COASTAL TEXAS CSRM STUDY:

FOUNDATION HEIGHT SAMPLING, STORAGE TANK DEPTH-DAMAGE RELATIONSHIPS AND NATIONAL OUTPUT LOSSES AVOIDED

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Overview of Presentation

- Introduction
- Foundation Height Sampling
- Storage Tank Depth-Damage Relationships
- Avoided Output Losses

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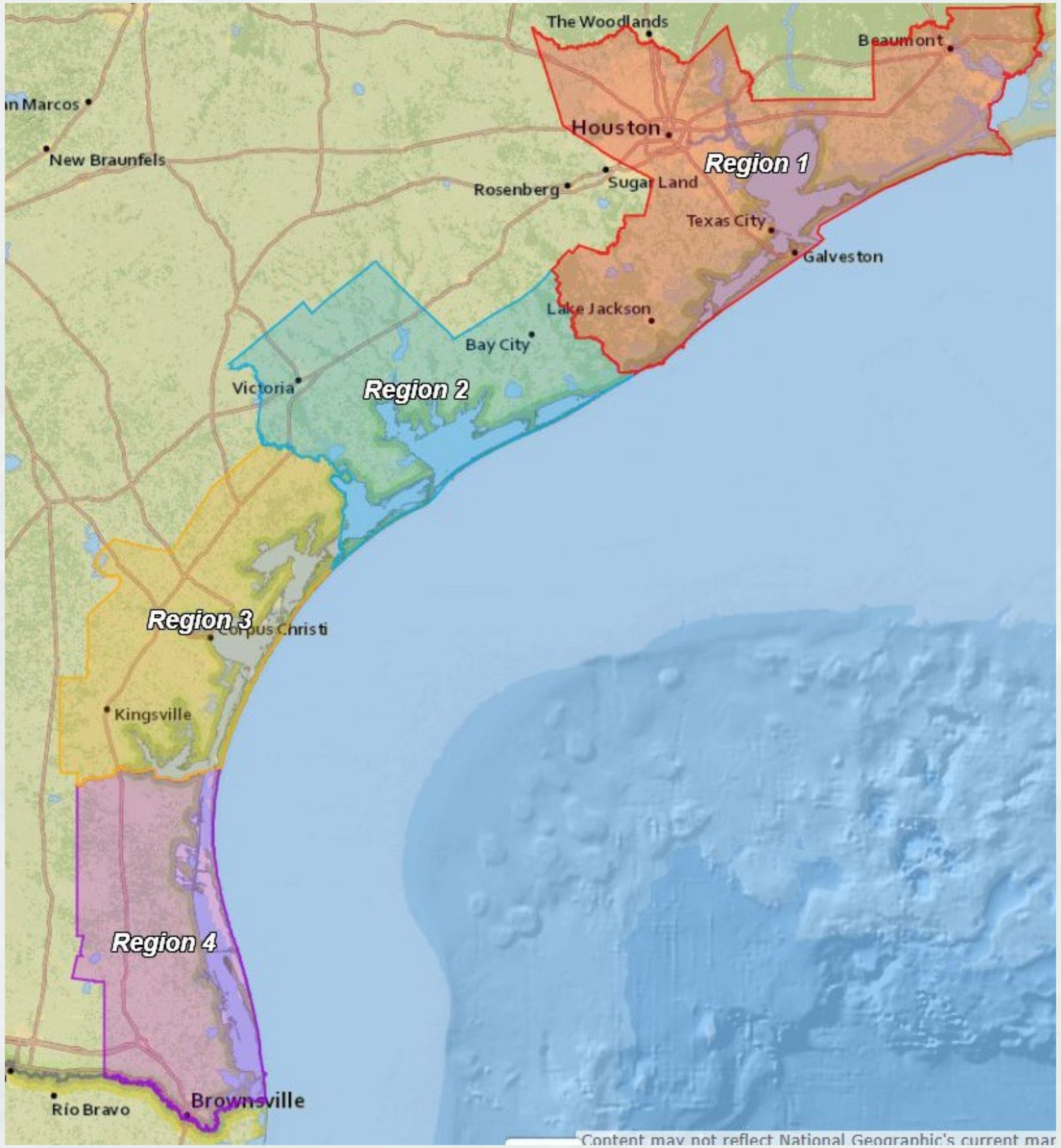
Coastal Texas Protection and Restoration Study Area



- Broad area of possible effects
- 4 regions identified in the Recon Report
- 9 Texas Congressional Districts and 6 counties
- U.S. Senators Cornyn and Cruz (TX)

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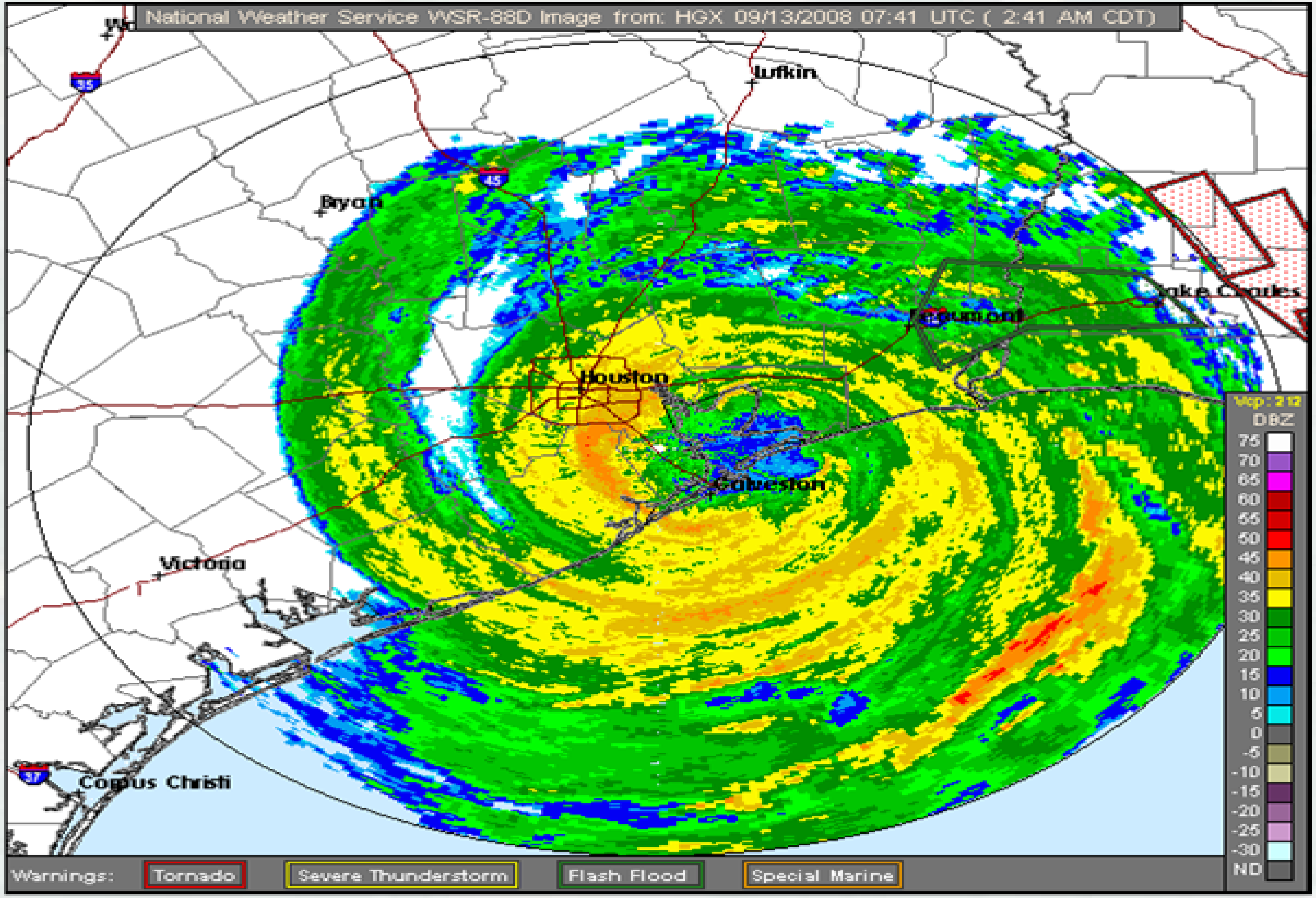
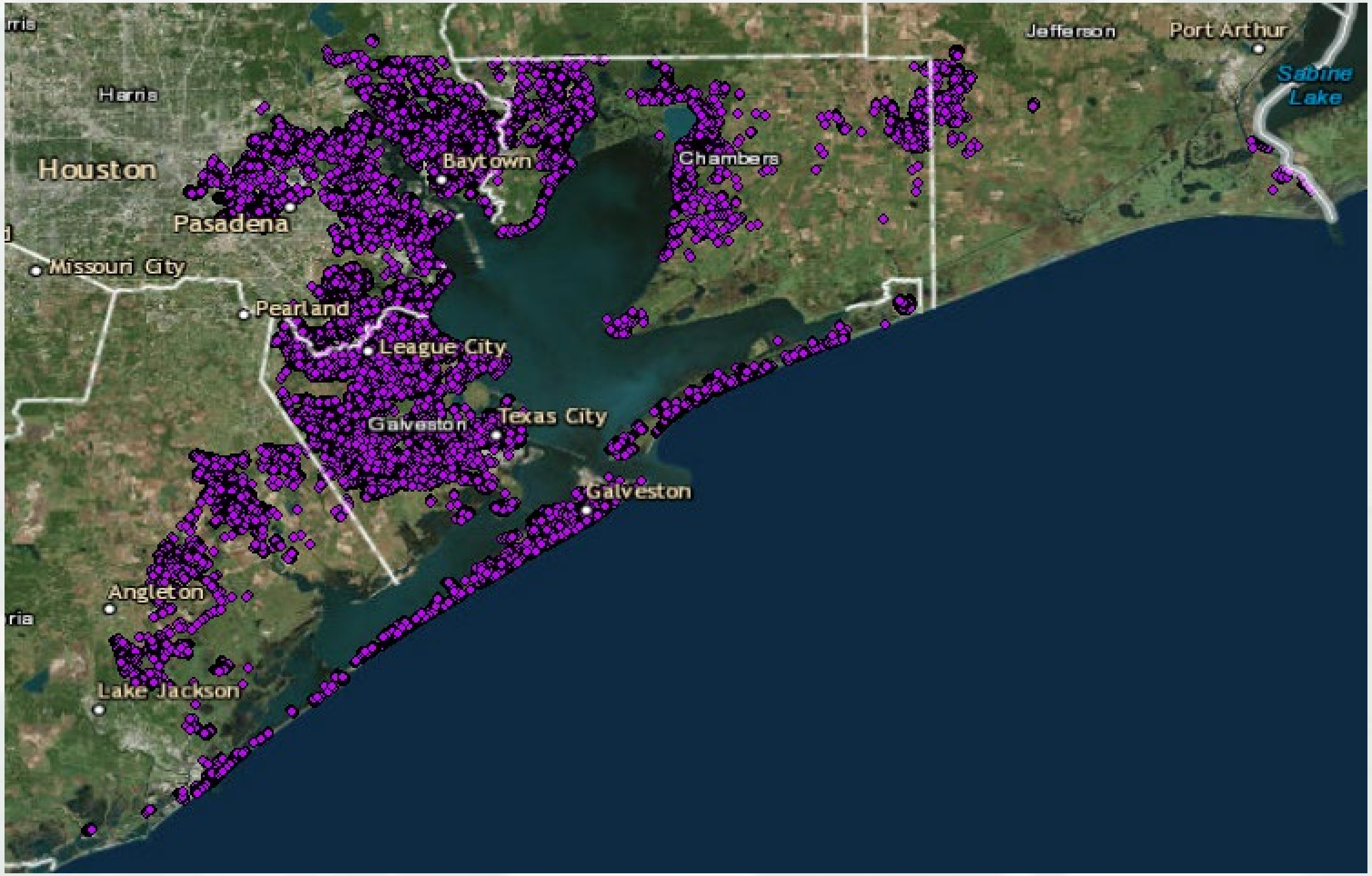
BUILDING STRONG®

Hurricane Ike (2008)



Current Structure Inventory – Region 1



Structure locations were obtained from 2014 county assessor data. The current inventory has 214,661 residential and non-residential structures.

Variation in Foundation Types and Heights Above Ground

Foundation Type (Pile, Pier, Crawlspace, Solid Wall, Basement)=P

Height above Ground = 2 ft.

Height above Ground = 3 ft.

Foundation Type (Pile, Pier, Crawlspace, Solid Wall, Basement)=P

Height above Ground = 12 ft.

Height above Ground = 7 ft.

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Variation in Foundation Types and Heights Above Ground

Foundation Type (Pile, Pier, Crawlspace, Solid Wall, Basement)=P

Height above Ground = 5 ft.

Height above Ground = 1.5 ft.

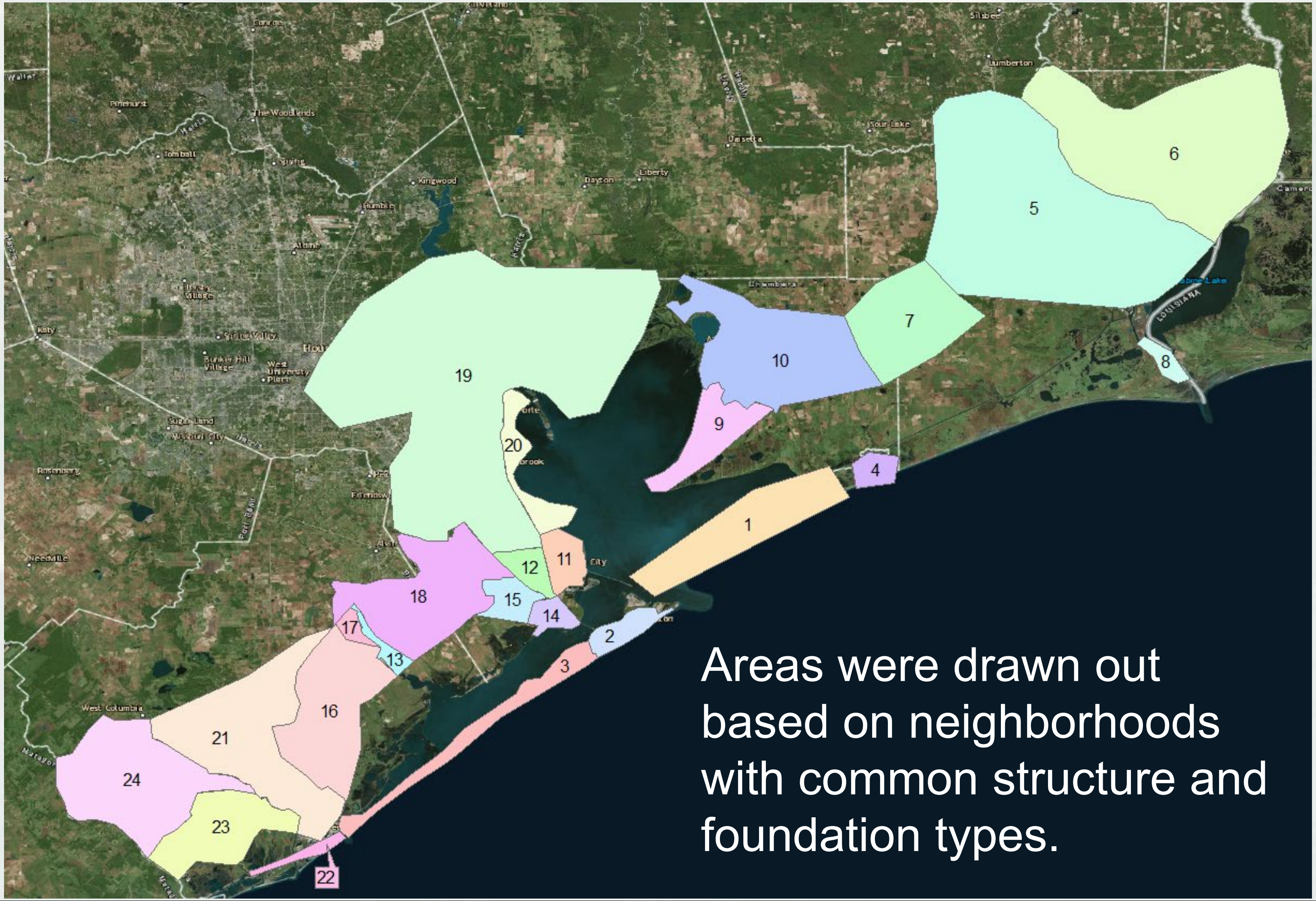
Slab on Grade

Height above Ground = 1 ft.

Height above Ground = 0.5 ft.

Sampling Areas

Step 1: Divide study area into distinct areas for sampling (aka Areas of Interest/AOIs)



Areas were drawn out based on neighborhoods with common structure and foundation types.

Sample Size for Foundation Height

Step 2: Obtain Statistical formulas

$$n = \left(\frac{z \cdot s}{E}\right)^2$$

- *n* is size of sample
- *E* is allowable error
  - Precision = 1.0 ft. pile foundation and 0.3 ft. slab foundation
- *z* is *z*- value
  - Accuracy (95% level of confidence) = 1.96
- *s* is sample SD
  - Pilot survey
  - Guesstimate (max height –min height)/6

Sampling Formula Example

Step 2: Obtain Statistical formulas

$$n = \left(\frac{Z \cdot S}{E}\right)^2$$

- E = 1.0 feet for pier foundation structures
- z = 1.96 (95 percent level of confidence)
- s = 1.83 feet (maximum pier height 13 feet & minimum pier height 2 feet or 13-2=11ft) divided by 6 (11ft/6 sigma) = 1.83

$$s = \left(\frac{13 - 2}{6}\right) = 1.83$$

- n = 13 structures

$$n = \left(\frac{1.96 \cdot 1.83}{1.0}\right)^2 = 13$$

Sample Size for Proportion of Pier to Slab Foundation

Step 2: Obtain Statistical formulas

$$n = p(1-p)\left(\frac{z}{E}\right)^2$$

- *n* is size of sample
- *E* is allowable error
  - Precision = 5%
- *z* is *z*- value
  - Accuracy (95% level of confidence) = 1.96
- *p* is proportion with the characteristic (pile foundation)
- 1-*p* is proportion without the characteristic (slab foundation)

Proportioning Sampling Formula Example

Step 2: Obtain Statistical formulas

$$n = p(1-p)\left(\frac{z}{E}\right)^2$$

- p = 0.95 (proportion of pier foundations)
- 1-p = 0.05 (proportion of slab foundations)
- z = 1.96 (95 percent level of confidence)
- E = 0.05 (allowable proportion error)
- n =73 structures (sample size);

$$n = 0.95(1-0.95)\left(\frac{1.96}{0.05}\right)^2 = 73$$

Note: If there is a 50/50 proportion of slab to pier, then n= 384

$$n = 0.5(1-0.5)\left(\frac{1.96}{0.05}\right)^2 = 384$$

Total Structures Sampled

AOI Id	Method (Type of Foundation)	Structure Count	Number of Structures to be Sampled
1	Sample (Mainly Pilings)	3,148	73
2	Detailed Sample	14,972	361
3	Sample (Mainly Pilings)	8,122	71
4	Sample	211	136
5	Remove	41,526	0
6	Remove	26,620	0
7	Sample (Mainly Slab)	1,409	288
8	Sample (Mainly Pilings)	74	38
9	Sample	367	148
10	Sample (Mainly Slab)	1,565	288
11	Sample (Mainly Slab)	9,945	195
12	Sample (Mainly Slab)	8,534	195
13	Detailed Sample	700	169
14	Sample	2,708	333
15	Detailed Sample	3,345	383
16	Sample	3,967	384
17	Sample (Mainly Slab)	424	158
18	Sample (Mainly Slab)	14,380	289
19	Sample outside of 100 yr Floodplain	125,766	288
20	Detailed Sample	9,893	384
21	Remove	33,088	0
22	Sample (Mainly Pilings)	348	77
23	Remove	2,618	0
24	Remove	10,508	0
Total		**209,878**	**4,258**

Information Collected from Samples

Step 3: Assign unique ID number to population of structures in area
Step 4: Determine information to be collected from samples

Structure ID	Height above Ground Front door threshold above ground elevation in feet (half-foot =0.5)	Foundation Type (Pile, Pier, Crawlspace, Solid Wall, Basement=P Slab on grade=S	No. of Stories (1-story=1, Split-Level= 1.5, 2-story or more=2)	Structure Category (Residential = R, Commercial = C)	Notes (Enter any comments about a structure)
48872	8	P	1	R	Enclosed pile
50894	8	P	1	R	Open pile
70598	0.3	S	1	C	Restaurant

Residential Results by AOI

Step 5: Collect samples using Google Earth Street View and GIS tools
Step 6: Assign foundation heights to sampled structures
Step 7: Develop results for each AOI

1-Story Pier Foundation				**1-Story Slab Foundation**			**2-Story Pier Foundation**			**2-Story Slab Foundation**			
AOI	Average Height Sampled	Number of Structures in Sample	Percent of AOI	Average Height Sampled	Number of Structures in Sample	Percent of AOI	Average Height Sampled	Number of Structures in Sample	Percent of AOI	Average Height Sampled	Number of Structures in Sample	Percent of AOI	Total Number of Sampled Structures in AOI
1	12.04’	66	90.4%	0.40’	1	1.4%	14.20’	6	8.2%				73
2	5.23’	170	50%	0.84’	71	20.9%	4.20’	73	21.5%	1.03’	26	7.6%	340
Study Area	5.23’	1,669		0.68’	1,637		7.32’	299		0.70’	380		3,985

Foundation Height and Standard Deviation by AOI

Step 8: Assign foundation heights to the structure inventory

AOI	1-Story Pier Avg. Hgt. (feet)	1-Story Pier Std. Dev. (feet)	1-Story Slab Avg. Hgt. (feet)	1-Story Slab Std. Dev. (feet)
1	12.04	3.3	0.4	0.00
2	5.23	3.01	0.84	0.67
3	9.47	1.6	N/A	N/A
4	2.18	1.45	0.70	0.45
7	2.05	0.91	0.6	0.35
8	10.94	2.24	0.40	0.14
9	6.27	3.91	0.51	0.35
10	2.14	0.73	0.68	0.43
11	2.11	1.11	0.52	0.29
12	1.64	0.50	0.65	0.39
13	5.18	3.84	0.50	0.27
14	9.21	2.56	1.36	0.75
15	2.67	1.62	1.00	0.22
16	4.11	3.09	1.00	0.11
17	2.48	1.11	0.63	0.39
18	2.53	1.22	0.45	0.22
19	2.99	2.53	0.56	0.24
20	4.61	3.49	0.49	0.24
22	7.87	1.6	0.60	0.00
Wgt. Avg.	**5.23**	**2.35**	**0.68**	**0.30**

Residential Sampling Results

Step 8: Assigned foundation heights to the structure inventory
Step 9: Use results to develop uncertainty ranges surrounding the foundation height for each occupancy

Structure Category	Average Foundation Height (feet)	Standard Deviation (feet)	Lowest AOI Average Foundation Height (feet)	Highest AOI Average Foundation Height (feet)
1-Story Pier	5.23	2.35	1.64	12.04
1-Story Slab	0.68	0.30	0.40	1.36
2-Story Pier	7.32	2.35	1.5	14.2
2-Story Slab	0.70	0.30	0.51	1.01

Non-Residential Sampling Results

Step 8: Assigned foundation heights to the structure inventory
Step 9: Use results to develop uncertainty ranges surrounding the foundation height for each occupancy

Structure Category	Average Foundation Height (feet)	Standard Deviation (feet)	Lowest AOI Average Foundation Height (feet)	Highest AOI Average Foundation Height (feet)
1-Story Pier	3.07	1.85	1.3	12.3
1-Story Slab	0.67	0.33	0.3	1.00
2-Story Pier	6.12	1.85	2.0	12.9
2-Story Slab	0.91	0.33	0.6	1.6

Quiz on Sampling

Which of the following statements about sample size is true:

a. Selecting a higher level of confidence in the sampling formula will reduce the sample size

b. Acceptance of a larger allowable error in the sampling formula will increase the sample size

c. Less variation in the parameter will reduce the sample size

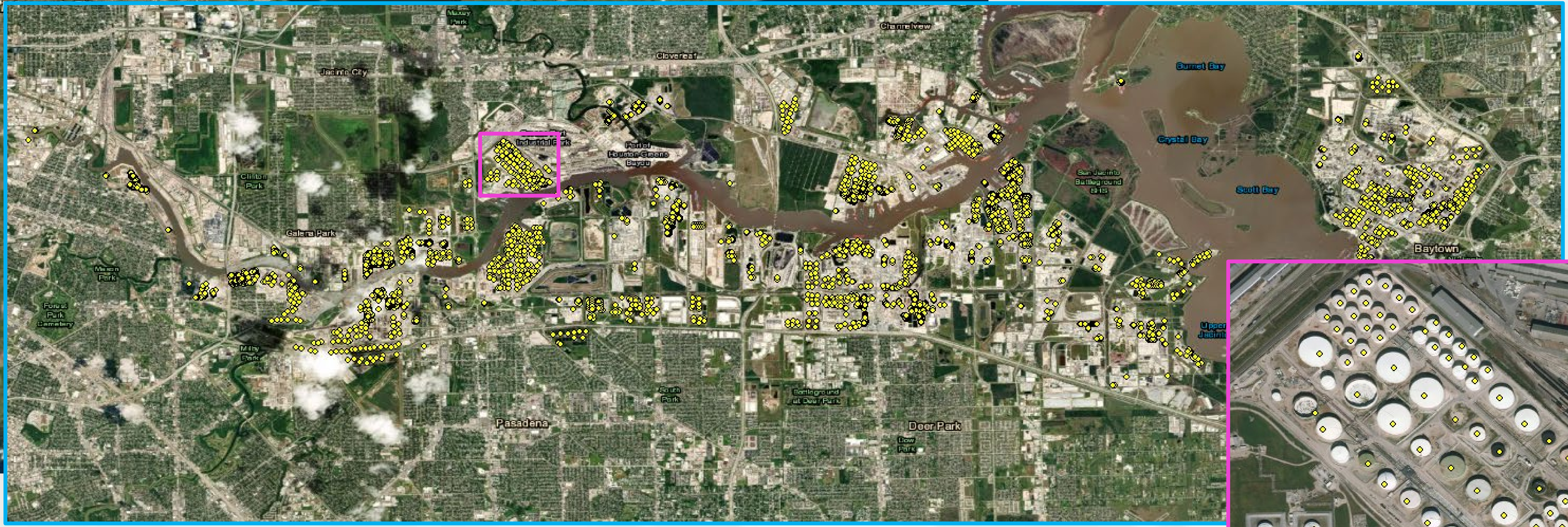
d. Large differences between the maximum value and minimum value of a parameter will reduce the sample size

Overview of Presentation

- Introduction
- Foundation Height Sampling
- Storage Tank Depth-Damage Relationships
- Avoided Output Losses

Current Storage Tank Inventory – Region 1

4,596 tanks plotted with GPS locations in Houston Ship Channel



Storage Tank Risk Assessment

Storm surge from Hurricane Katrina moved a tank off its base at the Murphy Oil refinery, spilling over a million gallons of crude oil into floodwaters. St. Bernard Parish, LA 2005

- Non-traditional NED benefit category
- Coastal Texas Protection and Restoration Feasibility Evaluation
- Develop generic depth-damage relationships for physical damage to storage tanks
- Based on 2016 journal article on the fragility assessment of above ground storage tanks from storm surge by Rice University Professors Kameshwar, S. and Padgett, J. E. (approximately 4,600 storage tanks in Houston Ship Channel Area)

Methodology

The 2013 Colorado Front Range Flood unseated and toppled several storage tanks, spilling thousands of gallons of crude oil. Weld County, CO 2013

- Floatation failures created when uplift created by surge is greater than the self-weight of the tank
- A buoyant tank may float away from its position and spill its contents
- Archimedes principle used to calculate the buoyancy forces exerted on a storage tank due to storm surge

Model Parameters

The 2013 Colorado Front Range Flood unseated and toppled several storage tanks, spilling thousands of gallons of crude oil. Weld County, CO 2013

- Buoyancy force on a tank considers:
  - Density of sea water
  - Inundation level in feet
  - Acceleration of water due to gravity
  - Height of the storage tank
- Resistance against buoyancy considers:
  - Thickness of tank shell, base, and roof shell
  - Relative density of steel
  - Level of liquid stored in tank
  - Relative density of the stored liquid

Storage Tanks Fragility Assessment Assumptions

Riverine floodwaters moved one storage tank off its foundation and caused leaking in other tanks, spilling ~2,145 barrels of crude and diesel oil. Coffeyville, KY 2007

- Amount of liquid is a uniformly distributed random variable between 0 and 90 percent of the tank capacity
- Contents are unknown, however, density of contents is a uniformly distributed random variable within the lower and upper bounds for contents using TCEQ permits
- As soon as a tank starts to float it fails, and all the contents are spilled out of the tank
- Effects of attached pipelines are not considered
- All tanks are un-anchored since it is commonly observed

Regression Model

Motiva oil refinery spill after Hurricane Harvey. Port Arthur, TX 2017

- Predicts floatation of storage tanks for given parameters and inundation depth
- Monte Carlo simulations are performed to re-produce the uncertainties in the liquid level and liquid densities to obtain the failure probability and the expected spill volume
- Failure analysis only considers floatation failure and not other failure modes such as buckling, debris and wave impact

Individual Storage Tanks

Specific Information by Individual Storage Tank

Tank ID	Latitude	Longitude	Tank diameter (m)	Tank height (m)	Content density lower bound (kg/m³)	Content density upper bound (kg/m³)	Capacity (m³)	Cost of tank (in 2016 $)
3053	29.682	-95.013	1.68	4.35	400	920	10	25,322
210	29.741	-95.128	14.63	17.88	600	950	3,004	281,689
850	29.751	-95.205	88.39	22.04	700	950	135,172	5,842,141

Failure Probability at Various Levels of Inundation

Tank ID	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	9 feet	10 feet
3053	0	12%	25%	37%	50%	62%	75%	83%	90%	95%
210	0	2%	4%	7%	9%	12%	14%	17%	19%	22%
850	0	0.2%	2%	4%	6%	8%	10%	12%	14%	16%

Proportion of Tank Capacity Spilled at Various Levels of Inundation

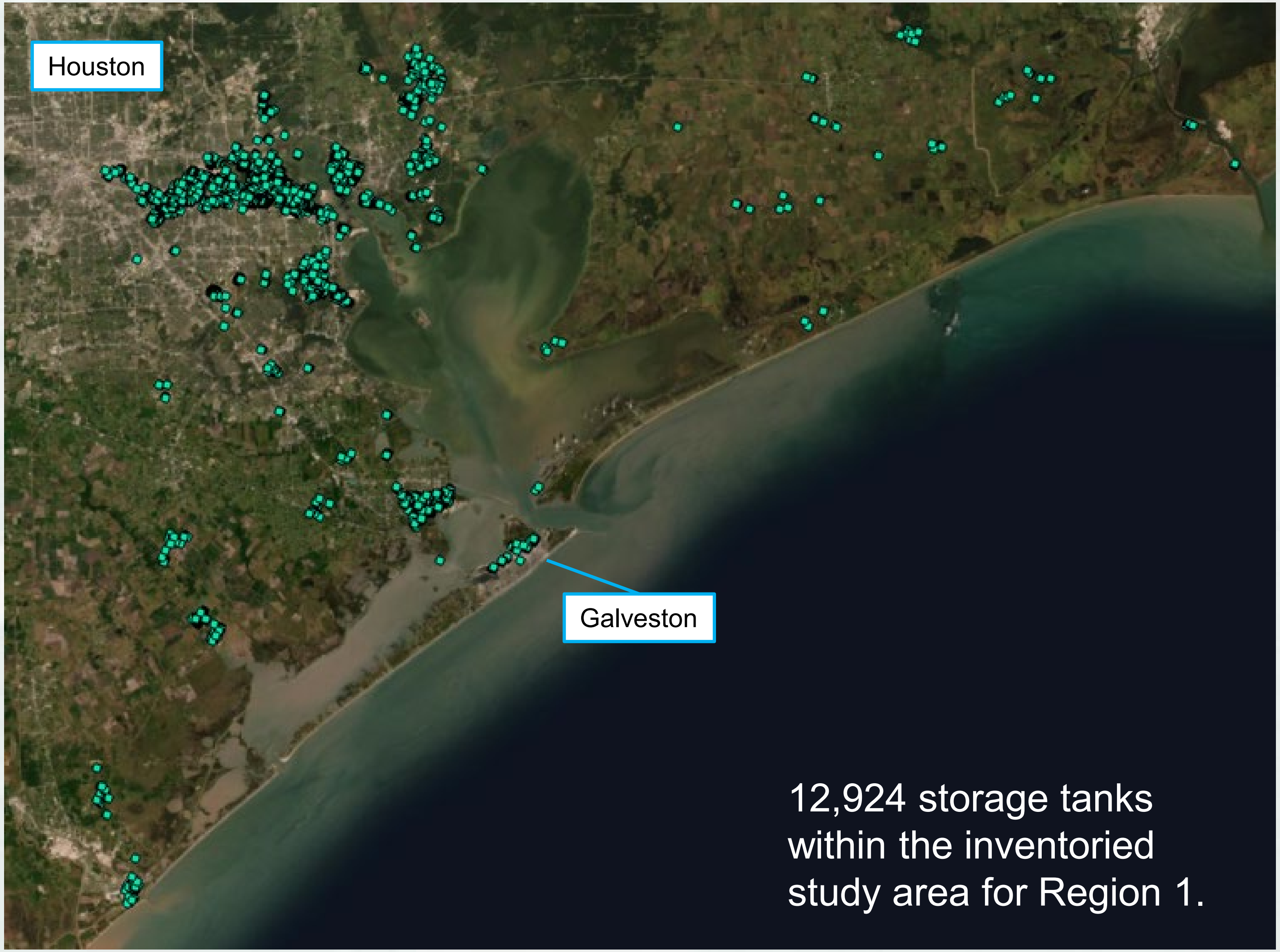
Tank ID	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	9 feet	10 feet
3053	0	0.7%	3%	7%	12%	19%	26%	32%	37%	41%
210	0	0.01%	0.08%	0.2%	0.4%	0. 7%	0.9%	1%	2%	3%
850	0	0.0001%	0.02%	0. 08%	0.2%	0.3%	0.4%	0.6%	0.9%	1%

Develop Generic Depth-Damage Relationships

Floodwaters surrounding storage tanks after Hurricane Rita. Port Arthur, TX 2005

- Values assigned to storage tanks in Houston Ship Channel could be used to develop a generic value for all tank structures and their contents in the area
- Use failure probabilities at each one-foot increment above the ground elevation as damage percentages for tanks
- Use proportion of tank capacity spilled at each one-foot increment to generate damage percentages for contents
- Develop uncertainty ranges

Storage Tank Inventory



HEC-FDA Modeling of Storage Tanks

- Incorporated generic storage tanks depth-damage relationships (DDF)
- Structure inventory included unique ground elevations and values assigned to each storage tank
- Without- and with-project stage-probability relationships were applied to each storage tank
- Uncertainty surrounding the key economic (DDF, ground, value) and engineering (stage-probability) parameters were included

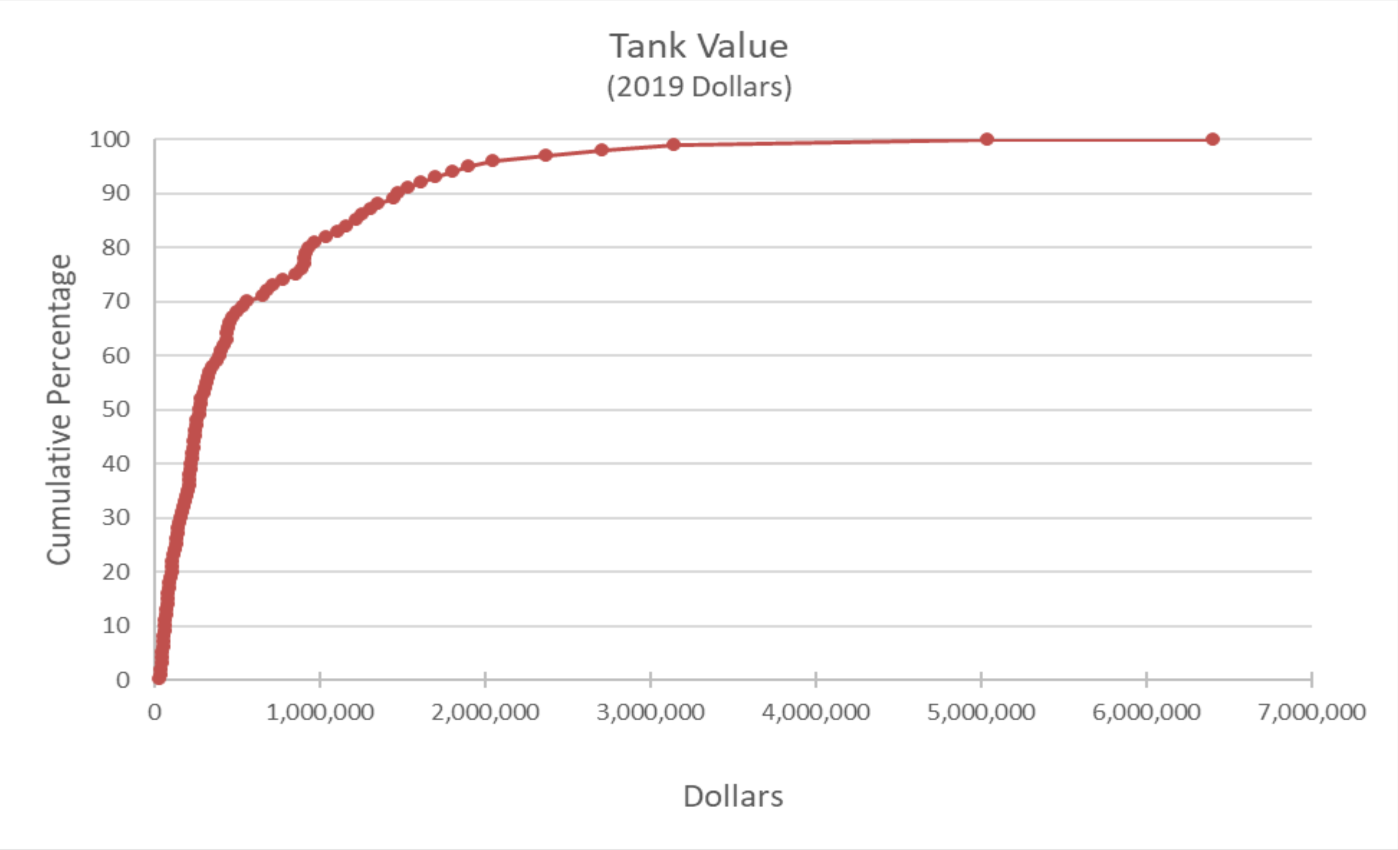
Structure Records

Struc_Name	Cat_Name	Stream_Name	Occ_Name	Station	Bank	Year	Struc_Val	Grnd_Stage	Mod_Name
10000	TANK	Gulf of Mexico	TANK	14054.44	Left	2019	187.061	22.405	Base
10001	TANK	Gulf of Mexico	TANK	14054.44	Left	2019	187.061	22.048	Base
10002	TANK	Gulf of Mexico	TANK	14054.44	Left	2019	187.061	20.259	Base
10003	TANK	Gulf of Mexico	TANK	14054.44	Left	2019	187.061	20.852	Base
10004	TANK	Gulf of Mexico	TANK	14054.44	Left	2019	187.061	21.208	Base

Each of the 12,924 tanks were assigned a most likely structure value of $187,061 based on the 20-increment breakdown (including the tanks from the Houston Ship Channel). They were also assigned a ground stage consistent with the hydraulics (feet NAVD88).

Storage Tank Cost

Condition	Tank Value (2019 Prices)
1st percentile	$41,000
Most Likely (20 Inc)	$187,000
99th percentile	$3,140,000

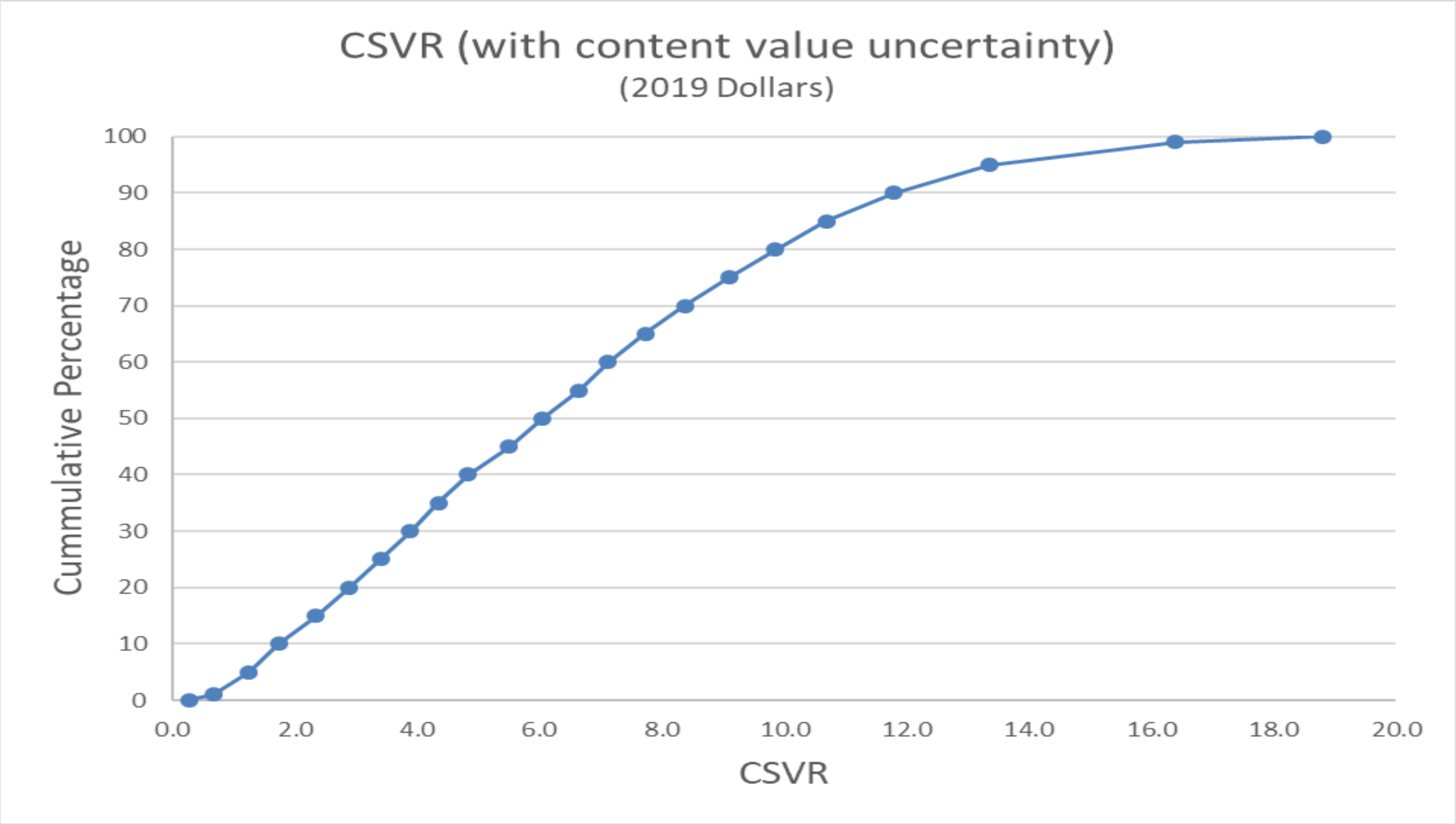


Commodity Values

Commodity	2017-2019 3-Yr Average $/US Gal
Residual Fuel Oil	1.35
Crude Oil	1.37
Naphtha	1.45
Gasoline	1.77
Distillate Fuel Oil #2	1.88
Benzene	3.06

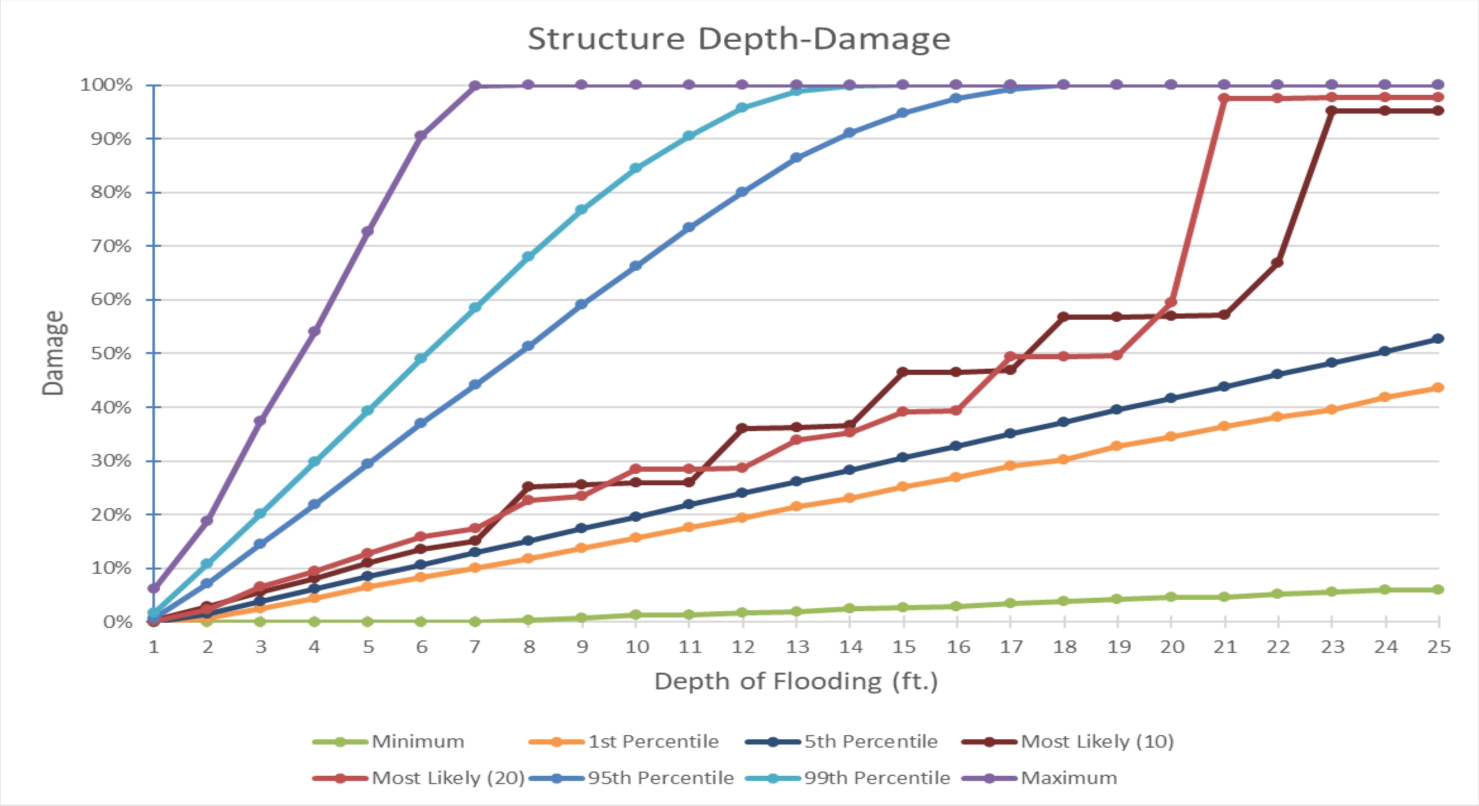
Contents-to-Structure Value Ratios

Condition	CSVR (with content value uncertainty; 2019 Prices)
1st percentile	0.66
Most Likely (20 Inc)	4.15
99th percentile	16.40



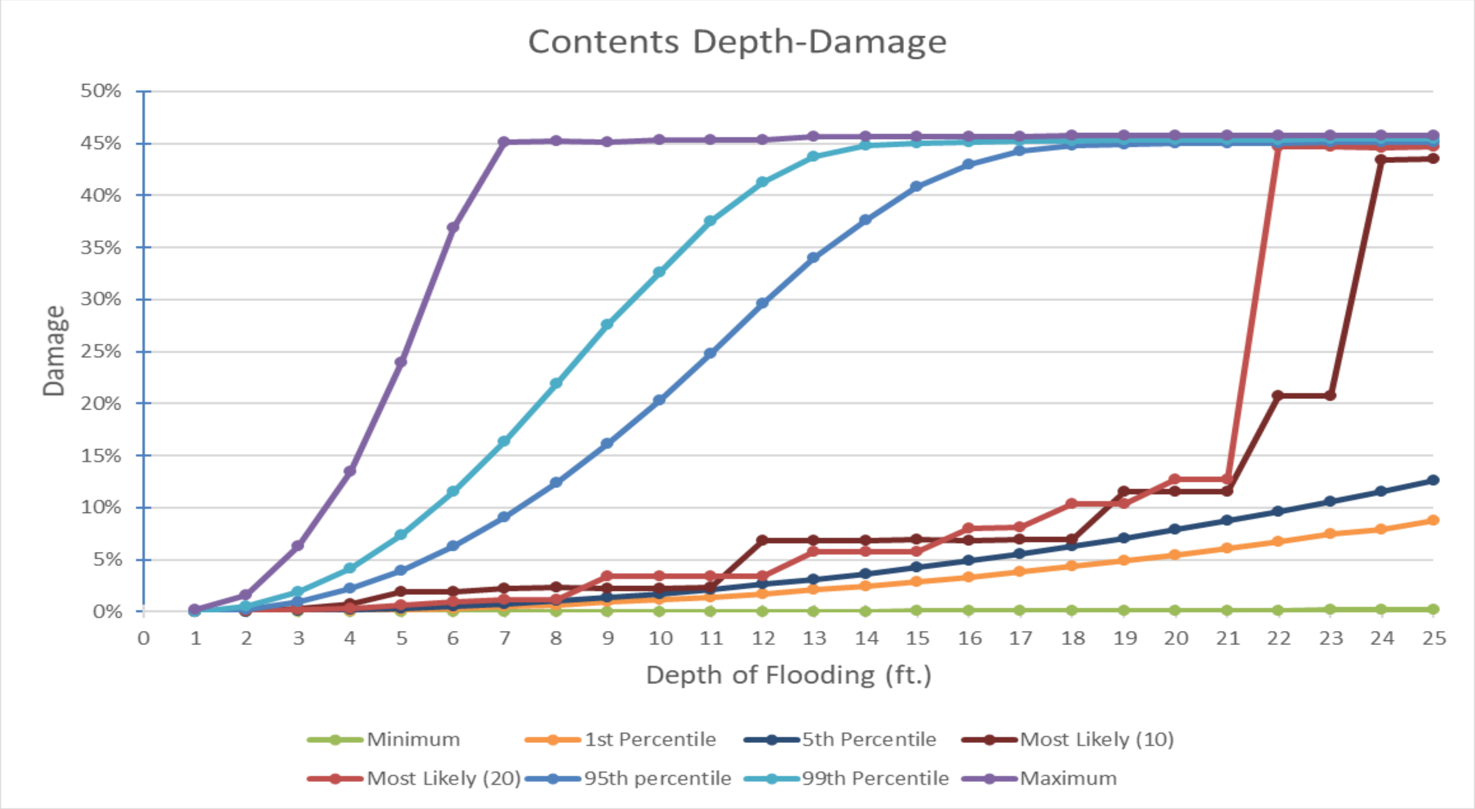
Structure Depth-Damage Selected Percentages

Flooding Depth (ft.)	1st Pctl.	Most Likely (20 Inc)	99th Pctl.
1	0.0	0.2	1.7
5	6.4	12.7	39.3
10	15.6	28.4	84.5
15	25.1	39.2	100.0
20	34.4	59.4	100.0
25	43.6	97.6	100.0



Contents Depth-Damage Selected Percentages

Flooding Depth (ft.)	1st Pctl.	Most Likely (20 Inc)	99th Pctl.
1	0.0	0.0	0.0
5	0.2	0.6	7.4
10	1.1	3.4	32.6
15	2.9	5.7	45.0
20	5.4	12.7	45.3
25	8.8	44.7	45.4



Damage and Benefit Results

- Total without project damages were $110,117,980 or approximately 3% of the total without project damages

- Total benefits associated with storage tanks were approximately $63 million or 3.2% of the total benefits for the Recommended Plan

Quiz on Storage Tanks

Which of the following statements about storage tanks is false?

a. HEC-FDA structure records can only be applied to residential and non-residential buildings
b. Uncertainty ranges can be applied to the value of the storage tanks and their contents
c. Reduction in damages to storage tanks is considered an NED benefit
d. Most FRM evaluations do not include damage reduction to storage tanks as an NED benefit category

Overview of Presentation

- Introduction
- Foundation Height Sampling
- Storage Tank Depth-Damage Relationships
- Indirect Business Losses

Indirect Business Losses

- Approximately one-third of energy for the U.S. is generated from the Galveston-Houston area
- Non-physical losses (National output and income losses as measured by changes in Gross Domestic Product (GDP))
- REMI Model – (Regional Economic Model, Inc.)
- Requires assumptions and configuration of REMI Model

Assumptions

- Only infrequent storm events (100, 250, 500 and 1,000- year recurrence events) used for the REMI analysis, since these events are most likely to result in permanent loss of production

- Only industrial occupancies related to warehouse distribution facilities were included for production losses

- Residential damages were used to inform demographic changes in the REMI modeling

REMI Model Construction

- 3 regions – six county area, rest of Texas and the rest of U.S.
- Partial equilibrium regional economic model – accounts for geographic distribution of production and geographic distribution of population
- 5 basic blocks of economic measures that comprise each regional economy
  - ►Output, labor and capital, population and labor supply, wages, prices, and costs, market shares that determine geographic activity

5 Basic Blocks for each Regional Economy

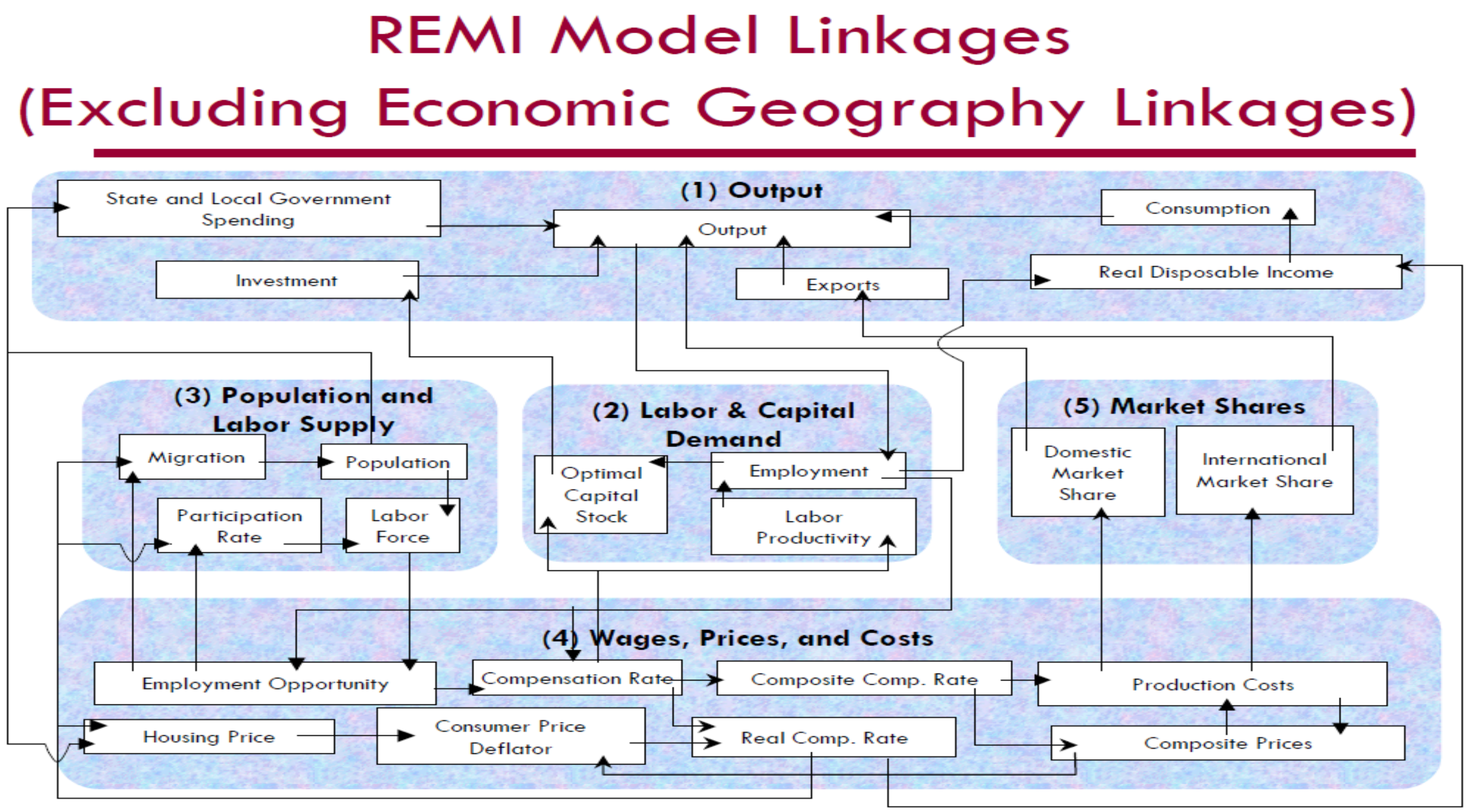


Figure 1: REMI Model Linkages

Policy Variables

- Change in regional nonresidential and residential capital stock (structures and contents)
  - avoided loss (measured as if the region gained the amount of capital that is loss)

- Loss of output from firms that own non-residential capital
  - avoided loss (measured as if region gained an equivalent amount of nonresidential capital thereby gaining output and employment)

- Avoided population migration (measured as lower out-migration)
  - Assumed 85 percent of pop. in damaged dwelling units will migrate, also assumed 90 percent move to rest of Texas region and 10 percent to rest of the US region

Indirect Business Losses

- Avoided national output losses totaled approximately $190 million

- The avoided national output losses were approximately 8 percent of total benefits for the Recommended Coastal Texas Plan

- Coastal Texas benefit results were presented without and with the avoided output losses

Approval of Non-Standard Benefit Category

3. I concur with the policy review team's assessment to approve the use of non-standard benefit calculations in the assessment of NED benefits for the subject study. If you have additional questions or concerns, please feel free to contact Katie Williams, Deputy Chief, Southwestern Division Regional Integration Team, at 202-761-0315 or kathleen.a.williams@usace.army.mil.

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Concluding Remarks

- Determine if the magnitude of the benefits could affect decision-making

- Use study funds wisely when estimating non-traditional NED benefit categories

- Important to incorporate risk and uncertainty in all benefit calculations

Quiz on Non-Standard Benefit Categories

Which of the following statements is false regarding non-standard benefit categories?

a. Avoided losses in national output are considered NED benefits
b. Approval for HQ is required for non-standard benefit categories
c. Uncertainty should be applied to the key economic parameters used in an economic model
d. Consideration should not be given to the study cost of including non-standard benefit categories

Wuzzles

Nonstructural Wuzzles – is a riddle that uses words, letters and/or graphics to create a disguised word, phase or saying.

Example, NOON GOOD = GOOD AFTERNOON

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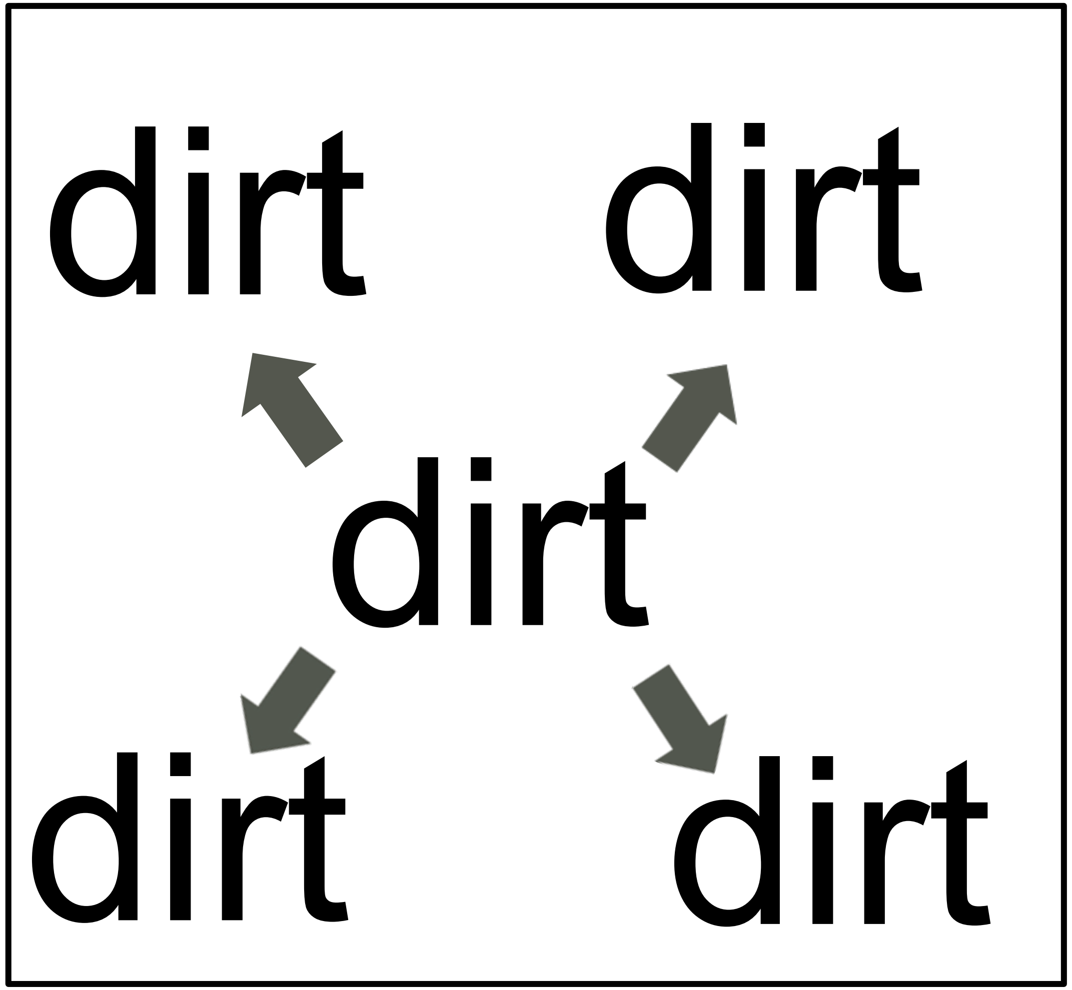

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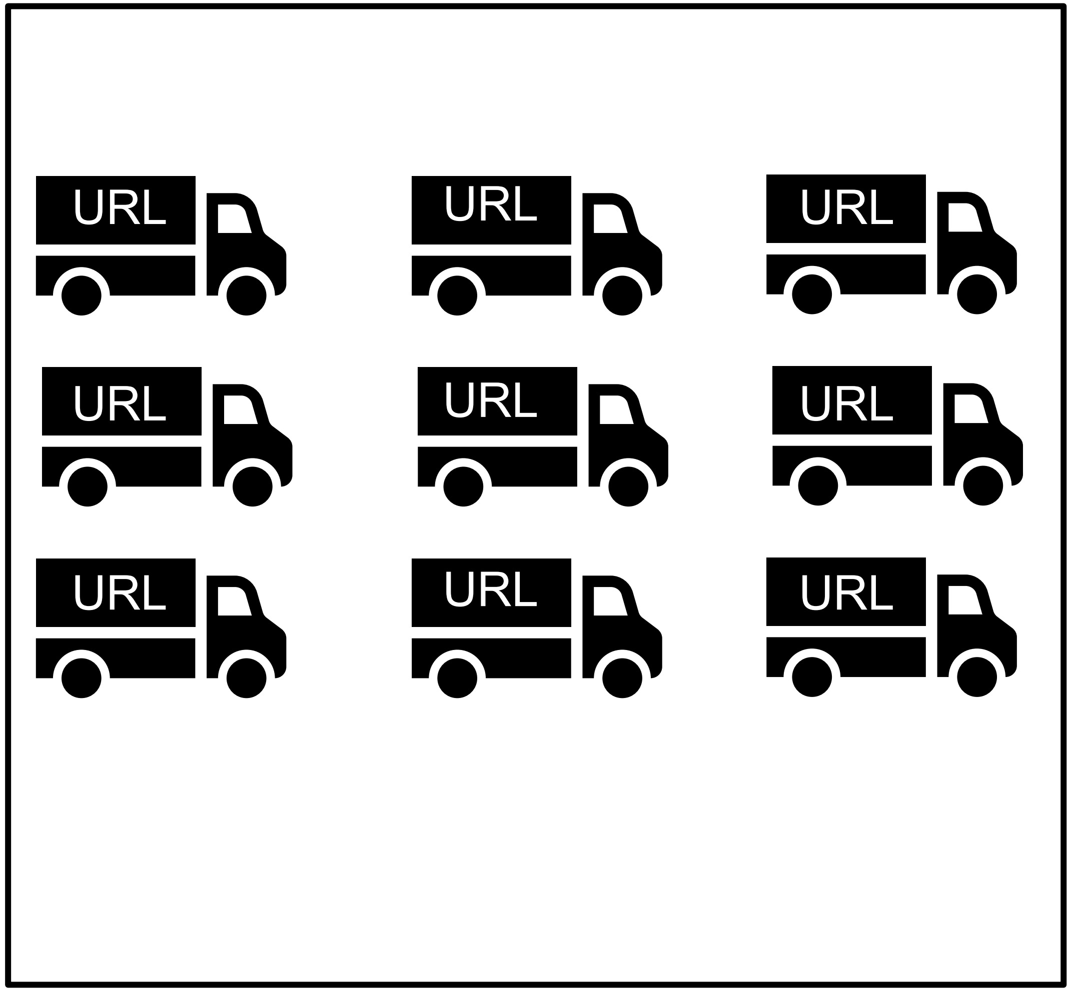
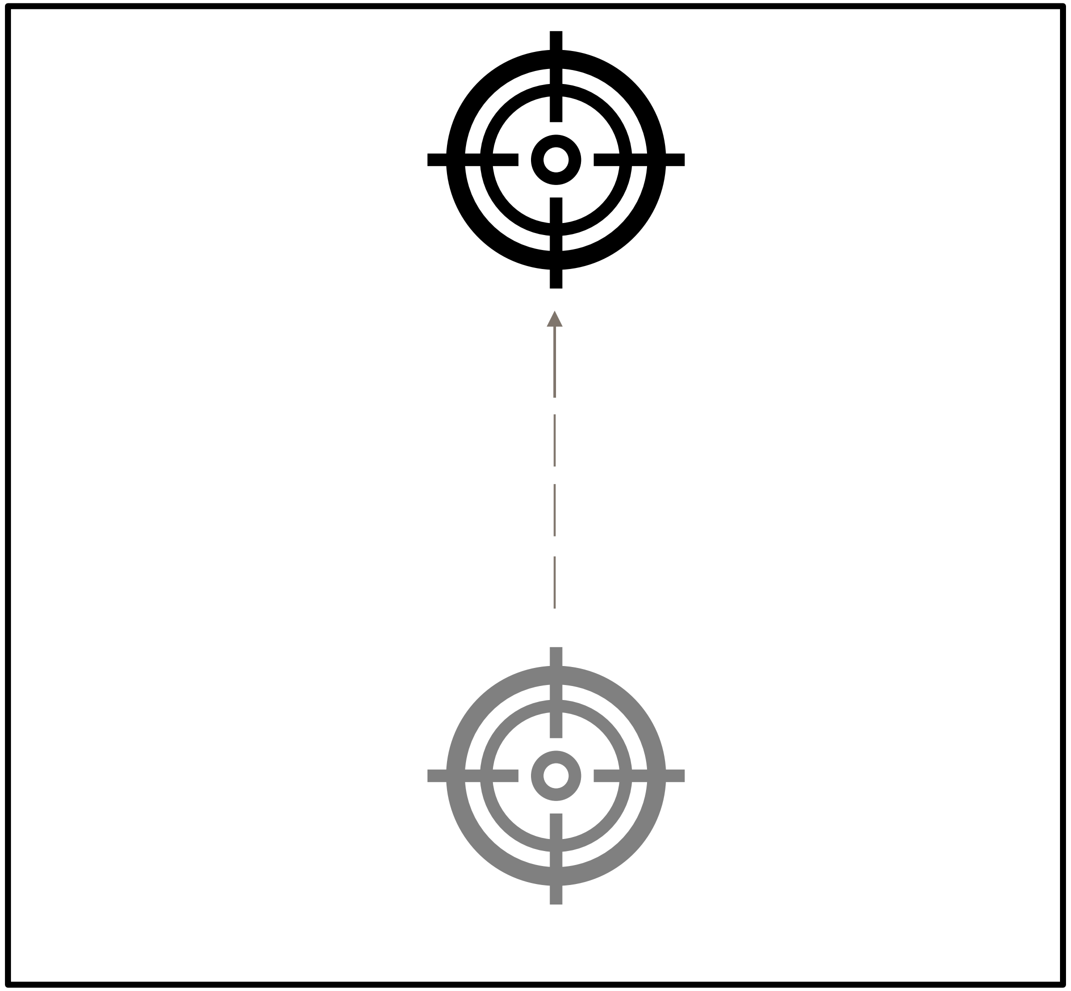
WUZZLES



NONSTRUCTURAL WUZZLES



Questions