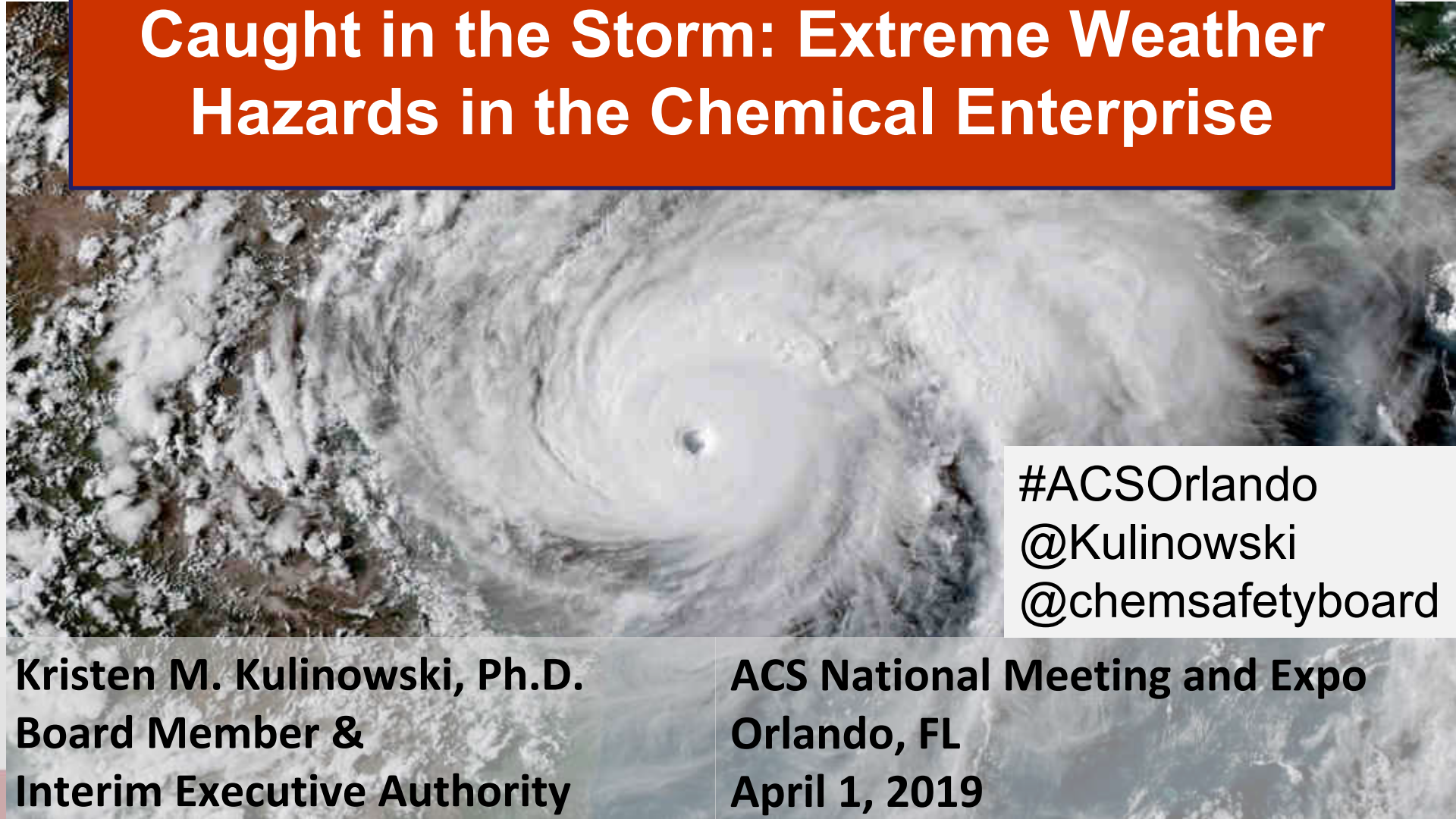




U.S. Chemical Safety and Hazard Investigation Board



Caught in the Storm: Extreme Weather Hazards in the Chemical Enterprise



#ACSOrlando
@Kulinowski
@chemsafetyboard

Kristen M. Kulinowski, Ph.D.
Board Member &
Interim Executive Authority

ACS National Meeting and Expo
Orlando, FL
April 1, 2019

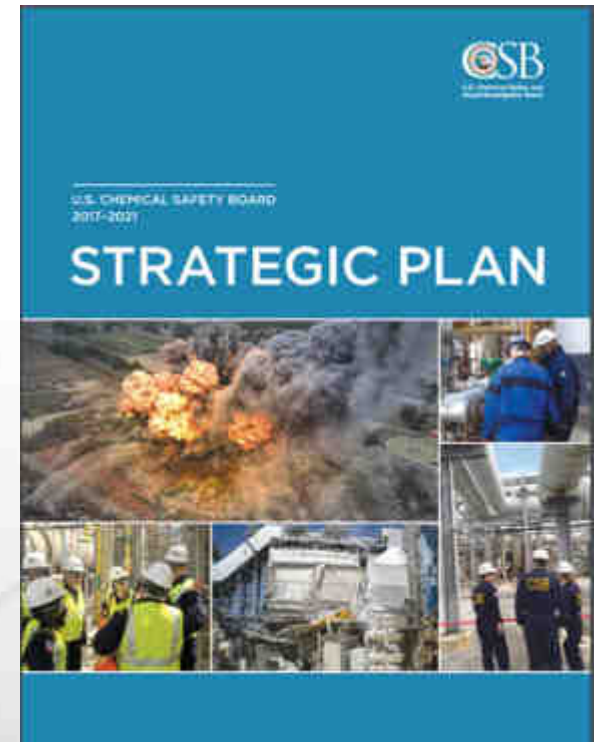


Vision:

A nation safe from chemical disasters.

Mission:

Drive chemical safety change through independent investigations to protect people and the environment.



ITC Fire – March 2019





Arkema Inc. Chemical Fire (August 2017)





Organic Peroxides

Table 1 Representative organic peroxides

Peroxyesters	Peroxydicarbonates	Dialkyl Peroxides	Diacyl Peroxides	Hydroperoxides	Peroxyketals	Ketone Peroxides
$\text{R}-\overset{\text{O}}{\parallel}-\text{OOC}-\text{R}$ <p>Luperox P (t-Butyl perbenzoate)</p>	$\text{R}-\overset{\text{O}}{\parallel}-\text{OOC}-\text{OOC}-\overset{\text{O}}{\parallel}-\text{R}$ <p>Luperox 223-M75S (Di-2-ethylhexyl peroxydicarbonate)</p>	$\text{R}-\text{OO}-\text{R}$ <p>Luperox DI (Di-t-Butyl peroxide)</p>	$\text{R}-\overset{\text{O}}{\parallel}-\text{C}-\text{OO}-\overset{\text{O}}{\parallel}-\text{C}-\text{R}$ <p>Luperox A98 (Benzoyl peroxide)</p>	$\text{R}-\text{OOH}$ <p>Luperox TBH70X (t-Butyl hydroperoxide)</p>	$\begin{array}{c} \text{R}'\text{OO} \quad \text{OOR}' \\ \diagdown \quad / \\ \text{R}-\text{C}-\text{R} \end{array}$ <p>Luperox 231 (1,1-Di-t-Butyl peroxy) 3,3,5-trimethyl cyclohexane)</p>	<p>Luperox DDM-9 (MEKP Solution in Plasticizer - 9% Active Oxygen)</p>
<p>Luperox® 26 (t-Butyl peroctoate)</p>	<p>Luperox 225-M60S (Di-sec-Butyl peroxydicarbonate)</p>	<p>Luperox 101 2,5-dimethyl-2,5-bis (t-Butyl-peroxy) hexane</p>	<p>Luperox LP (Lauroyl peroxide)</p>	<p>Luperox CU90 (Cumene hydroperoxide)</p>	<p>Luperox 331M80 1,1-Di (t-Butyl peroxy) cyclohexane</p>	<p>Luperox Delta-X9 (MEKP Solution in Plasticizer - 9% Active Oxygen)</p>
<p>Luperox 11M75 (t-Butyl peroxyvalate)</p>		<p>Luperox DC (Dicumyl peroxide)</p>				<p>Luperox DHD-9 (MEKP Solution in Plasticizer - 9% Active Oxygen)</p>
<p>Luperox 10M75 (t-Butyl peroxy neodecanoate)</p>		<p>Luperox F (2,2-bis (t-butyl peroxy) disopropylbenzene(s))</p>				<p>Luperox 224 (2,4-Pentanedione Peroxide Solution in Plasticizer)</p>

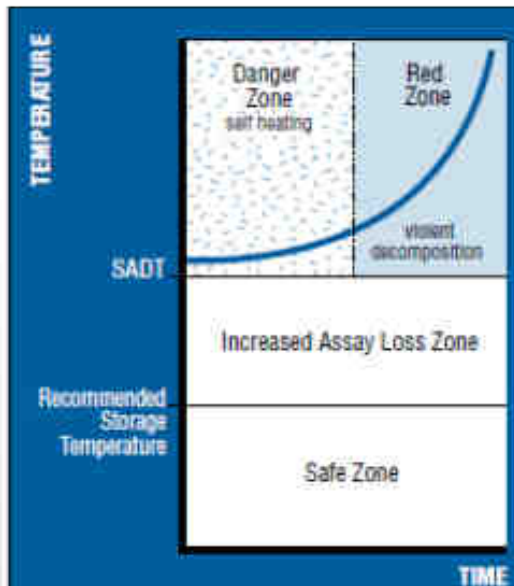
Note: Luperol® DDM-9®, DHD-9®, DDM-30® and Delta X-9® will change to Luperox and drop ® during 2001. Formulations will not change.

Luperol® and Luperox® are registered trademarks of Arkema Inc.

Organic Peroxides – Their Safe Handling and Use. Arkema



Self-Accelerating Decomposition Temperature (SADT)



Organic Peroxides – Their Safe Handling and Use. –Arkema

<https://youtu.be/98jOeCr06Xs>



Types of Organic Peroxides



Type	Description
A	Heating may cause a detonation or deflagration (explosion)
B	Heating may cause a thermal explosion or fire
C-F	Heating may cause a fire

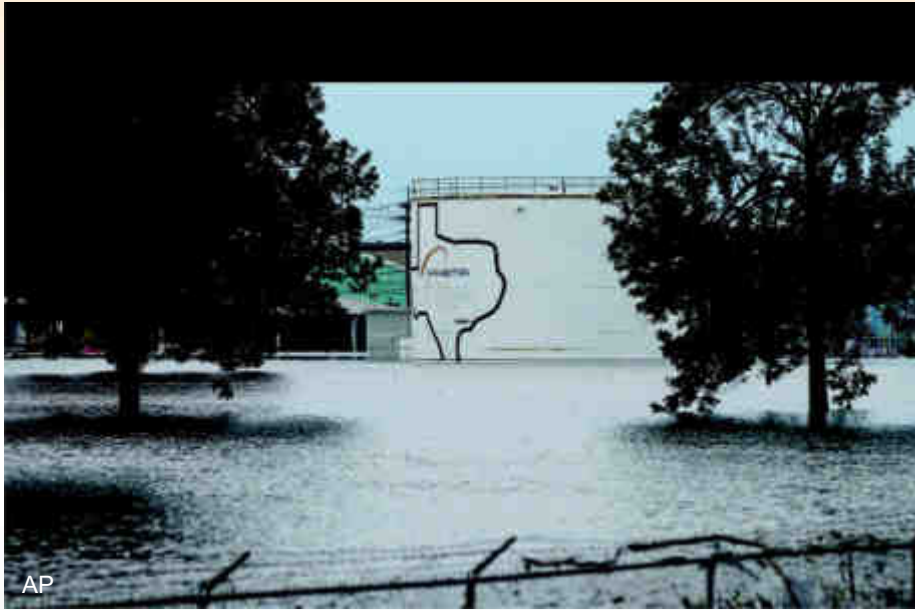


Refrigerated Organic Peroxide Inventory and Properties

Luperox™	Peroxide Chemical Family	Maximum Storage Temperature (°F)	SADT (°F)	Hazard Category (Type)
10	Peroxyester	14	70	D
10M75	Peroxyester	14	81	D
11M45	Peroxyester	32	113	D
11M75	Peroxyester	32	84	C
188M75	Peroxyester	5	59	D
221	Peroxydicarbonate	-9	23	C
233M75S	Peroxydicarbonate	14	68	D
223S	Peroxydicarbonate	0	59	C
223V75	Peroxydicarbonate	14	77	D
225M60	Peroxydicarbonate	14	50	C
546M75	Peroxyester	14	77	D
	Total Inventory (Pounds)	367,000		



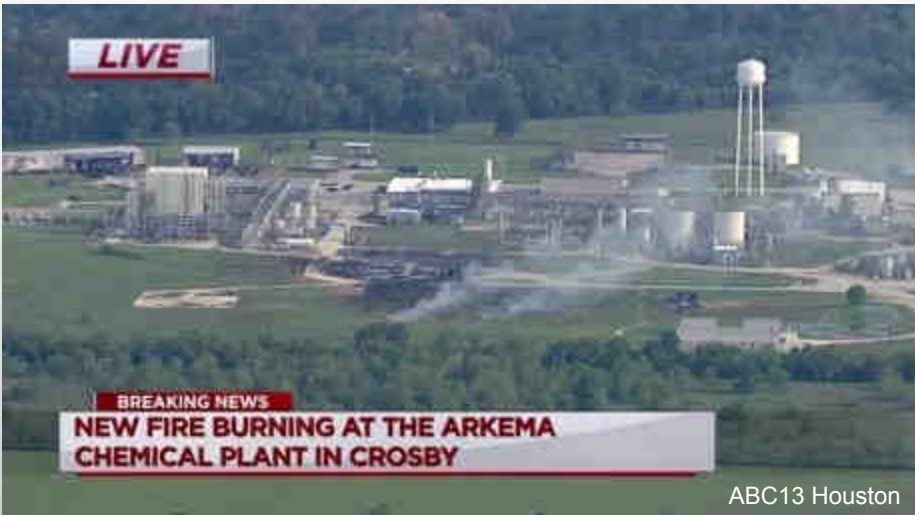
<https://youtu.be/jtWyBMwRt-A>



AP

“Certainly, we didn’t anticipate having six feet of water in our plant.”

Arkema President



ABC13 Houston



ABC13 Houston

TS Allison (2001)

2001

June – Tropical Storm Allison strikes first on June 5; returns three days later for a second round of storms. Texas Medical Center essentially shut down. North Downtown Houston decimated. Two million people impacted; 22 lives lost. More than 70,000 structures flood. Damages top \$5 billion.

“ALLISON: A NAME WE’LL NEVER FORGET”



Memorial Day Flood (2015)

2015

May 25-27 – Memorial Day Flood. More than 6,000 structures flood. Seven fatalities. Highest rainfall recorded in Buffalo and Brays watersheds. Nearly 11 inches in 3 hours on Brays Bayou.



Getty Images

“HIGHEST RAINFALL RECORDED”



Tax Day Flood (2016)

2016

April 17-18 - Tax Day Flood. Historic flood over northern and western Harris County results in seven fatalities. Average 12-16 inches of rain in 12 hours countywide; record pool levels in Addicks and Barker reservoirs. Estimated 9,820 structures flood in Harris County.

2016

May 26-27 - Memorial Day Flood. North and northwest Harris County hit with 8-13 inches of rain. Overbank and structural flooding along Spring, Willow, Little Cypress and Cypress creeks, San Jacinto River. More than 400 structures flood in Harris County and more than 600 in the Galveston



Leif Reigstad

“HISTORIC FLOOD”



Memorial Day Flood (2016)



Houston Chronicle

2016



Source: Harris County Flood Control District



Houston Floods.

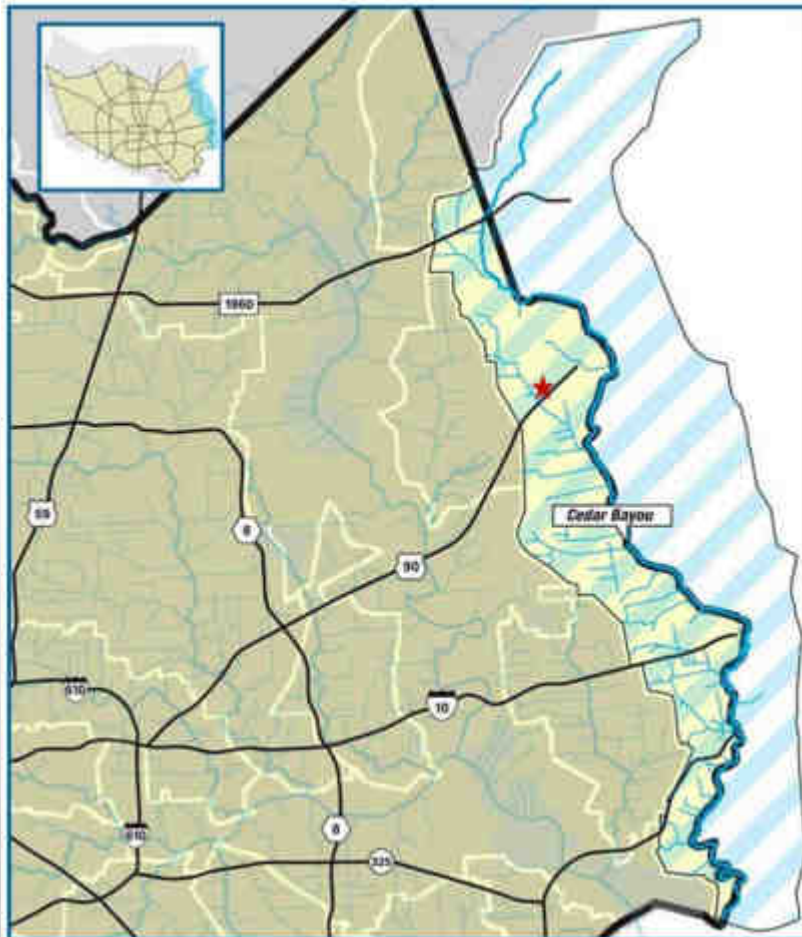
<p>1900</p> <p>September - Major hurricane hits Galveston. The "Great Galveston Storm" is the worst natural disaster in state in U.S. history. Loss of life reported to be 4,000 to 6,000 citizens. Harris County experiences widespread flooding, with property damage at \$30 to \$40 million.</p>	<p>1911-1914</p> <p>Houston Ship Channel construction begins.</p>	<p>1912</p> <p>December - Major Brown River storm spreads to Harris County. Entire area is hard hit. Buffalo, White Oak, Bayou and Greens Bayous are all out of banks. Many citizens evacuate.</p>	<p>1919</p> <p>April - Storm surge gulf starts beyond on Houston and Harris County and kills 14 hours. Many areas of county report rainfall close to 10 inches. Extensive damage sustained to all structures in almost all of Harris County. All Bayous are reported to be out of banks.</p>	<p>1922</p> <p>August - Hurricane hits Freeport, taking 40 lives. Harris County has widespread flooding on all Bayous.</p>	<p>1926</p> <p>November - Heavy rain last for 5 days in Northwest Harris County. 10,000 head of cattle lost.</p>	<p>1928</p> <p>February - Thunderstorm produces cold front, resulting in rivers banks opening out of banks. Area residents evacuated. Bayou also reports flooding.</p>	<p>1929</p> <p>June - Thunderstorm produces cold front and floods reach of northern Harris County. More than 700 families evacuate.</p>	<p>1932</p> <p>March - Thunderstorm produces cold front and floods reach of northern Harris County. More than 700 families evacuate.</p>	<p>1933</p> <p>September - Hurricane Carla pounds the Gulf Coast, taking 24 lives. It is the largest hurricane ever recorded, with property damage exceeding \$200 million. Heavy flooding reported in southern Harris County.</p>	<p>1934</p> <p>September - Hurricane strikes Harris County and brings 10-15 inches of rain. Dams and levees banks are reported out of banks. 10 lives are lost and damage exceed \$50 million.</p>	<p>1935</p> <p>June - Major storm hits Harris County. Texas and Louisiana banks are reported out of banks. Damage approach \$1 billion, mostly due to wind.</p>
<p>1900</p> <p>First drainage district created in Harris County in Bayou Seguin watershed.</p>	<p>1911</p> <p>Houston Ship Channel opens.</p>	<p>1912</p> <p>August - Another Galveston hurricane causes major damage throughout Harris County. Buffalo Bayou and White Oak areas of Houston experience heavy flooding. Damage estimated at \$50 million.</p>	<p>1919</p> <p>April - As the area is still reeling from the last storm, another major storm hits Harris County. Structural damage, heavy street flooding and widespread crop damage reported. San Jacinto River 20 feet above normal.</p>	<p>1922</p> <p>December - Massive storm inundates Houston and Harris County. Buffalo Bayou 12 feet above normal. Overflooding, inundation leads to creation of the Harris County Flood Control District in 1923.</p>	<p>1926</p> <p>July - Hurricane near Galveston causes extensive flooding to Harris County. \$14.5 million in damage.</p>	<p>1928</p> <p>October - Hurricane near Freeport. More than 11,000 structures flooded in Harris County.</p>	<p>1929</p> <p>June - Hurricane Audrey crosses the Louisiana/Texas coast. Flooding is reported in Harris County.</p>	<p>1932</p> <p>February - Thunderstorm produces cold front, flooding more than 250 area structures. Damage exceed \$2.2 million.</p>	<p>1934</p> <p>September - Five inches of rain falls south of downtown. More than 1,100 structures flood along Bayou Seguin. Damage loss \$38 million.</p>	<p>1935</p> <p>September - Tropical Storm Frances causes extensive flooding along White Oak Bayou and other bayous. More than 1,000 structures flood.</p>	<p>1936</p> <p>October - Hurricane strikes Harris County. Storm surge reaches 2,500 structures, causing damage to 1,200 more structures to flood. More than \$29 billion in damage.</p>
<p>1936</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1936</p> <p>September - Hurricane Ike, 3rd deadliest in U.S. history, strikes Galveston Island. Storm surges in Harris County. Storm surge reaches 2,500 structures, causing damage to 1,200 more structures to flood. More than \$29 billion in damage.</p>	<p>1937</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1938</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1939</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1940</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1941</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1942</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1943</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1944</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1945</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>	<p>1946</p> <p>April 13-28 (major extensive flooding; see children shown when a car goes into a Green Bayou. Military Service Highway closed, record high water on Bayou. Langham, Maple crests. 2,300 structures flood on Lighthouse Green and Buffalo Bayou. HCFCD records one-foot rainfall of 4.9 inches at Clear Creek.</p>
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Source: Harris County Flood Control District



Watershed and Gauge Station

Map of the Cedar Bayou Watershed in Harris County, Texas



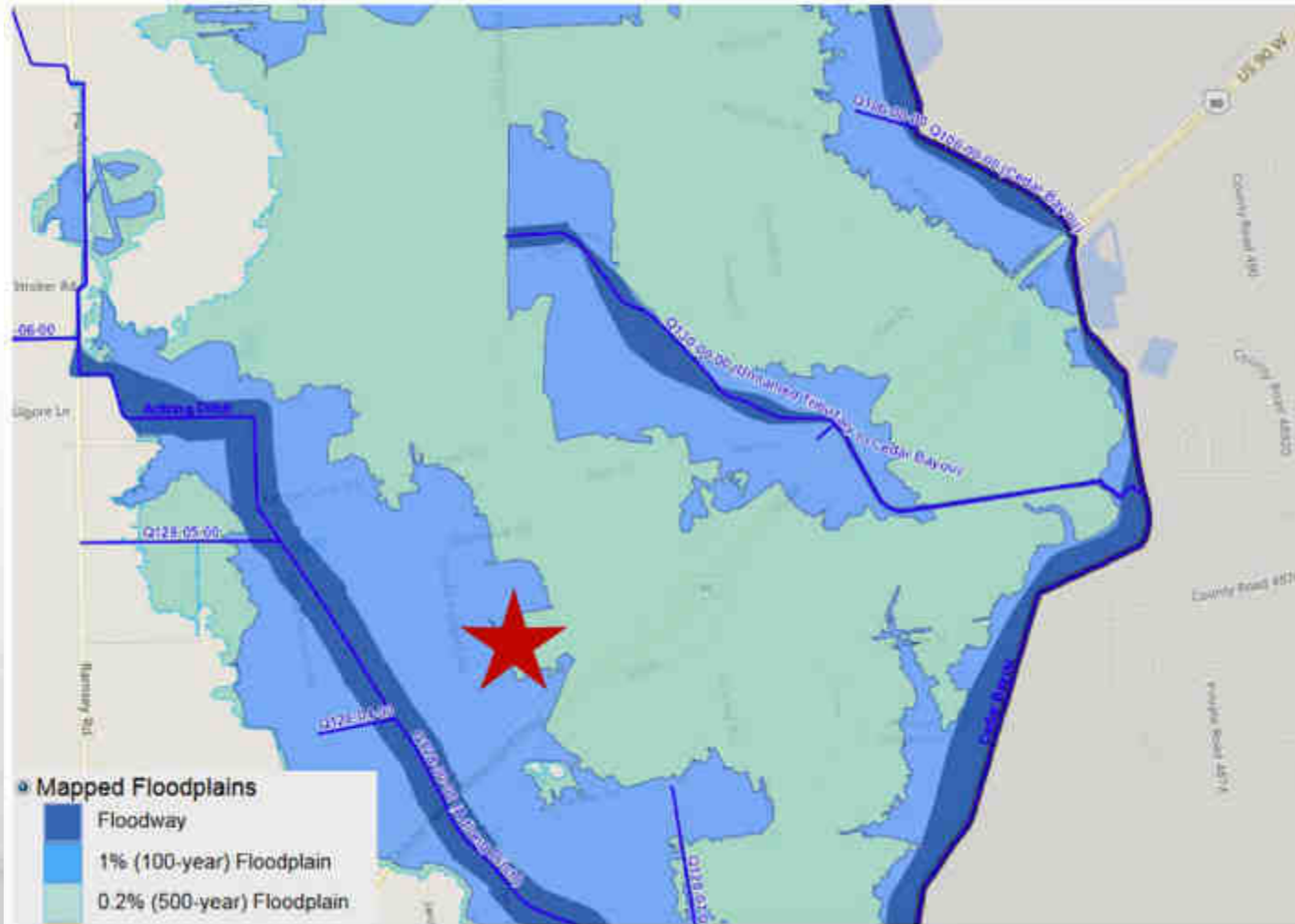
Arkema Crosby Facility and the Cedar Bayou Gauge Station 1740



<https://www.hcfd.org/projects-studies/cedar-bayou/>



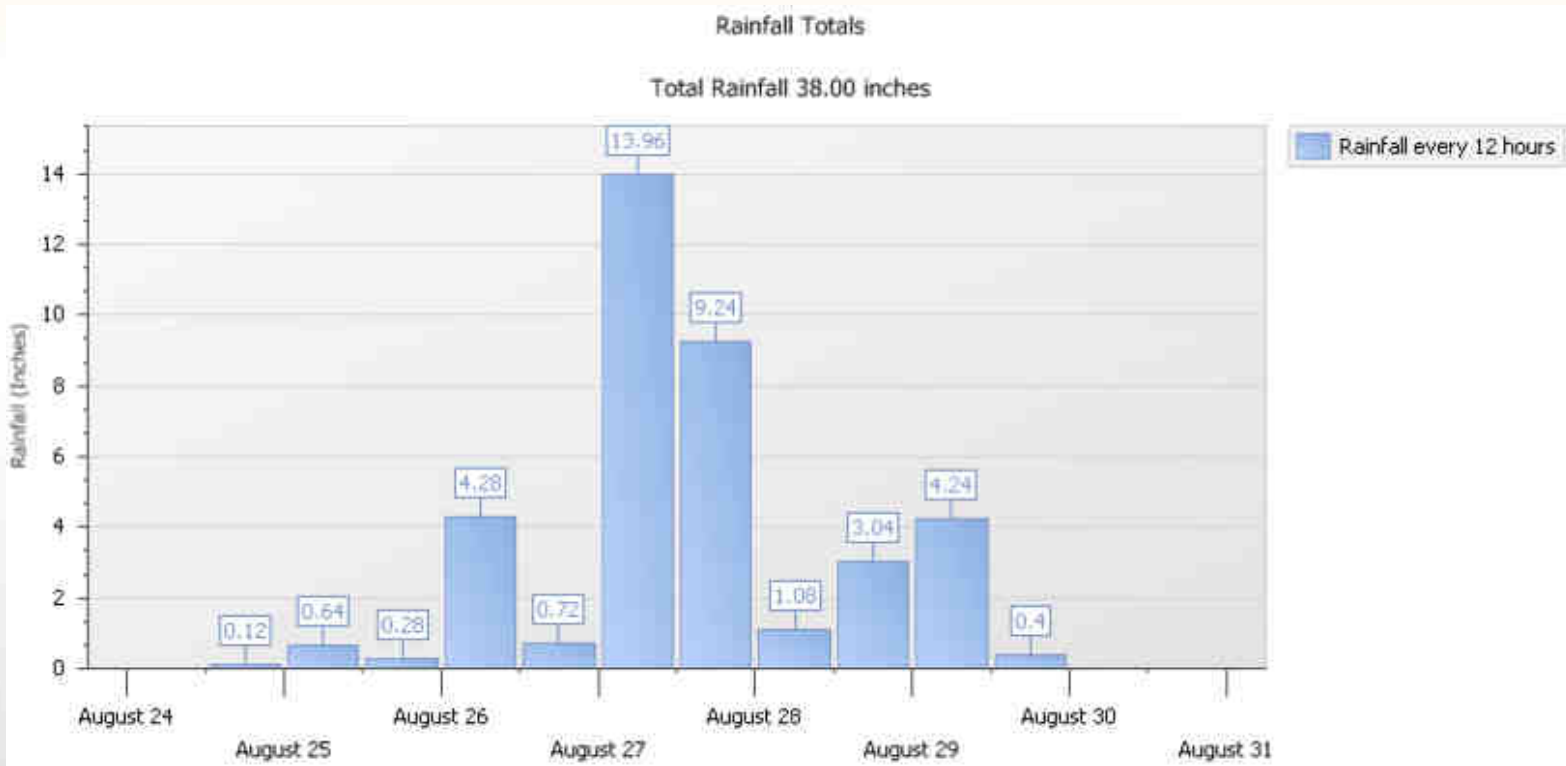
Floodplain Map



<http://www.harriscountyfemt.org/>



Rainfall Exceeds 500-yr Event



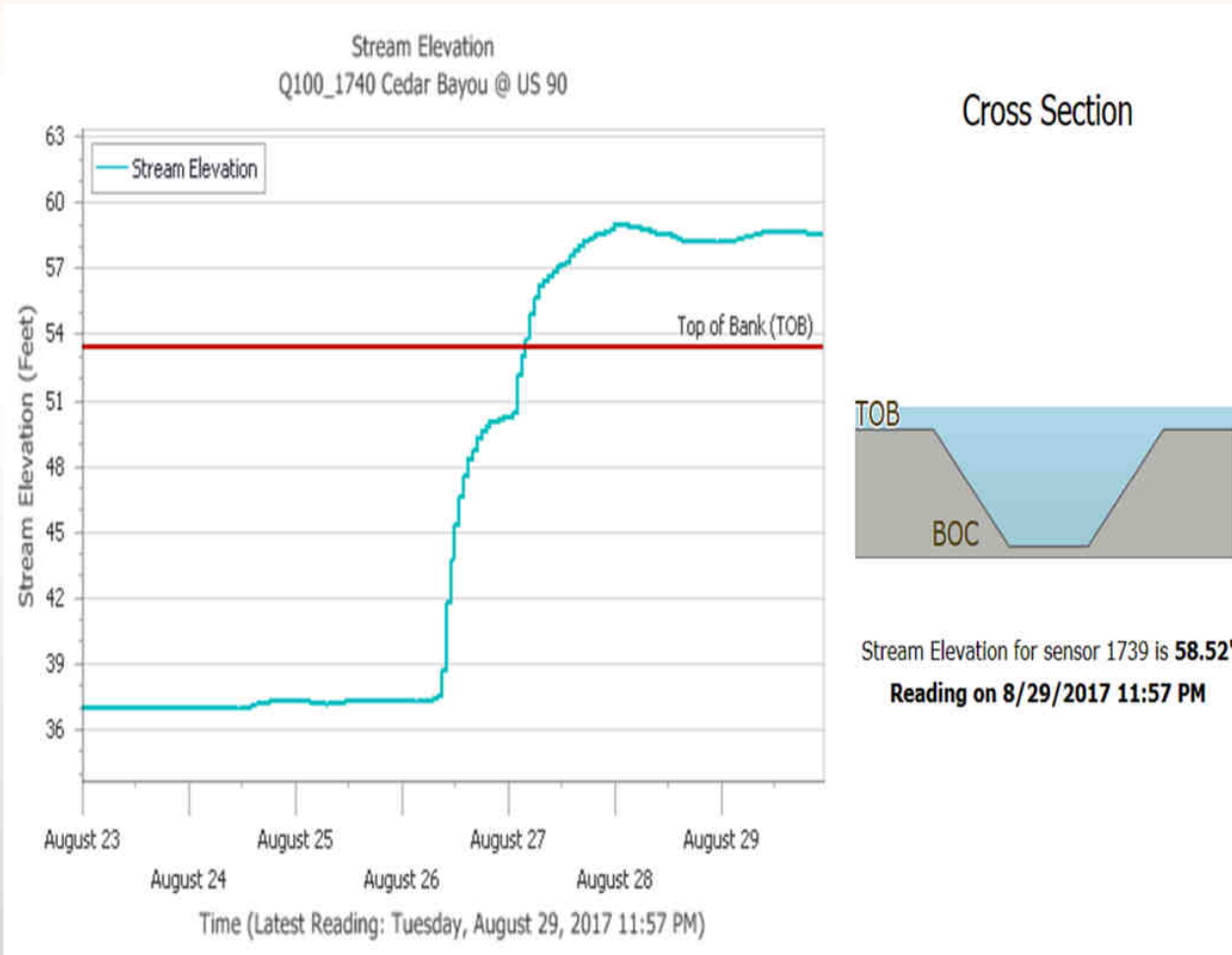
Harris County Flood Control District, "Gauge Station 1740 Data," 2017

For this region, a 500-year event is

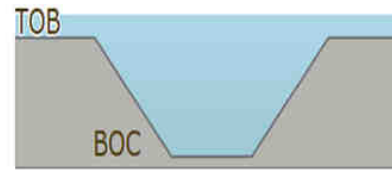
- 19.3 in / 24 hr
- 20.7 in / 48 hr
- 22.3 in / 96 hr



Cedar Bayou Stream Elevation



Cross Section



Stream Elevation for sensor 1739 is **58.52'**
Reading on 8/29/2017 11:57 PM

Predicted Flood Frequency Elevations

- 0.2% (500-yr)
- 1% (100-yr)
- 2% (50-yr)
- 10% (10-yr)



Historical Storm Elevation Data

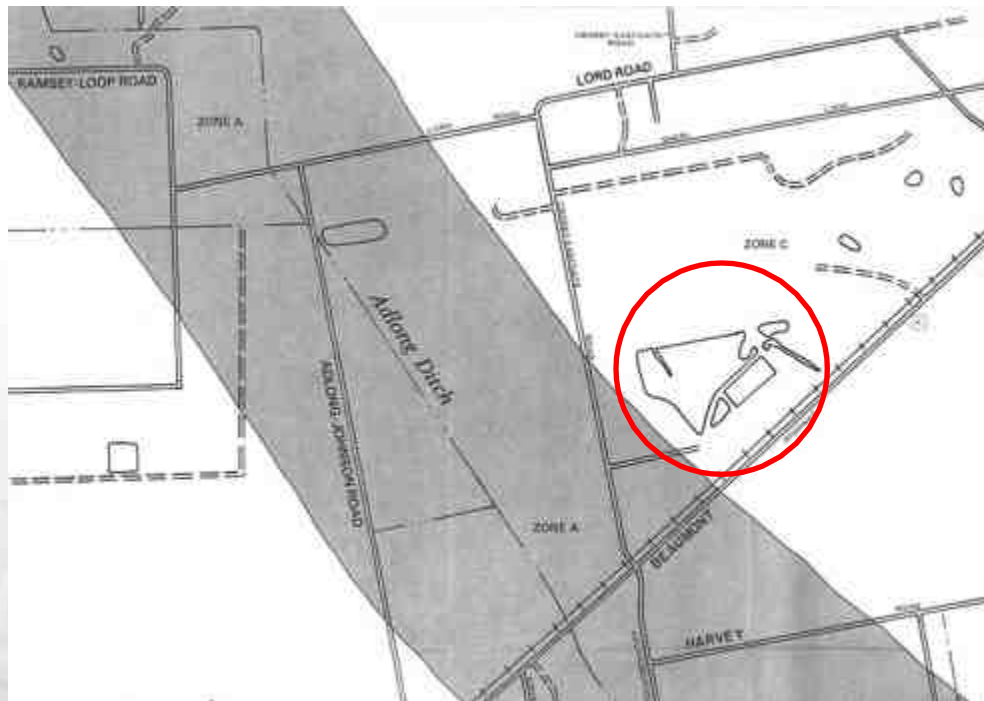
Historical Storm

Date	Event	Elevation
10/18/1994		56.08'
5/20/2000		50.08'
9/13/2008	Ike	53.70'
10/31/2015		55.10'
6/4/2016		50.40'
8/27/2017	Harvey	59.00'
High water mark elevations are approximate.		

HCFCD, "Gauge Station 1740 Data," 2017



Flood Insurance Rate Map - 1985



Zone C –
Area of Minimal Flooding

Zone A –
Areas of 100-year flood

FEMA Flood Map Service Center



Flood Insurance Rate Map - 1996



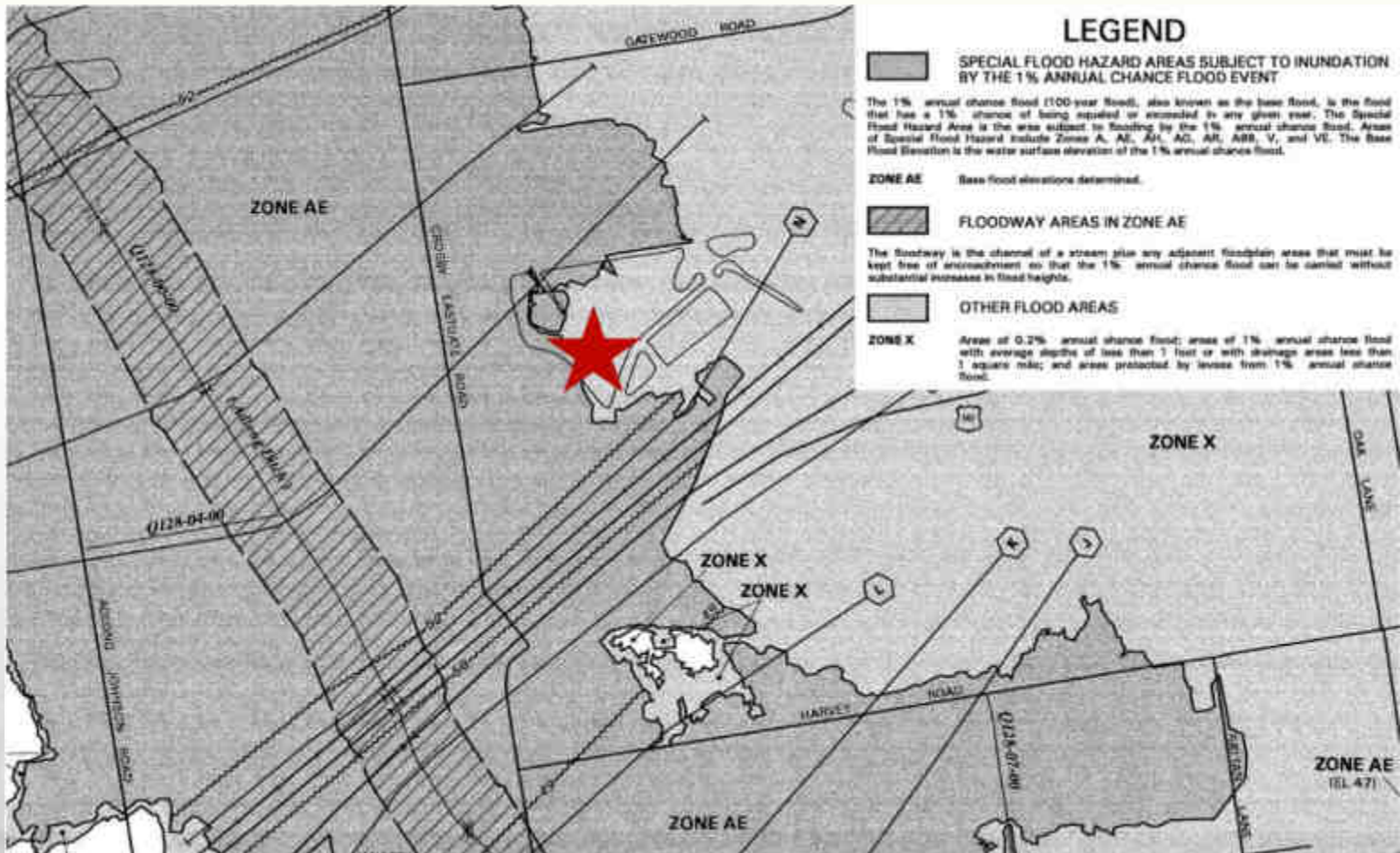
Zone X –
Areas determined to be
outside the 500-year
floodplain

Zone A –
Areas of 100-year flood

FEMA Flood Map Service Center



Flood Insurance Rate Map - 2007



FEMA Flood Map Service Center



Safety Critical Equipment in 100-yr Floodplain



Arkema electric utility supply and organic peroxide low-temperature warehouses now in the 100-year floodplain



Insurer Identified Flood Risk in 2016

- Engineers visited facility, met with plant manager, and produced a report identifying the flood risk
 - Adlong Ditch was source of flooding hazard
 - Site is in both 100-yr and 500-yr floodplains
 - Property damage and business interruption loss estimates computed
- Arkema Crosby facility fell in the bottom quartile of insurer's risk benchmarking tool, partly due to flood risk
- No recommendations were made but Arkema made some changes in response to the report



Key CSB Findings

- Four different layers of protection had common failure mode (flooding).
- Floodplain information is not required to be used in process hazard analyses.
- More robust industry guidance is needed to help hazardous chemical facilities better prepare for extreme weather events.
- Facilities should not rely on individual employees' experiences with past events to predict future risk.

Other Significant Releases



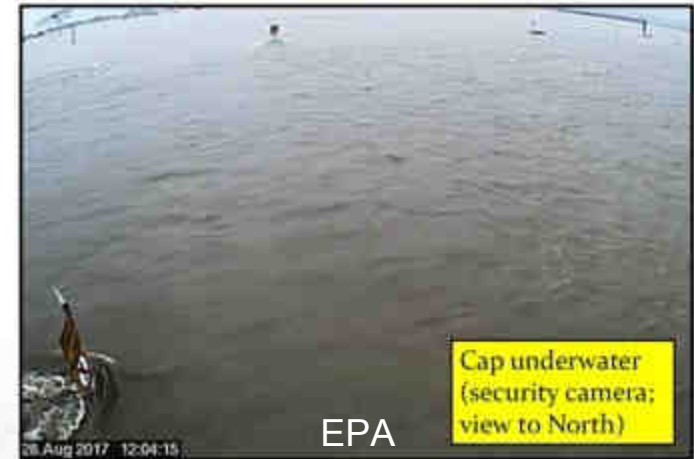
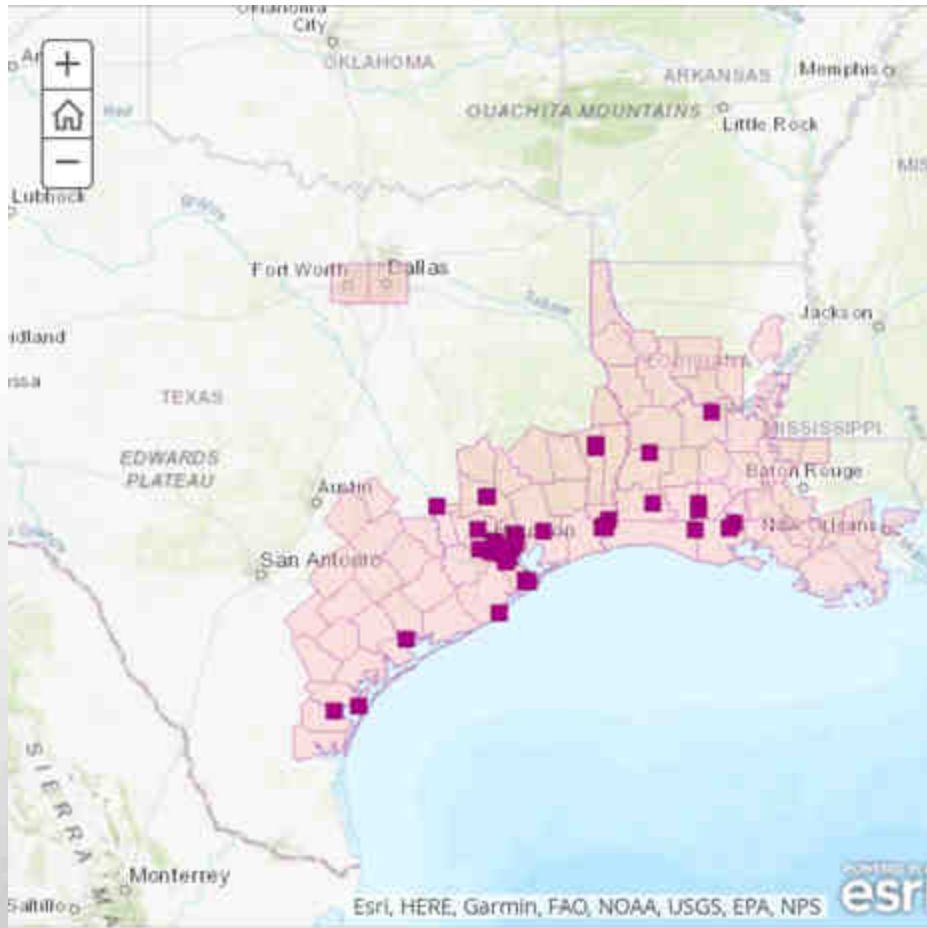
Magellan Midstream Galena Park
Tank leak released 11,000 barrels (461,000 gal) of gasoline. Some reached a local waterway.



Valero Houston Refinery
Floodwater lifted tank from foundation, releasing benzene, other compounds



Superfund Sites Affected by Harvey



San Jacinto River Waste Pits

- Protective cap damaged during flooding, exposing underlying waste
- Dioxin levels >70,000 ng (rec <30 ng)
- Erosion of river bottom under cap by ~12 ft



Flood Risks for Industrial Facilities

- Lift vessels from footings, causing release of contents
- Floating vessels impact other equipment
- Increased drag forces cause piping connections to fail
- Intrusion of water into electrical equipment
- Acceleration of corrosion of safety-critical equipment



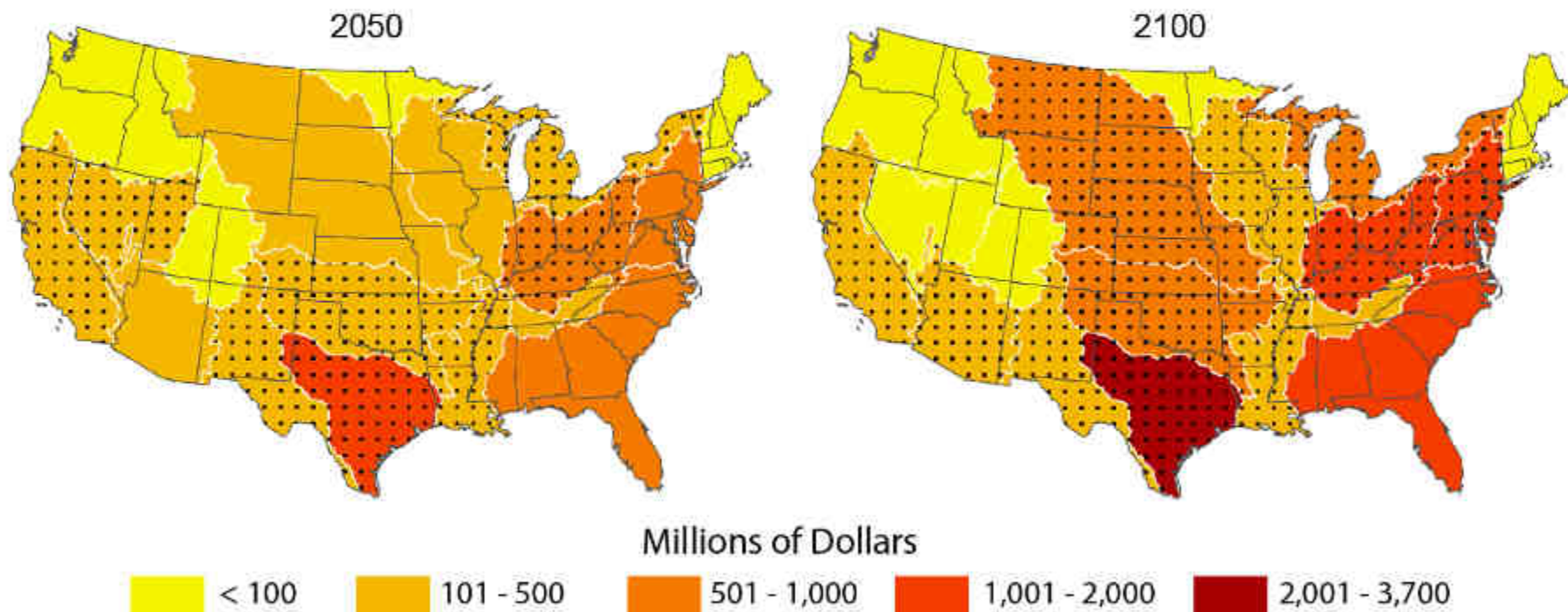
CSB Guidance to Industry

- Perform an analysis to determine susceptibility to extreme weather events and other natural disasters
- Apply a conservative risk management approach when evaluating and mitigating the potential effects of extreme scenarios
- Ensure that critical safeguards and equipment are not susceptible to common mode failures



Figure 1. Estimated Flood Damages Due to Unmitigated Climate Change

Estimated flood damages under the Reference scenario in 2050 and 2100 for the IGSM-CAM climate model (millions 2014\$). Results are presented for the 18 2-digit hydrologic unit codes (HUCs) of the contiguous U.S. Stippled areas indicate regions where the projected damages are significantly different from the historic period (at a 90% confidence interval).



For more information, visit EPA's "Climate Change in the United States: Benefits of Global Action" at www.epa.gov/cira.



U.S. Chemical Safety and Hazard Investigation Board

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