SWG'S HISTORY/CASE STUDIES OF FRAC-OUT AND OTHER HORIZONTAL DIRECTIONAL DRILLING (HDD) INSTALLATION ISSUES

SWG Levee Safety Team

2020

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PRESENTATION ITEMS

1. Objectives of This Presentation

2. Introduction of HDD
   - General Procedure
   - HDD Installation
   - Monitoring for Fluid Release
   - HDD Design and Construction Considerations

3. SWG's History and Case Studies of Frac-Out
   - Eleven (11) frac-outs since 1980
   - Photos and Locations for the frac-outs
   - Major Reasons Presumed for the eleven frac-outs above

4. Other HDD Installation Issues
   - Repair (or Mitigation) Method for Levee Damaged by frac-out
   - Monitoring Annular Pressure during HDD

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1. OBJECTIVES OF THIS PRESENTATION

- To share SWG's history/case studies of frac-out and other HDD installation issues
- To discuss ideas we explored regarding mitigation of frac-out potential during HDD installation
- To discuss new SWG policy on HDD installations on levees

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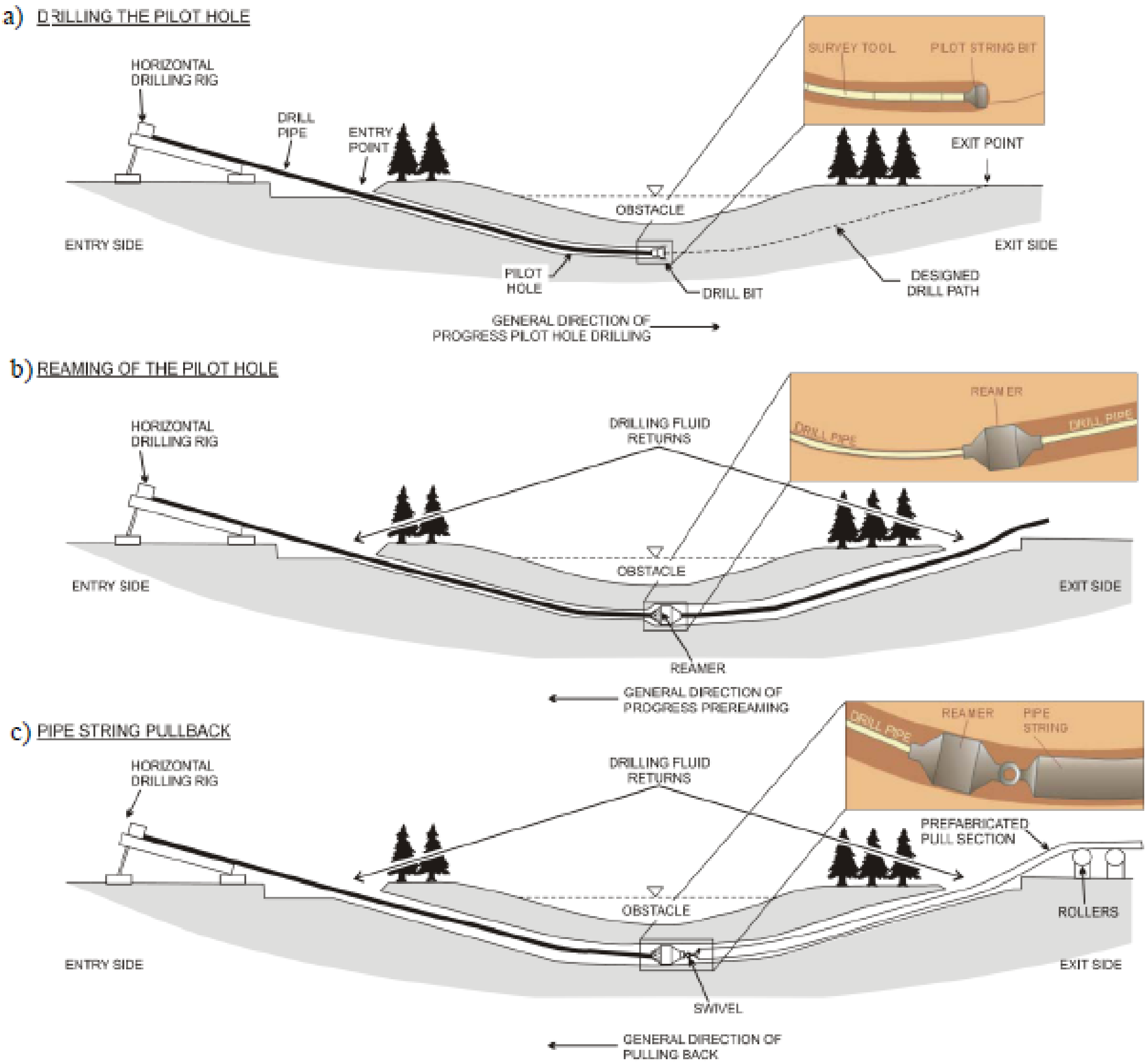
2. INTRODUCTION OF HDD (GENERAL PROCEDURE)



Stage 1: Directional drilling using small diameter pilot hole along the designed directional path (Pilot hole drilling)

Stage 2: Enlarging the pilot hole to a diameter suitable for installation of the pipeline (Reaming the pilot hole)

Stage 3: Pulling the pipeline back into the enlarged hole (Pulling back)

Reference: Canadian Association of Petroleum Producers, 2004)

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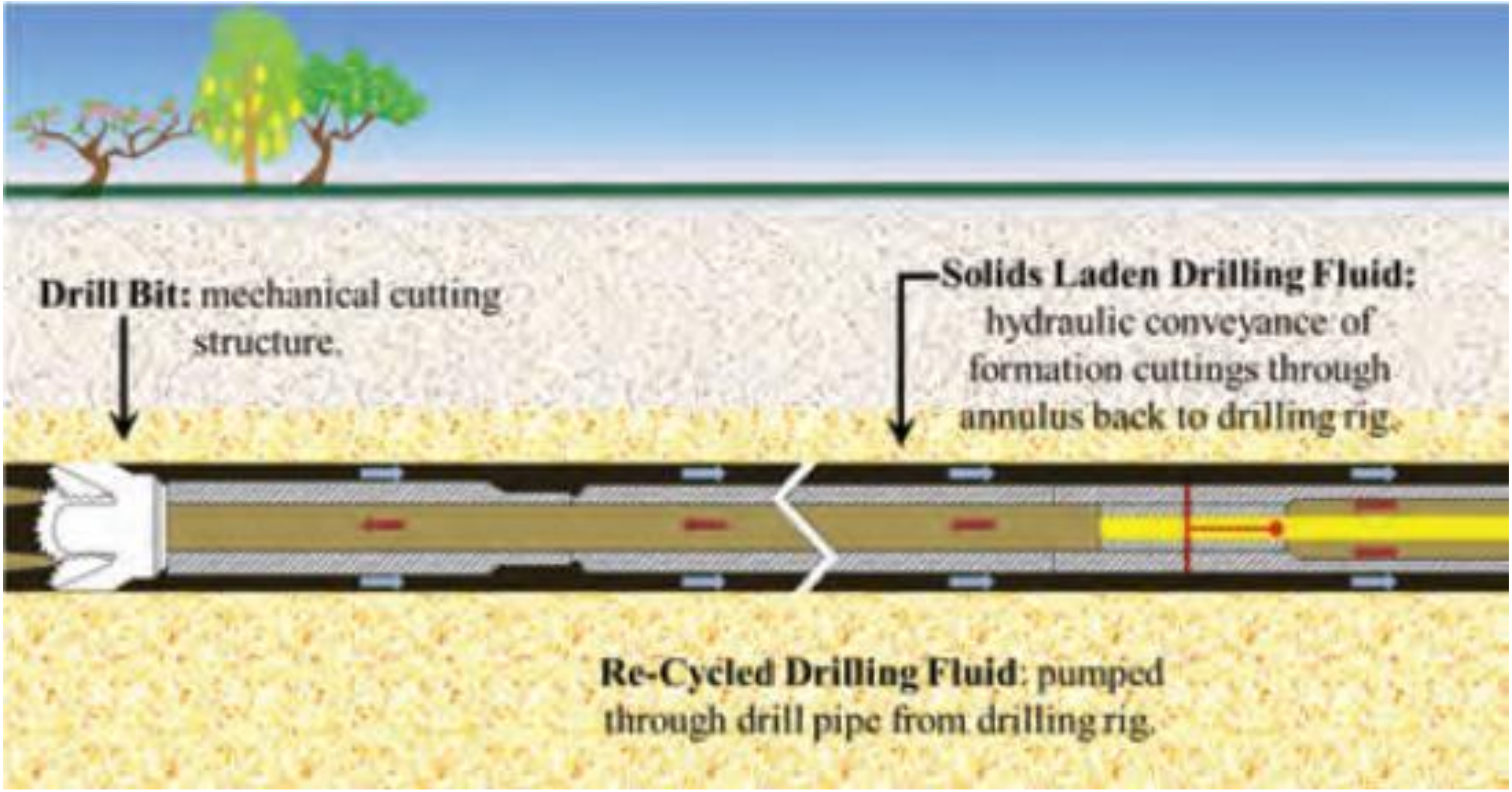
2.1 HDD INSTALLATION



Reference: Ali Rostami, et al, “Drilling Fluid Management During HDD”, Trenchless Technology 2014

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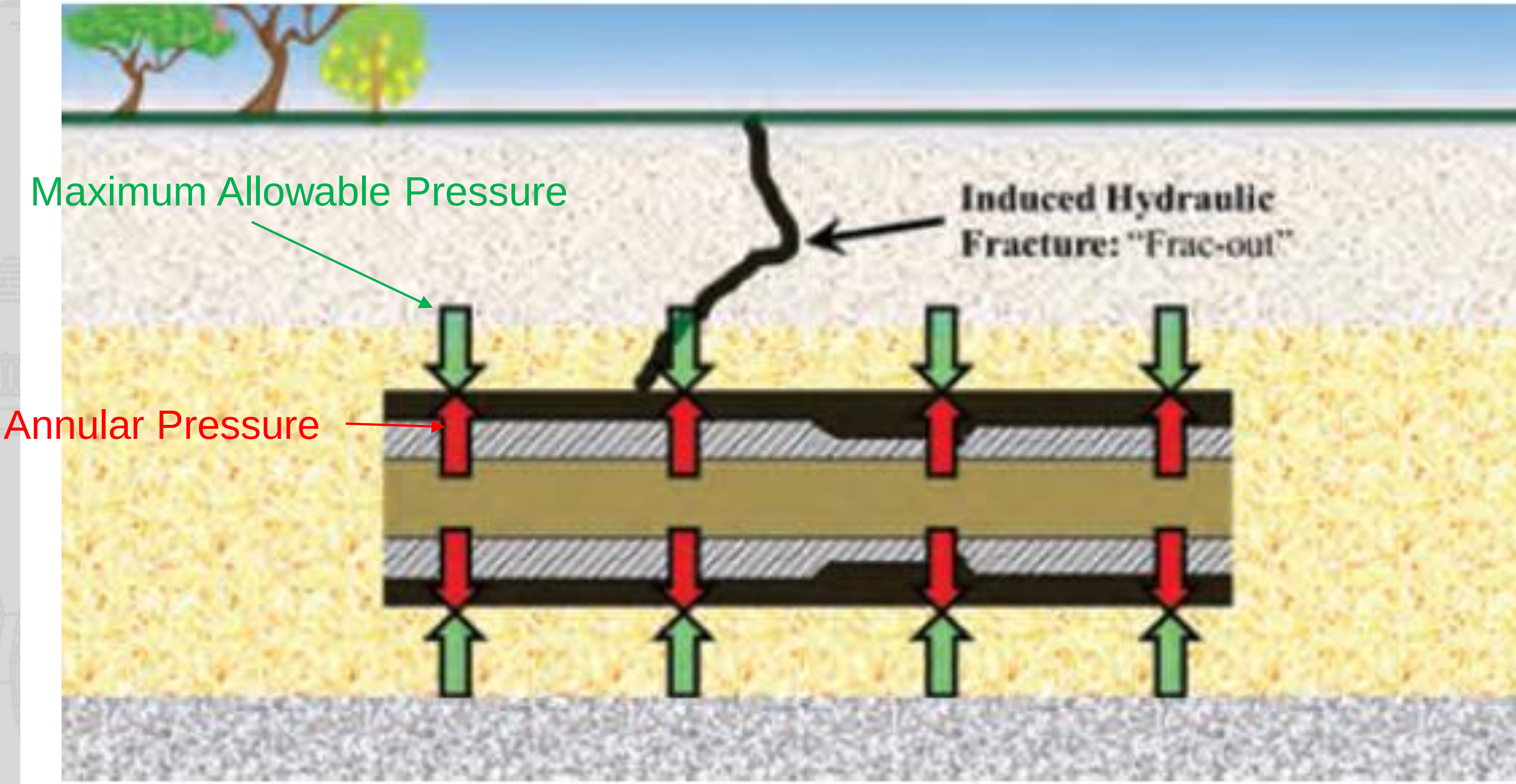
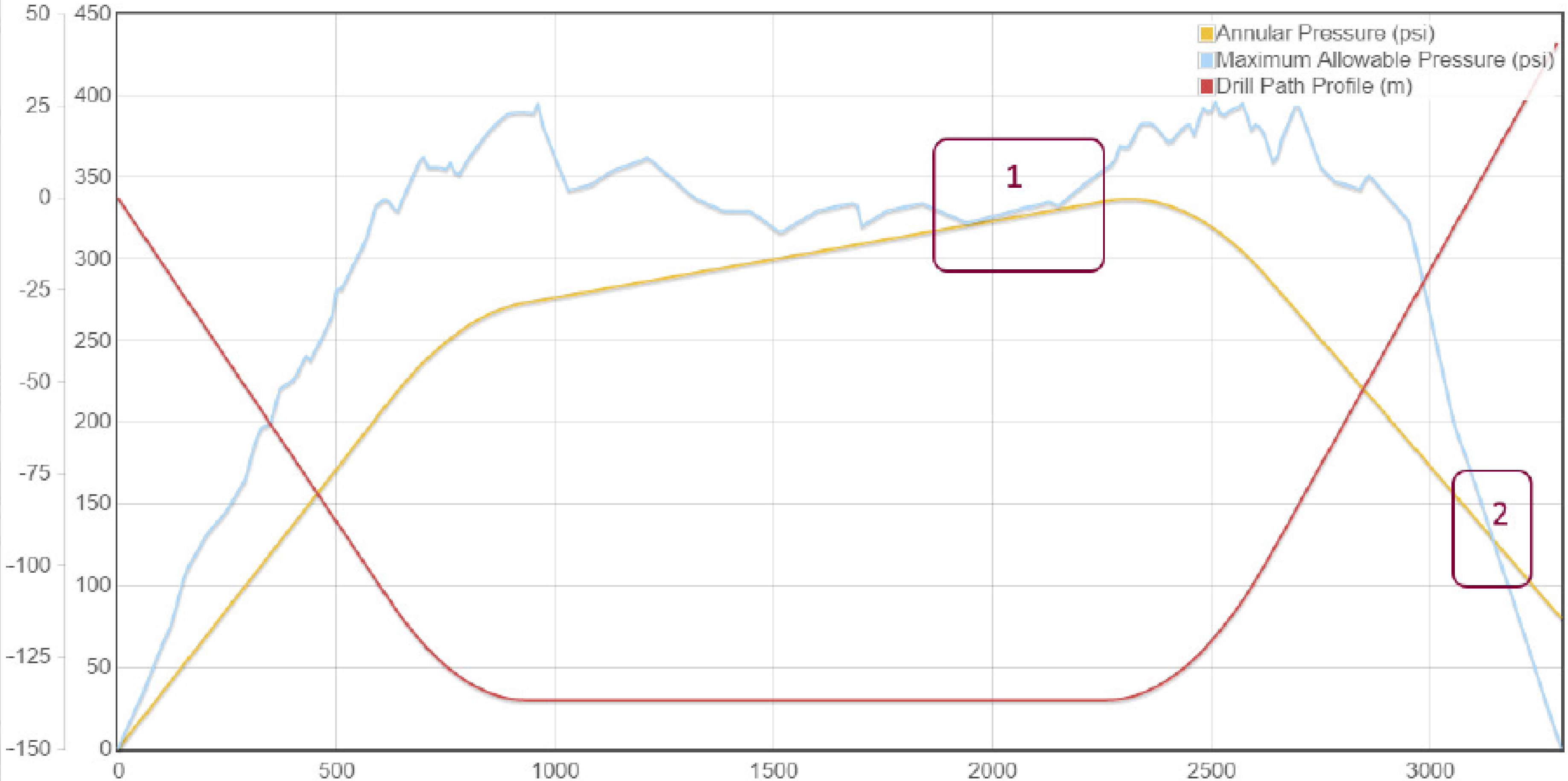
2.2 MONITORING FOR FLUID RELEASE

Annular pressure should be monitored closely for spikes and compared against the maximum allowable pressure. **<u>Frac-out occurs when the annular pressure is greater than the maximum allowable pressure.</u>**



Reference: Ali Rostami, et al, "Drilling Fluid Management During HDD", Trenchless Technology 2014

ANNULAR AND MAXIMUM ALLOWABLE PRESSURES CHART



Reference: Paul Yassa, "Hydraulic fracture Model in Horizontal Directional Drilling", 2015

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2.3 HDD DESIGN AND CONSTRUCTION CONSIDERATIONS

- Frac-Out simply means drilling fluid is released (or there is mud loss) to the ground surface during HDD installation.
- Drilling fluid release (or mud loss) has become a critical issue which engineers and contractors face during HDD because Frac-Out causes project delays and poses grave risks in environmental sensitive and urban areas.
- It is important to monitor the **annular pressure** and ensure it does not rise above the **maximum allowable pressure** in the borehole during HDD installation
- **Annular Pressure**: the pressure in the borehole annulus at the drill bit consisting of the hydrostatic pressure exerted by the drilling fluid column above the drill bit and the pressure from the buildup of cuttings. This pressure can be monitored from sensor attached at the drill bit.
- **Maximum allowable pressure**: the pressure from soil surrounding the borehole to contain the annual pressure before the frac-out occurrences. This pressure is estimated with soil's shear strength and the overburden pressure.

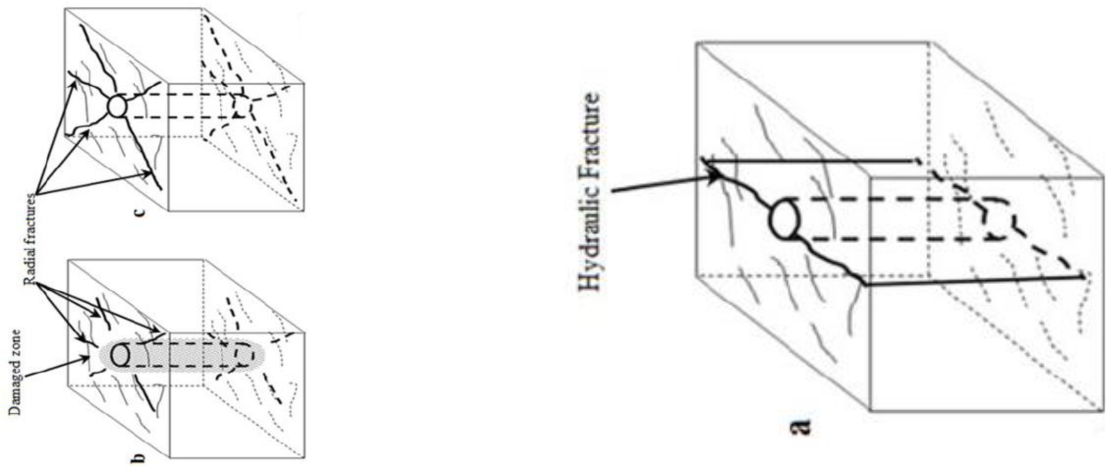
Reference: Paul Yassa, "Hydraulic fracure Model in Horizontal Directional Drilling", 2015

POTENTIAL HDD FAILURES

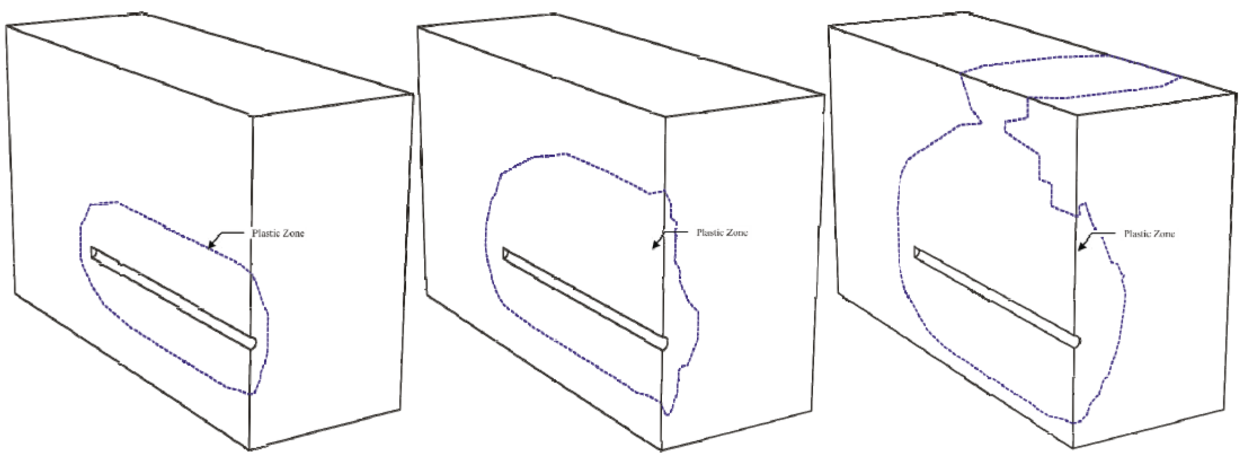
Failure Source	Cause(s)
Geotechnical Exploration	Soil borings not deep enough
	Soil borings not frequent enough
	Soil borings located on top of proposed pipe alignment
	Insufficient soil information obtained
Design	Utility/structure conflicts (SUE locates)
	Inadequate staging area
	Staging too close to obstacle
	3D alignment proposed
	Drill calculations not completed
	Drill angle of attack too shallow
	Drill radius too small
	Drill depth at mixed face soil conditions
	Insufficient overburden/cover
	Soft soils
	Improper pipe specified
	Flooded vs. unflooded installation
	Lack of constructability review
Construction	Equipment in disrepair
	Wrong drill rig for the job
	Wrong drill head for soil conditions
	Drill change by contractor
	Improper drilling fluid used
	Hydro-fracture
	Problematic soils causing the contractor to seek better soils

Reference: Blake Peters, et al, “Can You See It Coming? Examining and Mitigating the Common Causes of HDD FAilures”, 2014 NASTT No-Dig Show, Orlando, FL

2.4 FRAC OUT PATTERNS



Reference: Safari, et al, "Integrating Reservoir and Geomechanical Models to Compare the Productivity of Shale Reservoirs Using Different fracure Techniques." Society of Petroleum Engineers, Unconventional Resources Conference and Exhibition-Asia Pacific, Brisbane, Australia, 2013



Reference: Hongwei Xia, "Investigation of maximum mud pressure within sand and clay during HDD", Phd Thesis, Queen's University, Ontario, CA, 2009

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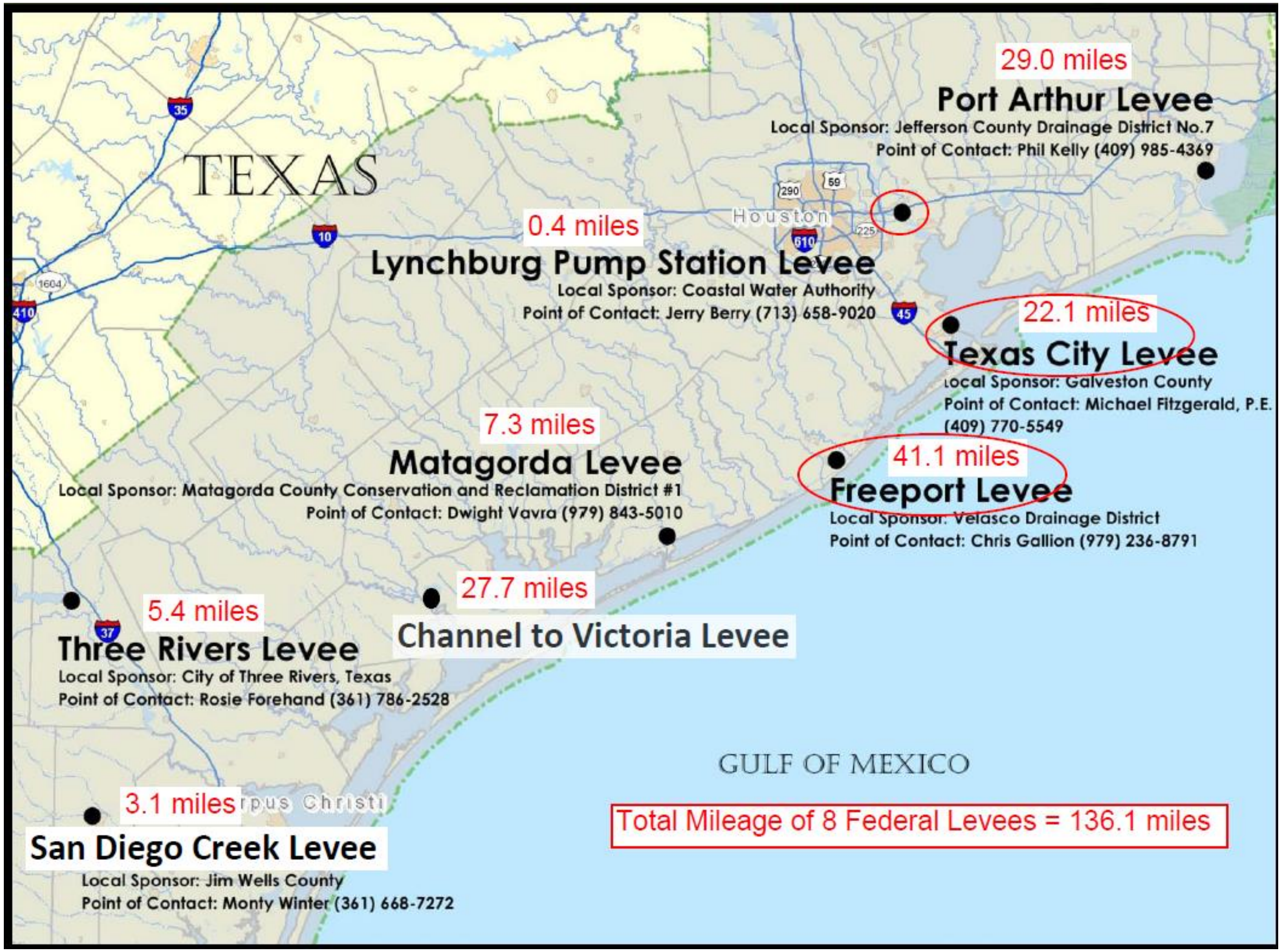
3. SWG'S HISTORY AND CASE STUDIES OF FRAC-OUT

- There have been **11 cases of hydraulic fractrure** of HDD installations in SWG: 7 from Freeport Levee system, 3 from Texas Levee System, 1 from Lynchburg Levee System.



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Freeport and Vicinity Hurricane Flood Protection

Legend

Name

- Extension of Oyster Creek Levee
- Oyster Creek Levee
- East Storm Levee
- Dow Barge Canal North Levee
- Dow Barge Canal South Levee
- Old River North Levee
- Old River South Levee
- South Wave Barrier
- North Wave Barrier
- South Storm Levee
- East Bank Brazos River Levee - 1
- East Bank Brazos River Levee - 2
- Leveed Area

For Official Use Only

Source: Galveston District National Levee Foot Print Database Survey Completed 14-20 May 2010. Created by Paul E. Szempruch for the 2012 Freeport HurricaneFlood Protection Levee Screening.

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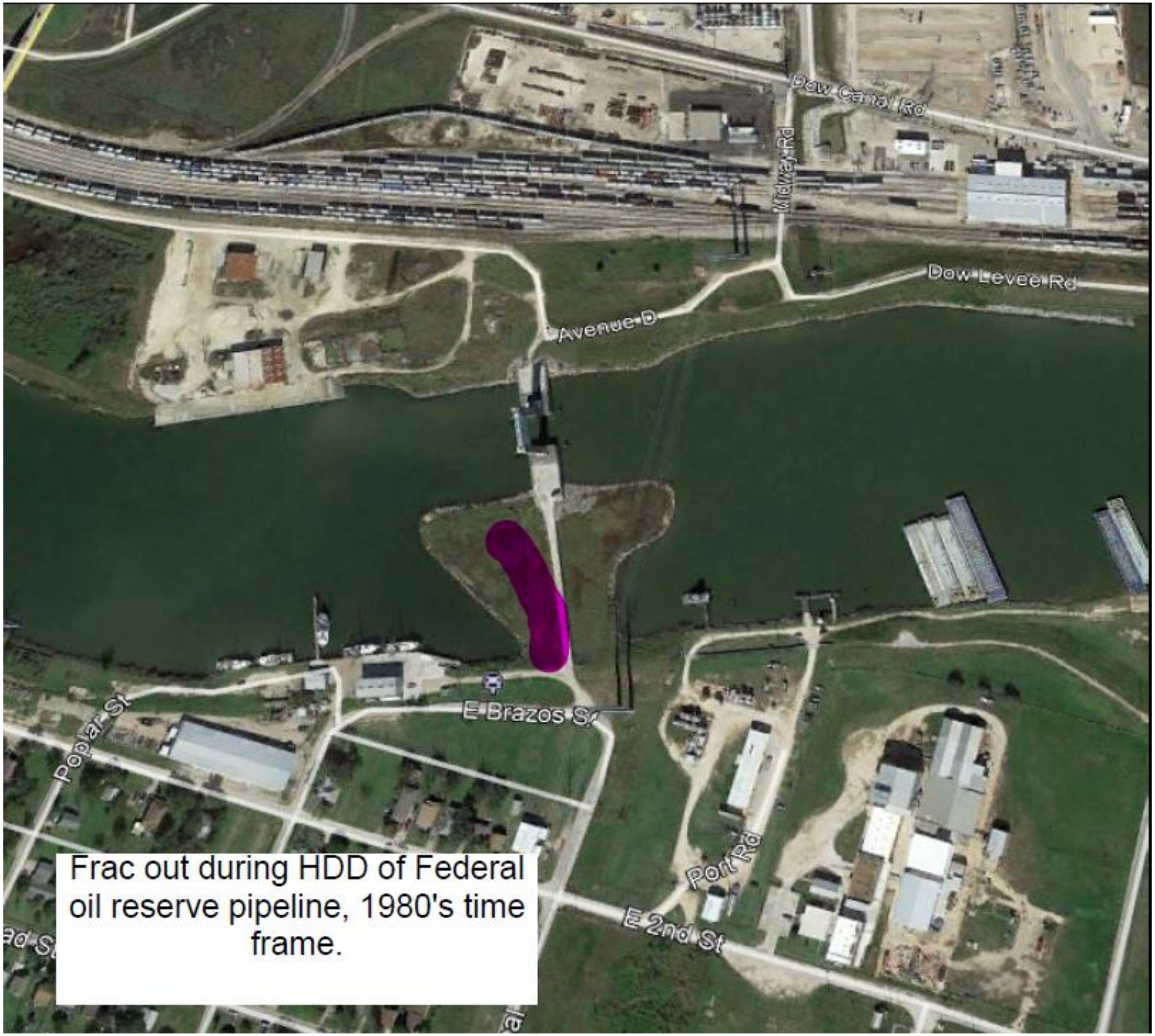
Date: 10/9/2012

Hydrofracture in Freeport Levee system (1)



Frac out during HDD of Federal oil reserve pipeline, 1980's time frame.

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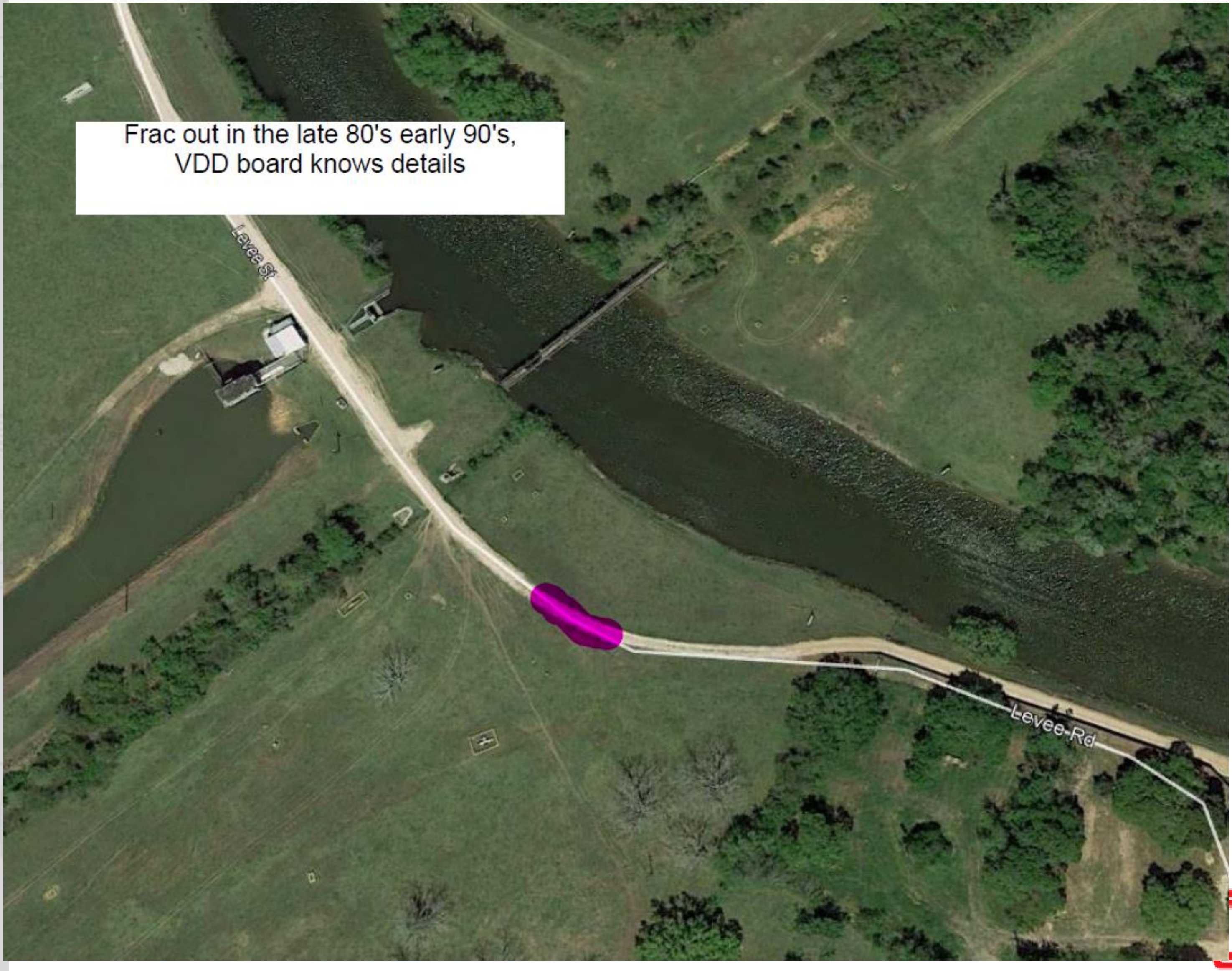
Hydrofracture in Freeport Levee system (2)



VDD means Velasco Drainage District who is the sponsor of Freeport Levee System

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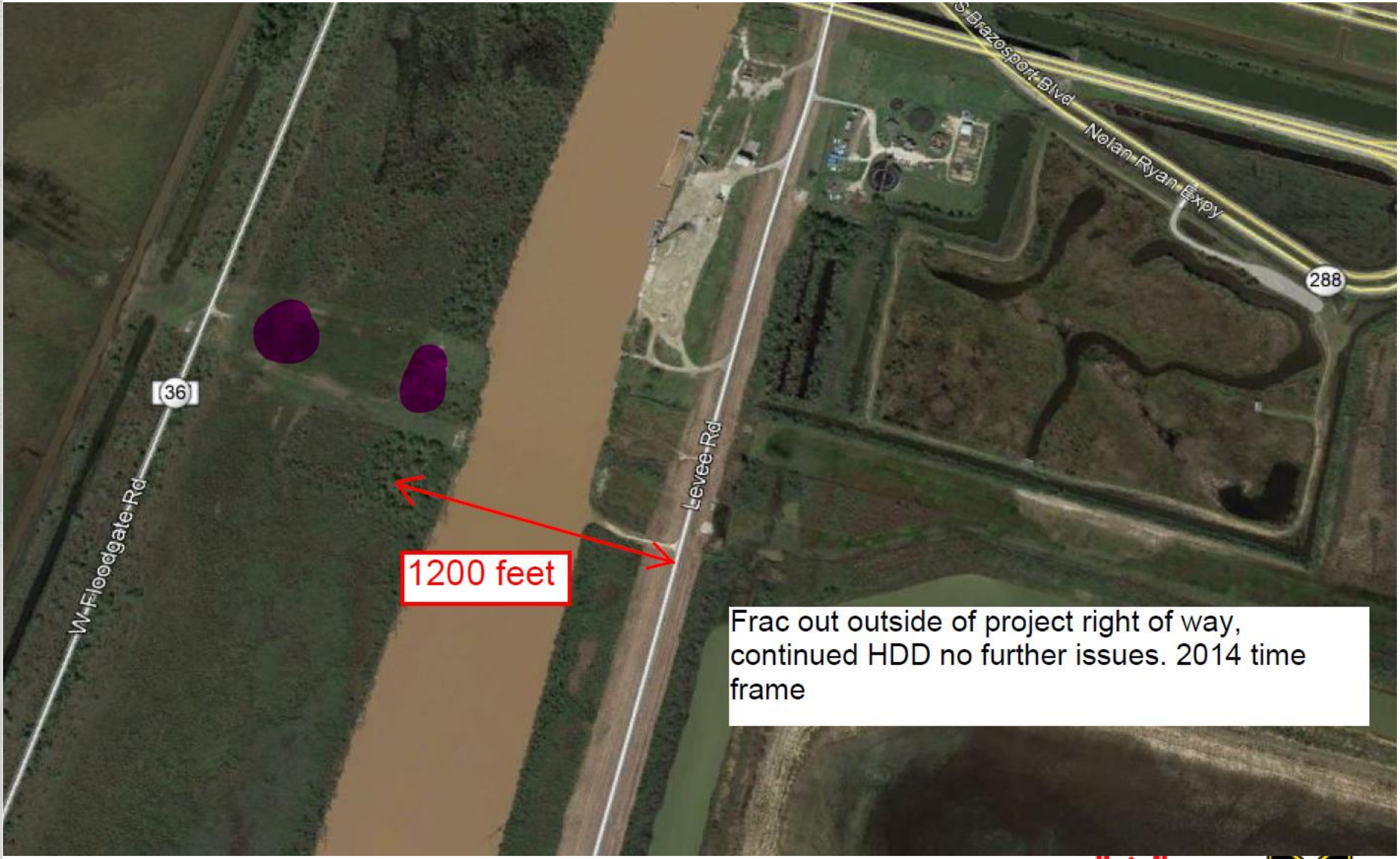
Hydrofracture in Freeport Levee system (3)



Frac out outside of project right of way, continued HDD no further issues. 2014 time frame

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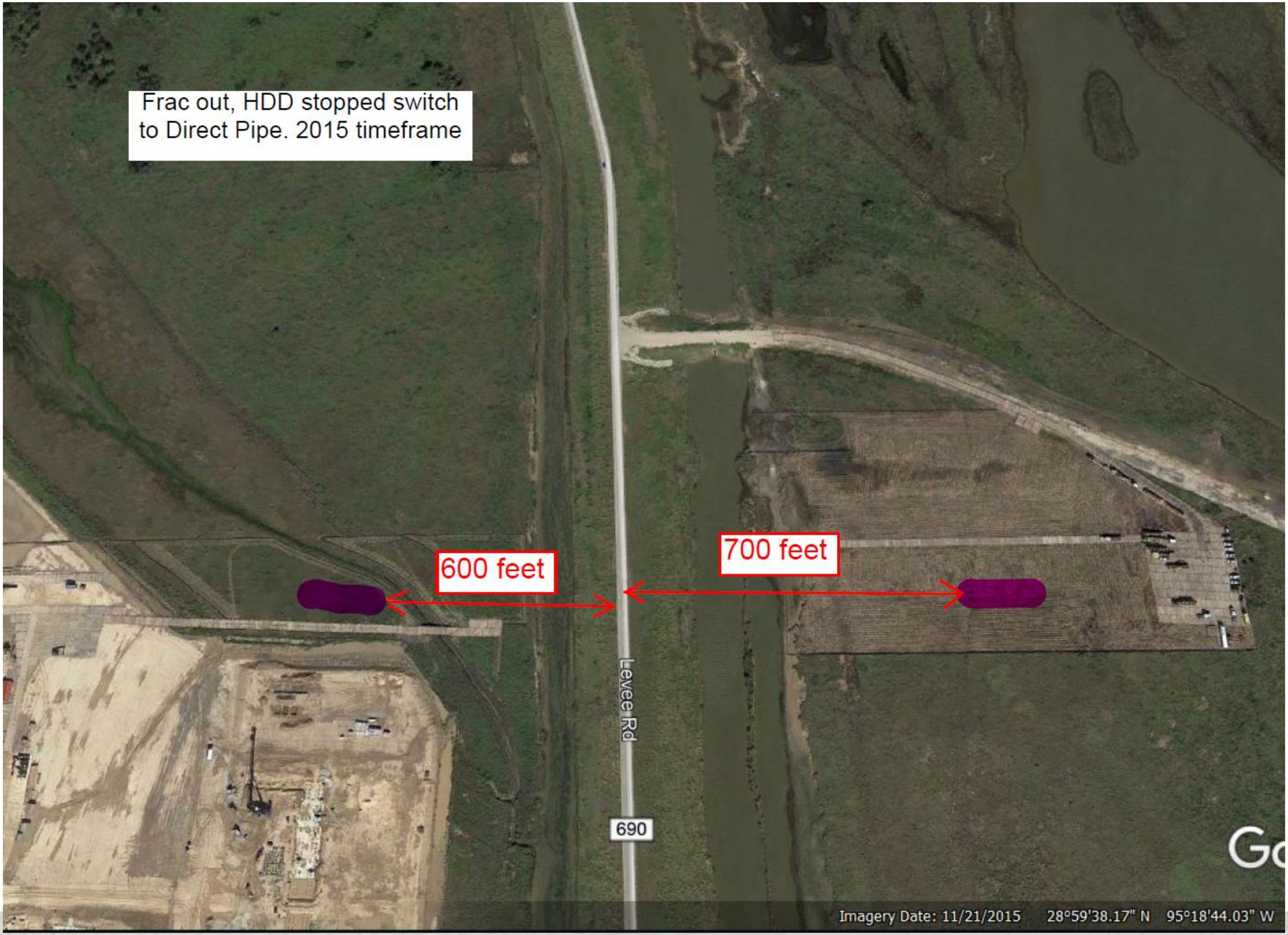
Hydrofracture in Freeport Levee system (4)



Hydrofracture in Freeport Levee system (5)

Frac out outside of levee right of way, within pressure monitoring zone. Drilling stopped pipeline went up and over, no more HDD at this location 2015 timeframe

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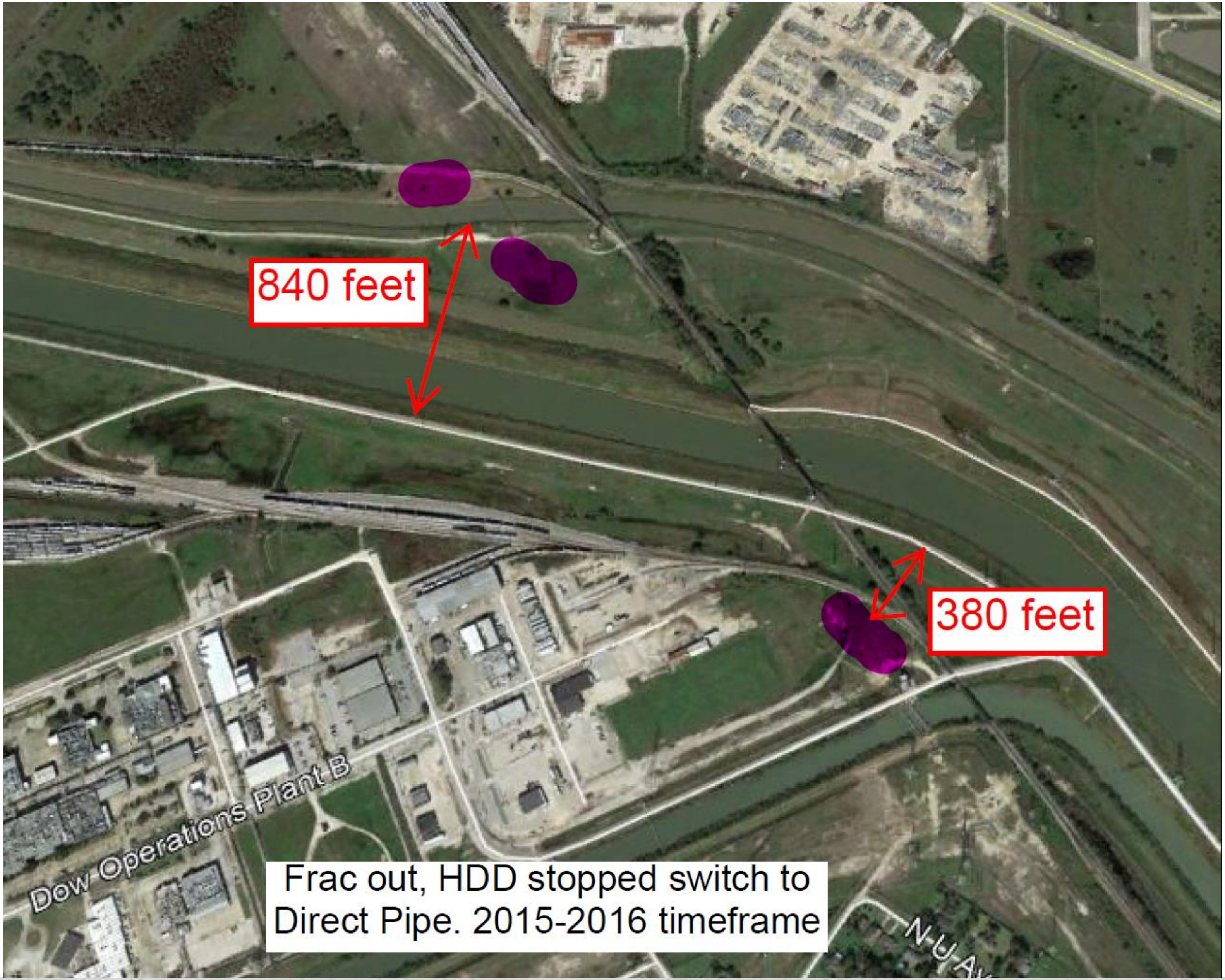
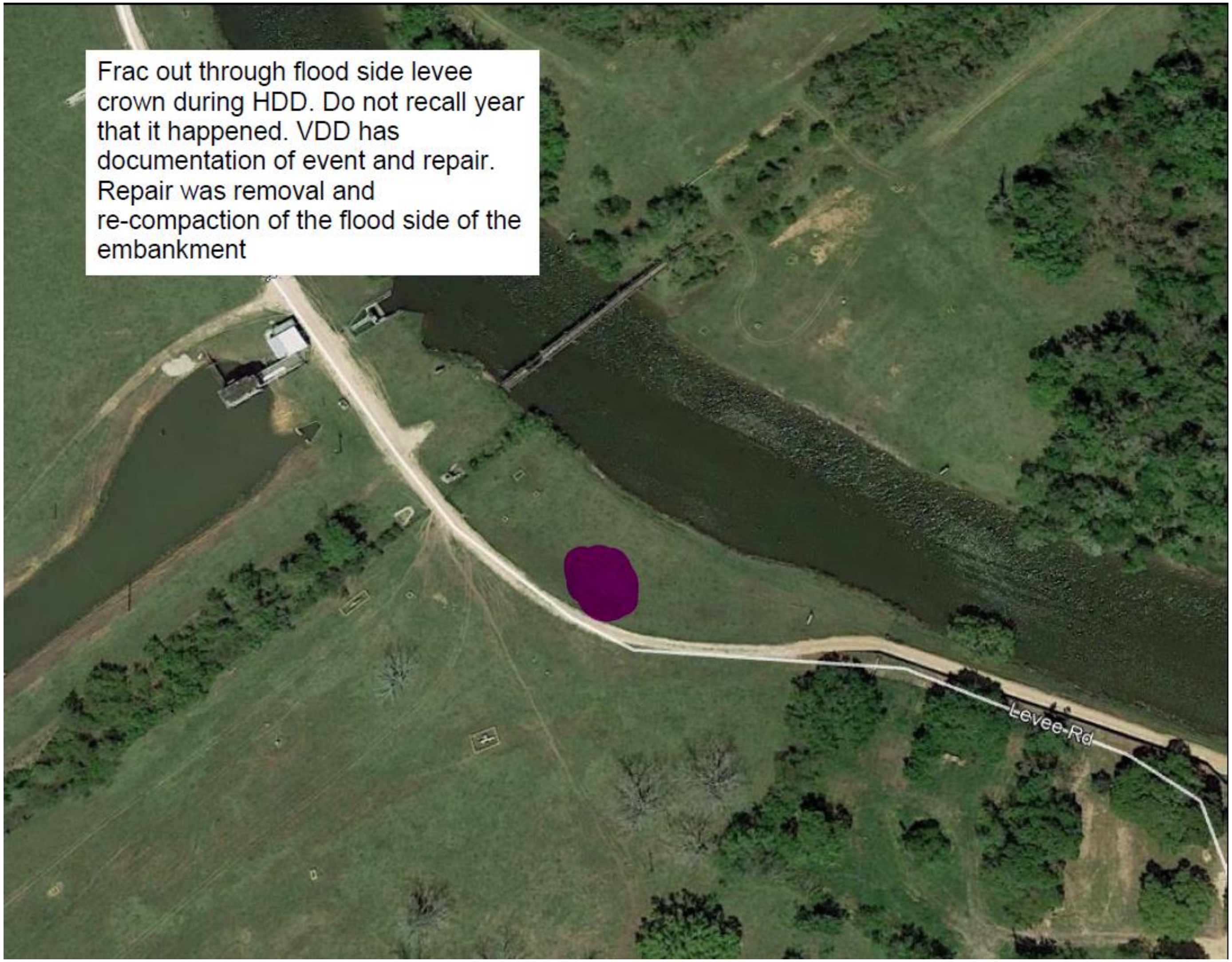
Hydrofracture in Freeport Levee system (6)



Hydrofracture in Freeport Levee system (7)



VDD means Velasco Drainage District who is the sponsor of Freeport Levee System

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Texas City and Vicinity Hurricane Flood Protect

Hydrofracture in Texas City Levee system (8)

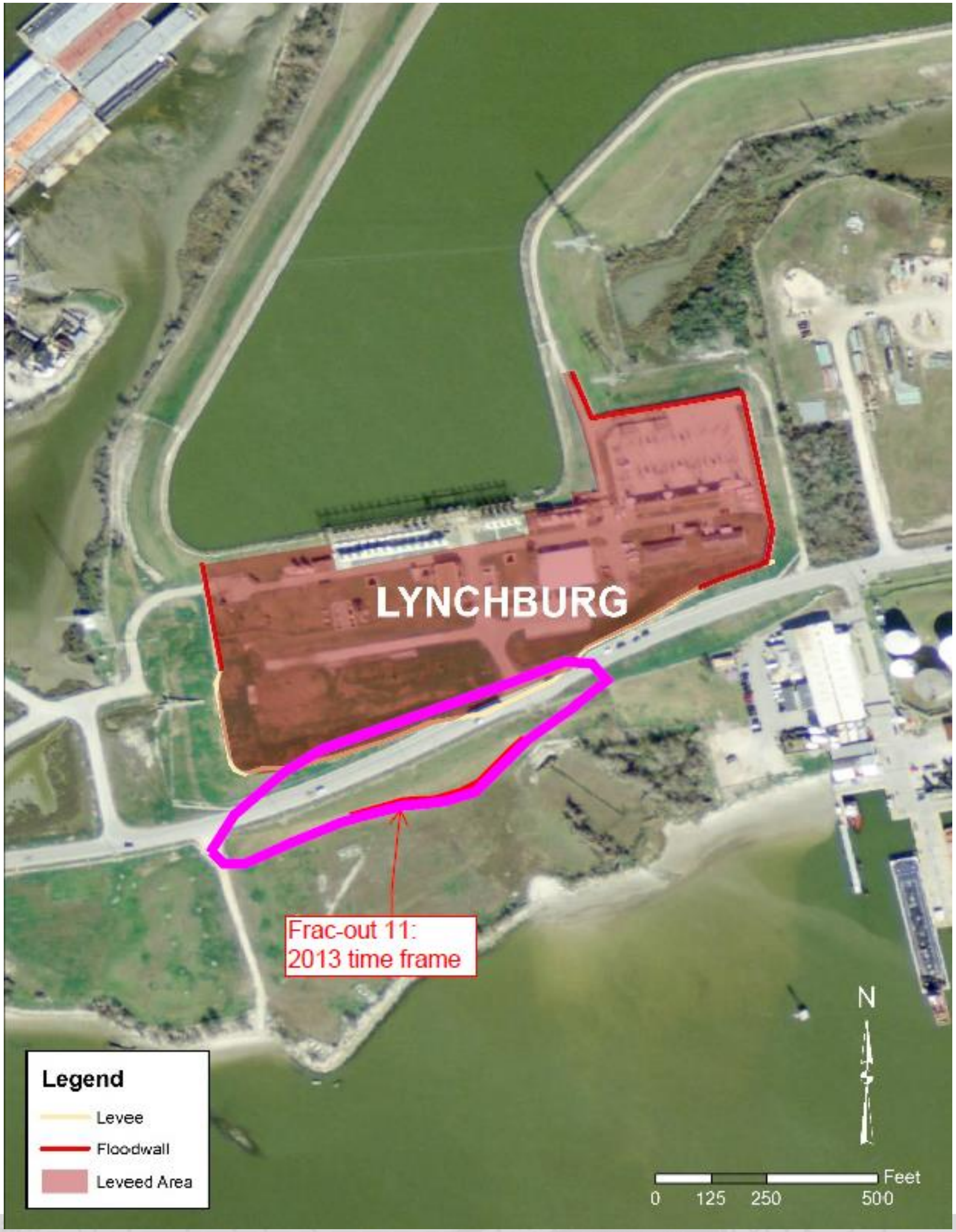
Hydrofracture in Texas City Levee system (9)

Hydrofracture in Texas City Levee system (10)

Most recent frac out

The issue with this frac-out seemed to stem from poor drilling procedures. The drillers had couple of days break during the installation time frame. This is why we need non-stop installation once the contractor began the drilling until complete the operation.

Lynchburg and Vicinity Hurricane Flood Protect



Lynchburg
Pump Station

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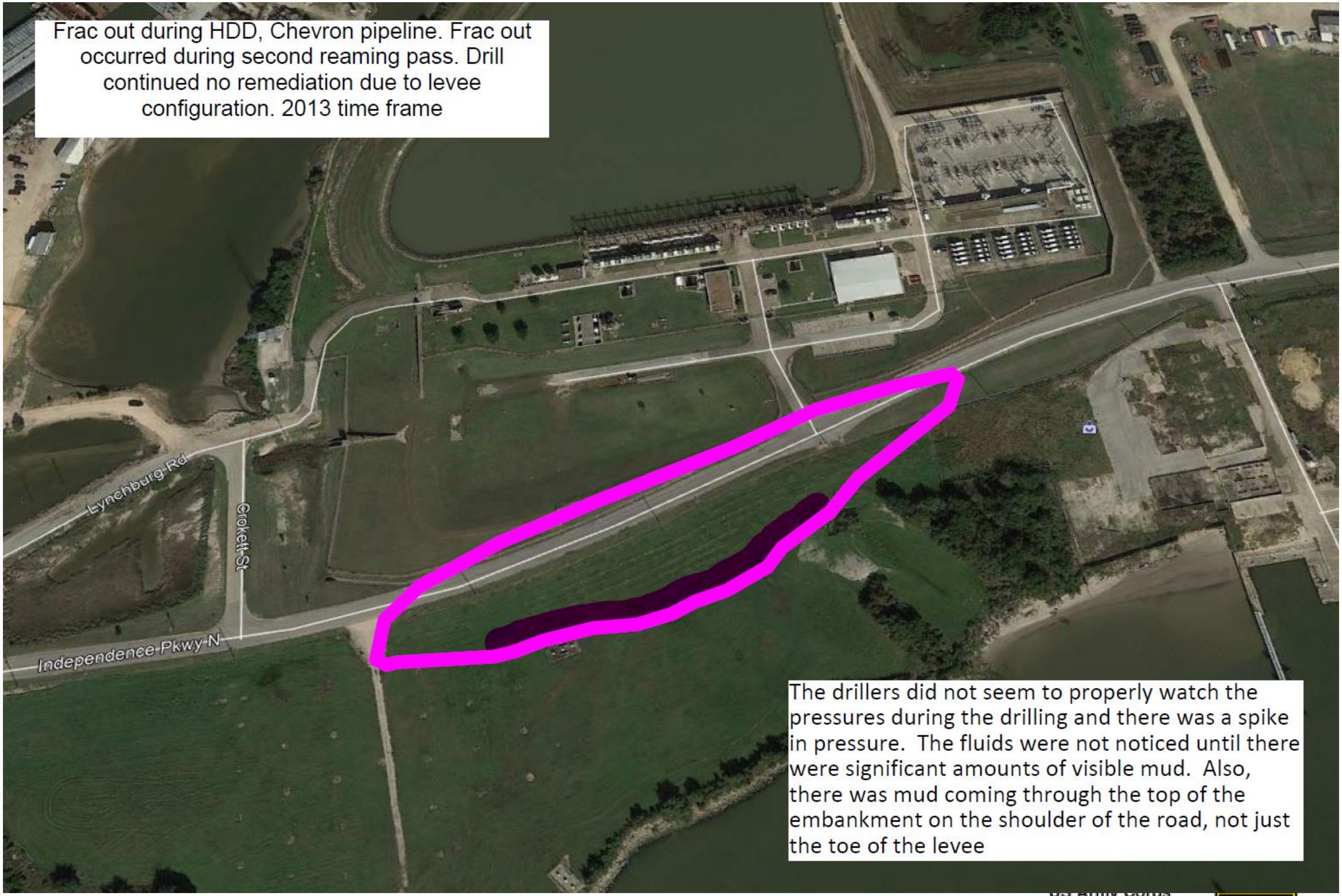
Hydrofracture in Lynchburg Levee system (11)



Five Major Reasons Presumed for the Eleven frac-Outs above

(1) The equation (Delft University's equation) used for maximum allowable pressures may not be accurate in all cases due to different site conditions and assumptions.

(2) **Beaumont clay may not be suitable soil in many cases for HDD installation** (Beaumont clay is a local soil deposit in Texas Gulf Coastal Areas).

(3) **Untrained or inexperienced driller's operation**. These drillers do not understand
how to keep from having pressure spikes during the drilling.
* Control progress (I.E. Limit Speed)
* Monitoring pressure & drill mud return, both quantity & condition

(4) Soil boring holes that were not properly grouted.

(5) Tension crack lines developed from clay's desiccation during dry season.

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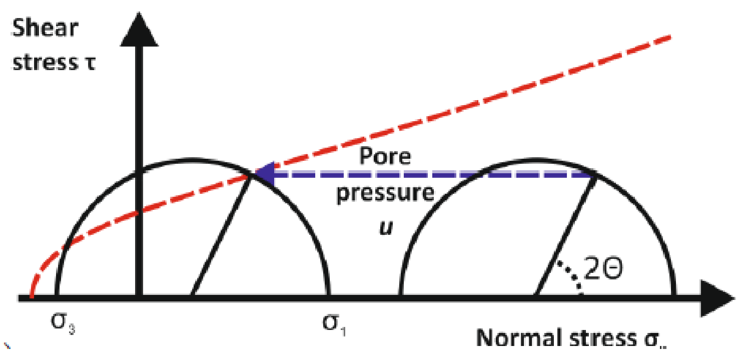
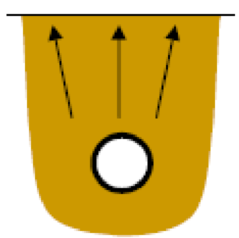
(1) The equation (Delft equation) used for maximum allowable pressures may not be accurate due to different site conditions and assumptions.

There are two dominant soil failure mechanism associated with fluid mud loss regarding frac-out: **Shear Failure** and **Tensile Failure**



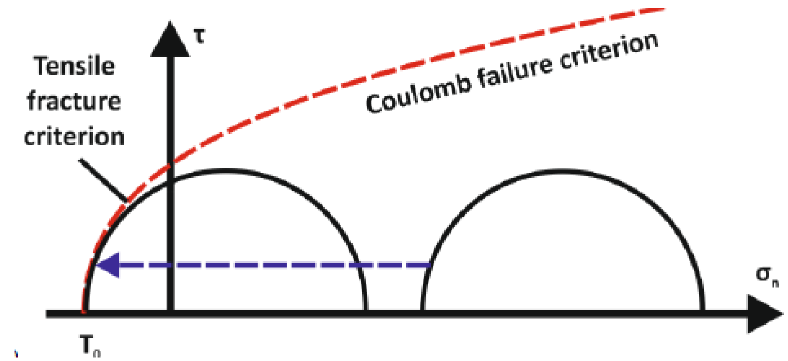
Reference: "Hydraulic fracuring: A Review of theory and field experience", British Geological survey, 2015



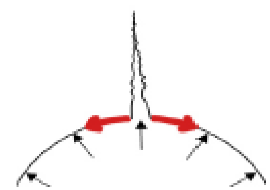
Slow and progressive developing

a. Shear failure - blowout

Reference: Hongwei Xia, "Investigation of maximum mud pressure within sand and clay during HDD", Phd Thesis, Queen's University, Ontario, CA, 2009



Reference: "Hydraulic fracuring: A Review of theory and field experience", British Geological survey, 2015



Quick and sudden developing

b. Tensile failure - hydraulic fracturing

Reference: Hongwei Xia, "Investigation of maximum mud pressure within sand and clay during HDD", Phd Thesis, Queen's University, Ontario, CA, 2009

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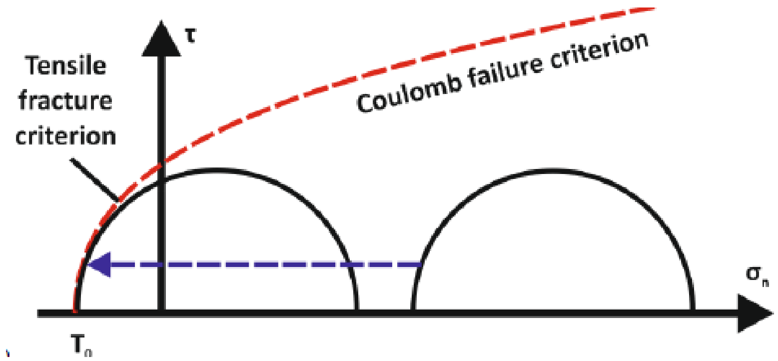
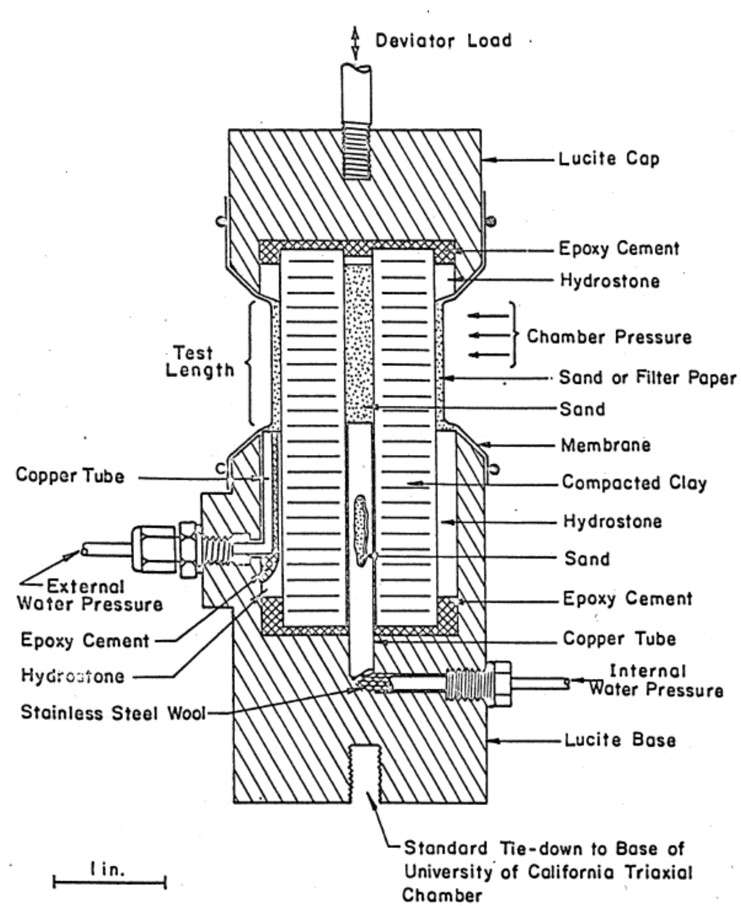
What is **Tensile Failure?**



Reference: "Hydraulic fracuring: A Review of theory and field experience", British Geological survey, 2015

A Soil Triaxial Testing System

Triaxial Test for Hydrofracuring Experiment



Reference: Duncan et al, "Hydraulic fracuring in zoned earth & Rockfill", ERDC in USACE,1973

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The equation (Delft University equation) used for maximum allowable pressures may not be accurate due to different site conditions and assumptions.

Delft equation was developed based on **shear failure** and was accepted by **USACE** since 2003 as "the state-of-art" practice to estimate the maximum mud pressure in clay and sand soils for HDD operation. Also, **the assumptions of this Delft University's equation** can be summarized as follows:

- The borehole is axially symmetric, and the **soil medium homogeneous**, isotropic, and of infinite size
- The soil medium is approximated to have an **isotropic initial stress condition (i.e. $K_0 = 1$)**.
- Its response is modeled as elastic until the onset of **shear failure**, defined using the Mohr-Coulomb failure criterion as a function of cohesion and friction angle.
- Increments of elastic deformation follow Hook's law
- Elastic deformations in the plastic zone are neglected
- Volume change in the plastic zone is assumed to be zero

$$P_{\lim} = \left(P_f + c\cot\phi\right)\left\{\left(\frac{R_0}{R_{p,\max}}\right)^2 + Q\right\}^{\frac{-\sin\phi}{1+\sin\phi}} - c\cot\phi$$

where:

$P_{\lim}$ Maximum allowable mud pressure

P_f Mud pressure at onset of plastic failure

$$P_f = \sigma_0'(1+\sin\phi) + c(\cos\phi)$$

σ_0' Initial effective stress

ϕ Internal friction angle

c Cohesion of hosting soil

Q A function of the shear modulus and effective stress

$$Q = \frac{\sigma_0'(\sin\phi) + c(\cos\phi)}{G}$$

G Shear modulus

R_0 Initial radius of the borehole

$R_{p,\max}$ Maximum allowable radius of the plastic zone

What if the soil is non-homogenous, non-isotropic (anisotropic), and non-shear failure?

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Our Approach to Solve Frac-Out Problem During HDD installation

- Requiring very high factor of safety

- IN THE PAST, we could allow a lower factor of safety for a clay layer, if a relatively **thick layer of sand** is overlying the clay layer.

- If the sand layer is relatively shallow, the sand layer may act as a conduit for transmitting the fluid pressure further away which can extend the frac-out areas.

- **BUT** Soil is not always homogenous

- Providing Construction Oversight

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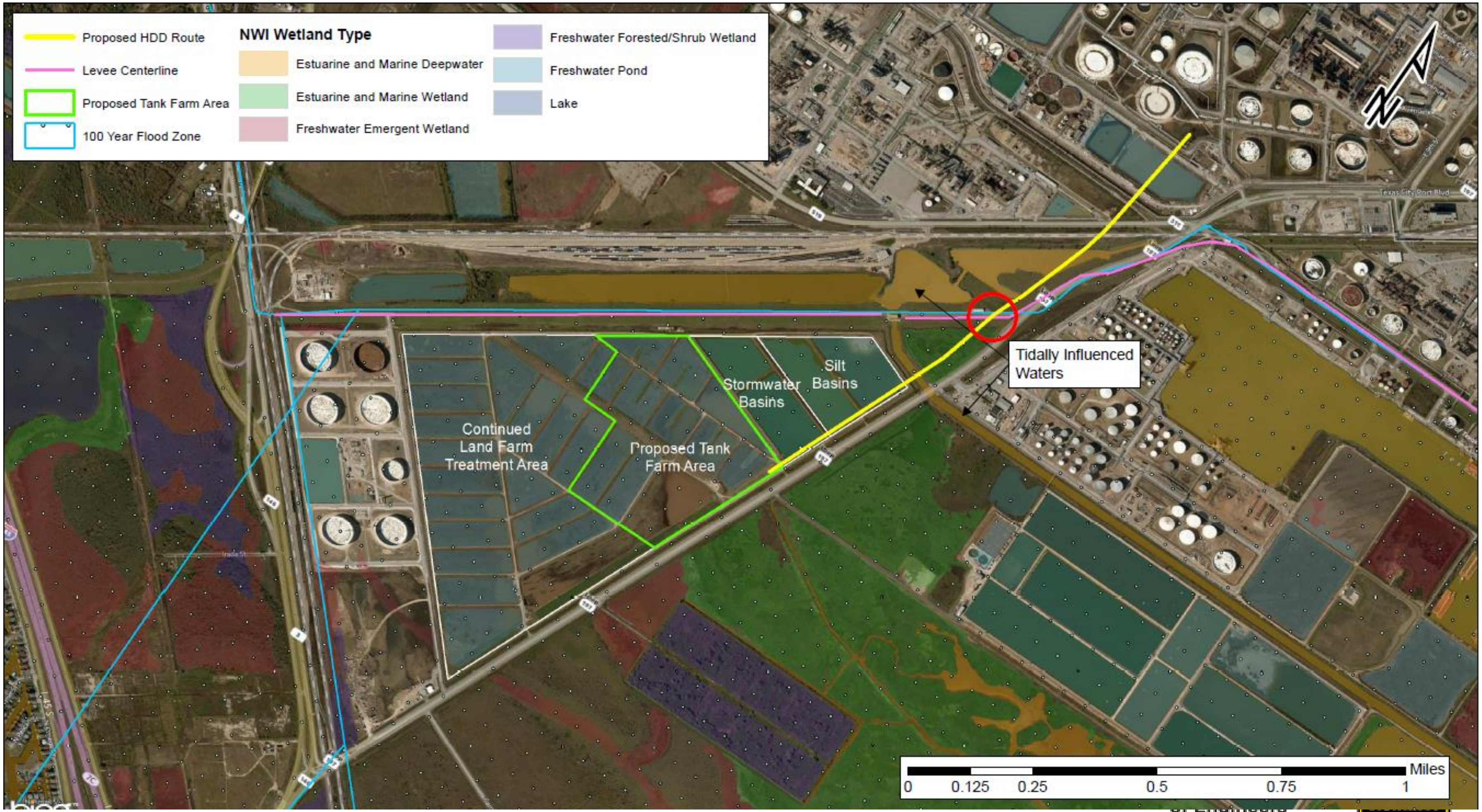
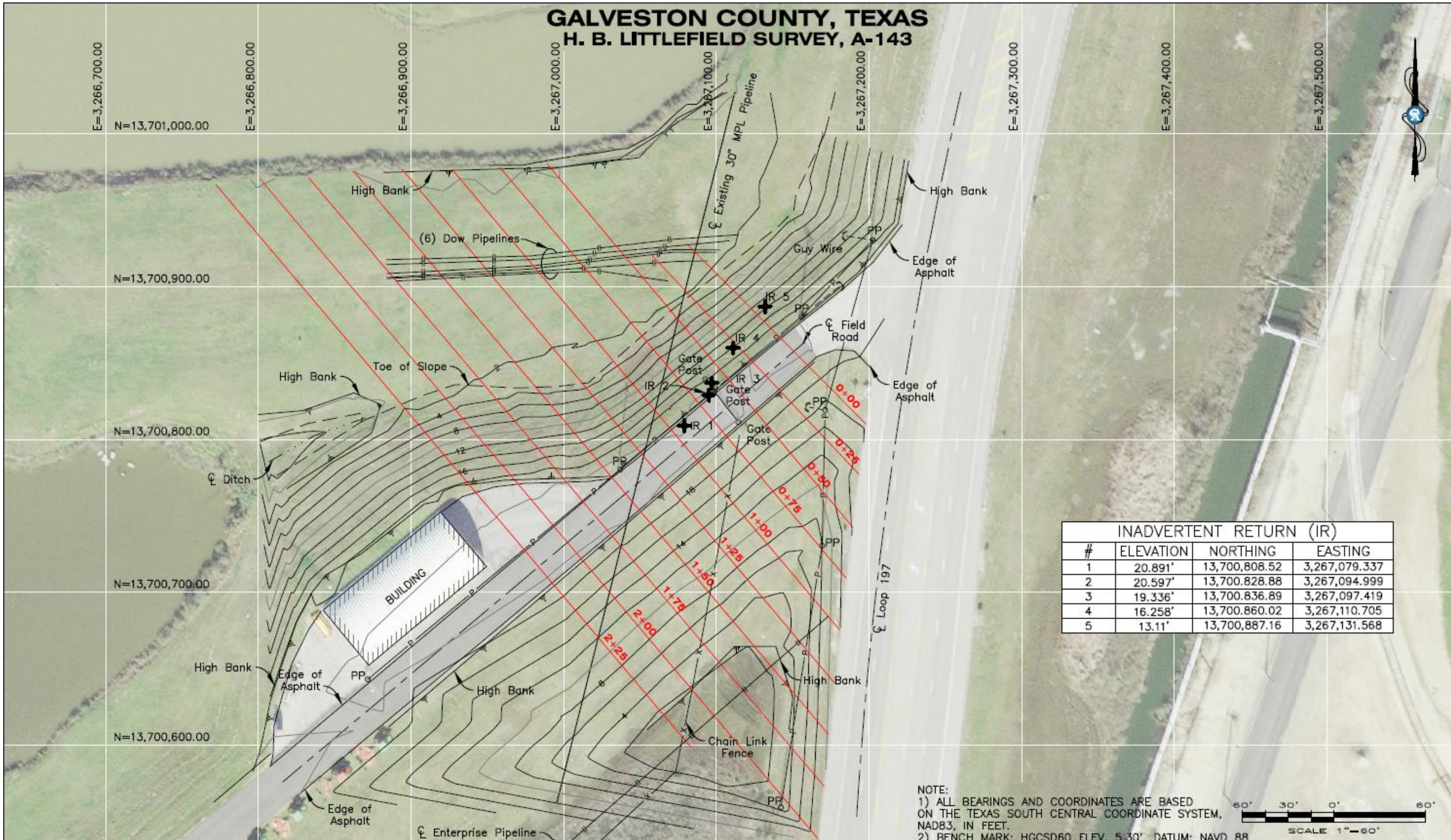
TEXAS CITY HDD FRAC-OUT CASE STUDY

Most Recent Hydrofracture (or Frac Out) in Texas City Levee system (10)



Locations of Hydrofractures



INADVERTENT RETURN (IR)

#	ELEVATION	NORTHING	EASTING
1	20.891'	13,700,808.52	3,267,079.337
2	20.597'	13,700,828.88	3,267,094.999
3	19.336'	13,700,836.89	3,267,097.419
4	16.258'	13,700,860.02	3,267,110.705
5	13.11'	13,700,887.16	3,267,131.568

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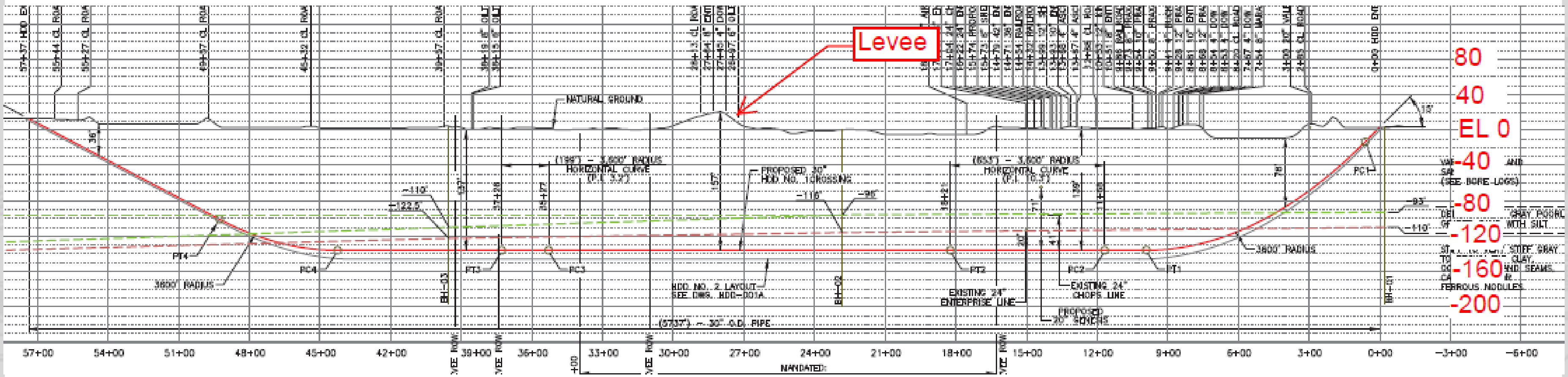
Photo for Locations of Hydrofractures

Photo for Locations of Hydrofractures

Section Profile of
Most Recent Hydrofracture (or Frac Out) in Texas City Levee system (10)



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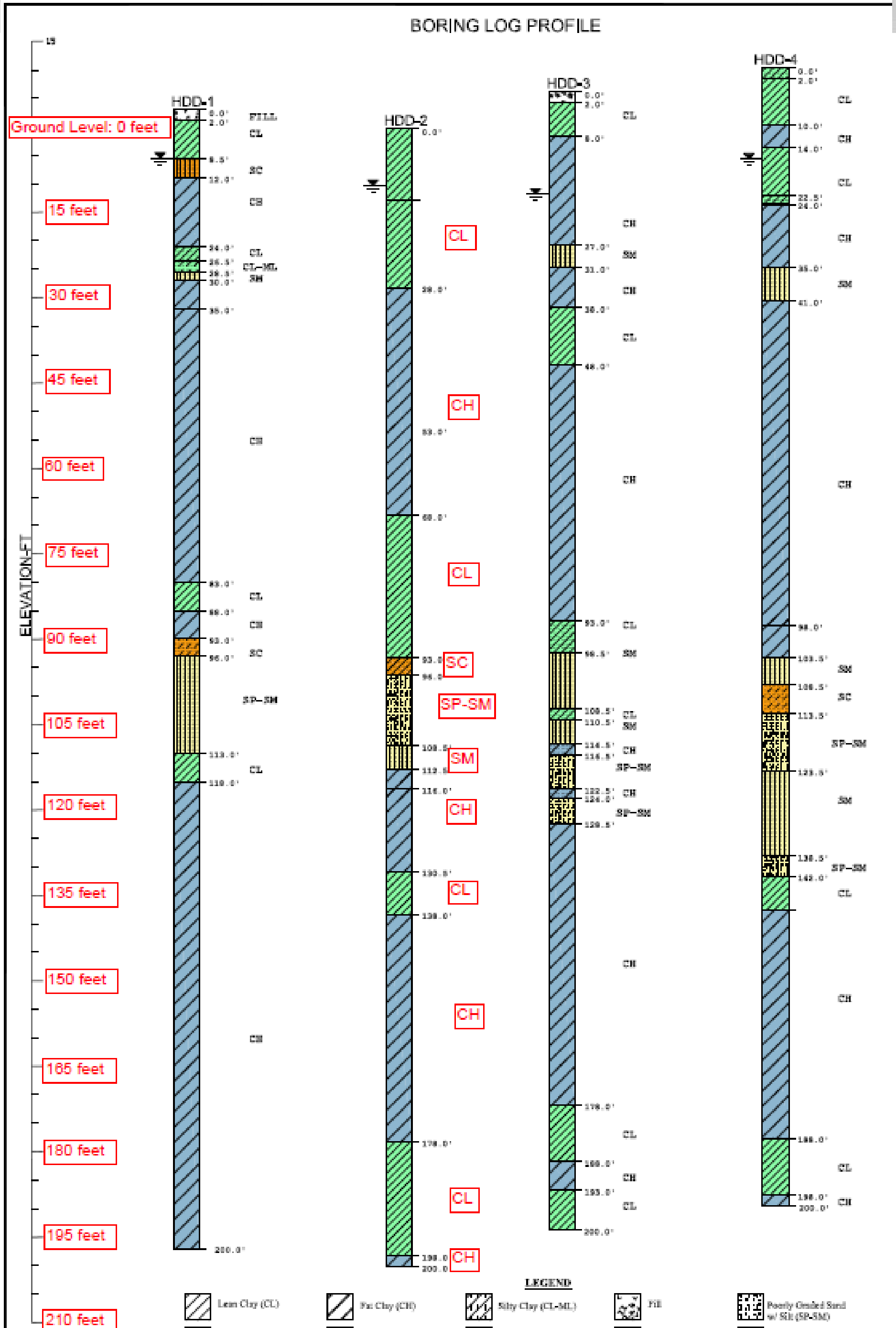

Soil Boring Logs Profile For Most Recent Hydrofracture (or Frac Out) in Texas City Levee system (10)

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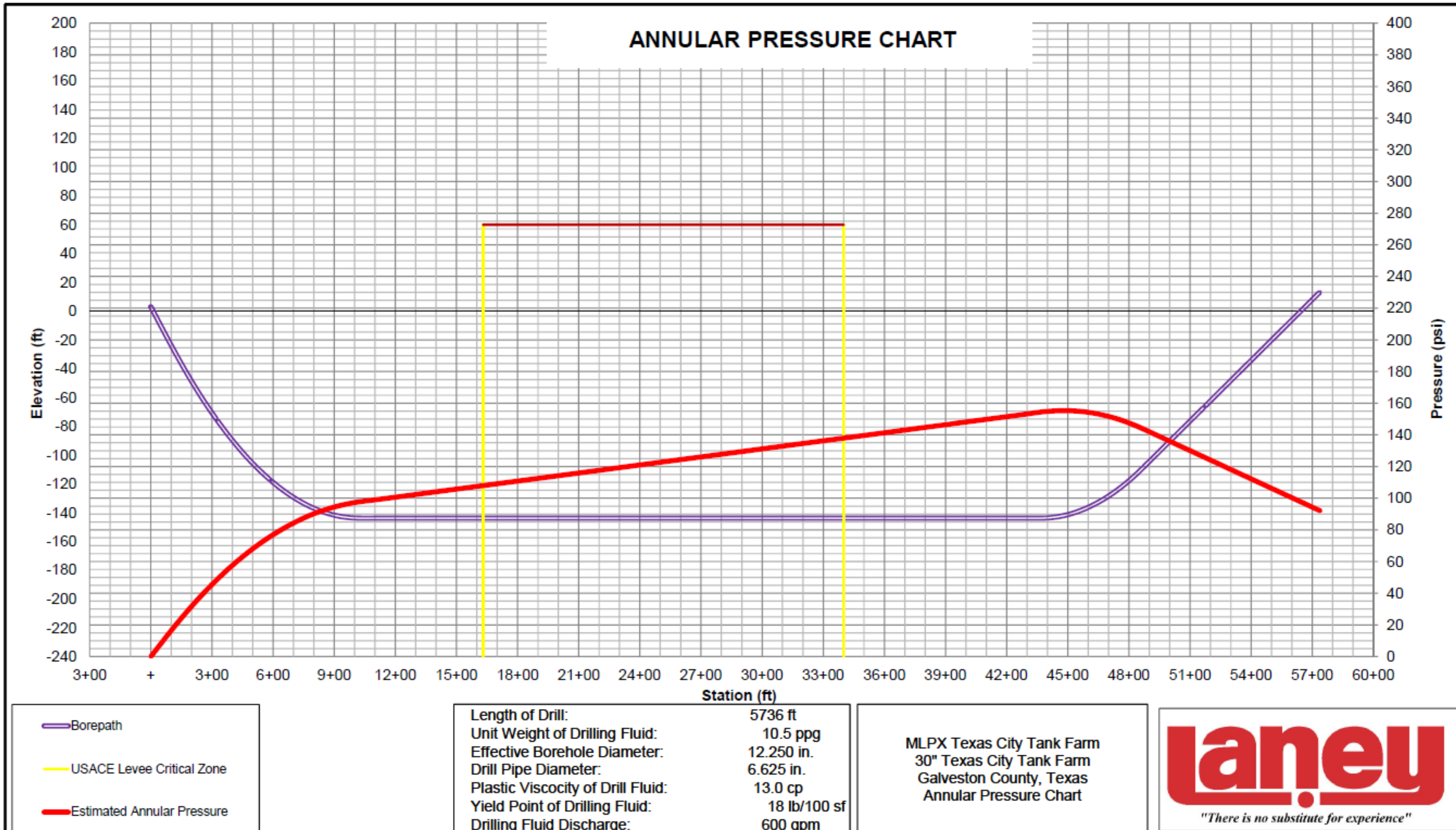
Annular Pressure Chart
Most Recent Hydrofracture (or Frac Out) in Texas City Levee system



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Repair (or Mitigation) Method for
Most Recent Hydrofracture (or Frac Out) in Texas City Levee system (10)

- The repair (or mitigation) options were established based on mainly **<u>seepage potential and slope stability</u>** as follows:

(1) Sheet pile to EL-26' on the flood side of the levee

(2) Overbuild with 25' clay on the protected side of the levee

(3) Construct a clay toe buttress from EL +8' to the natural grade extending horizontally 44' from the overbuild

- The analyses of seepage and slope stability were performed for the above repair (or mitigation).

- Both long-term and short tem cases were conducted for the above analyses.

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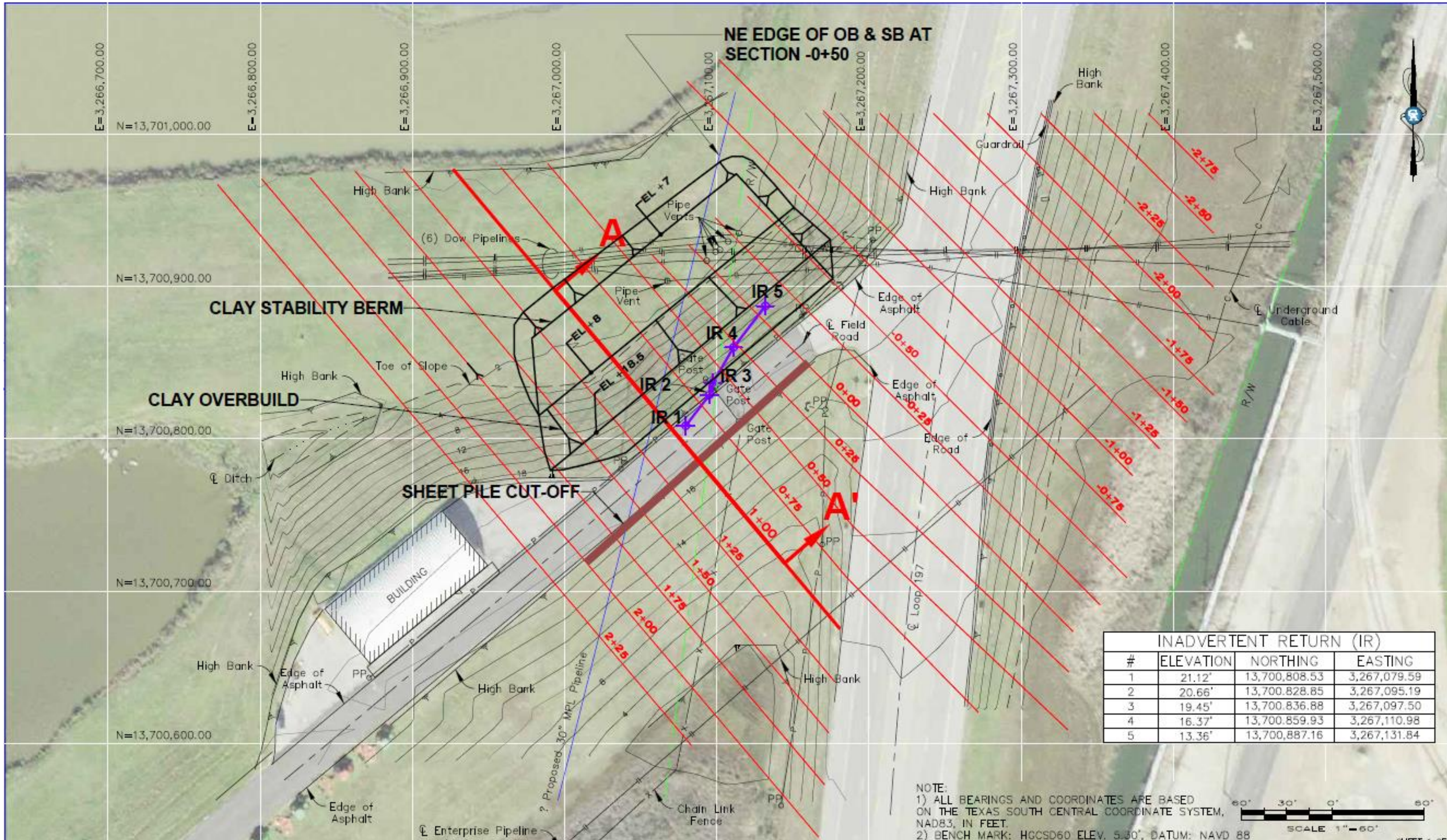
Plan View for Repair (or Mitigation) Method
Most Recent Hydrofracture (or Frac Out) in Texas City Levee system (10)



INADVERTENT RETURN (IR)			
#	ELEVATION	NORTHING	EASTING
1	21.12'	13,700,808.53	3,267,079.59
2	20.66'	13,700,828.85	3,267,095.19
3	19.45'	13,700,836.88	3,267,097.50
4	16.37'	13,700,859.93	3,267,110.98
5	13.36'	13,700,887.16	3,267,131.84

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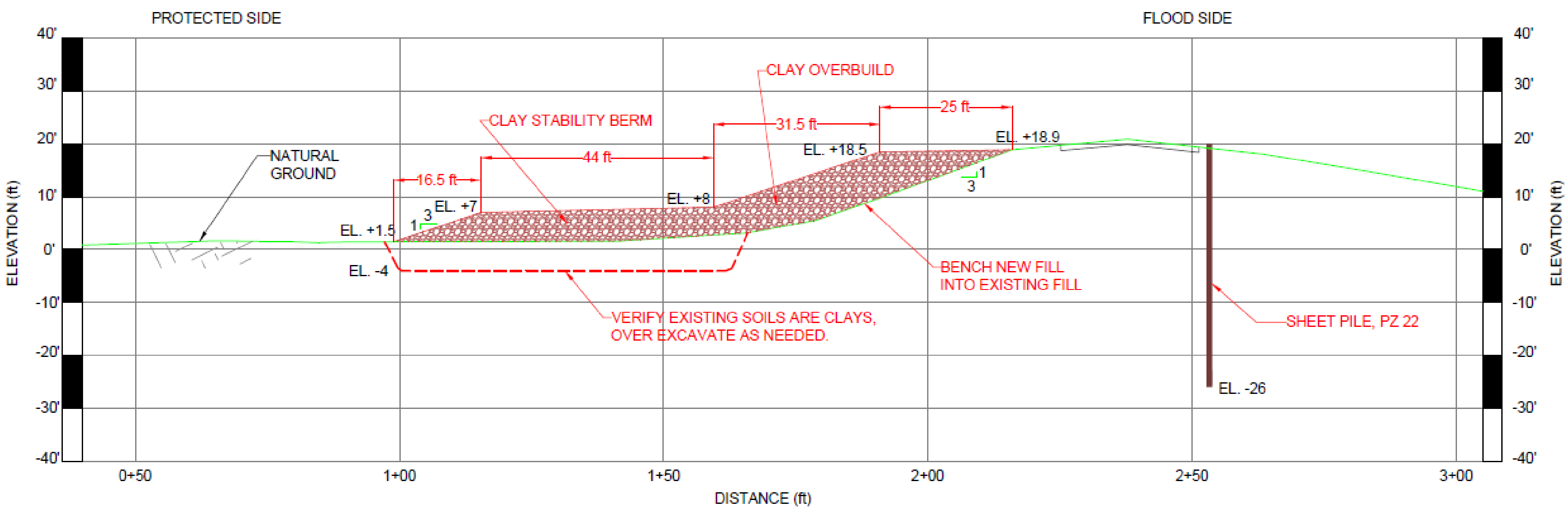
Section View for Repair (or Mitigation) Method
Most Recent Hydrofracture (or Frac Out) in Texas City Levee system (10)



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DISCUSSION

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