D·E·M Rhode Island Department of Environmental Management

An Evaluation of Aboveground Storage Tank Vulnerability Utilizing STORMTOOLS and Parameterized Fragility Functions for Planning Future Mitigation Strategies

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U.S. EPA and RIDEM

The U.S. EPA awarded the RIDEM – OCTA funding for a two-year Pollution Prevention grant entitled:

“An Evaluation of Aboveground Storage Tanks (ASTs) for Pollution Prevention and Risk Preparedness within High Risk, Flood-Prone Coastal Communities Subject to Storm Surge and Projected Sea Level Rise in Rhode Island”

Brief Overview of the RIDEM Pollution Prevention Grant

- **Primary Goals of the Grant:**

  - Identify and map the locations of above-ground storage tanks
  - Evaluate risk associated with AST facilities located in Flood-Prone Coastal Areas
  - Contact and conduct voluntary audits of AST facilities
  - Advise facilities on risk-reduction measures

- **In addition to ASTs, we are also concerned about:**

  - Facility permitting and emergency response planning
  - Facility operations, maintenance, and site security
  - Truck idling emissions and emergency generator use
  - Fire suppression and response measures (specifically firefighting foams containing per-fluorinated compounds)

Overview of the RIDEM Regulated AST Community

The AST Program is administered by the: RIDEM – Office of Emergency Response

There are approximately **700** registered facilities with an associated **2,000** ASTs located in the State of Rhode Island

Facilities are required to register ASTs with RIDEM if:

- The material being stored meets the definition of being an oil and;
- The combined oil storage volume for the facility is 500 gallons or greater

Under the RIDEM Oil Pollution Control Regulations "*oil*" is defined as:

"Petroleum, gasoline, tar, asphalt, or any product or mixture thereof, or any substance refined from petroleum or crude oil"

Current RIDEM Approach to Aboveground Storage Tank (AST) Flood Vulnerability Analysis in Rhode Island

Using:

GIS and STORMTOOLs

Developed by the University of Rhode Island and RI Coastal Resources Management Council

AST Fragility Functions

Developed by Rice University, Houston, TX

AST displaced by the 1938 Hurricane (East Providence, RI) Credit: NOAA

Common Aboveground Storage Tank Flood and Coastal Storm Failure Modes

With: **S – Surge Force, WL - Wind Load, PL - Precipitation Load**

a) **Buoyancy –** Flotation of tank due to flood inundation (omitting Surge-Force, negligible flood velocity)

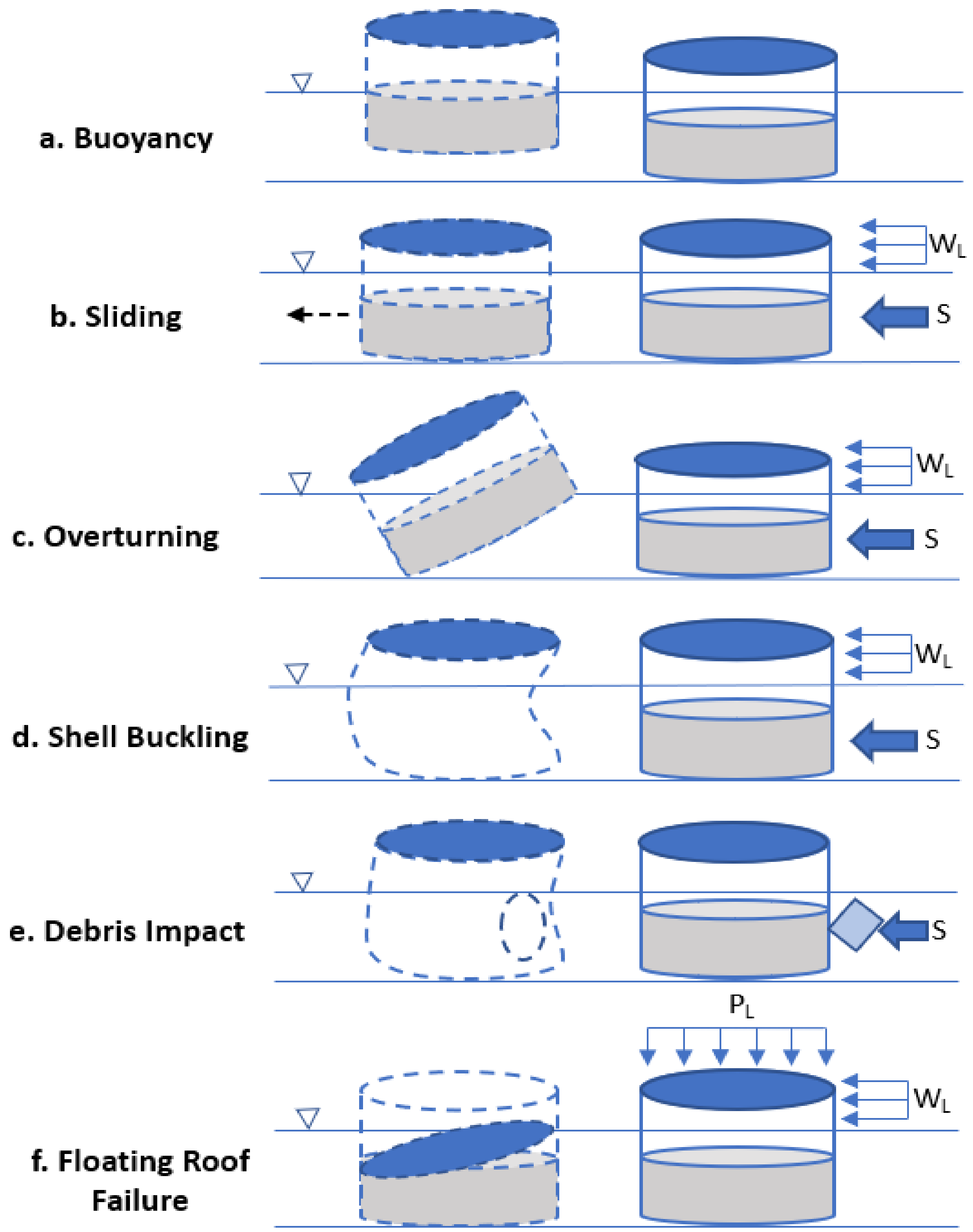
b) **Sliding –** Buoyancy force combined with Surge Force and Wind Load cause lateral movement of the tank

c) **Overturning –** Buoyancy force combined with Surge Force and Wind Load cause lateral and upward movement of the tank (i.e. for smaller volume tanks)

d) **Shell Buckling –** Damage due to external pressure caused by Wind and/or Storm Surge

e) **Debris Impact –** Damage caused from debris due to Storm Surge (i.e. large objects - shipping containers, larger rail-tanks, boats etc.)

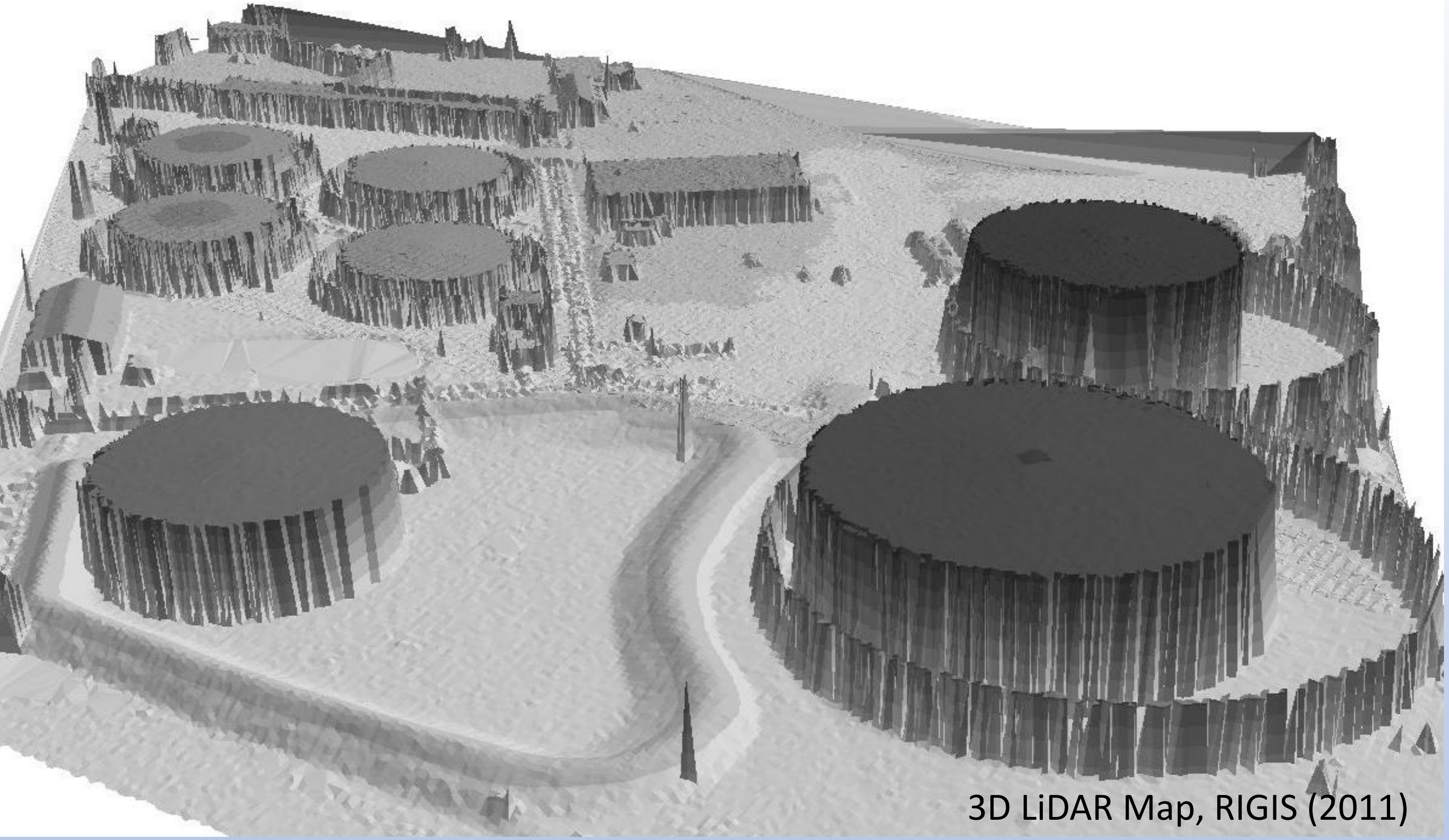
f) **Floating Roof Failure –** Damage due to Precipitation Load and Wind Load acting on an external floating roof tank



Overview of Data and Resources Utilized

1. The existing RIDEM AST Database
   - The location of ASTs have been incorporated into a GIS Geodatabase
2. STORMTOOLS Data* (URI/RICRMC, 2014)
   - Flood inundation layers for coastal storms with various return rates
   - Sea Level Rise (current NOAA predictions)
   - FEMA FIRM data layer
   - LiDAR elevation data (2011)
   - Depth of flood inundation calculated at select locations
3. AST fragility functions (RICE University, 2018)
   - Fragility functions for the probability of unanchored AST floatation

*STORMTOOLS maps are available online at: http://www.beachsamp.org/stormtools/
*STORMTOOLS GIS datasets are available online at: http://www.rigis.org/search?q=stormtools



3D LiDAR Map, RIGIS (2011)

Limitations and Assumptions

- **The method employed relies upon the accuracy of STORMTOOLS flood elevation data, LiDAR ground surface elevation data, and AST fragility functions. The intended use of this approach is <u>intended for planning use only</u>.**
- **Tank specific information regarding construction, dimensions, stored material, etc. were collected from existing AST registration resources.**
- **If tank dimensions are not included in the file, the <u>diameter is measured via aerial photography</u> and the <u>height is calculated from an equation for cylinder volume using the reported AST capacity</u>.**
- **LiDAR data utilized was processed to indicate "bare-earth" elevation, thus some <u>structures/barriers may not be accurately represented within the model</u>.**
- **Anchoring of ASTs is not currently required by the RIDEM Oil Pollution Control Regulations. Therefore, unless otherwise noted, <u>unanchored scenarios</u> were used for the project.**

Failure probability (flotation) of Unanchored ASTs

$$P(Flotation|D,H,S,\rho_l) = \int P(Floatation|D,H,l,S,\rho_l) f_L(l) dl$$

Source: Reference 1

- The fragility function for the probability of flotation of unanchored ASTs takes into account:

D – Tank Diameter	**H** – Tank Height
S – Flood Surge Height	**ρ_l** – Density of the stored liquid
L – Height of Liquid inside the AST	

- The liquid level (**L**) is varied as a uniformly distributed random variable "**$f_L(l)dl$**" and the failure probability is calculated at different surge heights.
- Uncertainty in liquid height is propagated through P(floatation function) by numerically integrating the fragility function with the probability density function (PDF) of liquid height (f_L)
- This approach does not take into account velocity and wave height.

Using MS Excel to Generate Flood Fragility Curves for an Unanchored AST

Notes:

- **Set maximum liquid height to 0.9 x tank height per API-650**
- **Use a small tank liquid level interval**
  (e.g. dl = 0.1m)
- **Estimate relative density of AST liquid contents by using known values published in various reference literature (S.G. @ STP)**
- **Ensure all elevation and tank dimension units are metric**
- **Account for the base elevation of AST and top elevation of any secondary containment structures/barriers/berms**
- **Design stress (Sd) - used to determine thickness of tank shell and self weight of AST (Sd not included in final unanchored AST Flotation probability density function (PDF).**

Logit function for unanchored floatation of ASTs

$$l_{unanc}(D,H,L,S,\rho_l) = -8.67 + 0.43D - 0.64H - 0.10L - 3.14\rho_l + 39.53S - 38.47L\rho_l - 4.47 \times 10^{-3}D^2$$

Source: Reference 1

Probability of Flotation for unanchored ASTs

$$P(Flotation|D,H,L,S,\rho_l) = \frac{1}{1+\exp(-l(D,H,L,S,\rho_l,S_d))}$$

Source: Reference 1

General Parameters and Required Inputs

Inputs for Example Tank (MS Excel)

Facility ID: **Tank ID: 1** **Diesel**

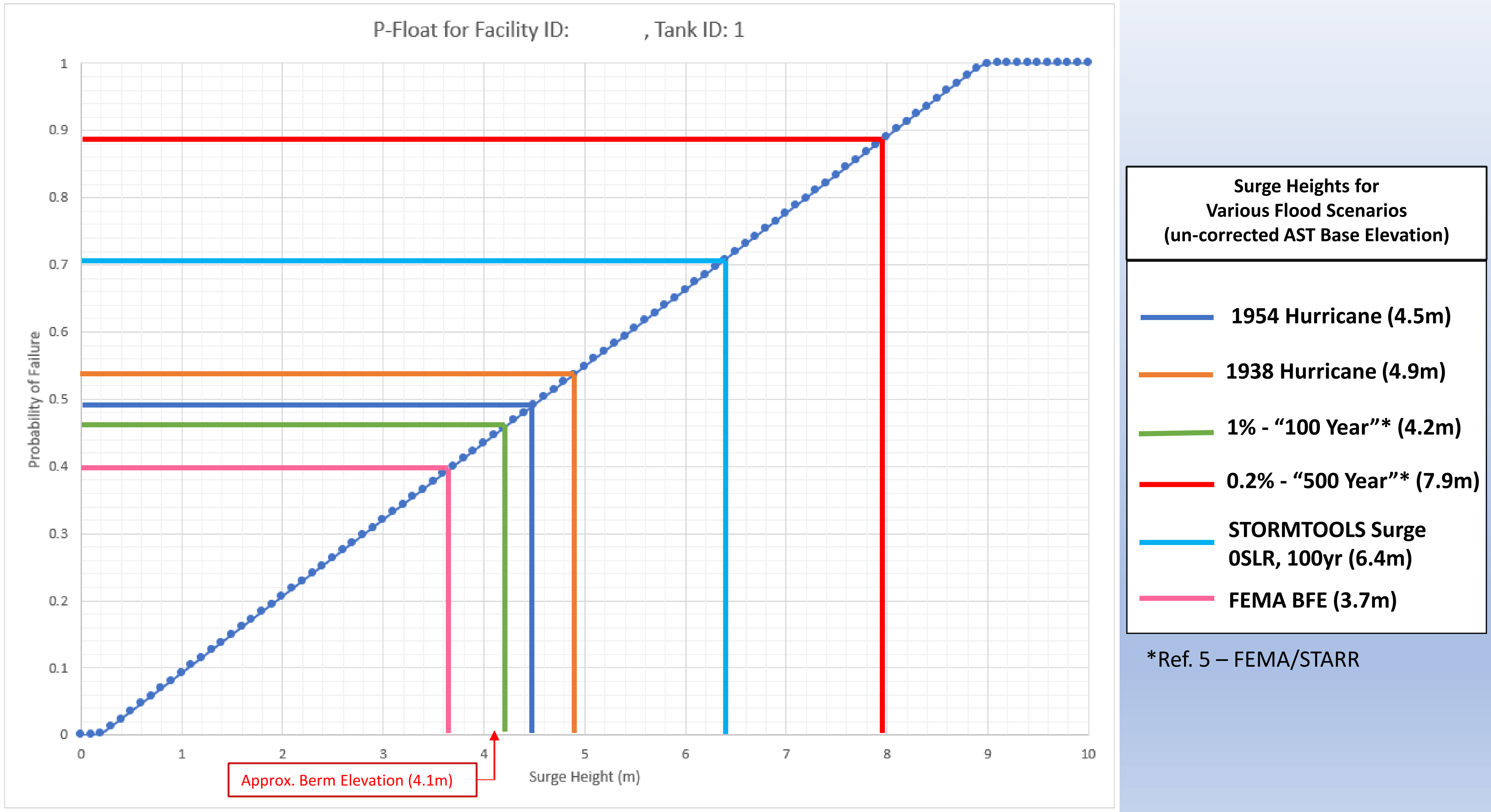
$g_{sua}(D,H,L,S,\rho_l) = -8.67 + 0.43D - 0.64H - 0.10L - 3.14\rho_l + 39.53S - 38.47L\rho_l - 4.47 \times 10^{-3} D^2$ **(Kameshwar and Padgett, ASCE 2018)**

Probability, $P(\text{Flotation} \mid D,H,L,S,\rho_l) = 1 / [1 + \exp(-g_{sua}(D,H,L,S,\rho_l))]$

Parameters	Parameter name	Values and/or Range	Input
D (m)	Diameter	5.0 - 70.0	36.36999893
H (m)	Height of Tank	–	11.93780994
H/D	Height-to-Diameter ratio	[exp((1 - 2lnD)/4)] – [exp(3 - 0.95lnD)]	-
ρ_l	Relative density of liquid	0.5 -1.0	0.832
L (m)	Max Height of liquid in Tank	0.9H	10.74402895
S (m)	External flood height	0.0 - 10.0	-
ρ_w	Relative density of water	0.98 - 1.02	-
	- Highlighted input parameters		

(Produces a Large Raw Data Table)

Fragility estimate for Example Tank 1 (Unanchored Flotation)
Un-corrected for AST Base Elevation With Various Flood Inundation Scenarios

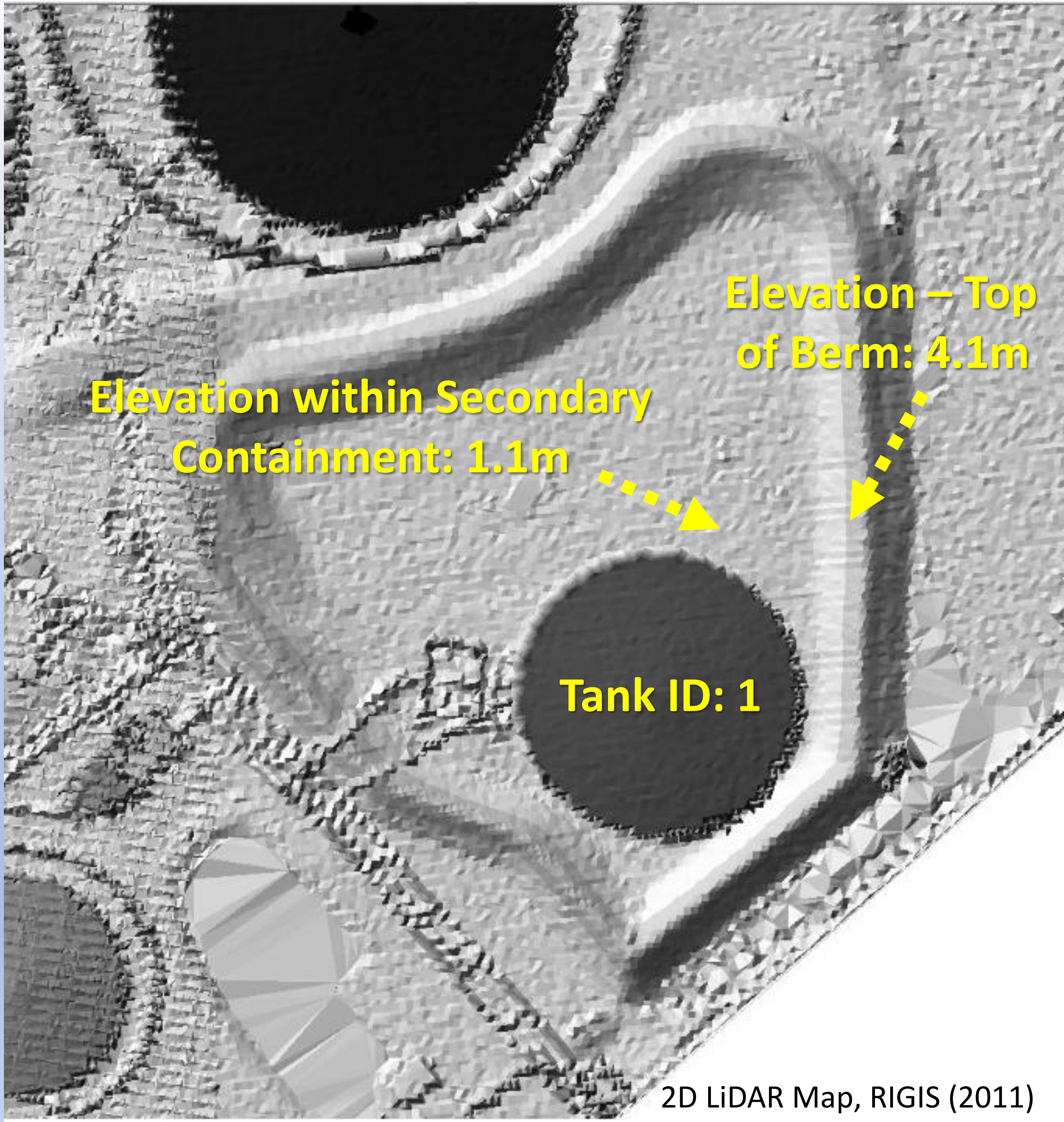


*Ref. 5 – FEMA/STARR

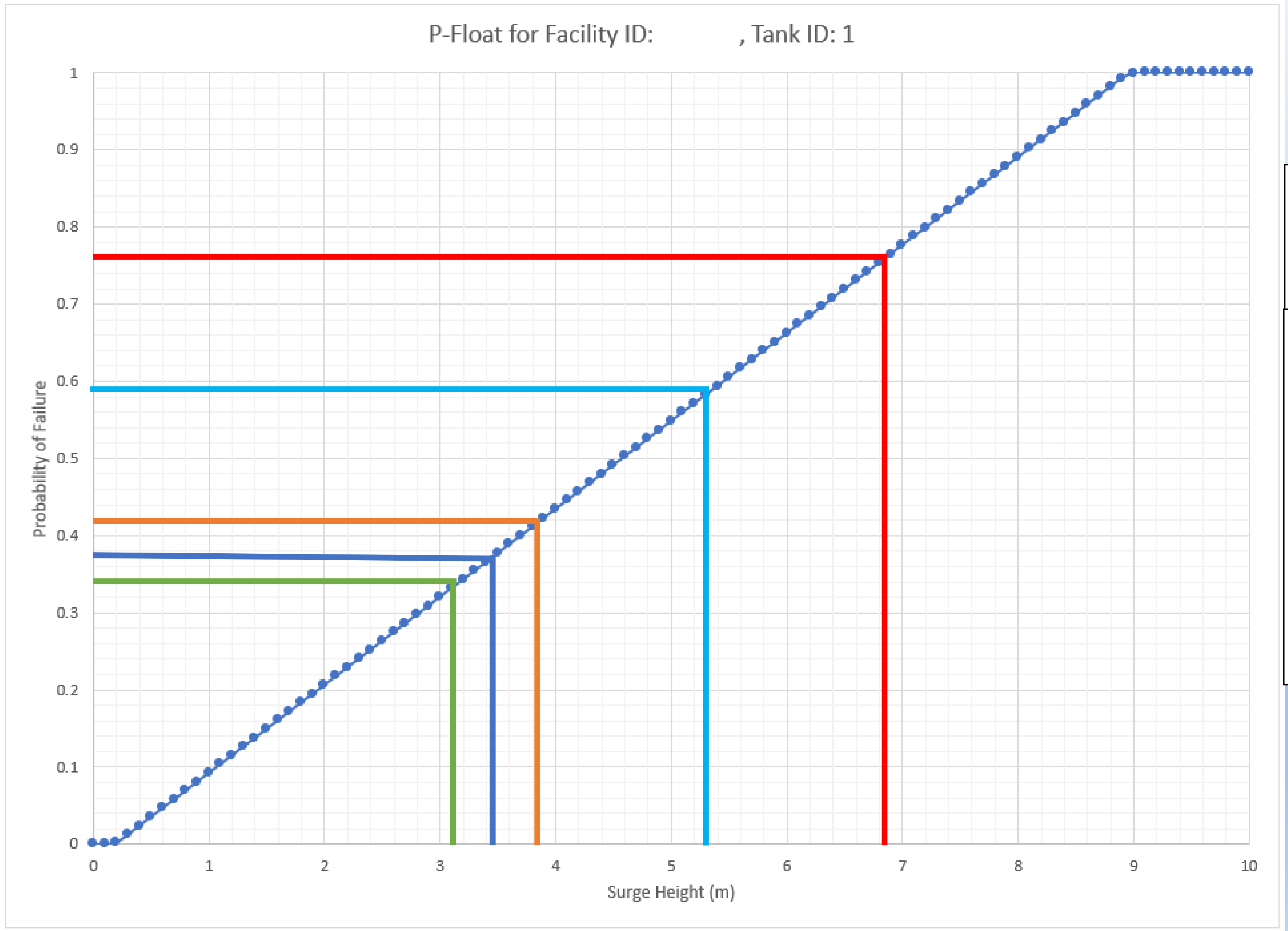
LiDAR Elevation Map for Example Tank ID: 1

- LiDAR elevation data indicates that the ground surface of the secondary containment area (in the vicinity of Tank 1) would be approximately: **1.1** meters (3.6 feet)

- For this particular tank, <u>1.1m should be subtracted from the storm surge elevation</u> (for historic hurricanes and storms with various return periods). The resultant value would be input into the fragility function as Surge level (**S**)



Fragility estimate for Example Tank 1 (Unanchored Flotation) Accounting for AST Base Elevation (~ 1.1 m) With Various Flood Inundation Scenarios



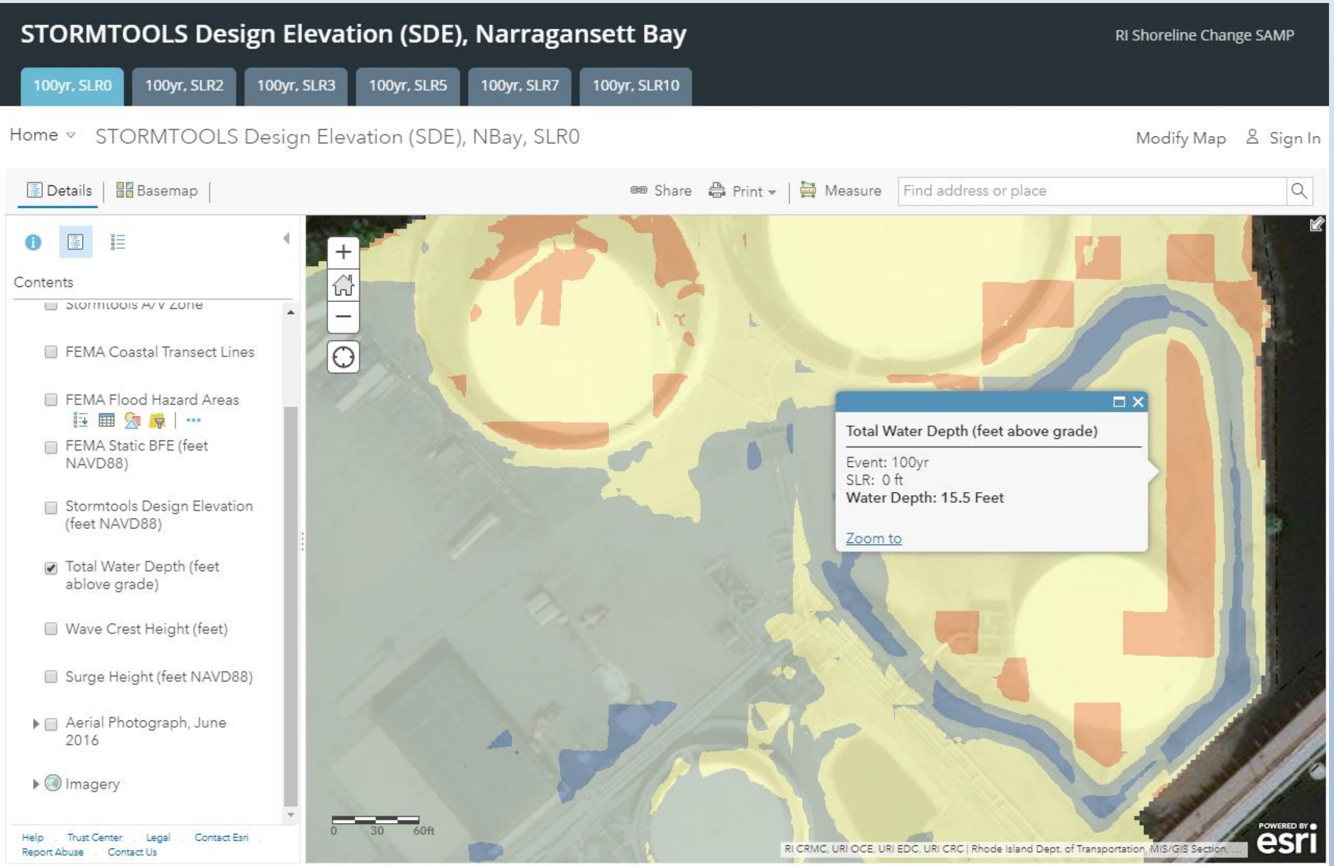
Surge Heights at Tank Corrected Elevations (Base Elevation – 1.1m)

- **1954 Hurricane (3.4m)**
- **1938 Hurricane (3.8m)**
- **1% - "100 Year"* (3.1m)**
- **0.2% - "500 Year"* (6.8m)**
- **STORMTOOLS Surge 0SLR, 100yr (5.3m)**

*Ref. 5 – FEMA/STARR

Additional Useful Tools/Info:

To Determine Surge (Total Water Depth) at Tank



STORMTOOLS Design Elevation Maps can also be used to estimate Surge Level at the Tank Using the <u>Total Water Depth Feature</u>

To Estimate a minimum Tank fill height

STORMTOOLS Surge Elevation - "100yr, SLR 0"

	meters	feet
Inundation Elevation (at Tank) =	5.3	17.4

Tank Liquid Height (m)	Tank Liquid Height (ft.)	Prob. Of Floatation
5.9	19.4	1.000
6	19.7	1.000
6.1	20.0	0.989
6.2	20.3	0.777
6.3	20.7	0.123
6.4	21.0	0.006
6.5	21.3	0.000
6.6	21.7	0.000
6.7	22.0	0.000
6.8	22.3	0.000
6.9	22.6	0.000

For a given storm surge elevation, a minimum tank fill height can be estimated from the raw data table produced from the Fragility Assessment

Summary of AST Flood Mitigation Strategies and Practices

Procedural Practices

- **Increasing the “self-weight” of unanchored ASTs by filling with product or water prior to a flood event**
  - **General Recommendation is to fill to a tank height 3 to 6 feet higher than anticipated flood surge elevation (Ref. 6)**
  - **Some uncertainty if forecasted surge elevation is underestimated**
  - **Could be unfeasible for high-translational speed storms (similar to the 1938 Hurricane event)**

Structural Practices

- **Anchoring of ASTs**
  - **Decreases buoyancy failure probability, but increases the probability of buckling failure**
  - **The use of stiffening rings (along tank shell exterior) can reduce buckling failure.**
  - **Cost Considerations**
- **Elevating and Hardening of existing secondary containment areas**
  - **Cost/Permit Considerations**
- **Engineered Levies or barriers for the protection of a larger area (comprising multiple properties)**
  - **Cost/Permit Considerations**

Summary of Current Guidance and Regulatory Authority

AST Specific

- **RIDEM:** Oil Pollution Control Regulations
  - ➢ Does not address Flooding or Siting Requirements
- **EPA:** 40 CFR part 112 (Subparts A through C) - Spill Prevention, Control, and Countermeasure (SPCC) Rule
  - ➢ Catchment basins must not be located in areas subject to periodic flooding
- **National Fire Protection Association:** NFPA 30 - Flammable and Combustible Liquids Code
- **American Petroleum Institute:** API STANDARD 650 - Welded Tanks for Oil Storage

Other Related Guidance

- **RI CRMC:** Shoreline Change Special Area Management Plan (SAMP), Volume 1 –June 2018
- **FEMA:** FEMA 543 Design Guide for Improving Critical Facility Safety from Flooding and High Winds
- **FEMA:** Reducing Flood Effects in Critical Facilities (Hurricane Sandy Recovery Advisory, RA2, April 2013)
- **National Flood Insurance Program:** NFIP-2018 I-Codes and ASCE 24 Checklist (December 2017)

Summary of RIDEM AST Facility Initiatives

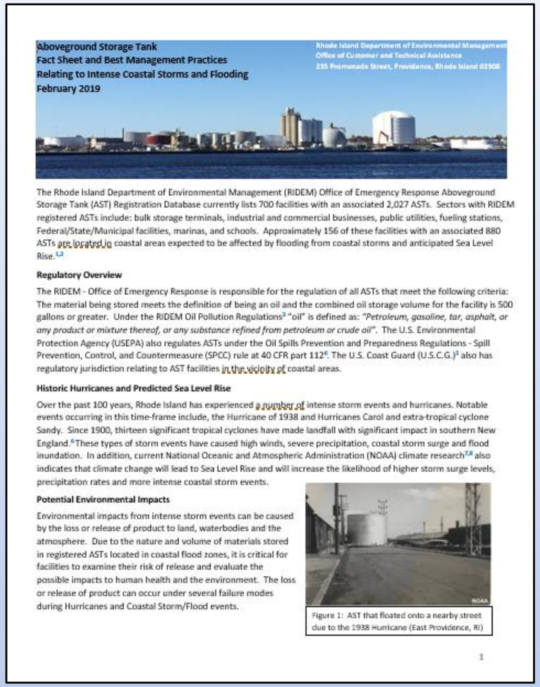
Draft Guidance and Best Management Practices (BMPs)

- Coastal Storm and Flooding BMP Fact Sheet (Draft Complete)
- Currently working on Guidance and BMPs relating to the use (and possible alternatives) of Fluorinated Firefighting Foams

Outreach to AST Facilities

- Performed Audits to Determine Current Practices relating to - Pollution Prevention and Flood Preparedness
- Sent an Industry Survey to Large Bulk Storage Facilities – (Storage Capacity > 100K Gallons) in October, 2018 to augment Audit information
- Initiate dialogue with industry/stakeholders about current regulatory topics pertaining to:
  - ➢ ASTs (State – Oil Pollution Control Regulations, Federal – SPCC Regulations)
  - ➢ Air (e.g. facility and/or truck idling emission reductions)
  - ➢ Water (e.g. Stormwater Management, Flood Vulnerability/Resiliency)
  - ➢ Waste (e.g. HW Reduction, Solvent/Cleaner Reduction or Substitution)

Draft BMP Fact Sheet



Aboveground Storage Tank
Fact Sheet and Best Management Practices
Relating to Intense Coastal Storms and Flooding
February 2019

Rhode Island Department of Environmental Management
Office of Customer and Technical Assistance
235 Promenade Street, Providence, Rhode Island 02908

The Rhode Island Department of Environmental Management (RIDEM) Office of Emergency Response Aboveground Storage Tank (AST) Registration Database currently lists 700 facilities with an associated 2,027 ASTs. Sectors with RIDEM registered ASTs include: bulk storage terminals, industrial and commercial businesses, public utilities, fueling stations, Federal/State/Municipal facilities, marinas, and schools. Approximately 156 of these facilities with an associated 880 ASTs are located in coastal areas expected to be affected by flooding from coastal storms and anticipated Sea Level Rise.[1,2]

Regulatory Overview

The RIDEM - Office of Emergency Response is responsible for the regulation of all ASTs that meet the following criteria: The material being stored meets the definition of being an oil and the combined oil storage volume for the facility is 500 gallons or greater. Under the RIDEM Oil Pollution Regulations[3] "oil" is defined as: *"Petroleum, gasoline, tar, asphalt, or any product or mixture thereof, or any substance refined from petroleum or crude oil"*. The U.S. Environmental Protection Agency (USEPA) also regulates ASTs under the Oil Spills Prevention and Preparedness Regulations - Spill Prevention, Control, and Countermeasure (SPCC) rule at 40 CFR part 112[4]. The U.S. Coast Guard (U.S.C.G.)[5] also has regulatory jurisdiction relating to AST facilities in the vicinity of coastal areas.

Historic Hurricanes and Predicted Sea Level Rise

Over the past 100 years, Rhode Island has experienced a number of intense storm events and hurricanes. Notable events occurring in this time-frame include, the Hurricane of 1938 and Hurricanes Carol and extra-tropical cyclone Sandy. Since 1900, thirteen significant tropical cyclones have made landfall with significant impact in southern New England.[6] These types of storm events have caused high winds, severe precipitation, coastal storm surge and flood inundation. In addition, current National Oceanic and Atmospheric Administration (NOAA) climate research[7,8] also indicates that climate change will lead to Sea Level Rise and will increase the likelihood of higher storm surge levels, precipitation rates and more intense coastal storm events.

Potential Environmental Impacts

Environmental impacts from intense storm events can be caused by the loss or release of product to land, waterbodies and the atmosphere. Due to the nature and volume of materials stored in registered ASTs located in coastal flood zones, it is critical for facilities to examine their risk of release and evaluate the possible impacts to human health and the environment. The loss or release of product can occur under several failure modes during Hurricanes and Coastal Storm/Flood events.

NOAA

Figure 1: AST that floated onto a nearby street due to the 1938 Hurricane (East Providence, RI)

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Concluding Statement

Based upon the results of project research, facility audits, and the industry survey, the RIDEM Office of Customer and Technical Assistance will be investigating potential pollution prevention strategies and best management practices for AST facilities.

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THANK YOU!

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