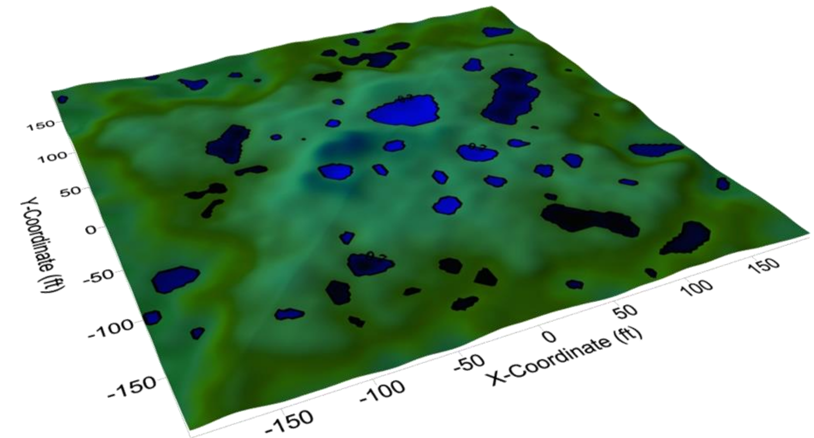

Probabilistic Modeling of Settlement Risk at Land Disposal Facilities (LDFs)

March 11, 2019

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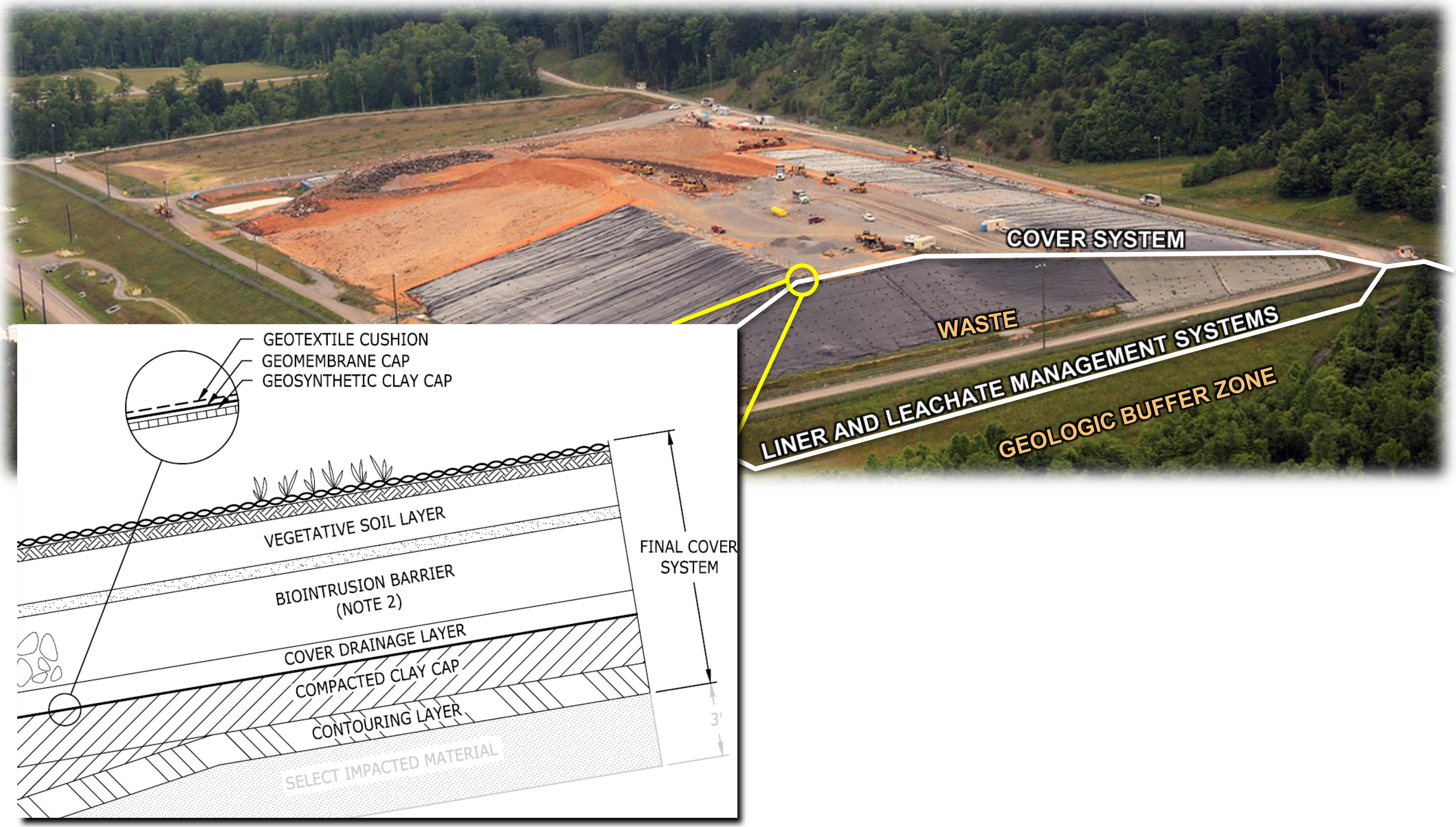
Outline

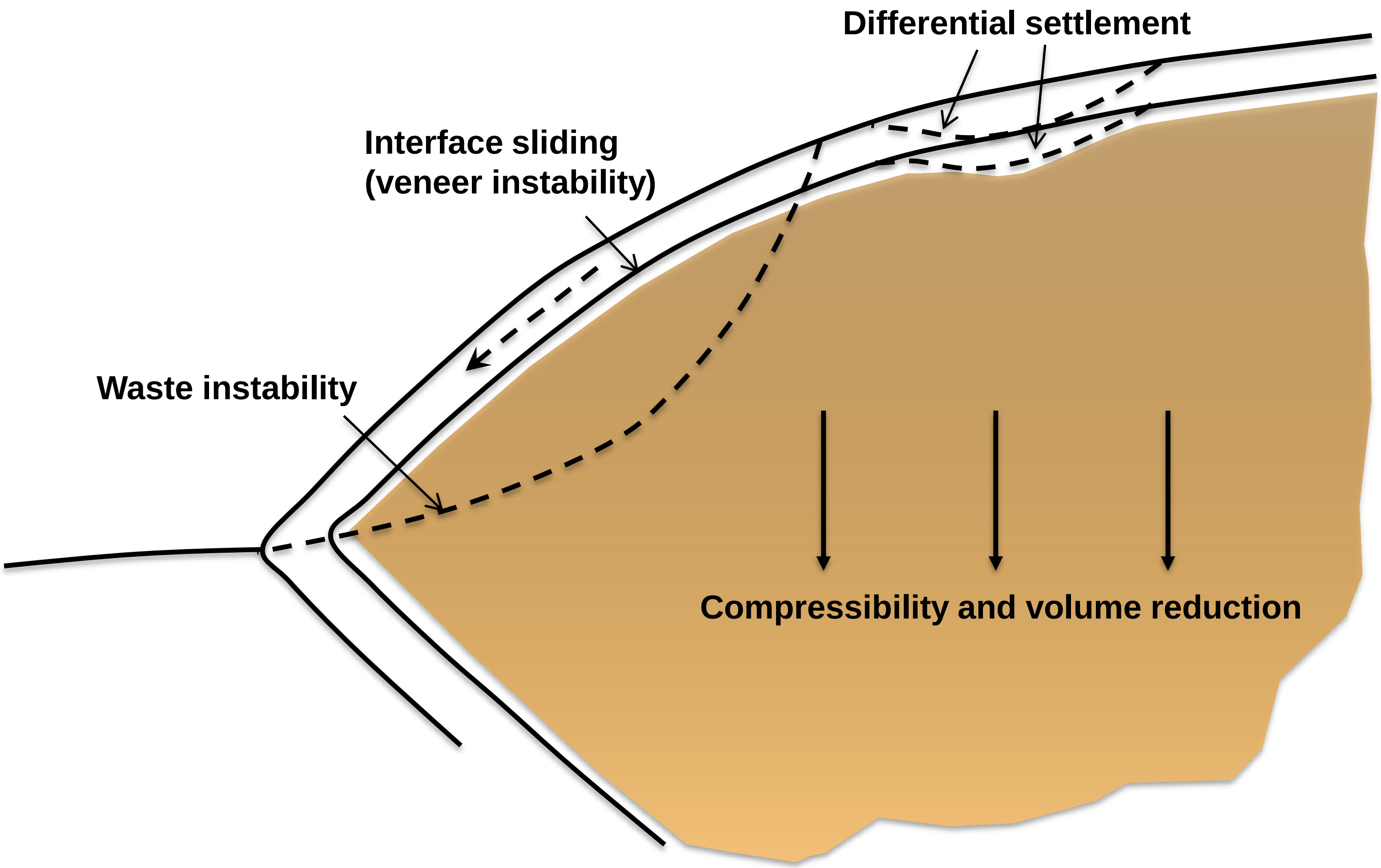
- Land Disposal Facility Anatomy
- Cover System Failure Mechanisms
- Concerns associated with cover system settlement
- Differential settlement examples
- Barriers' tolerance to differential settlement
- Motivation for a realistic modeling technique
- Proposed probabilistic modeling technique
- Proposed cover system design approach
- Case history – technique & approach demonstration
- Summary and conclusion

Land Disposal Facility Anatomy

Land Disposal Facility Anatomy



Cover System Failure Mechanisms



Concerns Associated with Cover System Settlement

- Settlement alters the performance of cover system
- Differential settlement is more common (and more troublesome) than uniform settlement
- Subsequent performance issues
  - damaged barrier (soil cracking and liner straining)
  - concentrated flow (water and gas)
  - increased leachate generation
- Other concerns
  - increased long-term maintenance costs
  - adverse impact on public perception

Differential Settlement Examples – 1 of 5

Typical final cover localized subsidence

Differential Settlement Examples – 2 of 5

Maxey Flats LLRW site

Differential Settlement Examples – 3 of 5

Los Alamos airport landfill

Differential Settlement Examples – 4 of 5

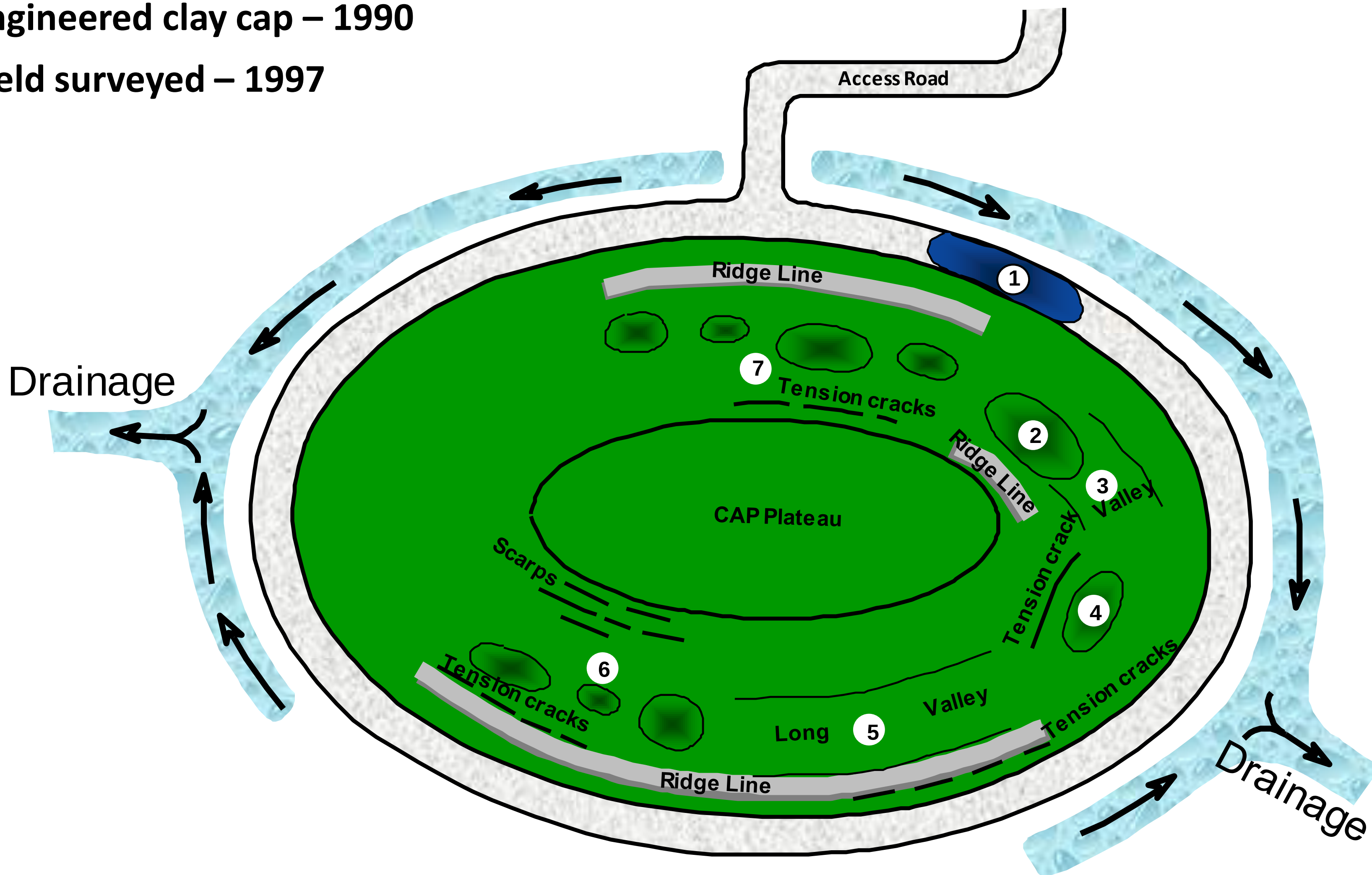
Beatty LLRW site

Differential Settlement Examples – 5 of 5

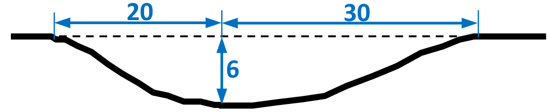
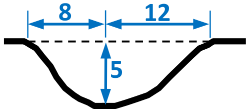
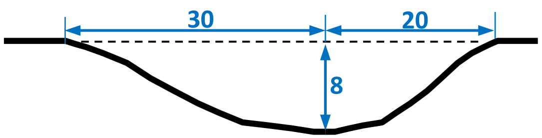
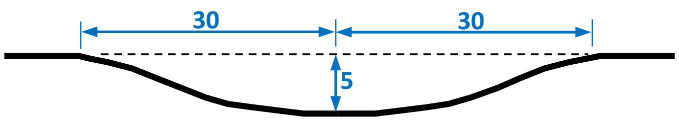
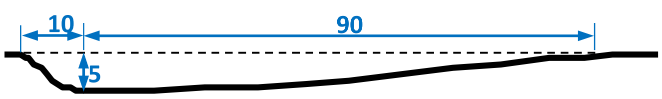
100 Acre MSW Landfill (1969-1978) - Field Survey

Engineered clay cap – 1990

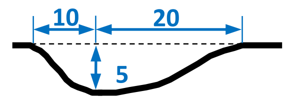
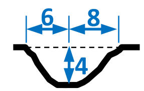
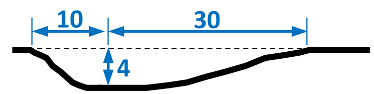
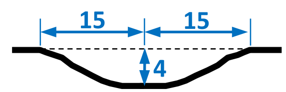
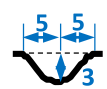
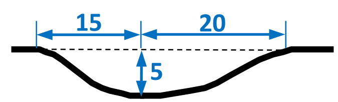
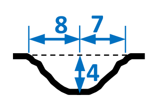
Field surveyed – 1997



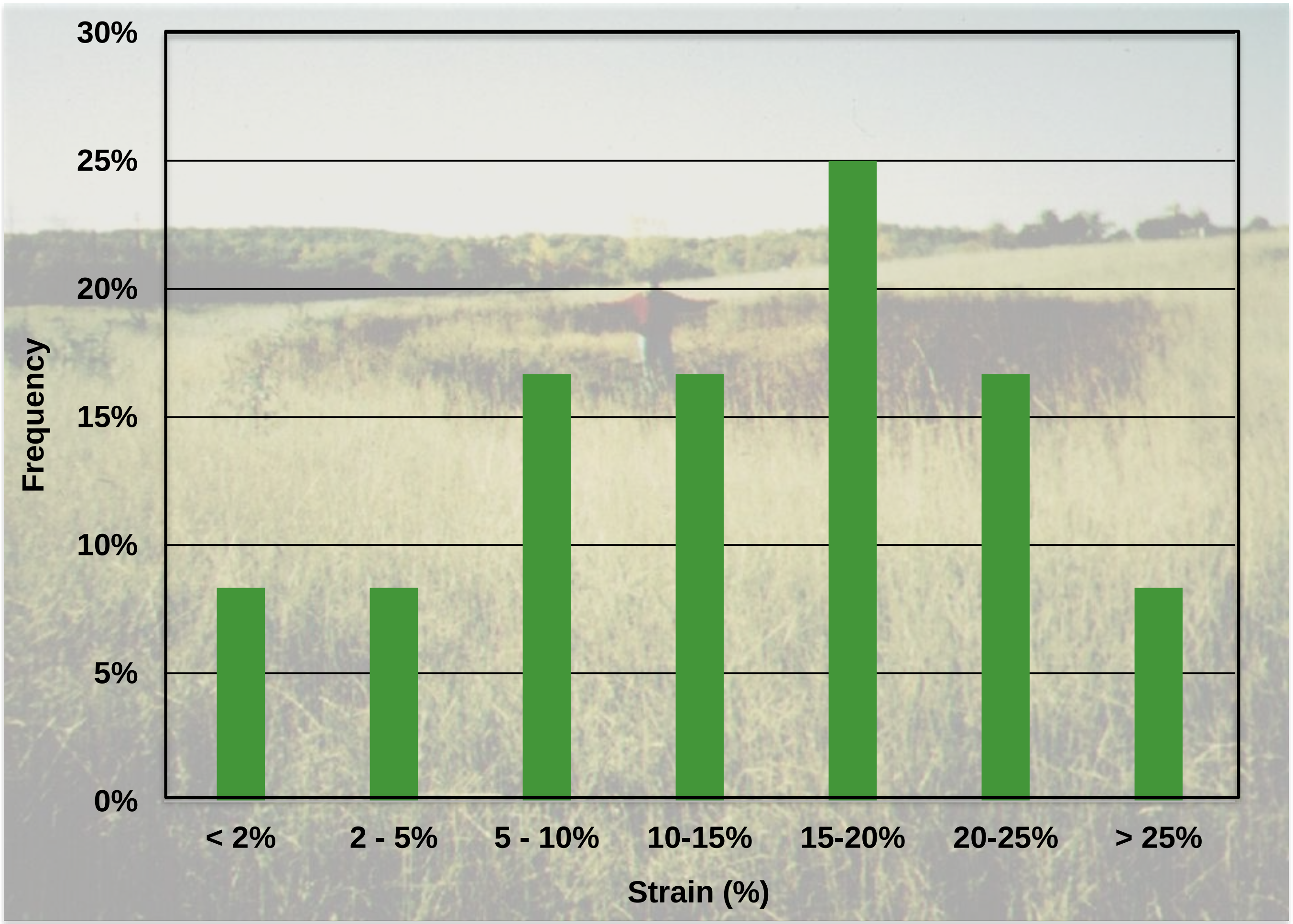
Subsidence Patterns and Corresponding Strains

Location	Description	Approximate Dimensions (ft)	Max. Strain (%)
1	Road subsidence		5.9
2	Major cater		24.3
3	100-ft long valley		10.4
4	Larger crater		1.8
5	350-ft long valley		15.9

Subsidence Patterns and Corresponding Strains (cont'd)

Location	Description	Approximate Dimenions (ft)	Max. Strain (%)
6	Three craters		15.9
			27.4
			10.4
7	Four craters		4.7
			22.5
			7.3
			15.9

Cover System Differential Settlement Examples – 5 of 5



Barriers' Tolerance to Differential Settlement

General Description	Type or Source of Material	Tensile Strain at Failure (%)	
Soil Barrier	Clayey Soil	0.80	0.07 - 0.84
	Illite	0.84	
	Kaolinite	0.16	
	Anonymous Dam	0.14	
	Rector Creek Dam	0.10	
	Woodcrest Dam	0.18	
	Wheel Oil Dam	0.07	
	Willard Embankment	0.20	
Geosynthetic Clay Liner (GCL)	Breakthrough in permeability	10 - 15	10 - 26
	Break in 3-D tension	15 - 26	
Geomembrane Liner	HDPE	25	25 - 100
	PVC	75	
	LLDPE	75	
	fPP-R	100	

Key Concepts to the Performance of LDFs

- Waste will settlement and will consequently impact the performance of cover system
- Settlement, especially differential/localized ones, can result in tensile strains in the cover system
- Some barrier materials have better tolerance to tensile straining than others (over 1,000 times differences)
- Capabilities to estimate the degree of differential settlement and choose the barrier material are essential and critical to a successful cover system design

Motivation for a Realistic Modeling Technique

- Waste settlement & impact on the cover should undergo rigorous review to ensure performance objectives are met
- Realistic modeling is needed for any type of barrier
- Wastes buried without proper control and/or documentation (composition, compaction, void space distribution, debris-soil mix ratio, etc.) is most concerning
- Deterministic approach cannot capture heterogeneity and uncertainty associated with those buried wastes
- Probabilistic approach is better suited for un-observed / un-measured variables as well as their scale of fluctuation

Proposed Probabilistic Modeling Technique

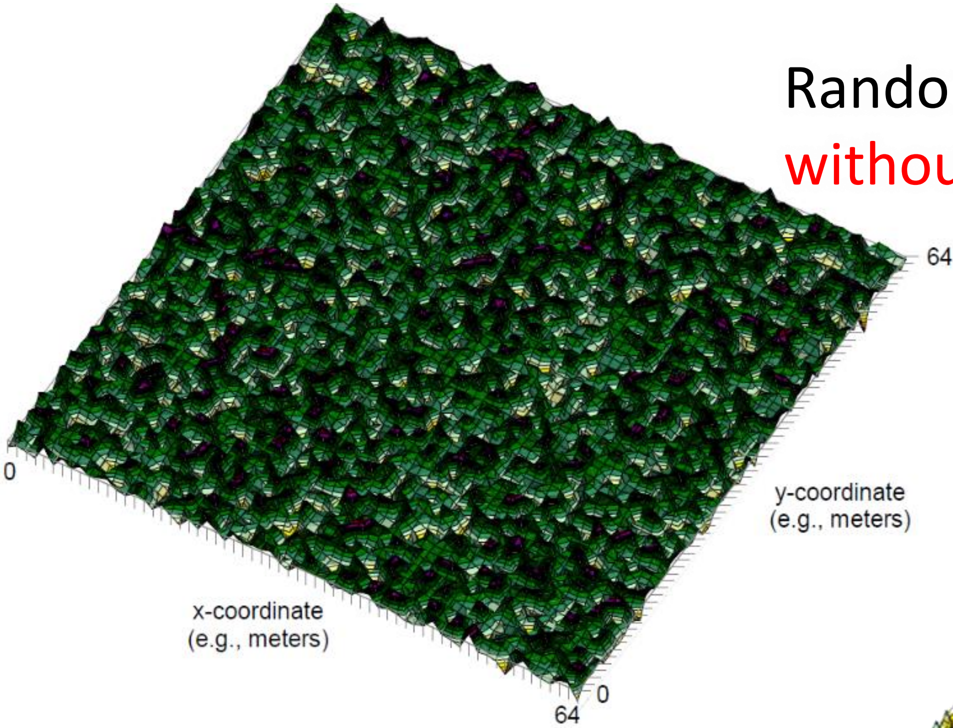
- Probabilistic Volume Loss (VL) model that predicts how settlement (collapsed void) at depth migrates to the surface
- The VL at depth is modeled with a distribution of possible values based on available data (type and age of waste, disposal methods, compaction criteria, trench geometries, capping techniques, etc.) from project or similar sites
- Calibrate the VL model to account for the presence of reinforcement (e.g., geogrids) which could reduce the localized effects of waste subsidence
- Factor in additional adjustments (e.g., the effect of creep on the reinforcement)

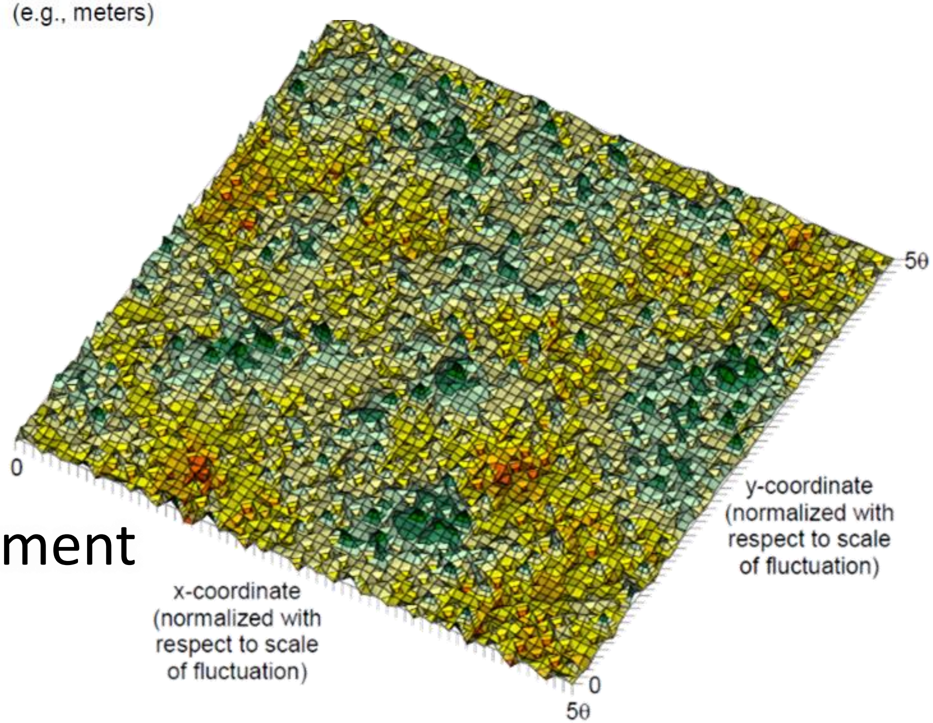
Proposed Probabilistic Modeling Technique (continued)

- Result of a settlement modeling (a realization) is a post-settlement profile, which will be used to calculate
  - post-settlement slope between neighboring points
  - frequency of occurrence of various slopes
- Modeling of a given design involves numerous realizations to meet the statistical standards
- This process will generate a large population of post-settlement profiles and subsequently, a histogram
- The histogram allows the designer to examine the validity of a given design by comparing with an acceptable criteria
- More will follow later in the design example

Random Fields for Variable Simulation

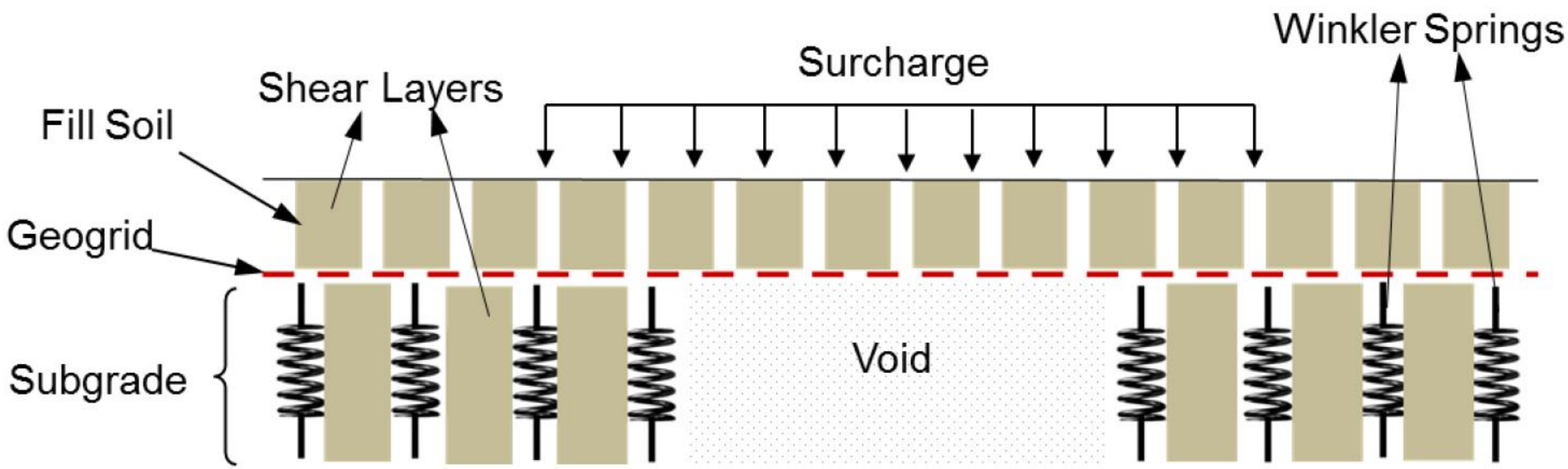
Random variability assignment **without** spatial correlation



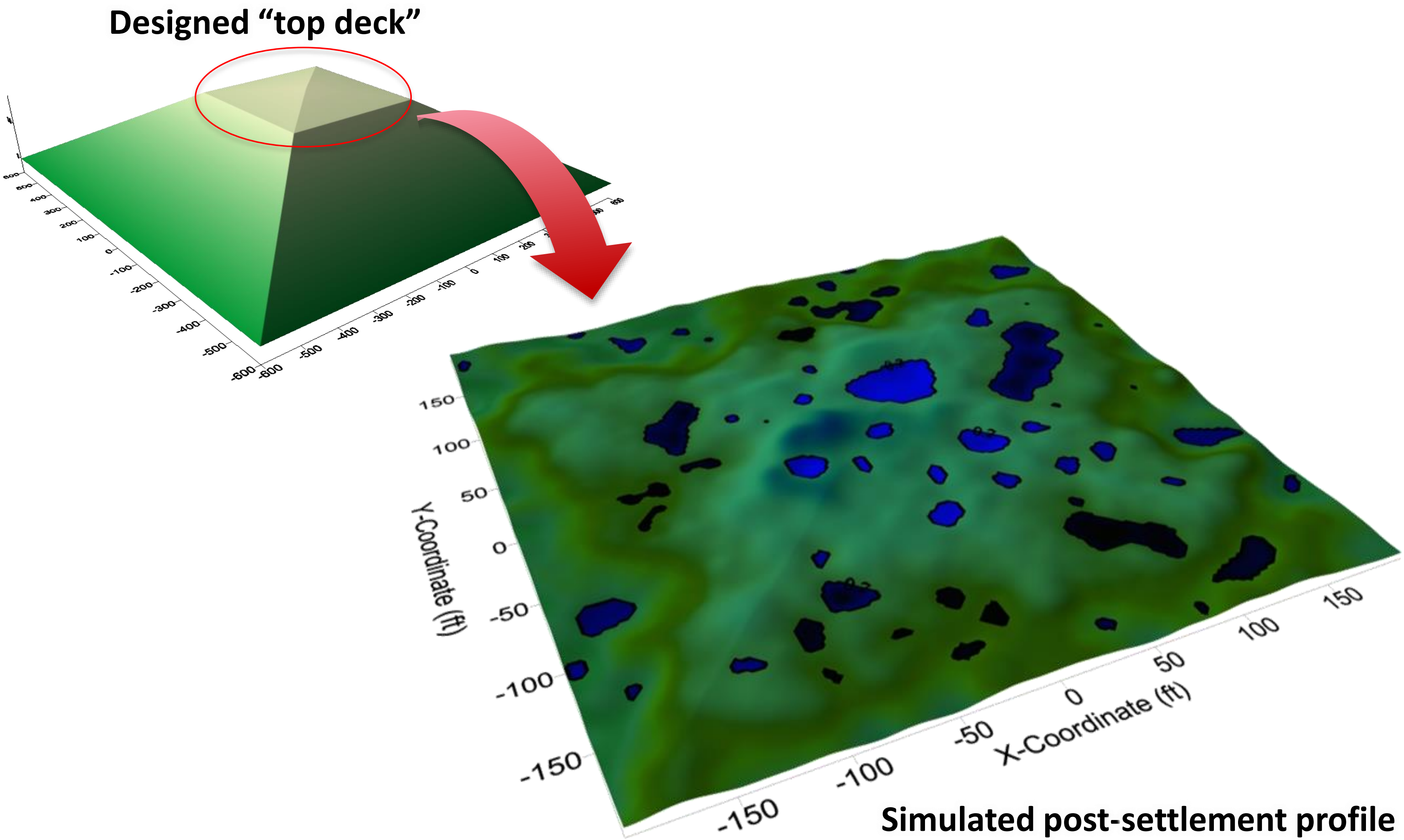


Random variability assignment **with** spatial correlation

Three-parameter (Tension-Spring-Shear) model for predicting the deformation of a reinforced cover above a depression



Example of a Simulated Post-Settlement Cover Topography



Proposed Cover System Design Approach

- Considers different combinations of design “tools”:
  - reducing subsidence potential by surcharging/pre-loading, chemical grouting, deep dynamic compaction, etc.
  - thickening the cover to attenuate the settlement effect
  - steepening the cover slope to facilitate storm water run-off and to minimize uncontrolled run-on or ponding
  - adding reinforcement to minimize localized surface depression
  - choosing the most suitable barrier system
- Models possible design options for post-settlement drainage performance and compares results against a pre-established Acceptable Performance Criterion (APC)
- Recommends an “optimized” design that is technically acceptable and most cost-effective

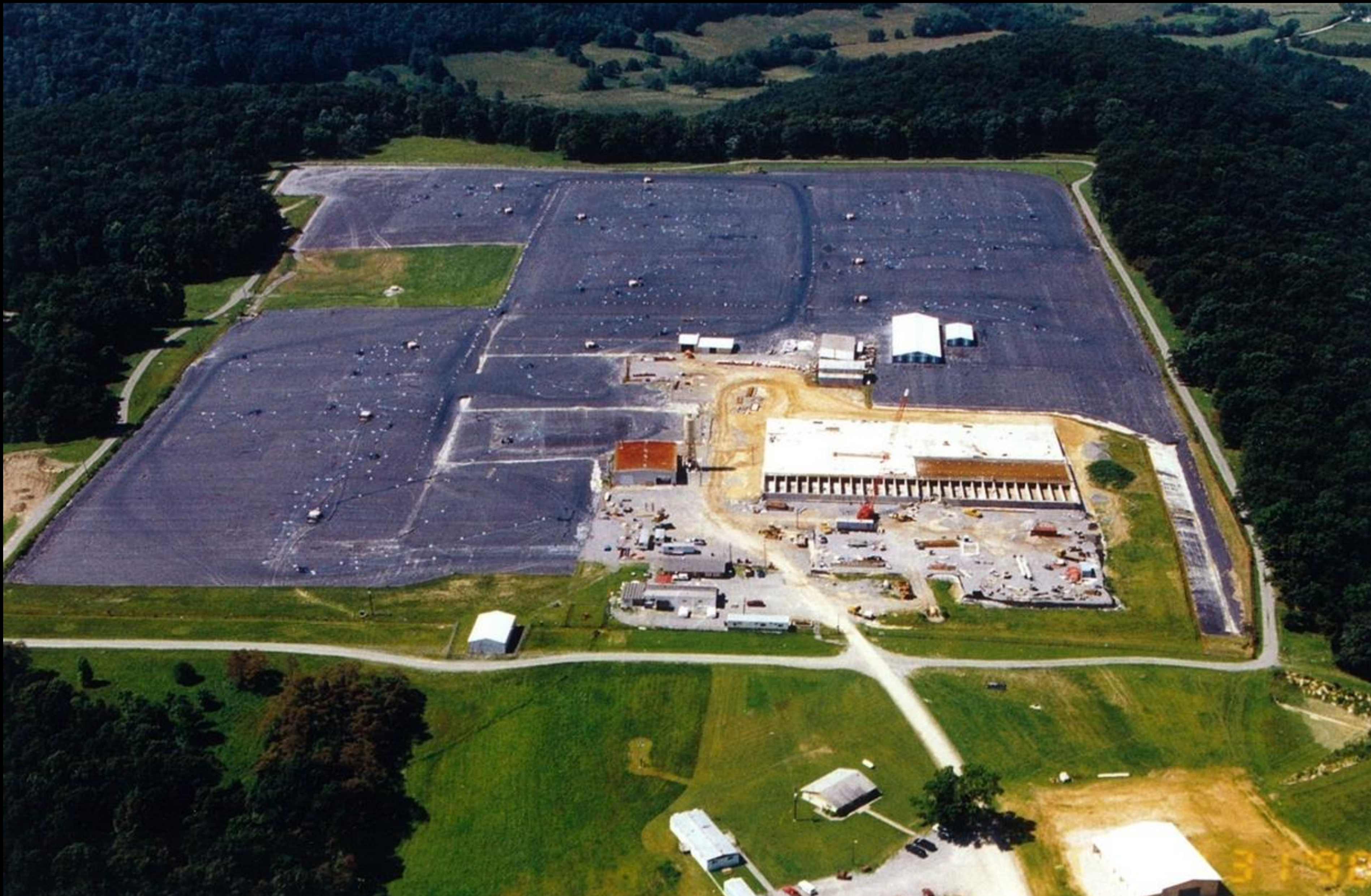
Case History – Technique & Approach Demonstration

LLW Disposal Site Final Closure, KY

- In operation between 1963 and 1977
- 60+ acres
- 4.8 million CF of waste / 2.2 million liters of solidified liquid waste buried in 53 trenches/pits
- Trench dimensions: 15-75’ (L) x 9-25’ (W) x 5-15’ (D)
- Most packaged waste was either very easily degradable or contained large voids
- Chemical agents in waste further accelerate degradation of containers
- Waste-to-trench volume ratio 0.009 to 0.78

Maxey Flats LLRW Site

53 Disposal Trenches and Pits



Initial Remedial Phase (IRP) began in 1996

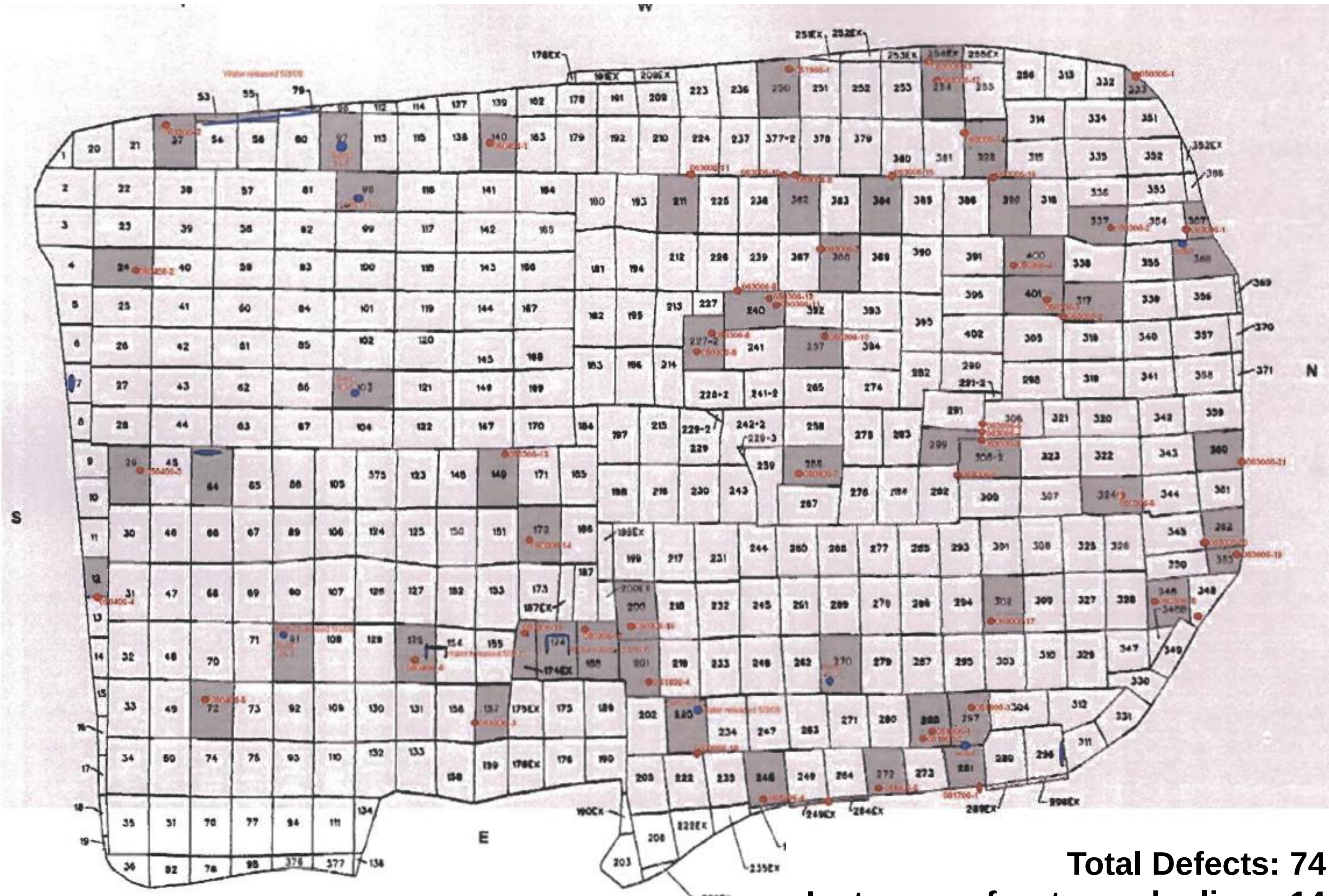
Initial Remedial Phase (IRP) Cover Completed in 2003

Surface Subsidence at Maxey Flats Disposal Site

- The wastes were deposited in a random manner with considerable void space in the packaging
- Rigid containers such as steel drums can develop rust and degrade, which caused the lost of structural support
- Additional voids were created with time as the waste or packaging degrades and decays
- Water percolated into the trenches and accelerated waste degradation and progressively worsened the subsidence of the trench cover
- Many trenches experienced substantial differential settlement and surface depressions

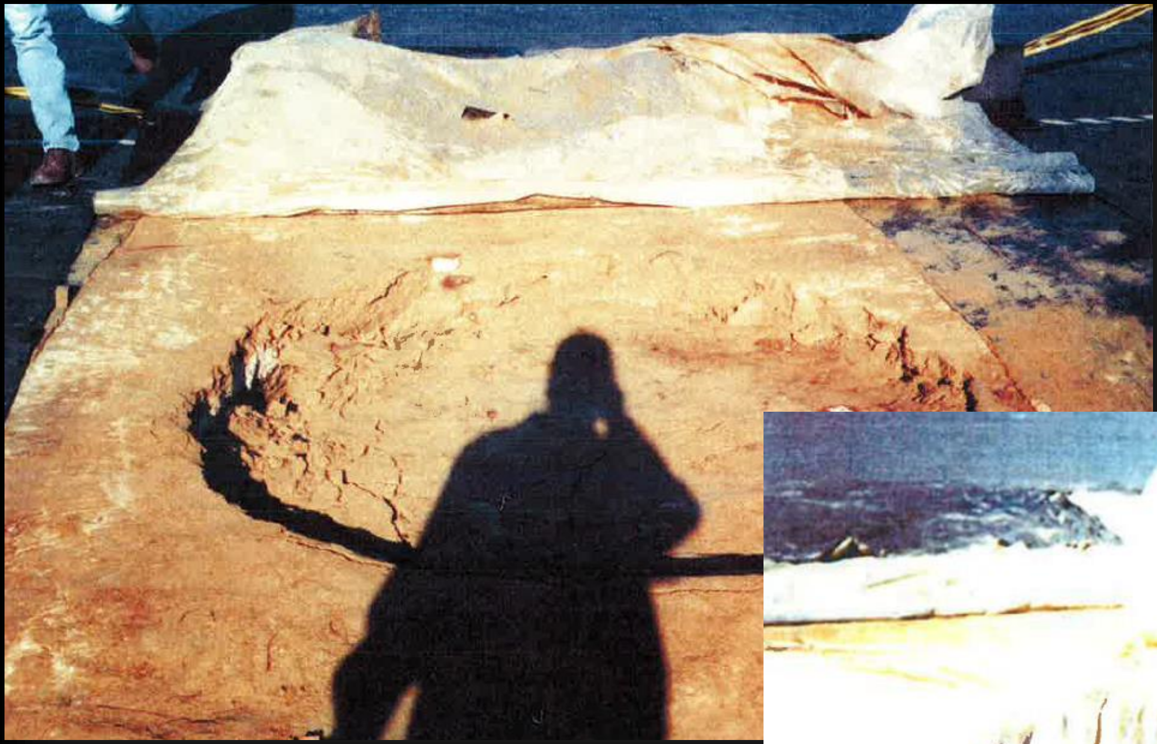
2006 “Defect” Map

(from EPA’s 2007 Five-Year Review Report)



Total Defects: 74

Instances of water under liner: 14



Depths of craters ranged from about 0.5 to 6 feet. Typical crater widths range from 2 to 8 feet.

Localized Subsidence (below IRP cover)

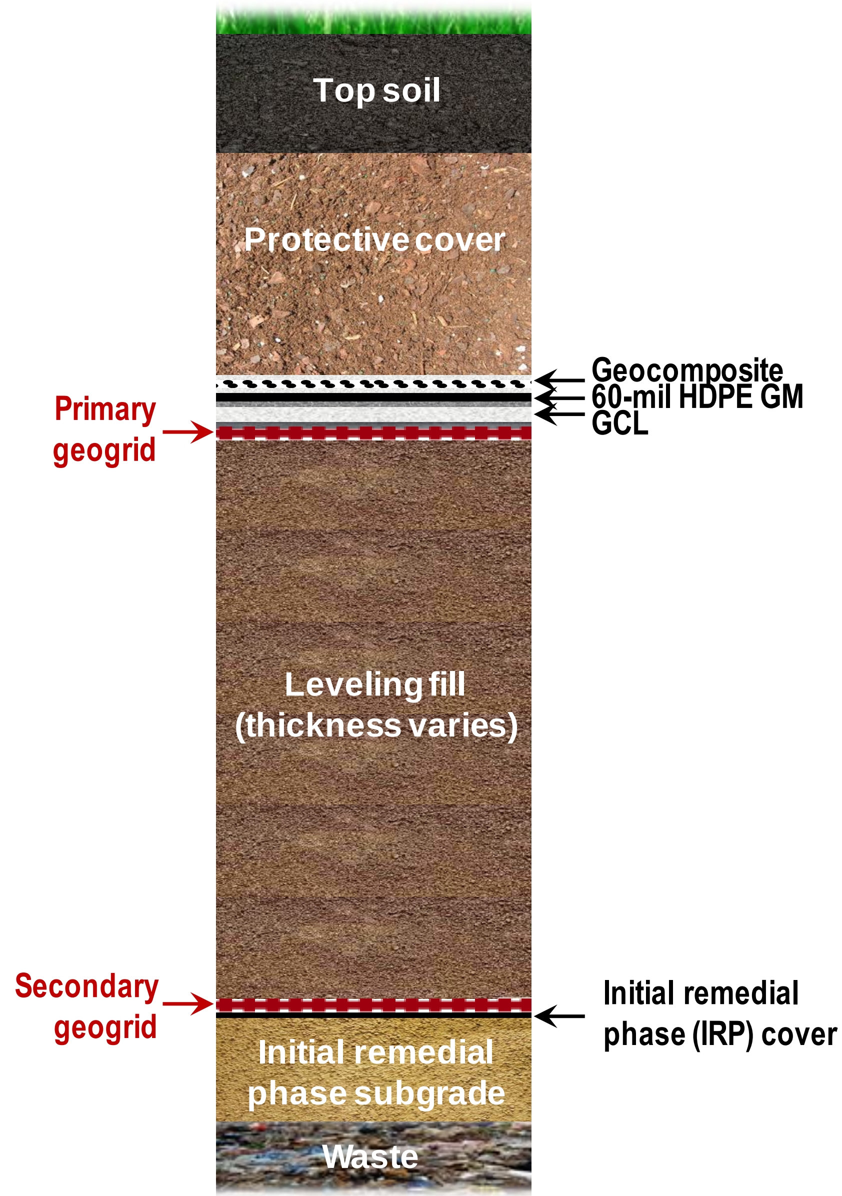
Several areas with 0.3 to 1.0 feet of subsidence distributed over areas exceeding 30 feet in width, causing shallow ponds on the IRP geomembrane.

Localized Subsidence (above IRP cover)

Proposed design – favored by KYDEP & approved by EPA R4

(To distribute settlement to adjacent areas, reducing the localized effects of waste subsidence.

(To span small voids, limiting their impact on the surface.)

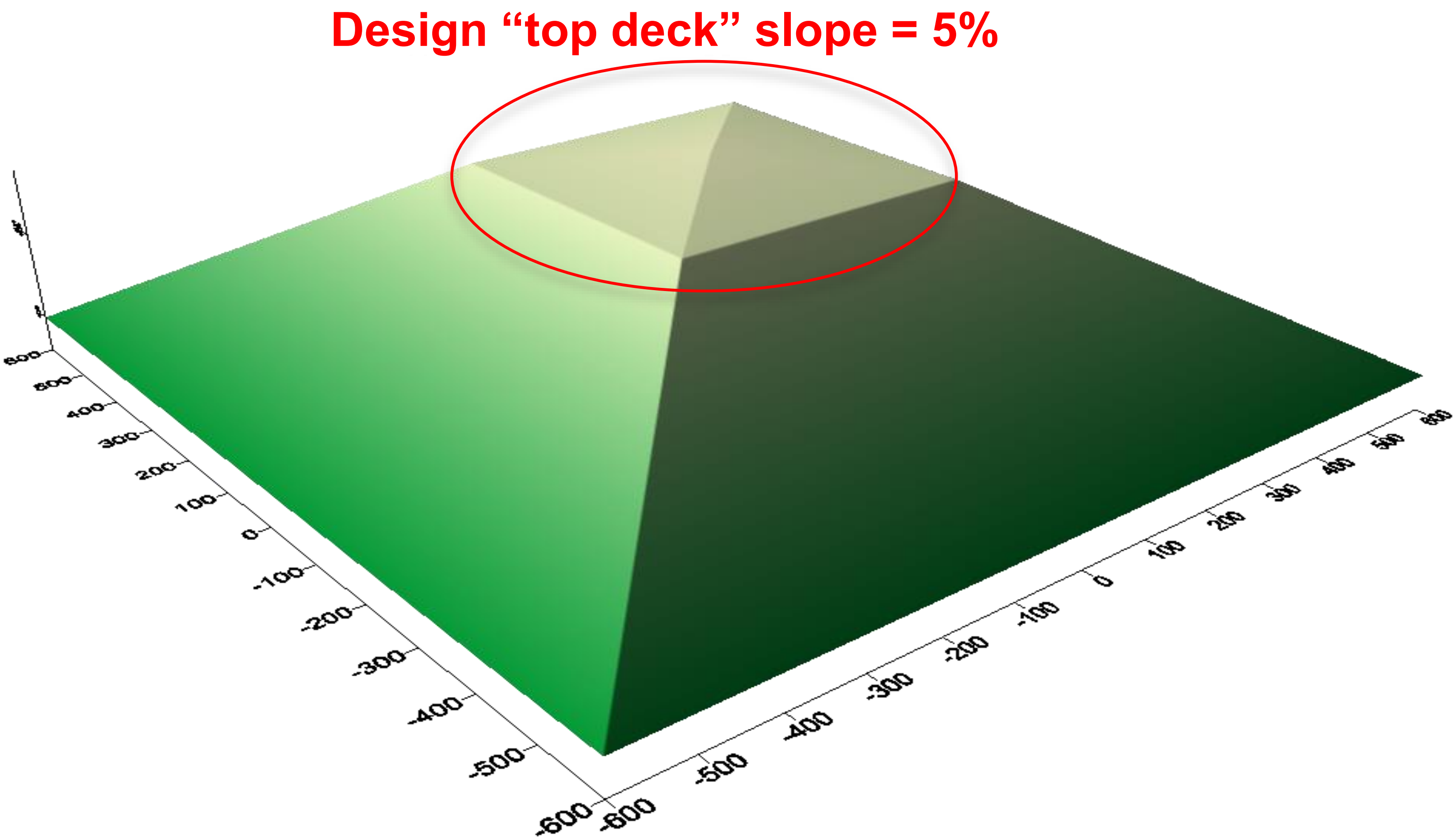


Modeled Post-Settlement Final Cover Profile (Example)

(shown with 2X vertical exaggeration)

Acceptable Performance Criterion (APC)

(Established based on a KYDEP approvable, prescriptive design)



Modeled Post-Settlement Final Cover Profile (Example)

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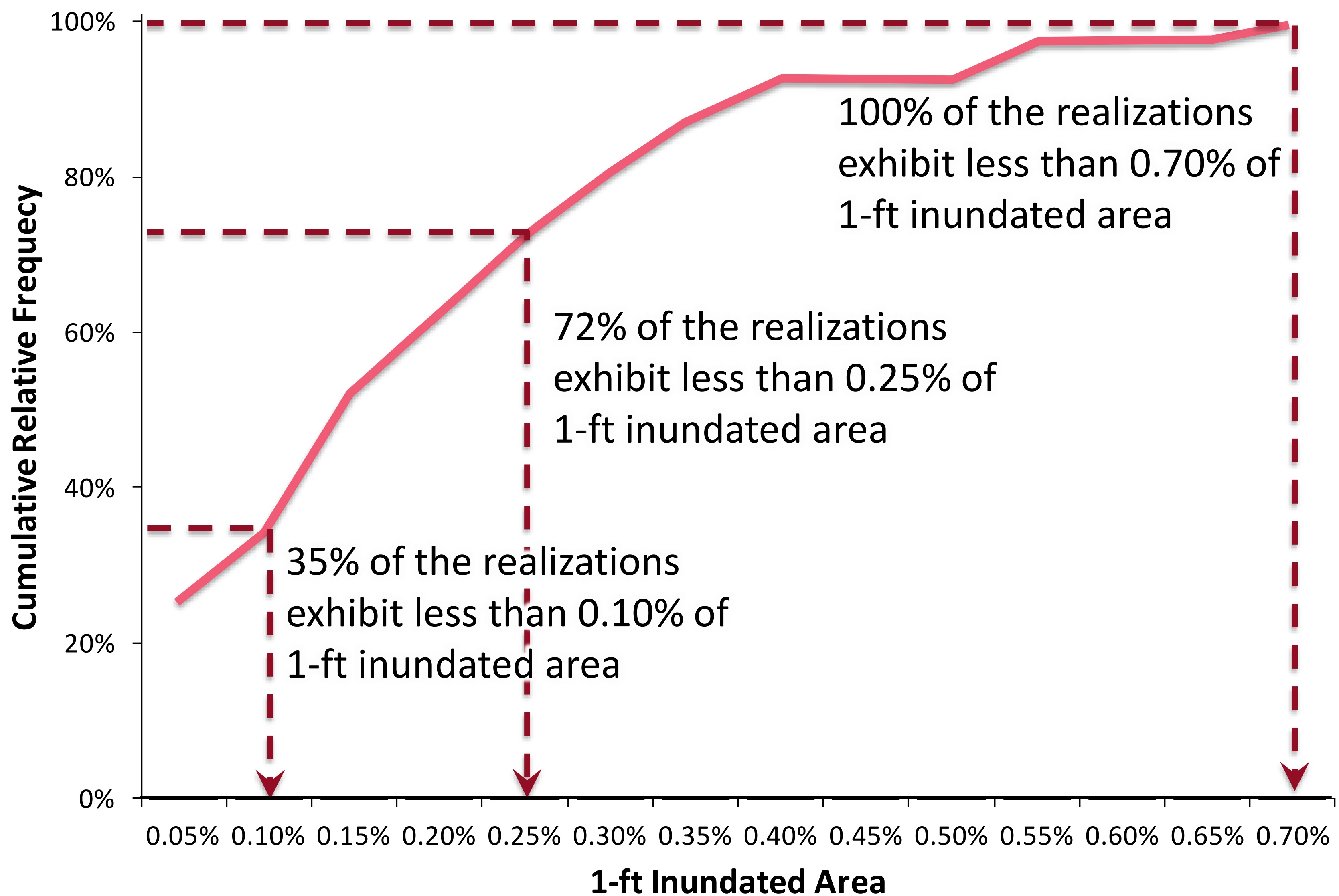

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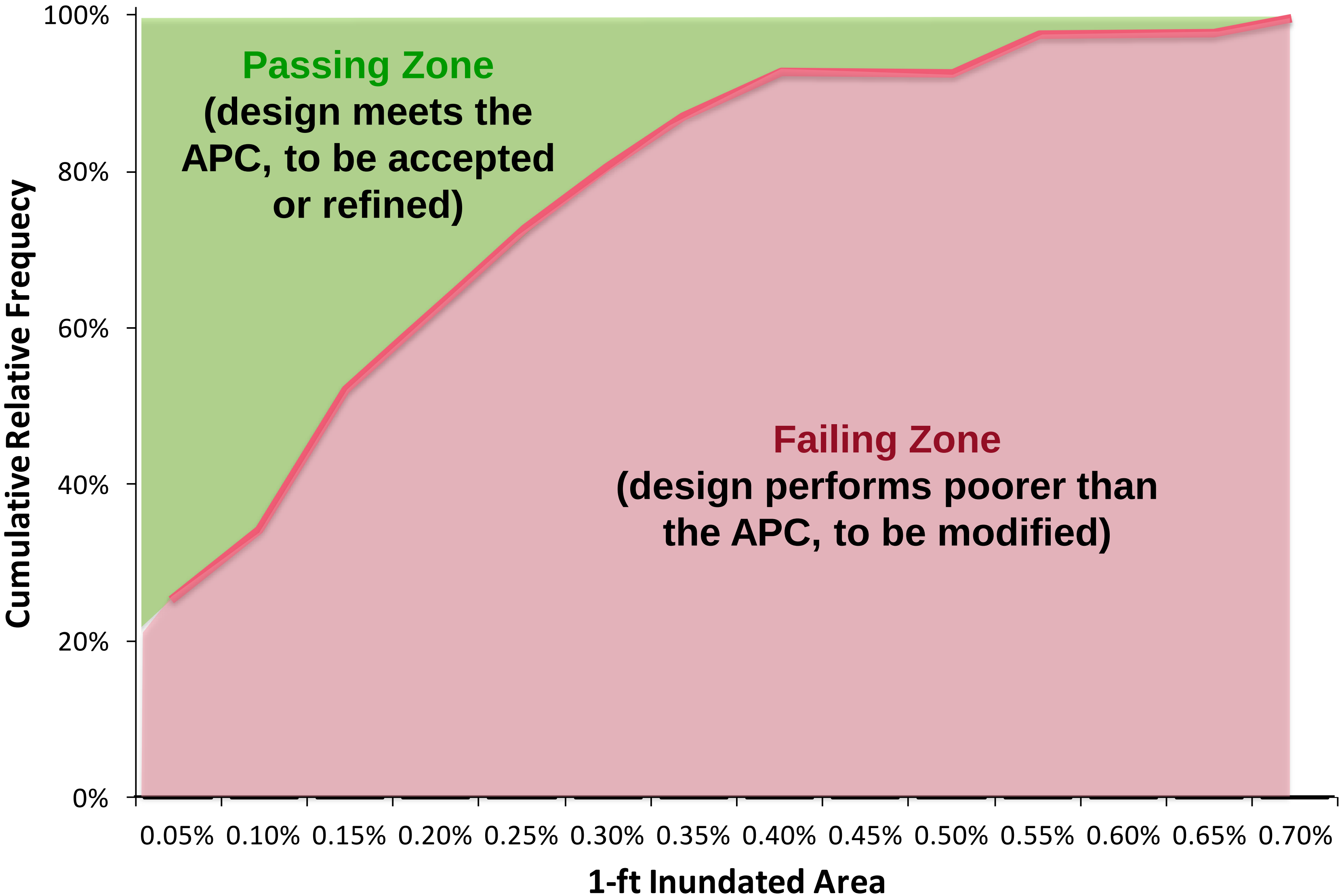
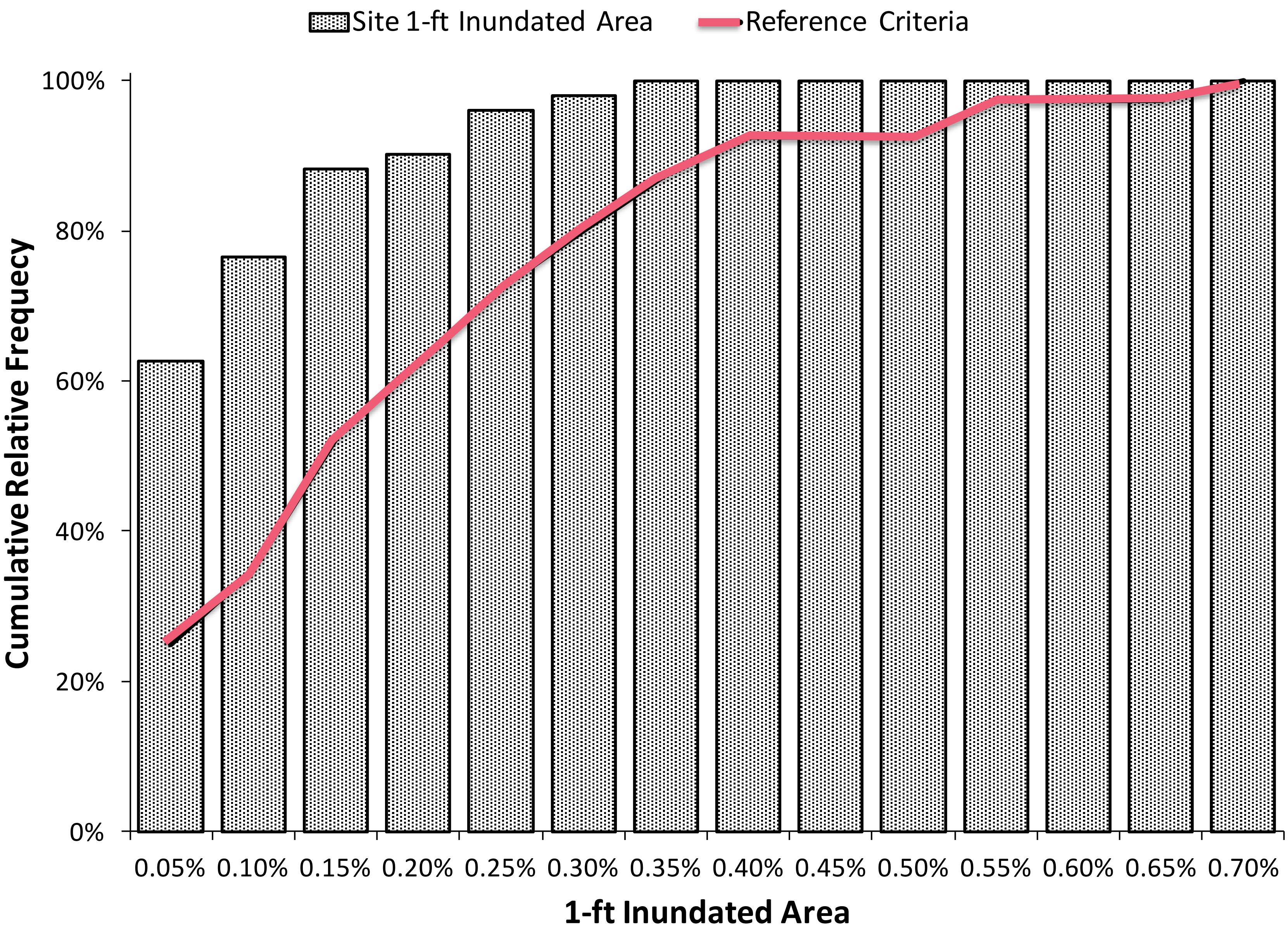


Validation of the Final Design Against APC




October 2013 - IRP cover


January 2017 - final cover

Deploying secondary geogrid over IRP cover

Deploying primary geogrid over leveling fill

Maxey Flats LLW Disposal Site Final Closure

Summary and Conclusion

- **Capability of predict waste settlement and subsequent cover system settlement is essential to ensure adequate long-term performance**
- **Sound quantitative practice that**
  - address waste's inherent spatial variability
  - optimize design features / cost
  - improve credibility of designs
  - increase public & regulatory confidence
- **Relevant applications include the closure of:**
  - waste disposal trenches, pits, shafts, vaults
  - MDAs
  - tank farms
  - new on-site waste disposal cells / facilities

Thank You!

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