ELL

"All installed geomembrane liners should be subjected to electric leak location survey."

-J.P. Giroud, Geosynthetics 2013 Panel Discussion

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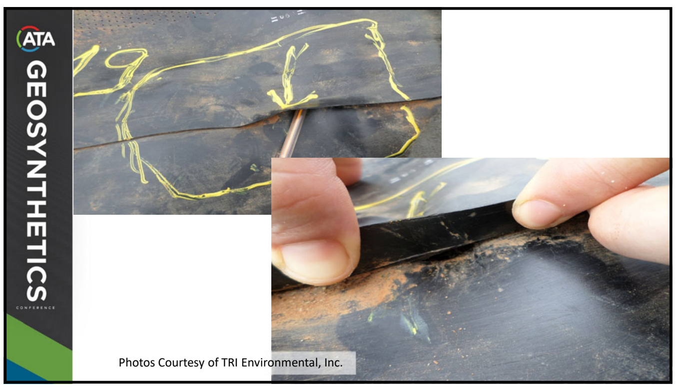

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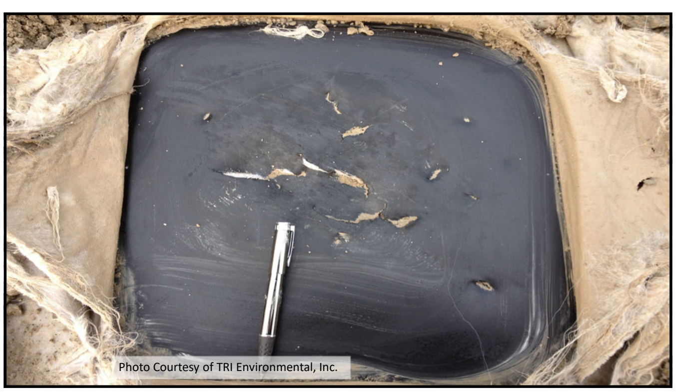
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Significance of ELL

"Many problems have been found by ELL surveys that would never have been located any other way, and this is even with good installers and good CQA."

-Richard Thiel, 2012

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How it works

- Geomembranes are made of electrically resistive material (polypropylene, polyethylene, polyvinyl chloride, etc.).
- Electricity is applied across geomembrane via a current injector above geomembrane, with current return below geomembrane.
- **Electricity flows through hole(s) in geomembrane.**

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HOW IT WORKS

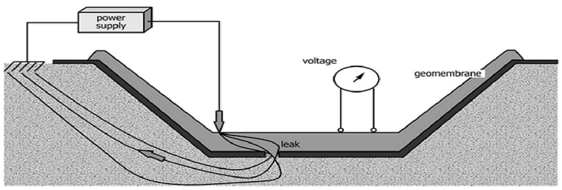

Figure from ASTM D6747

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ASTM Standardized Methods

- Most commonly used and effective methods standardized by ASTM
- Exposed geomembrane standard practices:
  – Water puddle method (ASTM D7002)
  – Water lance method (ASTM D7703)
  – Arc testing method (ASTM D7953)
  – Spark testing method (ASTM D7240)
- Covered geomembrane standard practices:
  – Dipole Method (ASTM D7007 and ASTM D8265)
  – Other electrical methods (ASTM D8265)

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Exposed Geomembrane Methods

- Water-Based Methods (water carries current):
  – Water Puddle Method
  – Water Lance Method
- High Voltage-Based Methods (air carries current):
  – Arc testing method
  – Spark testing method
- Sensitivity very reliable (pinhole leak detection)
- Real-time leak detection (audible alarm – no data collection)
- Extremely operator dependent

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Water Puddle Method (ASTM D7002)

Photo Courtesy of TRI Environmental, Inc.

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Water Lance Method (ASTM D7703)

Photo Courtesy of Weaver Consultants

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Water-Based Exposed Geomembrane Methods

- Tolerant of wet/dirty sites
  - Extensive areas of standing water should be removed, but okay with scattered puddles
- Leak detection depends on water flow THROUGH hole
  - Less effective than high voltage methods on steep slopes/walls
  - Repair patches, etc. may require extended time for water infiltration
- Survey area must feature low spot for applied water
  - Water must not be allowed to flow off of geomembrane
- Water puddle method is fastest exposed geomembrane method (with 2m wide double roller)
- Requires water source and distribution (hoses)

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High Voltage-Based Methods

- Survey area must be clean and dry
  - Moisture causes "false positive" signals, resulting in a lowering of the sensitivity of the instrument.
- Difference between arc and spark testing:
  - Arc testing does not require a specialty geomembrane.
  - Spark testing is applied to conductive-backed geomembranes only.
- Arc testing method does not work well on wrinkles
  - ~2.5 cm maximum arc length
  - Geomembrane must maintain intimate contact with subgrade.
- By definition, Spark testing is best method for detecting leaks on wrinkles or other poor contact conditions

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Arc Testing Method

Photo Courtesy of TRI Environmental, Inc.

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Spark Testing Method

- Induces voltage differential across geomembrane using pulsed power supply (rather than direct ground to substrate)
- Tests one panel at a time using neoprene grounding pad placed on the panel being tested
- Will not effectively test fusion-welded seams unless conductive-backed geomembrane installed as an electrically isolated conductive-backed installation
  - This is due to conductive backing remaining intact through the fusion weld.
  - "Isolated" installation includes several installation steps including the use of the "isowedge".

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Exposed Geomembrane Testing Methods

- Technically easy to perform (simple sensitivity adjustment)
- Each method has unique advantages and disadvantages
- All methods equally "sensitive" in eyes of ASTM standard practices
- All of the standard practices allow for the use of alternative methods if more practical or effective.
  - Overnight rain storm can dictate method change
- Sometimes the methods are combined for maximum effectiveness
  - i.e. water puddle method on floor of pond, arc testing method on steep side slopes
- All methods very dependant on operator care
  - High voltage-based: keep probe in intimate contact with surface of geomembrane
  - Water-based: Allowing sufficient time for infiltration
  - Testing survey area completely with sufficient overlap between test lanes

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Exposed Geomembrane Testing Methods

- Once equipment functionality is demonstrated, very little can go wrong during testing with careful equipment operator
- Leaks easily pinpointed and visually identified
- Missed leaks are typically due to conditions specific to leak and method-specific limitations (poor contact with substrate, not large enough for applied water infiltration)
- Important to understand technical limitations of each method and get professional recommendation for most suitable method for specific project AND site conditions
- Consider use of conductive-backed geomembrane for critical projects
  - Be mindful of "isolated" installation guidelines
  - Only spark testing method can be performed if "isolated" installation guidelines not used.

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Factors in Leak Detection Sensitivity - Exposed Geomembrane Methods

- Physical obstacles/penetrations
  - Conductive penetrations biggest problem
- Survey area slope
  - More of a problem for water-based methods
- Lack of low point for water to collect
  - Only a problem for water-based methods
- Dirt/moisture present in survey area
  - More of a problem for high voltage-based methods
- Wrinkles and other poor contact conditions
  - Not a problem for spark testing
  - Big problem for arc testing
- Tortuous leak paths
  - Not a problem for spark testing

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EXPOSED GEOMEMBRANE TESTING

Photo Courtesy of TRI Environmental, Inc.

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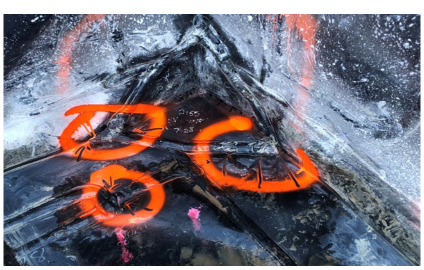
Exposed Geomembrane Testing



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Exposed Geomembrane Testing

Photo Courtesy of TRI Environmental, Inc.

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Exposed Geomembrane Testing

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Exposed Geomembrane Testing

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Exposed Geomembrane Testing

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Covered Geomembrane Testing Methods

- Requires high level of expertise to perform
- Sensitivity is highly dependent on site conditions
  - The sensitivity cannot be guaranteed
  - Methods may not work with poor site conditions
- Hydraulic gradient over the geomembrane at the time of testing can cause covered geomembrane methods to locate leaks that were missed during exposed geomembrane testing (when site conditions are good).
- Two available ASTM standard practices
  - ASTM D7007
  - ASTM D8265

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Dipole Method

- Most effective method for relatively thin cover material (10-15 ft max)
- Other electrical methods exist but they are not frequently performed.
  - Exception: deeply filled ponds
- Survey area is covered with liquid or earthen material(s)
- Limit: the survey area needs to be isolated from the underlying conductive layer **(only electrical path through leaks)**
- Introduce voltage potential across geomembrane and track where current is flowing through it
- Definition of “dipole” is that the measuring instrument measures voltage across two closely spaced points

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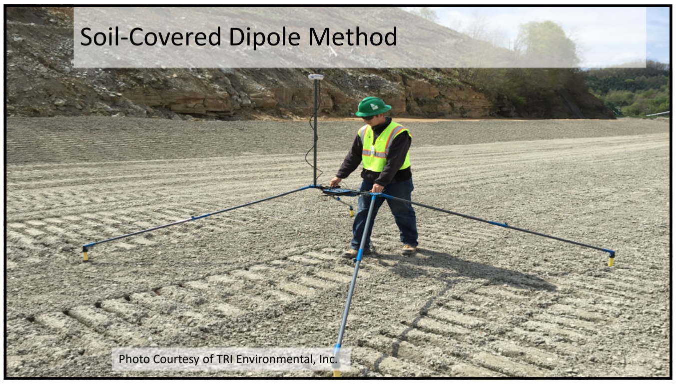
Soil-Covered Dipole Method



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Dipole Method

- ASTM D7007
  - Report output: whether or not leaks were found and where
  - Suggests proper site isolation "when practical"
  - In the case of poor sensitivity, requires tighter grid spacing for measurements (does not fix improper site conditions)
  - No technical documentation other than "signal to noise ratio" on artificial leak (not meaningful*)
  - No data recording for water-covered survey areas
- ASTM D8265
  - Published 2019; mainly to address inadequacies of D7007
  - Details proper site preparation and requires **documentation of improper site preparation**
  - Requires complete electrical map of testing results

*Gilson-Beck and Ferreira. "Maximizing the Effectiveness of Electrical Leak Location for Covered Geomembranes". *Geosynthetics 2017,* October 18-20, 2017, Santiago, Chile.

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ASTM D7007

Photo Courtesy of TRI Environmental, Inc.

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ASTM D7007

LEAK	LOCATION	DESCRIPTION
1	In the sump, approximately 6 feet from the toe of the north side slope and approximately 95 feet from the west tie-in.	Extrusion weld on patch
2	On the slope, approximately 190 feet from toe of the south side slope and approximately 60 feet from the west tie-in.	6.5-foot by 2.0-foot tear
3	On the slope, approximately 195 feet from toe of the south side slope and approximately 55 feet from the west tie-in.	6.0-foot by 2.5-foot tear

B. Leak Detection Sensitivity Test

The leak location equipment was tested for sensitivity and proper operation using an artificial leak. This procedure was conducted at the beginning and end of the day by personnel to verify equipment functionality. A 0.25-inch diameter artificial leak was placed directly above the liner and leak location survey lines were run along both sides of the test leak. Leak location survey measurements were collected to determine the maximum distance the leak could be reliably detected. The leak detection distance was greater than 10 feet; however, the survey data was collected on survey lines spaced approximately five feet apart. Thus, measurements were made within 2.5 feet of every point above the soil covered geomembrane.

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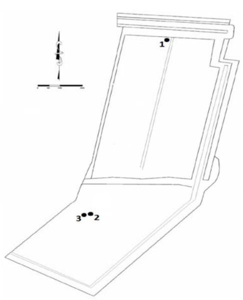
ASTM D7007



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D7007 Water-Covered Dipole Method

Photo Courtesy of TRI Environmental, Inc.

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ASTM D8265

- Report site conditions during survey
- Report voltage applied and site response current throughout testing event
  - Provides calculation to determine whether artificial leak should be disconnected before commencing survey
- Report voltages obtained on artificial leak at “best case” and “worst case” positions
- Requires survey transects along every edge of the survey area
- Recognizes potential need for second survey to locate all damage (not required)
- Details systematic leak excavation to increase detection sensitivity

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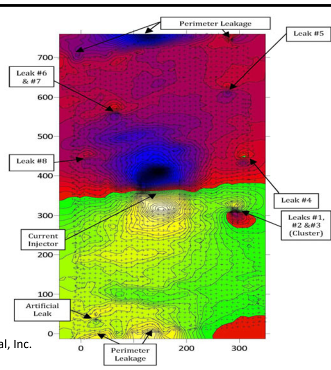
ASTM D8265



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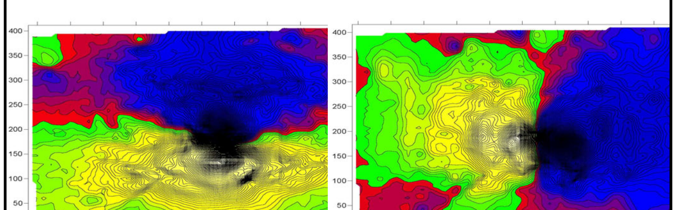
SURVEY AREA EDGES



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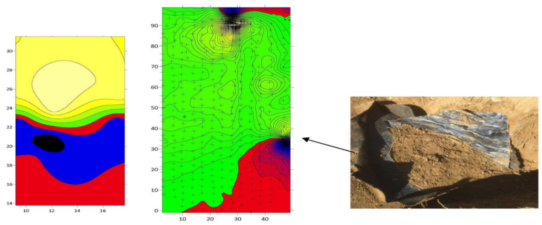
EFFECT OF HOLES PRESENT-SURVEY 1



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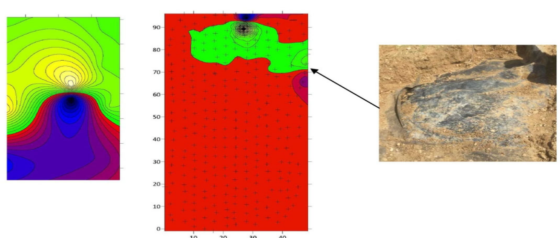
EFFECT OF HOLES PRESENT-SURVEY 2



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D7007 vs. D8265 Case Study

Photo Courtesy of TRI Environmental, Inc.

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ASTM D7007 RESULTS

- Artificial leak did not give sufficient signal to noise ratio of 3:1, so measurement density was increased to 1 measurement per square meter and the survey was performed.
- No leaks were found.

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D8265 Applied

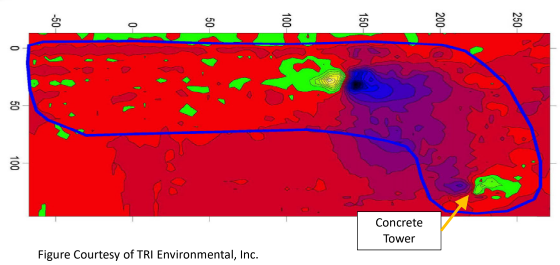

Figure Courtesy of TRI Environmental, Inc.

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D8265 Applied

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D8265 Applied

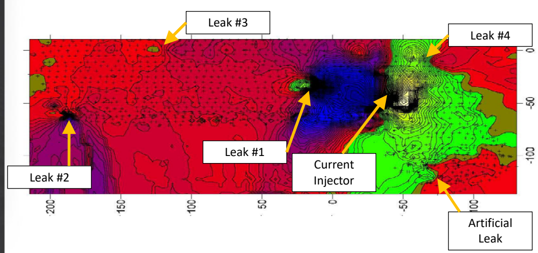

Figure Courtesy of TRI Environmental, Inc.

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D7007 vs. D8265 (Soil-Covered)

D7007 – 16

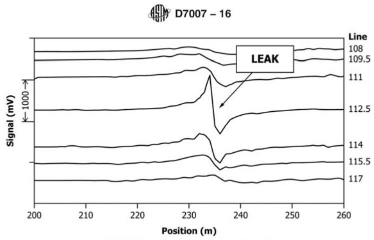

FIG. X1.1 Example of Graphical Data Analysis

Figure from ASTM D7007

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Why Keep D7007?

- It is still being used
- A survey area might be too small or awkward for voltage mapping to make sense
- Quick check for leaks in an area (no formal survey)

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Dipole Method – Factors Affecting Sensitivity

1. **Site conditions:**
   - Moisture in survey area
   - Degree of isolation of cover material
2. Dipole spacing (distance between dipole probes)
3. Cover material minerology
   - Electron exchange within cover material can create erratic readings
4. Cover material thickness
   - The thinner the better; maximum thickness approximately equal to dipole length
5. Measurement Density

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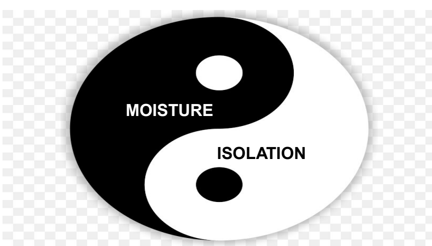
Dipole Method Site Preparation



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HOW MUCH MOISTURE TO ADD???

Photo Courtesy of TRI Environmental, Inc.

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Water Requirement

- Three reasons for adding moisture:
  - Cover material (full thickness) needs to be adequately conductive
    - Requirement: 0.5-6.0% M.C., depending on material
  - Small holes (where cover material does not fall in/fill) need to be moist for electricity to travel through them
    - Requirement: Liner needs to have actually leaked at some point in the past (hopefully right before or during test)
  - Dipole probes need good contact with the cover material, which can desiccate on the surface (especially gravel)
    - Requirement: Spray surface during/immediately before testing – climate and cover material dependent
- The requirement for watering during testing is usually ONLY to address the last reason (surface desiccation)

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Moisture on top of Geomembrane Documentation (ASTM D8265)

Photo Courtesy of TRI Environmental, Inc.

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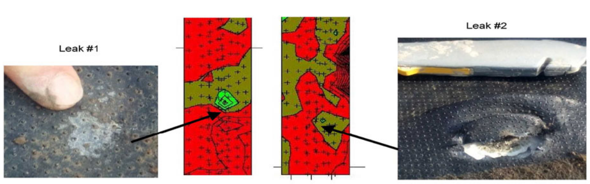
EFFECT OF MOISTURE



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Survey Area Isolation

Existing LF

Isolation Trench is Critical

Photo Courtesy of TRI Environmental, Inc.

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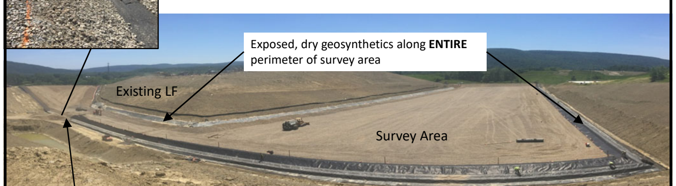
DIPOLE SITE PREPARATION: ISOLATION

Exposed, dry geosynthetics along **ENTIRE** perimeter of survey area



Access Road Cut

Photos Courtesy of TRI Environmental, Inc.

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Dipole Site Preparation: Isolation

Photo Courtesy of TRI Environmental, Inc.

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Dipole Site Preparation: Isolation

Photo Courtesy of TRI Environmental, Inc.

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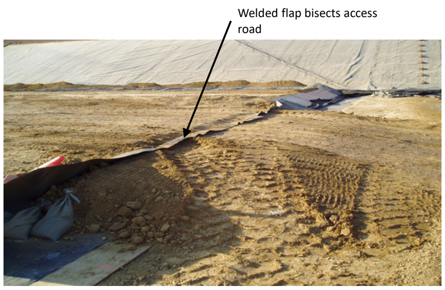
Access Road Option



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Case Study without Isolation Trench Along Tie-in

- Testing primary geomembrane of double-lined facility
- Surveyed as-is, since artificial leak was visible
  - BUT, artificial leak was placed in location away from tie-in area
- Monitored leakage, and known hole(s) were present
- Found one hole away from tie-in during first testing event but did not solve problem
- Resurveyed at four times the measurement density (1.5m x 1.5 m rather than 3m x 3m)
- Still could not locate problem, so excavated isolation trench for resurvey – **7 holes found**

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Undetected Hole in Survey Area without Isolation Trench

Photo Courtesy of TRI Environmental, Inc.

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Largest Factor in Leak Detection

- Electricity will find **path of least resistance** from current injector to current return electrode.
- A leak is only detectable if current is flowing through it.
  - So leak(s) must be moist and/or filled with conductive material (soil)
- If there are easier paths than the leak(s) for the current to flow through, there may or may not be enough current traveling through leak(s).
- Force current through leaks and only leaks for maximum method effectiveness

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Tie-in Run-off Testing Interference

Photo Courtesy of TRI Environmental, Inc.

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Tie-in Run-off Testing Interference

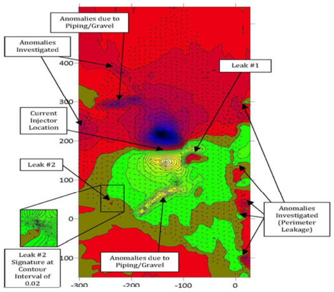

Figure Courtesy of TRI Environmental, Inc.

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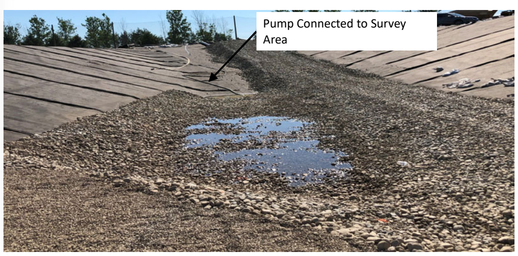
Survey Area Isolation Effect on Sensitivity



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Artificial Leak Signal with Pump Connected

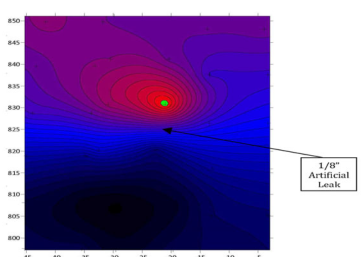

Figure Courtesy of TRI Environmental, Inc.

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Artificial Leak Signal with Pump Removed

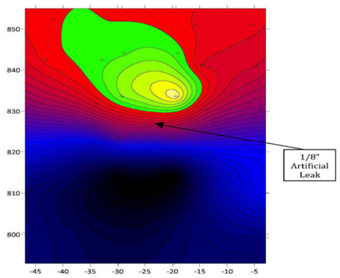

Figure Courtesy of TRI Environmental, Inc.

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Measurement Density and Dipole Spacing

- Dipole spacing is single largest factor in method sensitivity other than survey area isolation and adequate moisture.
- An increase in measurement density to make up for poor site conditions (as prescribed in D7007) can result in additional survey costs without additional method sensitivity.
- Recent research* showed effect of dipole spacing and measurement density on method sensitivity
  - Result: Grid spacing should be no greater than dipole spacing
- ASTM D8265 updated in 2021 to limit grid spacing to dipole spacing

*Gilson-Beck, A. "Dipole Measurement Density and Dipole Spacing for Electrical Leak Location". *Geosynthetics Conference 2021,* February 21-24, 2021, Kansas City, MO.

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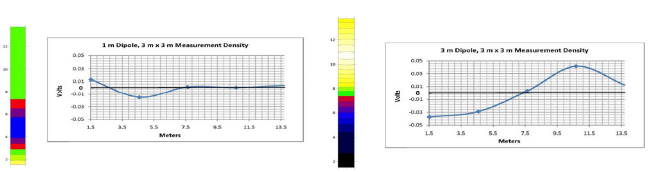
MEASUREMENT DENSITY AND DIPOLE SPACING



- A three meter (10-foot) dipole produces a much larger leak signal and leak detection distance than a one meter (3-foot) dipole.

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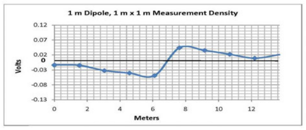
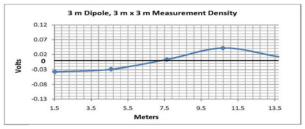
MEASUREMENT DENSITY AND DIPOLE SPACING





- At measurement grid spacing equal to dipole spacing, a three meter (10-foot) dipole produces a larger leak detection distance with NINE times fewer data acquisition points than a one meter (3-foot) dipole.

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Dipole Method Sensitivity

- Simply applying the dipole method is not a guarantee of a certain level of sensitivity
- Sensitivity is mostly a function of site conditions, so site conditions should be controlled by project specifications
- Neither ASTM (D7007 or D8265) specifies a dipole spacing, but that is the only thing other than site conditions that significantly boosts method sensitivity.
- How do we determine “sensitivity” as part of the testing event???

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Detectability of Artificial Leak

- A general indicator of site-specific conduciveness to test method
- Should be used as a method functionality test more than a “sensitivity test”
- Contact more important than size
- Sometimes signal from an artificial is drastically different from actual leak
  - Sometimes easier to detect
  - Sometimes harder to detect
- True “sensitivity test” is smallest actual leak found

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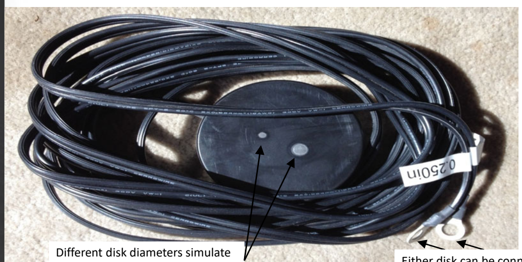
Artificial Leak



Different disk diameters simulate different leak sizes.

Either disk can be connected to the underlying conductive layer

Photo Courtesy of TRI Environmental, Inc.

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Artificial Leak

Photo Courtesy of TRI Environmental, Inc.

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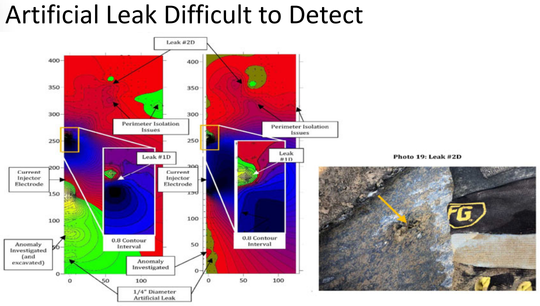
Artificial Leak Difficult to Detect



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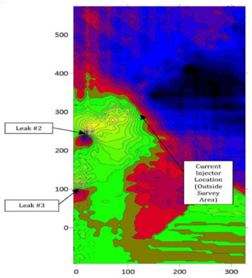
Artificial Leak Impossible to Detect



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Artificial Leak Easy to Detect

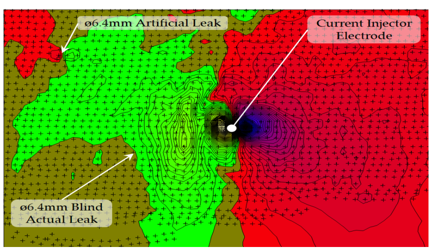

Figure Courtesy of TRI Environmental, Inc.

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ASTM D7909 – "Blind Leak" Guide

- "Blind Leak": Leak created at location unknown to ELL practitioner
- Guide for placement of leaks intentionally to ensure that site conditions are favorable and leak location survey performed appropriately
- Guidelines for drilling leaks properly per ASTM
- Guidelines for protocol if "blind leak(s)" not detected
- Recently revised (2021)

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Recent Revisions to ASTM D7909

- Requires actual leak to be pointed out to ELL contractor
- ELL contractor makes sure that site conditions are sufficient for detecting actual leak
- Site conditions are improved if cannot detect
- Optional, “Blind Leak(s)” can also be used
- Caveat: significant leak(s) in the lining system can preclude detection of a given leak; this takes significant expertise to be able to determine
- Can excavate actual leak before survey, so leak should not be located where it cannot be dried out.

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Method specification Example – Bare Geomembrane

- Water puddle method is fastest method
- Must have water truck with hoses, plus laborers for hose movement
- Better at detecting holes on wrinkles than arc testing
- Better on patches than arc testing

Photo Courtesy of TRI Environmental, Inc.

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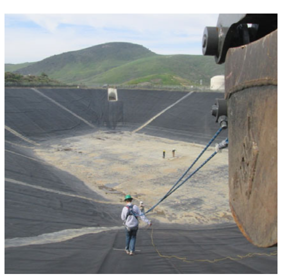
Method specification Example - Pond with Steep Slopes

- Water puddle method on floor
- Arc testing on side slopes
- Any steeper than 3H:1 water-based methods not as effective as arc testing
- Must use harness for non-textured, steep slopes



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Method specification Example - Vertical Walls

- Water-based methods will not work well or at all
- No need for containment of water
- Distance between geomembrane and conductive element should not exceed ~1"

Photo Courtesy of TRI Environmental, Inc.

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Method specification Example – Landfill Tie-in Area

- Bare edges located in the isolation trenches
- Can test tie-in seam
- Arc testing does not require application of water, so no run-off interference
- May not work on wrinkles

Photo Courtesy of TRI Environmental, Inc.

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Method Specification – Soil covered

- Specify ASTM D8265 but also provide site preparation details in Specifications to make Contractor aware of support requirements
- Dipole Method Proper Site Preparation
  1. **Complete electrical isolation of survey area from ground**
  2. **Cover material and subgrade sufficiently electrically conductive**
  3. **Sufficient water over geomembrane to cause leakage (electrically connecting leaks to testing circuit)**
     - **If geosynthetics (geotextile, geocomposite) are dry during testing, dipole method will only find damage that goes THROUGH those dry layers**

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Dipole Method Required Isolation

- Consider isolation for temporary project configuration
  - Tie-ins
  - Temporary Terminations
  - Anchor Trenches
- Consider direction of run-off for isolation trenches
  - Will they empty on their own after rain events?
- Consider use of geomembrane flaps for isolative features
  - Access Roads
  - In areas subject to run-off
  - At tie-ins or terminations

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Optional Addition to Specifications

- Measurement Density: Grid spacing (distance between measurement points) should be no greater than the distance between dipole measurement points (dipole width).
- GPS-based data acquisition system
  - Allows for returning to area(s) in question at any time after survey occurs
  - Allows for oddly-shaped survey areas
- GPS-based data acquisition guidance system
  - If not guided by GPS, string lines are used, which can blow away and are not always straight; don't have same accuracy as GPS
  - Saves days of labor laying out string lines preceding survey
  - Will capture more data points in oddly-shaped survey areas

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Optional Addition to Specifications

- Use "Placement of (Blind) Actual Leaks during Electrical Leak Location Surveys of Geomembranes" – ASTM D7909-21
- Use actual leak to correct site conditions before survey
- Make sure to properly create hole
  - Create hole during or directly following GM installation
  - Make sure to record GPS location
  - Any air pocket/void through hole can cause non-detect; make sure leak is in contact with subgrade
- Read through details in D7909 Guide beforehand and make sure everyone involved in the project is on board with plan for actual leaks.

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ELL Specifications

- Do not "shelve" specifications
- Onsite CQA agency should be confirming contractor compliance with site preparation
- This is the most important test Engineers will specify as part of a containment facility project
- THANK YOU ENGINEERS for participating in this short course today; testing quality starts with your specifications.
- Please contact an ELL expert for advice on ELL specifications if you are not sure.

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QUESTIONS?

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Designing for a Zero-Leak Containment Facility

CLAIM CODE XXXX

10-MINUTE BREAK

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