

Post-Event Evaluation of Natural Gas Pipeline System After Hurricane Sandy

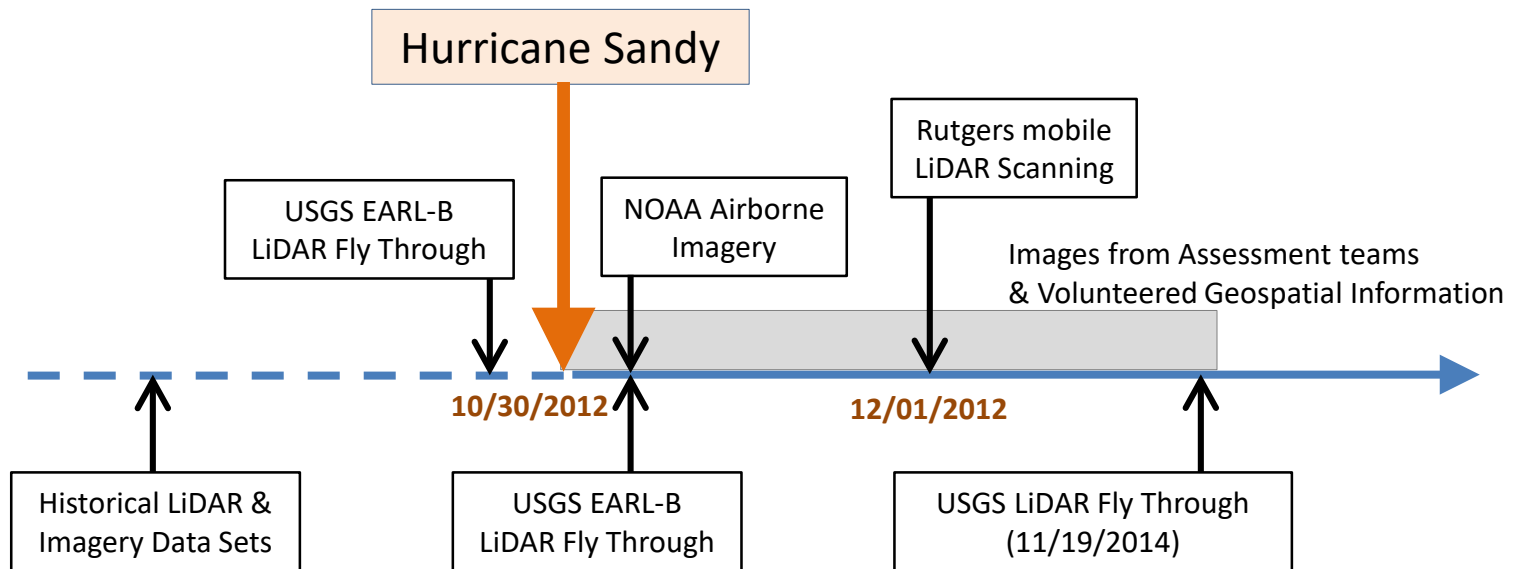
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Gas Technology Institute

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Department of Civil and Environmental Engineering
Rutgers, The State University of New Jersey

Natural Gas Pipeline System After Hurricane Sandy



Timeline for Spatial Sensing Technology Deployment During Hurricane Sandy



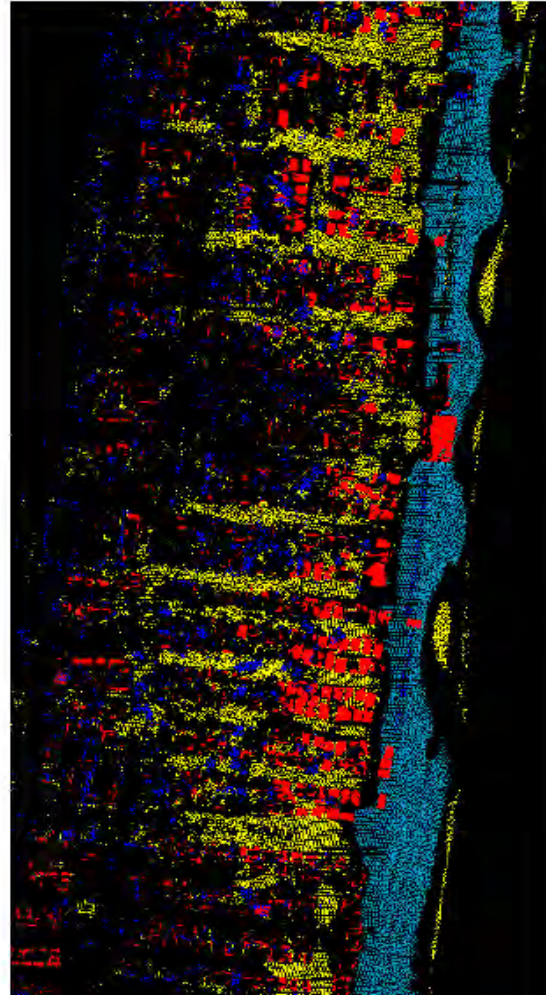
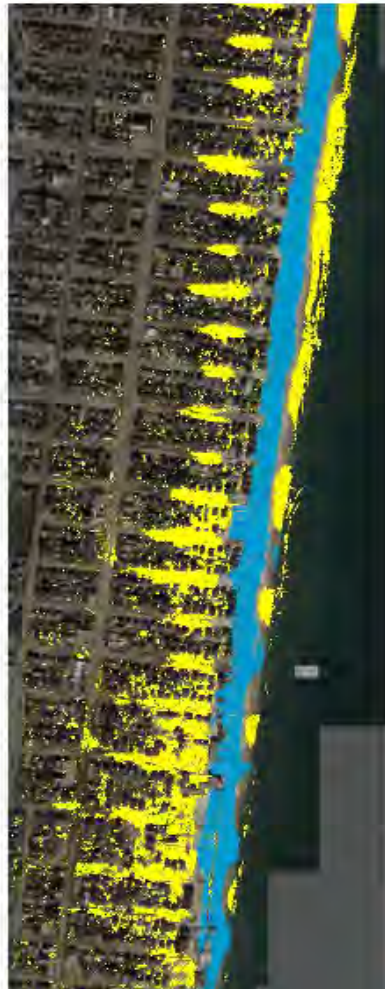
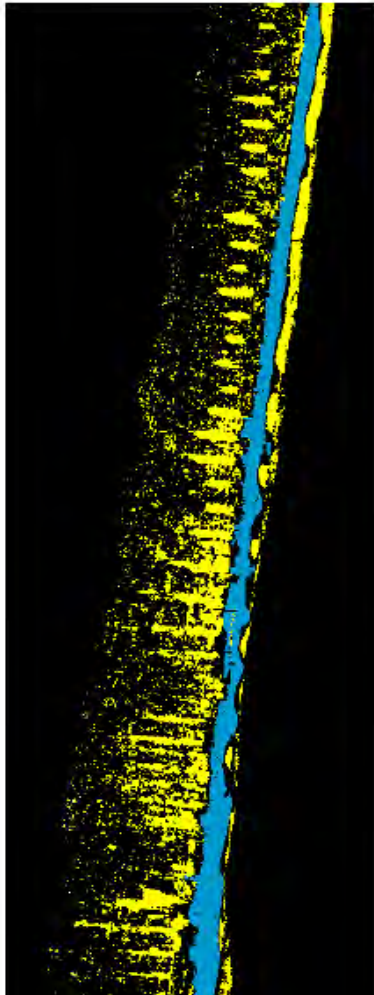
Rutgers Integrated Mobile LiDAR System



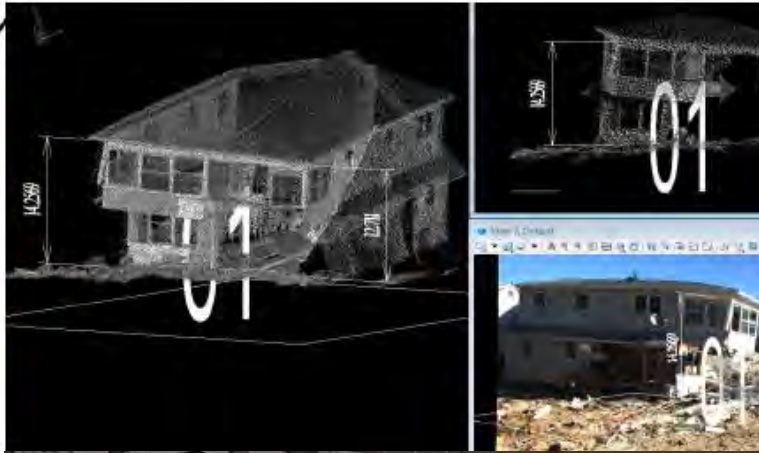
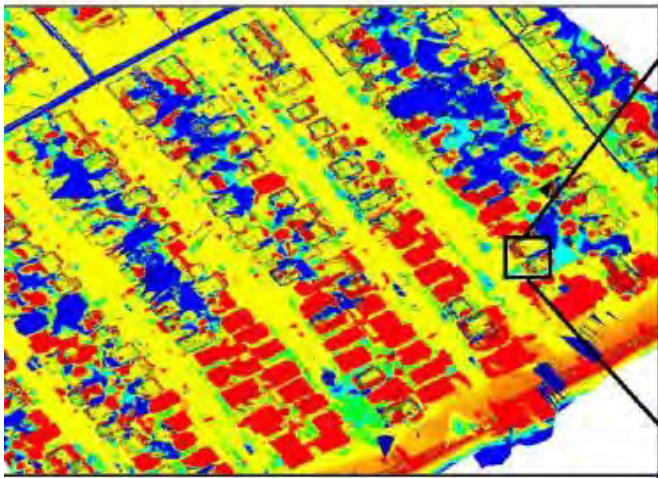
Rutgers Post-Hurricane Sandy Study



Debris Field and Flow at Ortley Beach

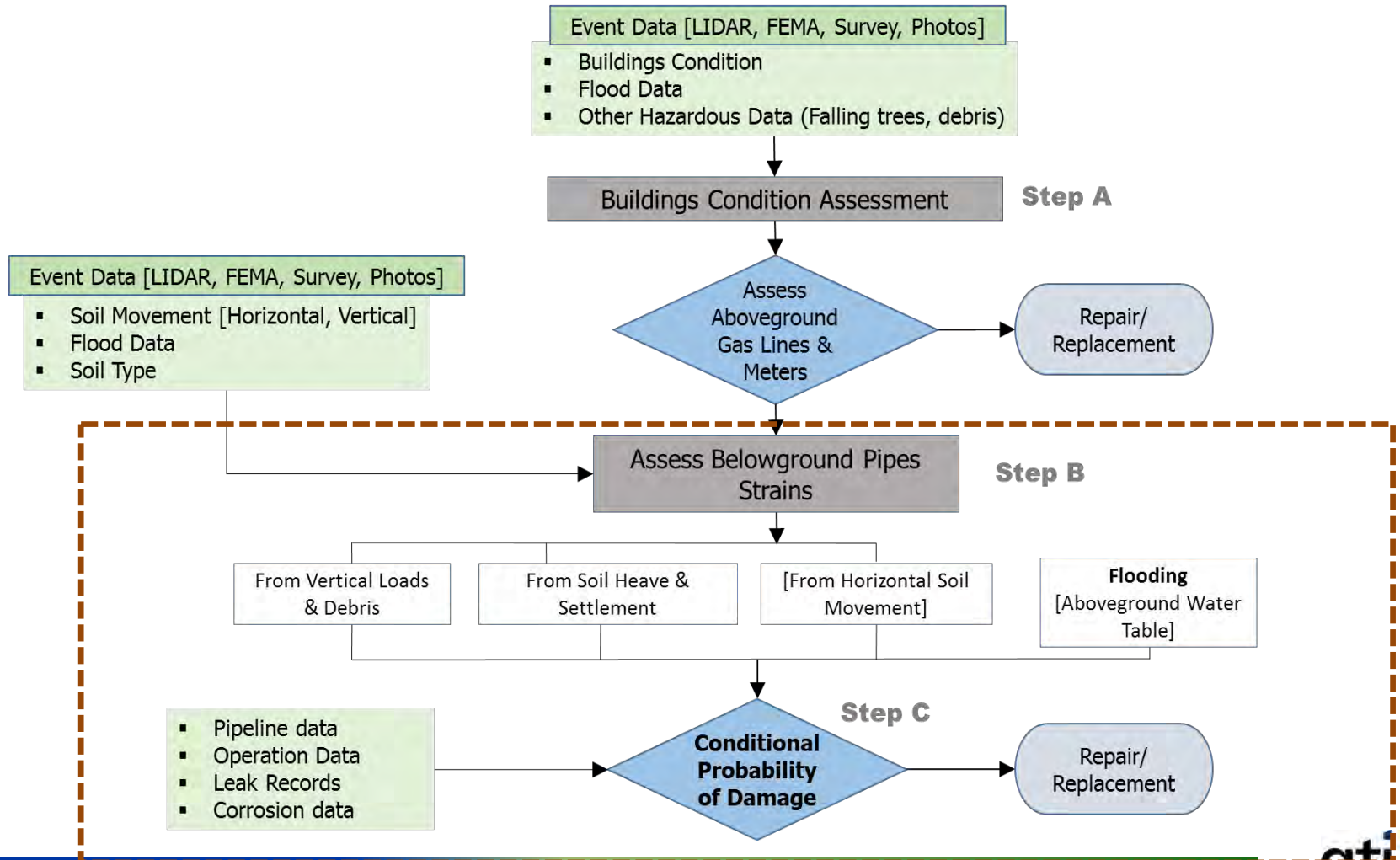


- **Yellow:**
Sand Debris
- **Cyan:** Erode
Dunes
- **Red:**
Destroyed
Buildings
- **Blue:**
Building
Debris or
Changes



Building Displacement

Integrated Post-Sandy Infrastructure Analysis



Aboveground Buildings Movement [FEMA DATA]



- ◆ Affected
- ◆ Minor
- ◆ Major
- ◆ Destroyed

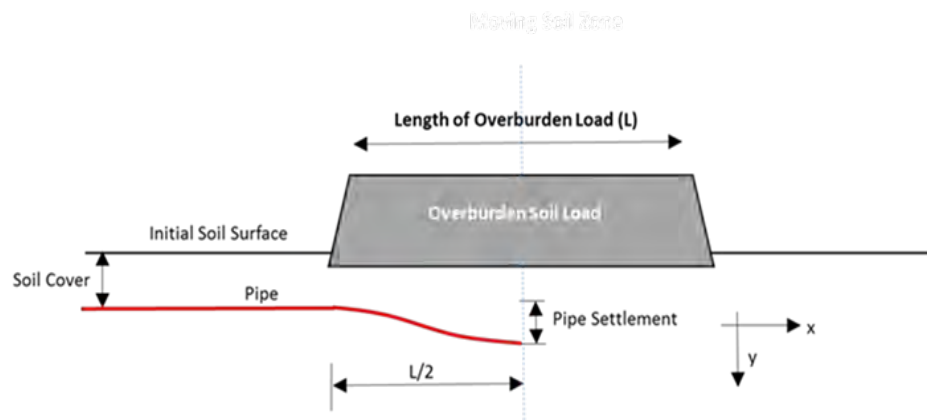
FEMA DAMAGE CLASSIFICATION		VISIBLE IMAGERY BASED CLASSIFICATION			
DAMAGE LEVEL	OBSERVED DAMAGE	Roof Covering	Roof Diaphragm	Collapsed Walls	Other Considerations
Affected	Generally superficial damage to solid structures (loss of tiles or roof shingles); some mobile homes and light structures damaged or displaced.	Up to 20%	None	None	Gutters and/or awning; loss of vinyl or metal siding
Minor	Solid structures sustain exterior damage (e.g., missing roofs or roof segments); some mobile homes and light structures are destroyed, many are damaged or displaced.	>20%	Up to 20%	None	Collapse of chimney; garage doors collapse inward; failure of porch or carport Mobile homes could be partially off foundation
Major	Wind: Some solid structures are destroyed; most sustain exterior and interior damage (roofs missing, interior walls exposed); most mobile homes and light structures are destroyed.	-	>20%	Some exterior walls are collapsed.	Mobile home could be completely off foundation – if appears to be repairable.
	Storm Surge: Extensive structural damage and/or partial collapse due to surge effects. Partial collapse of exterior bearing walls.			Some exterior walls are collapsed	
Destroyed	Wind: Most solid and all light or mobile home structures destroyed.	-	-	Majority of the exterior walls are collapsed.	-
	Storm Surge: The structure has been completely destroyed or washed away by surge effects.	-	-	Majority of the exterior walls are collapsed	

137,369

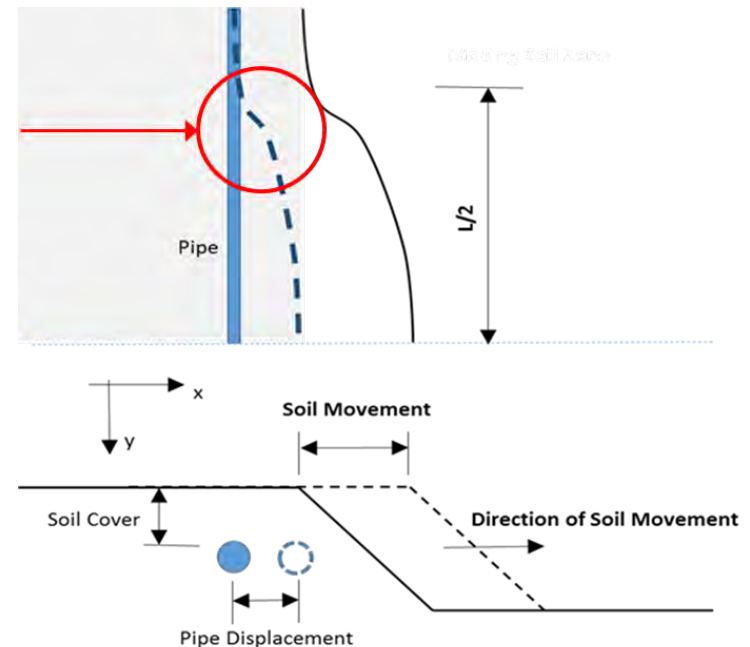
21,981

841

Natural Forces Threats – Belowground Pipes

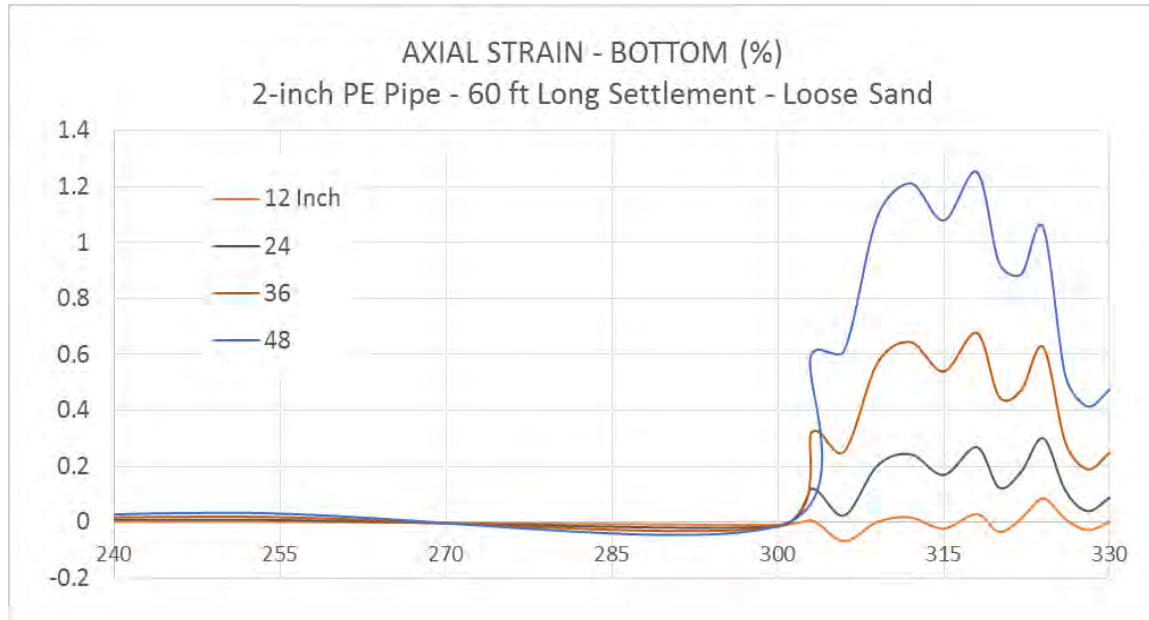


Vertical Displacement

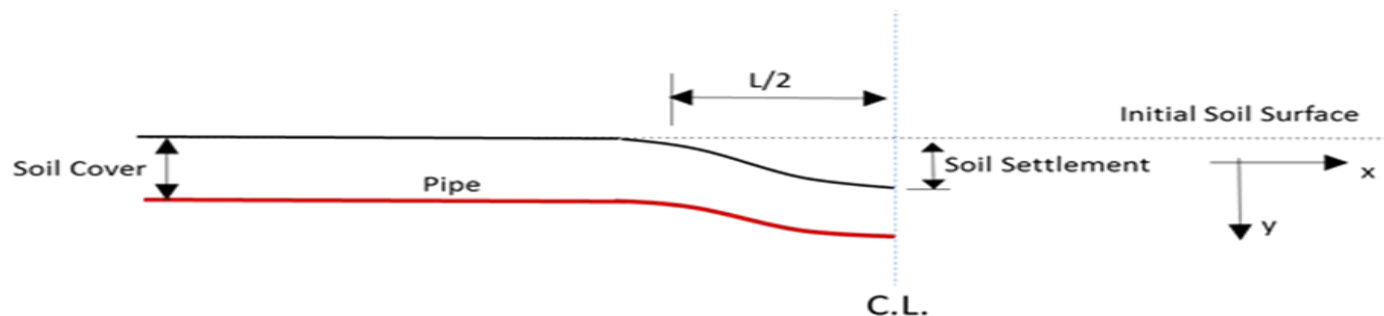


Horizontal Displacement

Natural Forces Threats – Belowground Pipes

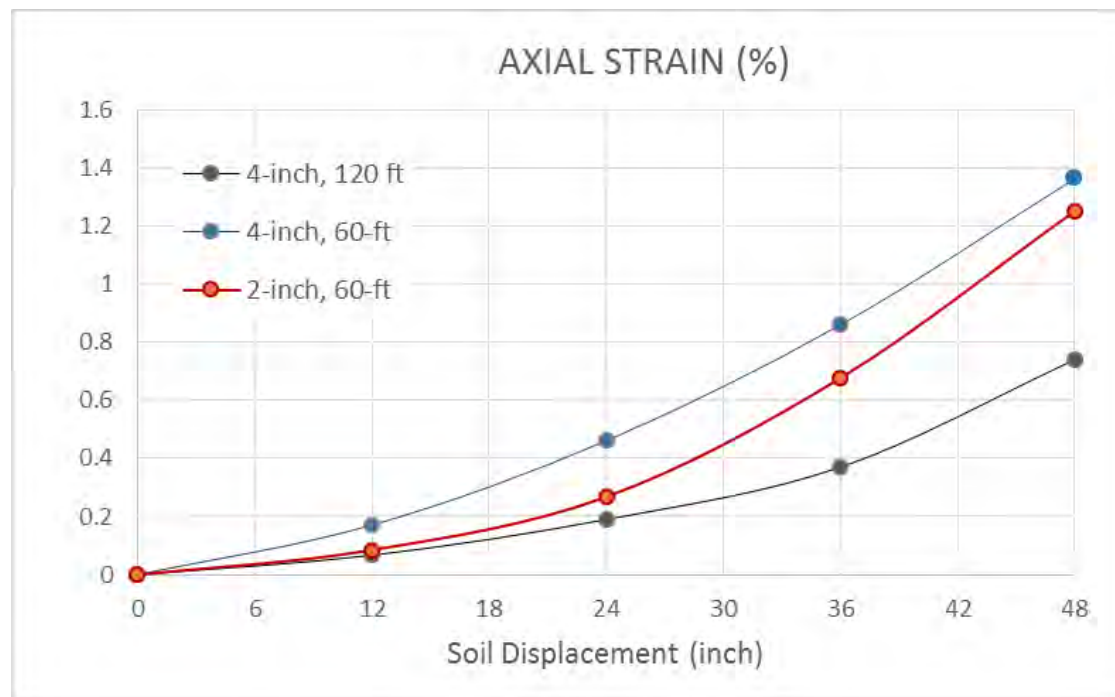


PE-Pipe Deformation
Due to Vertical Soil
Movement



Natural Forces Threats – Belowground Pipes

PE-Pipe Deformation Due to Vertical Soil Movement

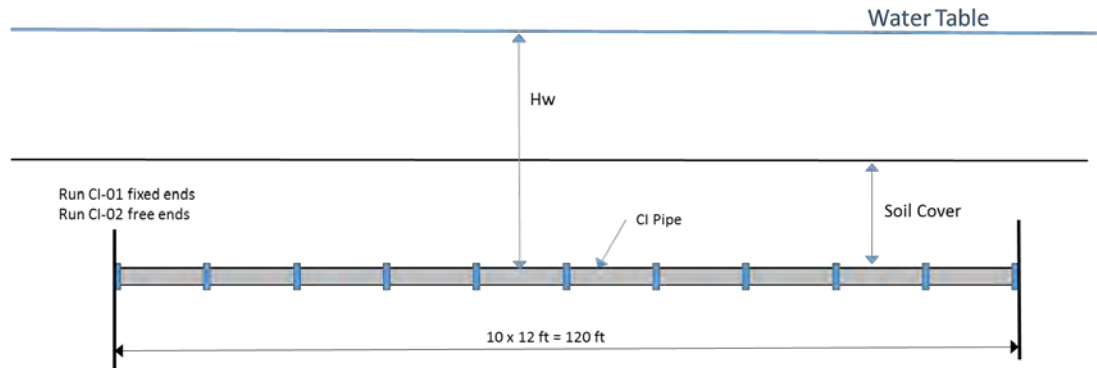


2 – 4 inch PE Pipe
Loose Sand – Settlement Length 60 -120 ft

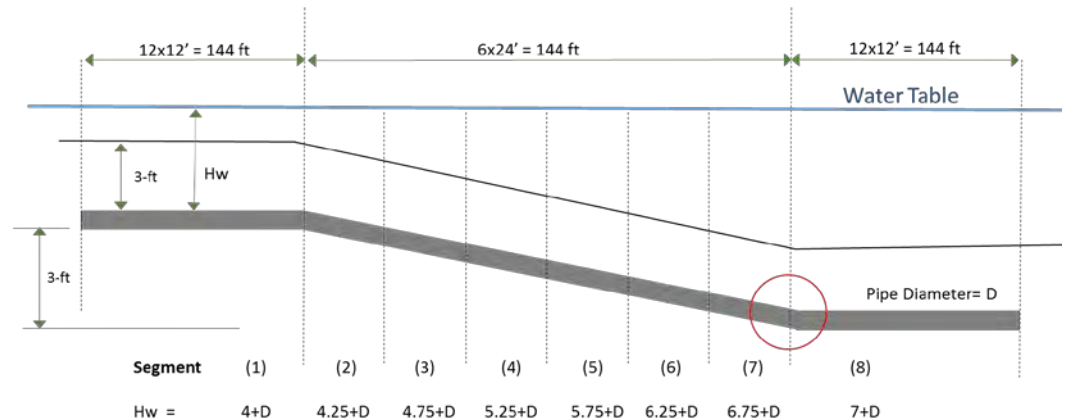
Natural Forces Threats – Belowground Pipes

Water Intrusion and Uplift Due to Flooding

- a) In CI pipes:
Water intrusion when:
 $\gamma_w \cdot H_w > \text{Pipe pressure}$



- b) In all pipes:
Uplift load depends on
water table and pipe size.

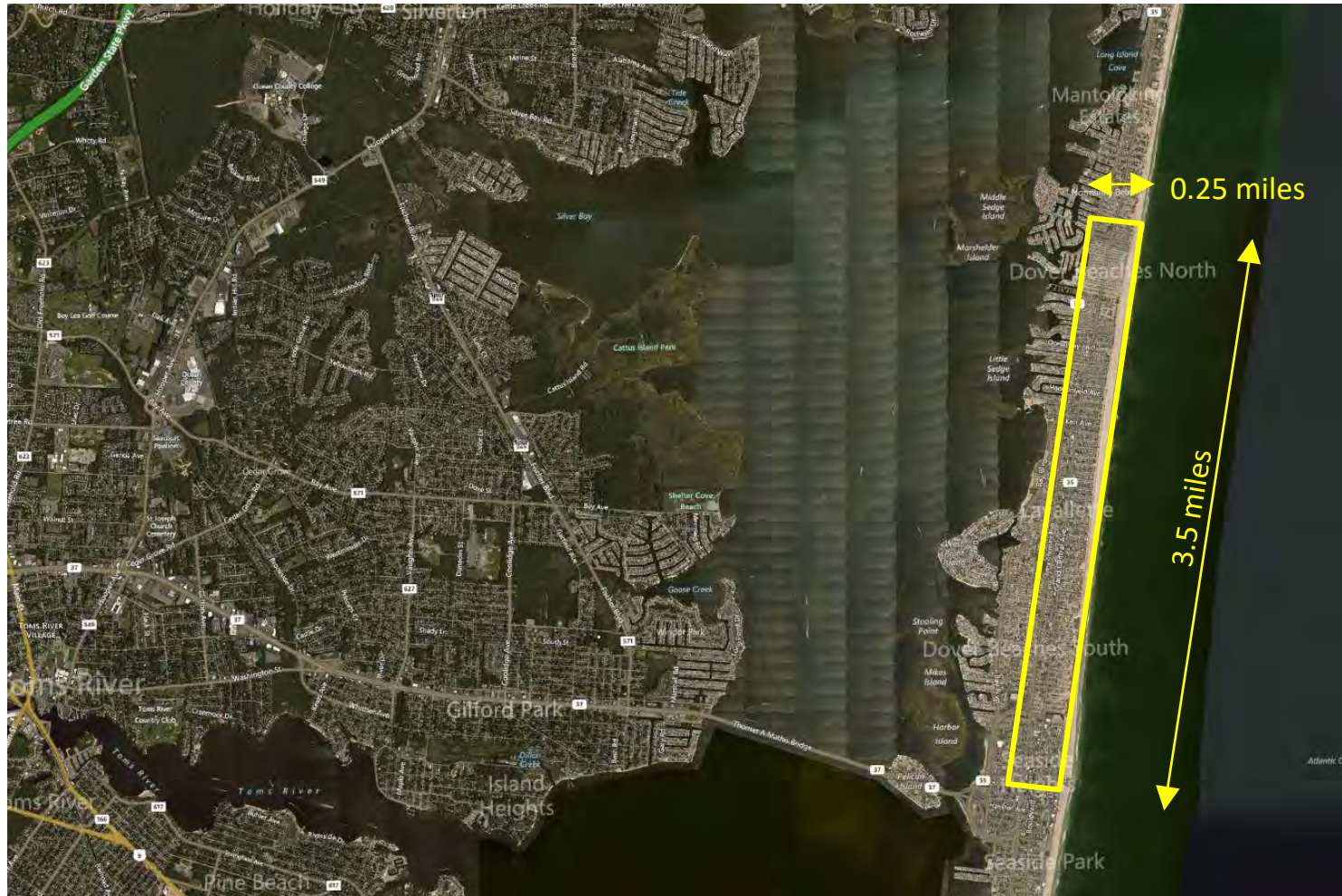


Natural Forces Threats – Belowground Pipes

Determining the Risk Levels

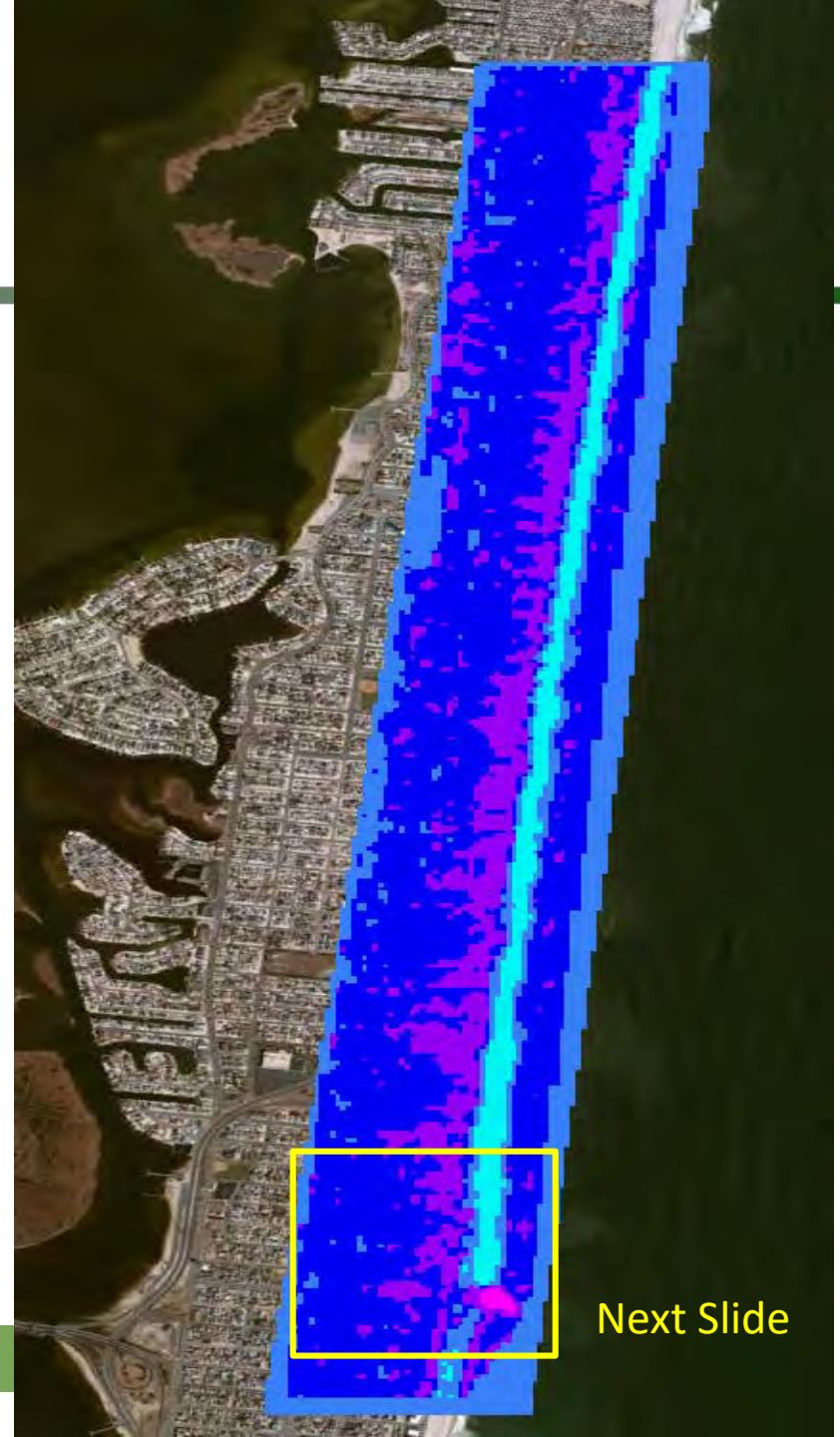
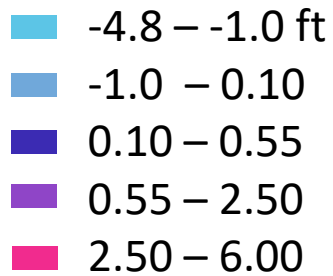
Loading Condition	Allowable Load or Stress	Allowable Deformation or Strain
Hoop stress from internal pressure and fluid transients	Code allowable for internal pressure	N/A
Through-wall bending from earth loads (static, live, surface impact)	Bending stress $< 0.5 \sigma_y$	N/A
Hoop compression from earth loads (static, live, surface impact)	Compressive stress $< 0.5 \sigma_y$	N/A
Ring buckling from earth loads (static, live, surface impact)	Compressive load $< \frac{1}{FS} \sqrt{32 R_{ff} B' E' \frac{EI}{D^3}}$	Strain limits: Mortar-lined and coated = 2% D Mortar-lined & flexible coated = 3% D Flexible lining & coated = 5% D
Bending stress from buoyancy	Bending stress $< \sigma_y^6$	Strain limits: Tension: 0.5% Compression: 0.5%
Thermal expansion	Code allowable for secondary loading ¹	N/A
Movement at bends	Code allowable for primary loading ¹	N/A
Longitudinal strain from ground movement due to earthquake, landslide, or mine subsidence, combined with thermal strain	N/A ²	Operable limits^{4,5} Tension strain limit 2% Compression strain limit $0.50 \left(\frac{t}{D'} \right) - 0.0025 + 3000 \left(\frac{pD}{2Et} \right)^2$ $D' = \frac{D}{1 - \frac{3}{D} (D - D_{mm})}$ Pressure integrity limits^{4,5} Tension strain limit 4% Compression strain limit $1.76 \frac{t}{D}$
Wave propagation ^{4,5}	Bending stress $< \sigma_y$	Tension strain limit 0.5%

Buried Pipes Assessment – Ortley Beach



Soil Movement, [LiDAR DATA]

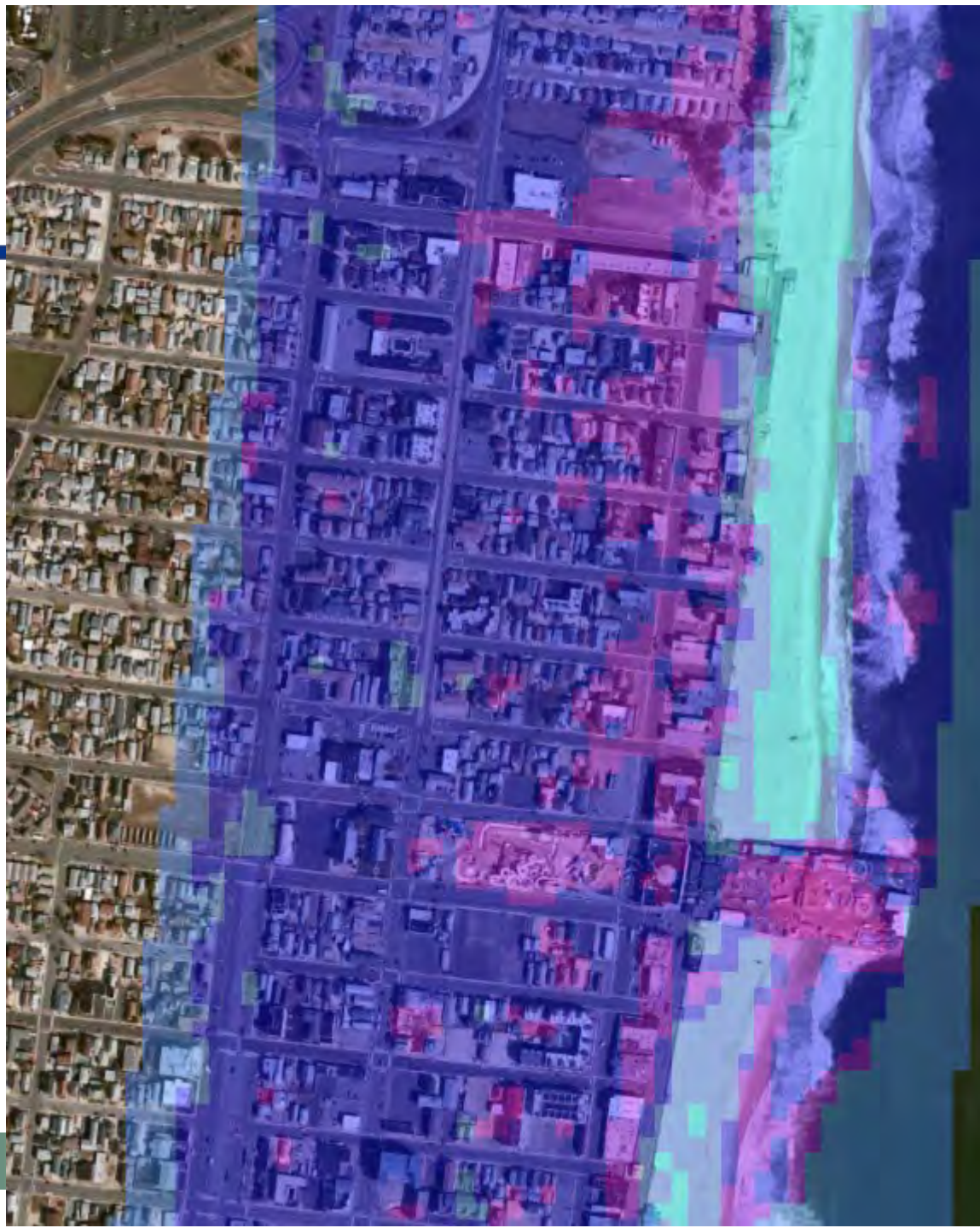
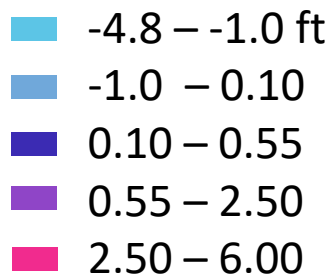
Mean Change of Soil Elevation
[Before & After Sandy]



Next Slide

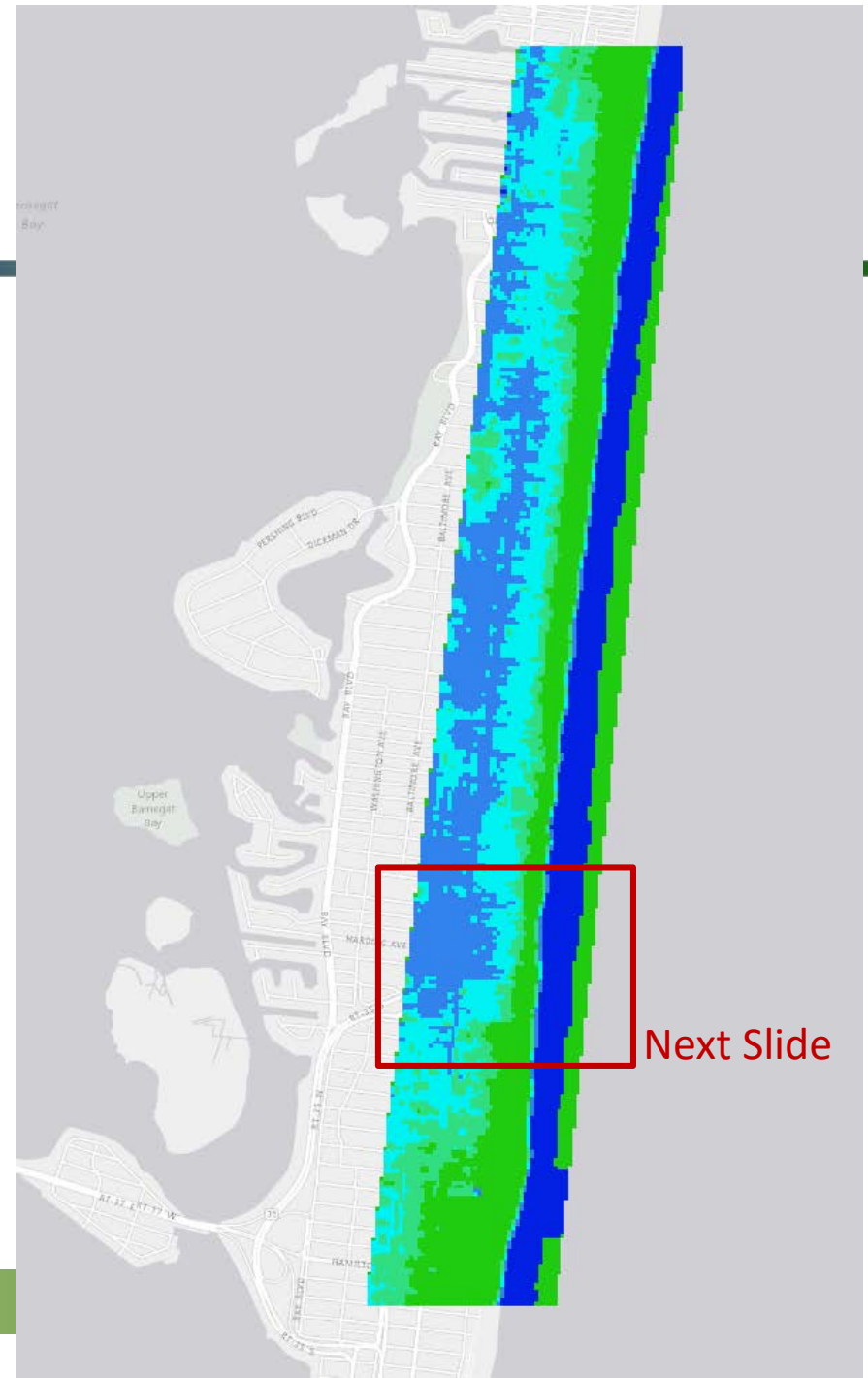
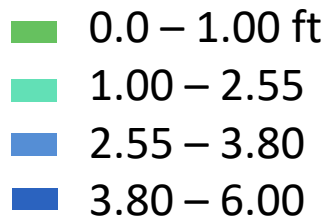
Soil Movement, [LiDAR DATA]

Data Tabulated in 50-ft
Grids, Change of Soil
Elevation



Flooding, [FEMA DATA]

Flood Levels After Sandy



Flooding, [FEMA DATA]

Flood Levels After Sandy

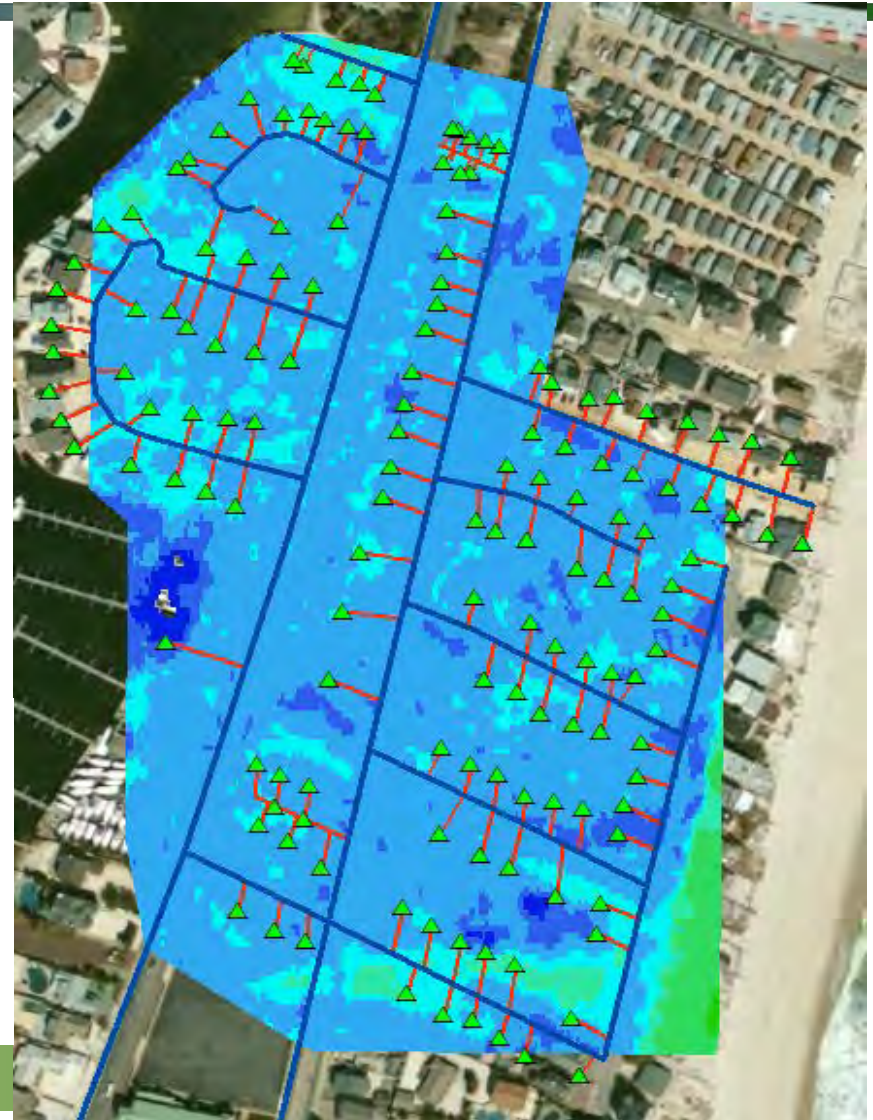
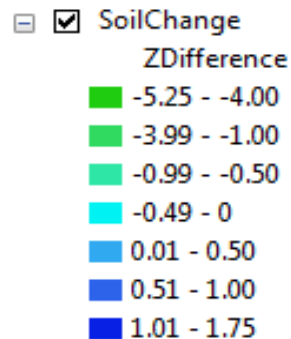
- 0.0 – 1.00 ft
- 1.00 – 2.55
- 2.55 – 3.80
- 3.80 – 6.00



Buried Pipes Assessment

Spatial Changes in soil elevation before and after Sandy.

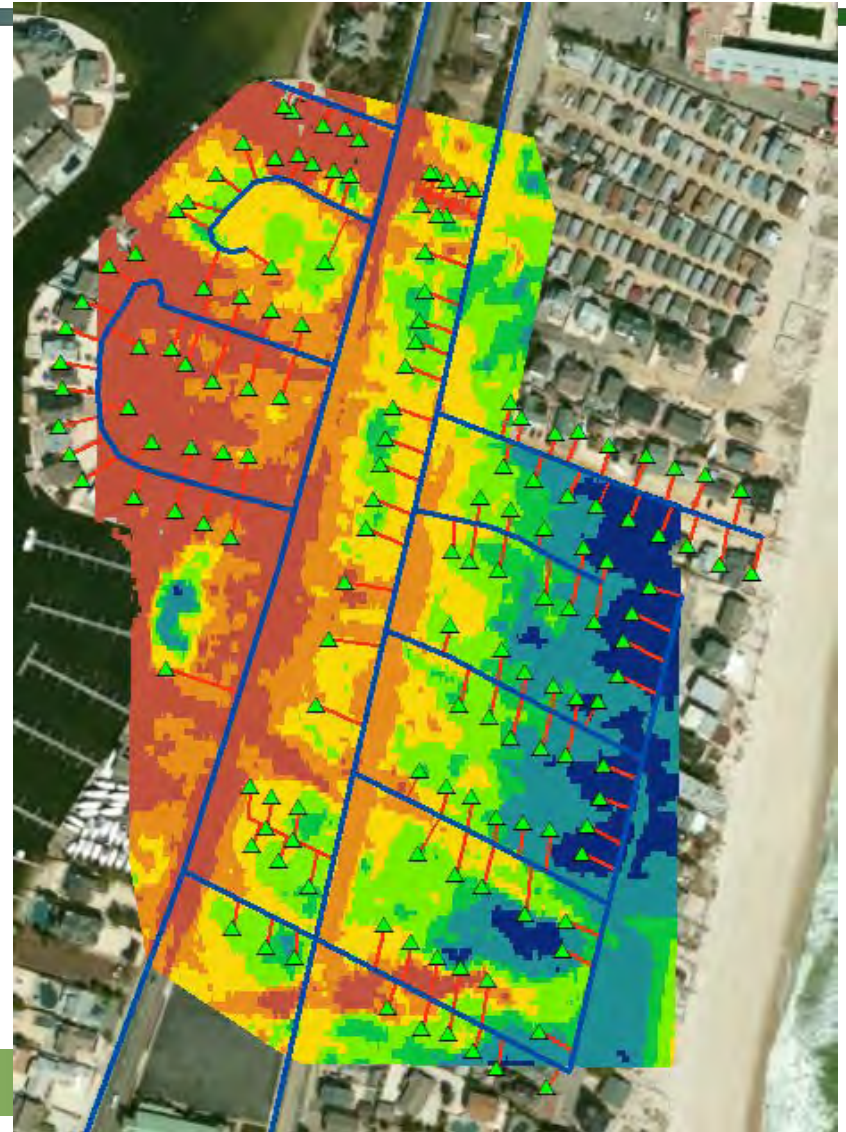
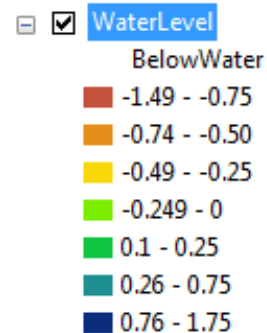
[Note: Z in this figure is in meters]



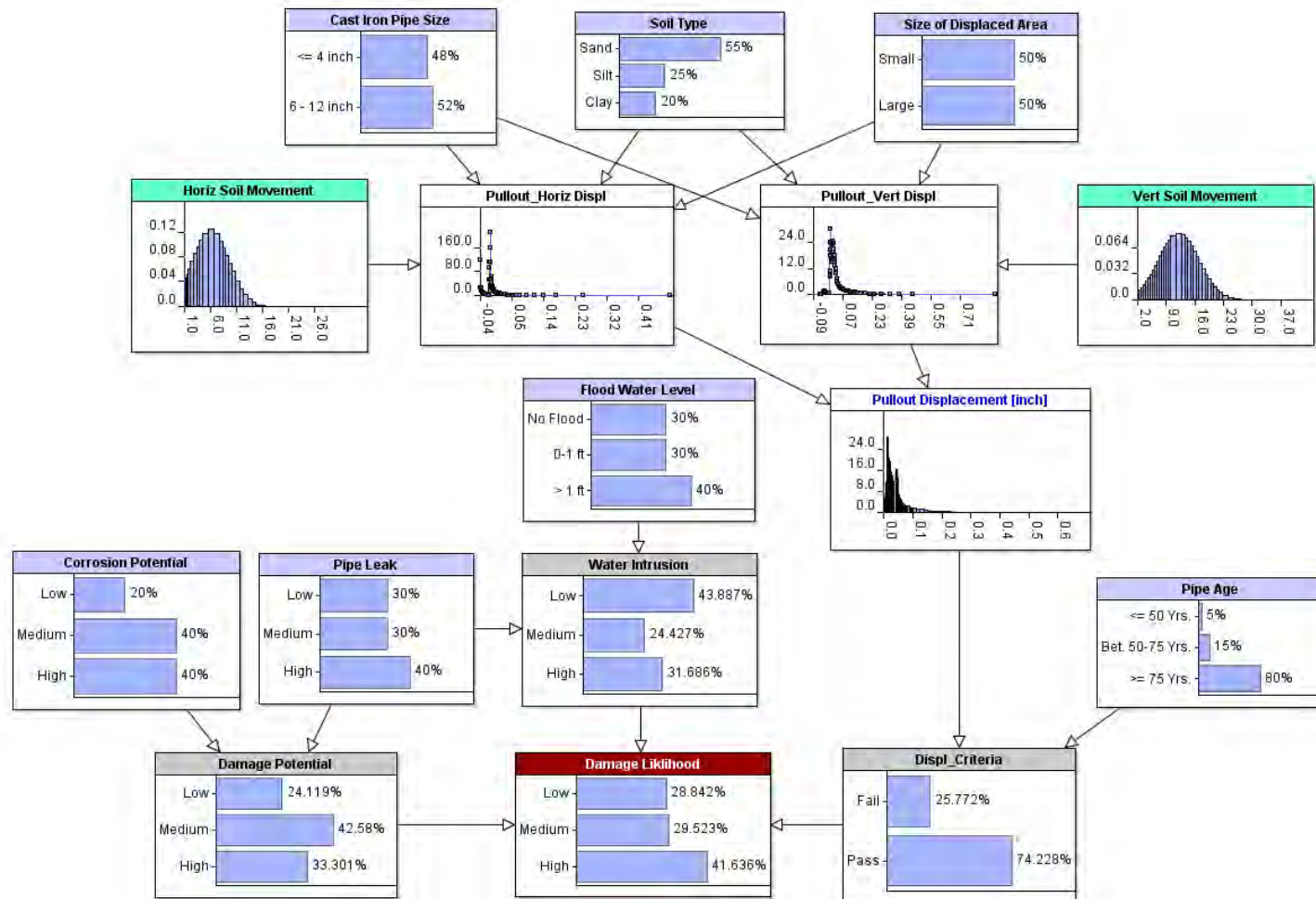
Buried Pipes Assessment

Spatial Changes in water elevation before and after Sandy.

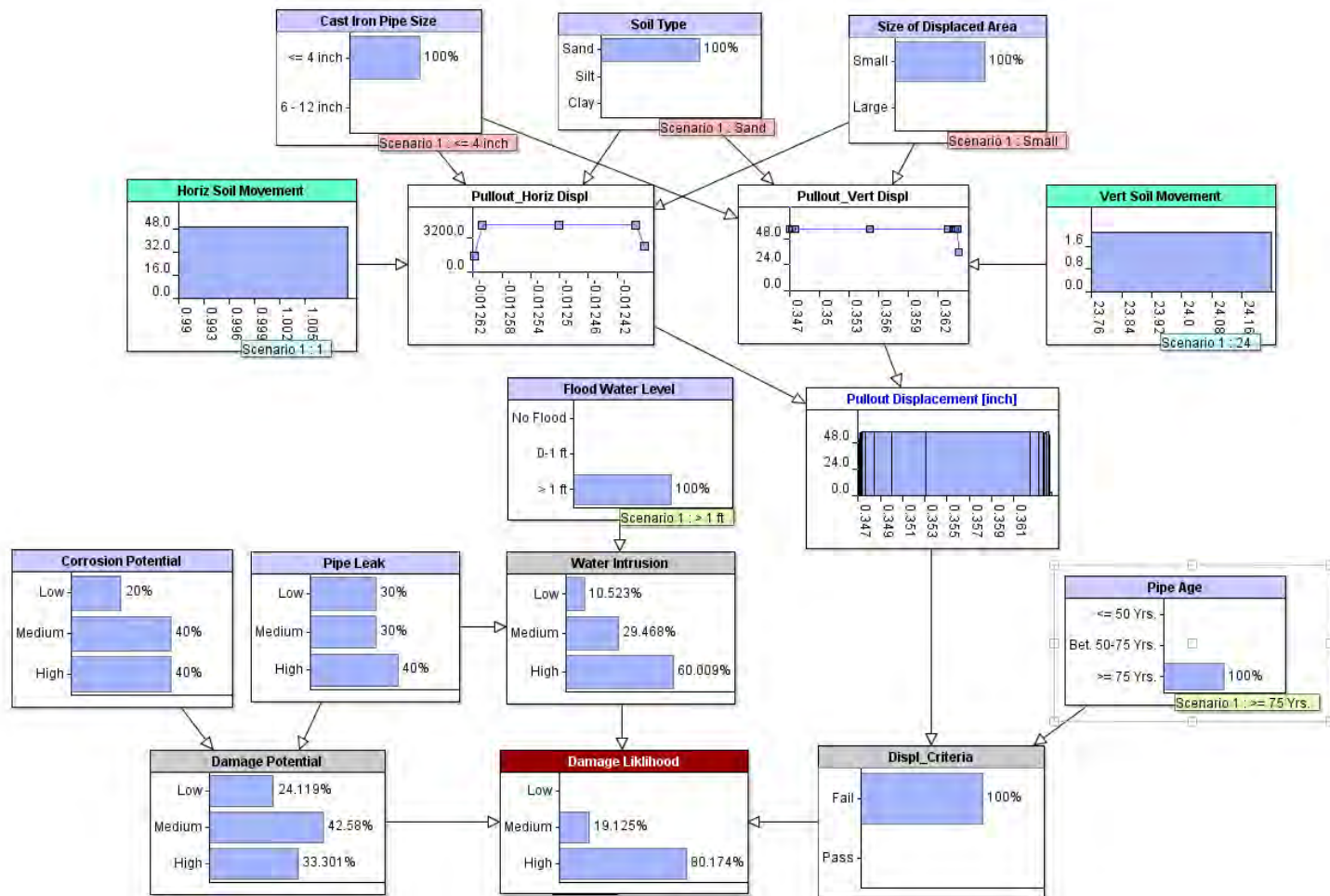
[Note: Z in this figure is in meters]



Integrated Risk Model, Bayesian Network



Integrated Risk Model, Bayesian Network.



Integrated Risk Model, Bayesian Network.

Risk model output in a sample GIS grid:

Damage Likelihood:

- High
- Medium
- Low



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Questions?

