Coastal Restoration Project Geotechnical Analysis, Design, and Construction

2022 COASTAL INDUSTRY WEEK
WEBINAR SERIES – SESSION 3

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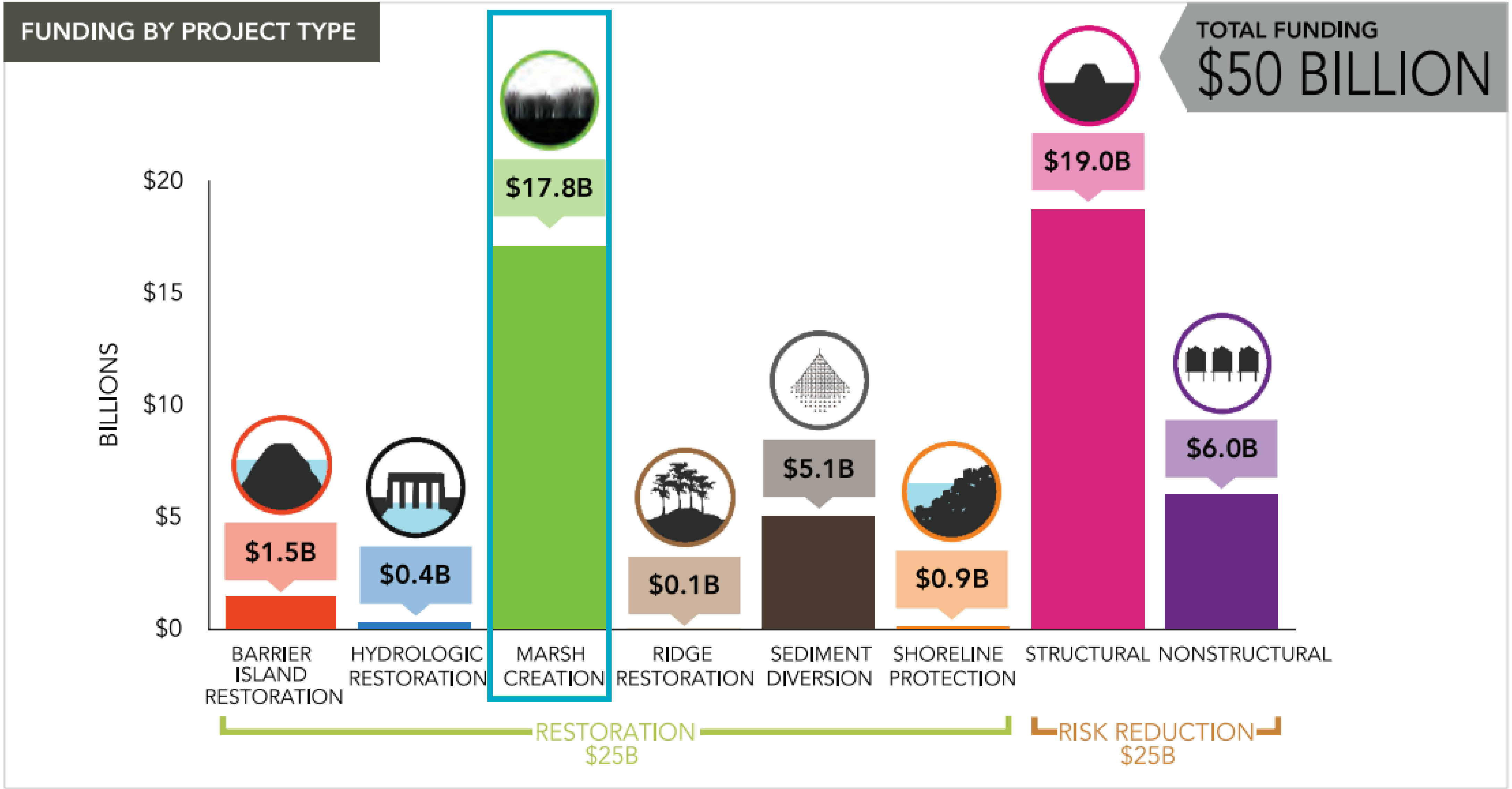
CPRA's Coastal Master Plan



Overview

- Marsh Creation Design Guidelines
- Review of Existing Data
- Subsurface Investigations
  - Boring/CPT Layout
  - Sampling Frequencies and Depths
- Laboratory Testing
  - Testing Types and Frequencies
- Data Synthesis
  - Subsurface and Parameter Profiles
- Marsh Creation Settlement Analysis
- Earthen Containment Dike Design
  - Slope Stability
  - Settlement Analysis
- Construction Monitoring and Instrumentation

Marsh Creation Design Guidelines

- Created in November 2017 to serve as the minimum design standard consistent for the design and construction of marsh creation projects within the Louisiana Coastal Zone.
  - NOT intended to replace professional engineering judgement of the design engineer.

- The ***Marsh Creation Design Guidelines (MCDG)*** provide an overview of subsurface investigations (Section 3.5.3), geotechnical engineering of marsh creation projects (3.5.4), and overall marsh creation design (3.6).

- Appendix B of the ***MCDG*** contains the ***Geotechnical Standards for Marsh Creation and Coastal Restoration Projects***, intended to be used as minimal standards for marsh creation projects, and includes guidance for:
  - Subsurface Investigations
  - Laboratory Testing Requirements
  - Earthen Containment Dike Geometry and Slope Stability Design
  - Estimated Consolidation Settlement Design Requirements

- The ***MCDG*** an appendices contain information on the topics discussed in this presentation.

https://coastal.la.gov/engineering-and-design-standards/

Review of Existing Data

SOURCES AND IMPACTS TO SUBSURFACE INVESTIGATIONS

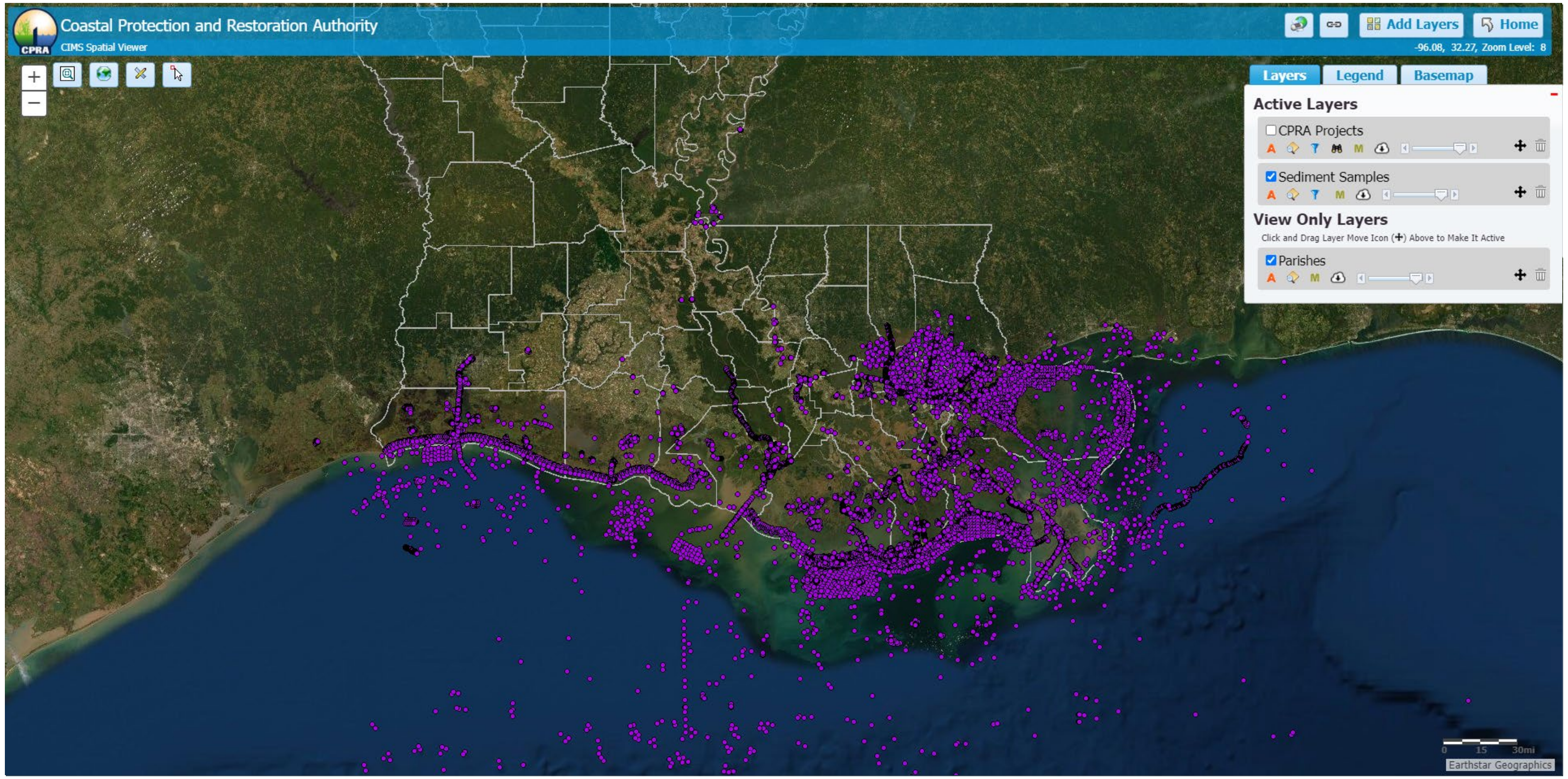
- A review of existing data can influence the scope of work and scheduling requirements of a subsurface investigation, as well as laboratory testing needs. More specifically, existing data sources can influence items such as:
  - Assessing equipment needs and/or access requirements;
  - Depth, frequency, and layout of borings and cone penetrometer tests (CPTs), and;
  - Determination of sampling locations for a potential borrow source or other project features.

- Existing data sources may include, but are not limited to:
  - Geologic and geomorphic maps;
  - Aerial imagery;
  - Existing borings logs and CPTs;
  - Published papers and reports, and;
  - Information from local, state, and federal agencies.

Review of Existing Data

COASTAL INFORMATION MANAGEMENT SYSTEM (CIMS)

- **Link:** https://cims.coastal.la.gov/MapHome.aspx
- **Main Spatial Viewer** – full featured GIS for CPRA projects, monitoring data, restoration and project features, geotechnical data, and geophysical information.



Subsurface Investigations & Laboratory Testing

Subsurface Investigations

SAMPLING TYPE, DEPTH, AND FREQUENCY/SPACING

SAMPLING TYPE (BORINGS VS. CPTS)

- Cone Penetrometer Tests (CPTs):
  - Allows for continuous soil profiling at an increased production rate.
  - Does not provide physical soil samples.
  - Penetration depth limited in very dense sands/gravels or stiff clays.
  - Poor resolution in highly sensitive materials (i.e. organic clays or peats).
- Soil Borings:
  - Profiling is often not continuous beyond 20 feet.
  - Provides physical soil samples for laboratory testing.
  - Allows for classification of highly-sensitive materials and very dense sands/gravels or stiff clays.

SAMPLING DEPTH

- Dependent on specific project feature and required analysis (slope stability, settlement analysis, etc.)

FREQUENCY/SPACING

- Also feature-dependent, but can also be dependent on variability in subsurface materials.

Subsurface Investigations

SPACING AND DEPTH BY PROJECT FEATURE

Table B- 1: Suggested Soil Boring Spacing, CPT Spacing, and Depth for Restoration Projects (revised 2.2019).

Restoration Project Feature	Soil Boring & CPT Location	Type	Soil Boring & CPT Spacing (ft.)	Soil Boring & CPT Depth (ft.)
Marsh Creation (MC) Area	Proposed MCA	3" Undisturbed Boring	2 Soil Borings per MCA	30' max.
Earthen Containment Dike (ECD)	Centerline	CPT/ 3" Undisturbed Boring	2,500' CPT's; 5,000' Soil Borings	30', 2@50' max.
MC "Inland" Borrow Area	Proposed Borrow Area	*Vibracore / 3" General Type Boring	1 per 25 acres of borrow area	‡ 25'
MC "Offshore" Borrow Area	Proposed Borrow Area	*Vibracore / 3" General Type Boring	1 per 25 acres of borrow area	‡ 25'
"Mississippi River" Borrow Area	Identified Borrow Area	3" General Type Boring/ *Vibracore / CPT	10 per borrow area	‡ 60'
Barrier Island Beach Dune	Centerline	CPT / 3" Undisturbed Boring	2,500' CPT's; 5,000' Soil Borings	40', 2@60' max.
Oyster Barrier Reef	Centerline	CPT / 3" Undisturbed Boring	2,000' CPT's; 4,000' Soil Borings	30', 2@50' max.
Shoreline Protection	Centerline	CPT / 3" Undisturbed Boring	2,000' CPT's; 4,000' Soil Borings	40', 2@60' max.
Ridge Restoration	Centerline	CPT / 3" Undisturbed Boring	2,500' CPT's; 5,000' Soil Borings	40', 2@60' max.
Earthen Terraces	Centerline	CPT / 3" Undisturbed Boring	1 per 75 acres	30' max.

Note: *Vibracores may be taken in conjunction with soil borings if disturbed soil samples are required to determine material properties required for hydraulic dredging.

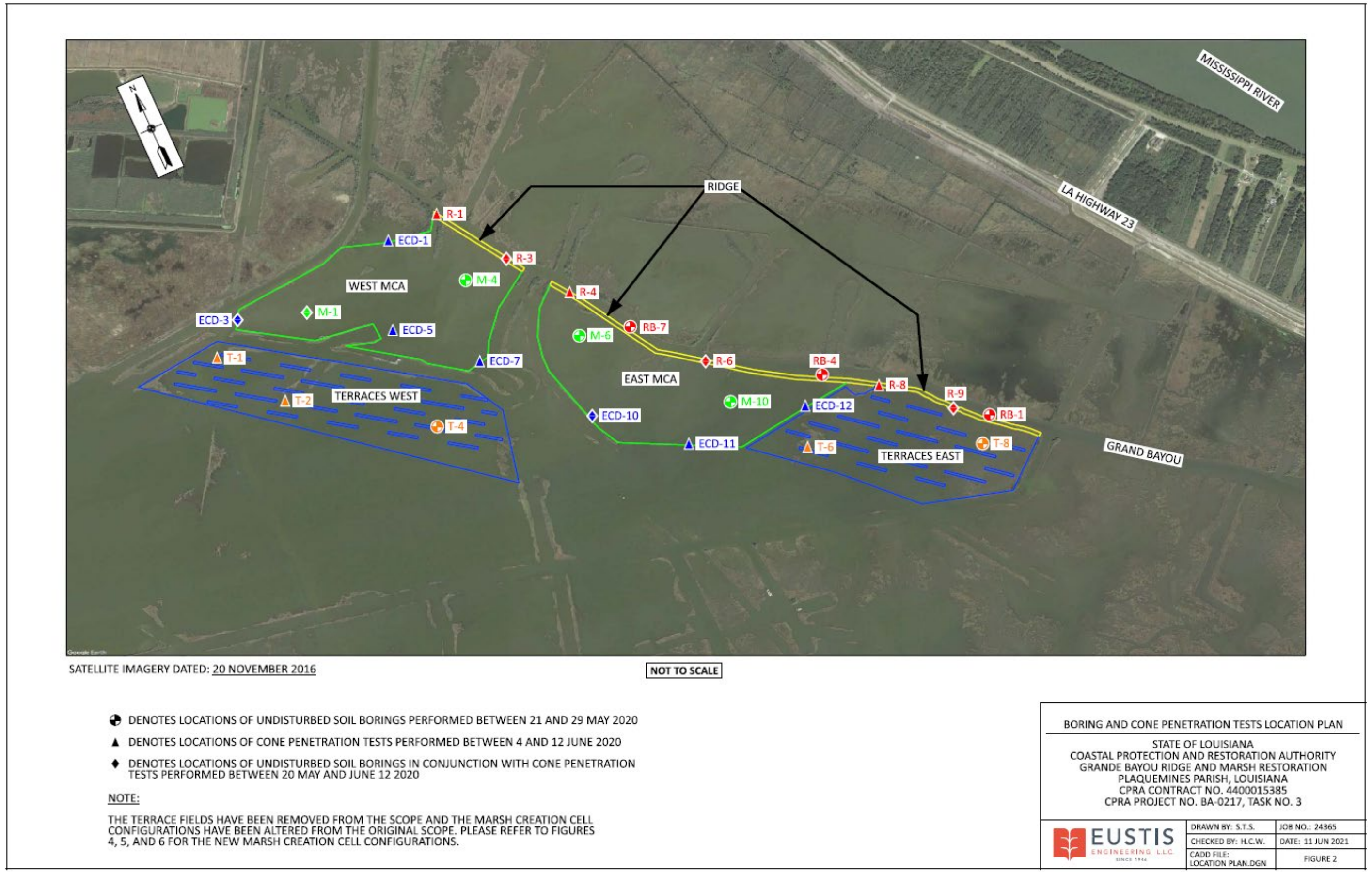
**See current version of the CPRA General Guidelines, Exploration for Sediment Resources for Coastal Restoration.

‡ The soil boring depth should be advanced to the maximum extent of the proposed dredging/excavation Work.

Subsurface Investigations

EXAMPLE SUBSURFACE INVESTIGATION

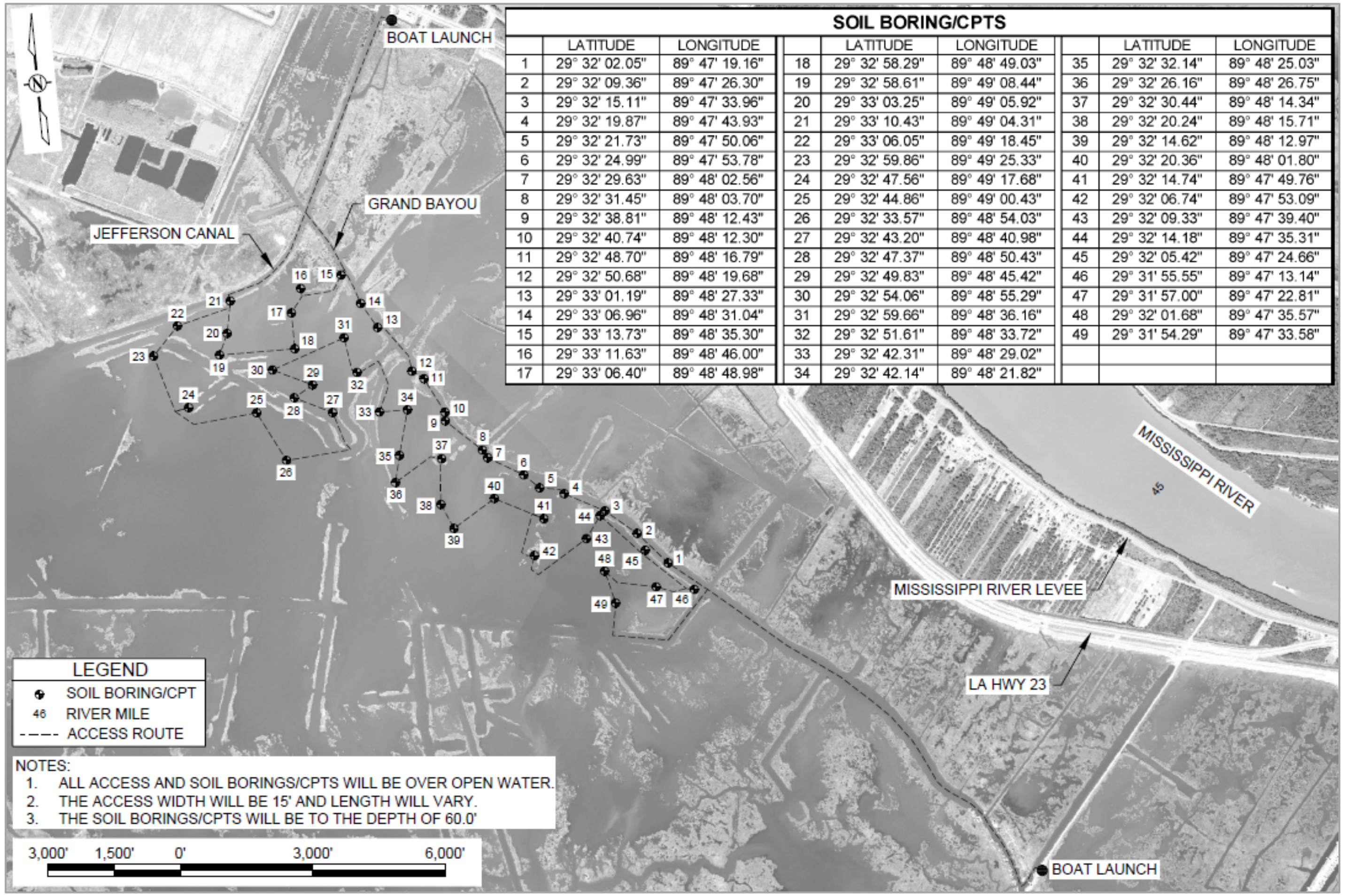
- <u>Marsh Creation Areas (MCAs):</u>
  - 2 in each MCA (1 per 90 acres)
  - 40-ft depth
- <u>Earthen Containment Dikes (ECDs):</u>
  - 7 CPTs & 3 co-located borings (1 per 2,700 LF)
  - 40-ft depth
- <u>Earthen Ridge:</u>
  - 6 CPTs & 3 co-located borings (1 per 1,800 LF)
  - 50-ft depth
- <u>Terrace Fields:</u>
  - 2 borings & 3 CPTs (1 per 70 acres)
  - 40-ft depth
- <u>Earthen Ridge Borrow</u>:
  - 3 borings
  - 20-ft depth



Subsurface Investigations

EXAMPLE PERMITTING LAYOUT

- 49 permitting locations narrowed down to 28 locations for final scope.
- Over-permitting allows for additional CPTs/borings to be performed in the future, if needed.
- Denoting locations as both borings and CPTs provides flexibility in planning.



SOIL BORING/CPTS

	LATITUDE	LONGITUDE		LATITUDE	LONGITUDE		LATITUDE	LONGITUDE
1	29° 32' 02.05"	89° 47' 19.16"	18	29° 32' 58.29"	89° 48' 49.03"	35	29° 32' 32.14"	89° 48' 25.03"
2	29° 32' 09.36"	89° 47' 26.30"	19	29° 32' 58.61"	89° 49' 08.44"	36	29° 32' 26.16"	89° 48' 26.75"
3	29° 32' 15.11"	89° 47' 33.96"	20	29° 33' 03.25"	89° 49' 05.92"	37	29° 32' 30.44"	89° 48' 14.34"
4	29° 32' 19.87"	89° 47' 43.93"	21	29° 33' 10.43"	89° 49' 04.31"	38	29° 32' 20.24"	89° 48' 15.71"
5	29° 32' 21.73"	89° 47' 50.06"	22	29° 33' 06.05"	89° 49' 18.45"	39	29° 32' 14.62"	89° 48' 12.97"
6	29° 32' 24.99"	89° 47' 53.78"	23	29° 32' 59.86"	89° 49' 25.33"	40	29° 32' 20.36"	89° 48' 01.80"
7	29° 32' 29.63"	89° 48' 02.56"	24	29° 32' 47.56"	89° 49' 17.68"	41	29° 32' 14.74"	89° 47' 49.76"
8	29° 32' 31.45"	89° 48' 03.70"	25	29° 32' 44.86"	89° 49' 00.43"	42	29° 32' 06.74"	89° 47' 53.09"
9	29° 32' 38.81"	89° 48' 12.43"	26	29° 32' 33.57"	89° 48' 54.03"	43	29° 32' 09.33"	89° 47' 39.40"
10	29° 32' 40.74"	89° 48' 12.30"	27	29° 32' 43.20"	89° 48' 40.98"	44	29° 32' 14.18"	89° 47' 35.31"
11	29° 32' 48.70"	89° 48' 16.79"	28	29° 32' 47.37"	89° 48' 50.43"	45	29° 32' 05.42"	89° 47' 24.66"
12	29° 32' 50.68"	89° 48' 19.68"	29	29° 32' 49.83"	89° 48' 45.42"	46	29° 31' 55.55"	89° 47' 13.14"
13	29° 33' 01.19"	89° 48' 27.33"	30	29° 32' 54.06"	89° 48' 55.29"	47	29° 31' 57.00"	89° 47' 22.81"
14	29° 33' 06.96"	89° 48' 31.04"	31	29° 32' 59.66"	89° 48' 36.16"	48	29° 32' 01.68"	89° 47' 35.57"
15	29° 33' 13.73"	89° 48' 35.30"	32	29° 32' 51.61"	89° 48' 33.72"	49	29° 31' 54.29"	89° 47' 33.58"
16	29° 33' 11.63"	89° 48' 46.00"	33	29° 32' 42.31"	89° 48' 29.02"			
17	29° 33' 06.40"	89° 48' 48.98"	34	29° 32' 42.14"	89° 48' 21.82"			

Subsurface Investigations

OTHER CONSIDERATIONS

- Subsurface investigations can be performed in a phased approach.
- A few CPTs should be co-located with borings to provide a site-specific cone factor necessary to better process CPT data.
- Additional investigations may be necessary due to factors such as geologic variability, weak or compressible soils, need for reduced spacing, or by engineering judgement.
- Over-permitting allows for flexibility in performing additional borings/CPTs in the future, should the need arise, without the need for a permit modification.

Laboratory Testing

TESTING TYPES AND IMPORTANCE IN DESIGN

Category	Test Name	Use in Analysis/Design
Classification Tests	Moisture Content	To help define subsurface stratigraphy, use in established correlations to other properties, estimate soil behaviors during construction, and more.
	Atterberg Limits	
	Particle-Size Distribution	
	Organic Content	
	Unit Weight	A key input parameter for settlement and slope stability analyses.
Strength Testing	Unconsolidated Undrained (UU)	For use in slope stability analysis of earthen containment dikes, earthen ridges, and other earthen features.
	Unconfined Compression (UC)	
Consolidation	Consolidation Testing	For use in estimating magnitude and time-rate settlement of foundation soils
Dredge Slurry Testing	Settling Column	For use in estimating magnitude and time rate settlement of dredged materials.
	Low Stress Consolidation Testing	

Data Synthesis and Interpretation

Data Synthesis and Interpretation

BORING LOG DEVELOPMENT

Drilled — Start 4/18/2018, End 4/18/2018	Total Depth (ft): 60	Logged By: SJW; Checked By: IAH	Driller: Specialized Environmental Resources, LLC	Drilling Method: Wet Rotary	
Surface Elevation (ft): -3; Vertical Datum: NAVD88		Hammer Data: Cathead Hammer 140 (lbs) / 30 (in) Drop		Drilling Equipment: Pontoon Drill Rig	
Latitude: 29.2543; Longitude: -90.1823		System Datum: Geographic NAD83 (feet)		Depth of water to mudline at time of exploration (ft): 5.0	
Notes: Cement-bentonite grout full depth					

Depth (feet)	Recovered (in)	Sample Name	Group Classification	MATERIAL DESCRIPTION	Water Content, %	Dry Density, (pcf)	Shear Strength, (KSF)	Confining Pressure, (PSI)	Strain, %	Liquid Limit (LL), %	Plasticity Index (PI), %	Passing No. 200 Sieve, %	Minivane Shear Strength (KSF)
0	22	1	PT	Dark brown peat with organic clay (organic content = 14.1%)	210								
	24	2		Dark brown peat with organic clay (very soft)	443	14.1	0.04	5	6	211	162		0.04
	22	3	CL	Gray clay with silt, sand lenses and silt layers (very soft) (specific gravity = 2.67)	50	68.6				43	21		0.06
	21	4	CH	Gray clay with silt layers, sand pockets, shells and organic matter (very soft)	102	48.5	0.12	5	5				
	23	5		Gray clay with silt layers and shell fragments (very soft)	72	59.4	0.13	5	4				0.16
10	25	6	CL	Gray clay with silt, sand and shell fragments (very soft)	57	69.6	0.23	5	6				
15	25	7		Gray sandy clay (very soft)	31	85.2	0.2	6.4	6				
20	23	8	SC	Gray clayey sand	30					26	9	36	0.07

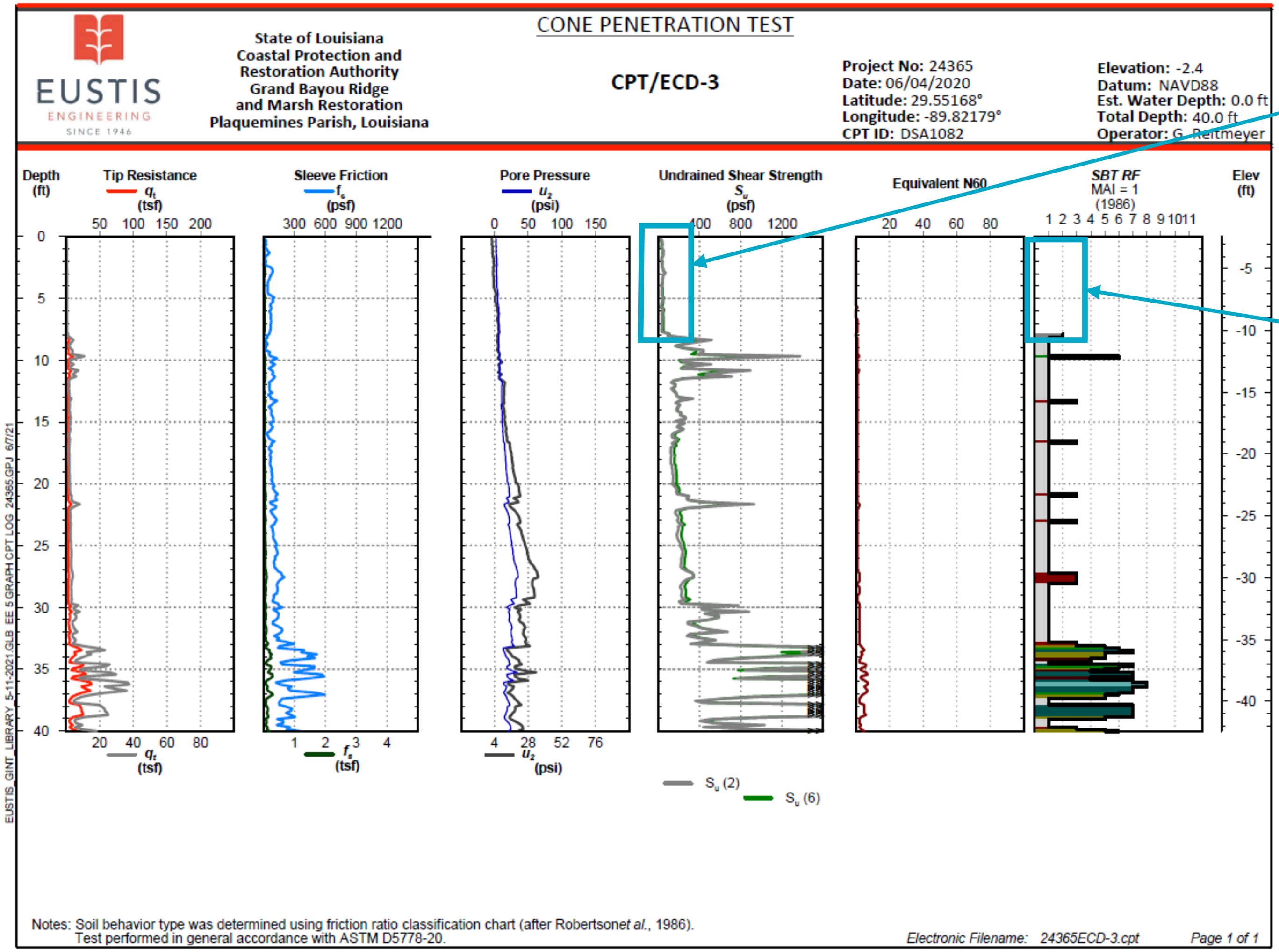
High moisture content

Low shear strength

Boring Log Credit: GeoEngineers

Data Synthesis and Interpretation

CPT LOG DEVELOPMENT



Low shear strength

Difficult determining SBT in highly-sensitive materials

Data Synthesis and Interpretation

DEFINING SUBSURFACE AND PARAMETER PROFILES

- After completion of the subsurface investigation, laboratory testing, and development of the boring/CPT logs, subsurface stratigraphy profiles are often generated next.

- Depending on the subsurface stratigraphy of the project area, multiple profiles or “reaches” may be necessary to define the entire site.

- While reaches are commonly defined on the basis of subsurface soil stratigraphy, they can also be defined based on the results of the laboratory testing (i.e. consolidation parameters, shear strength, moisture content, etc.).

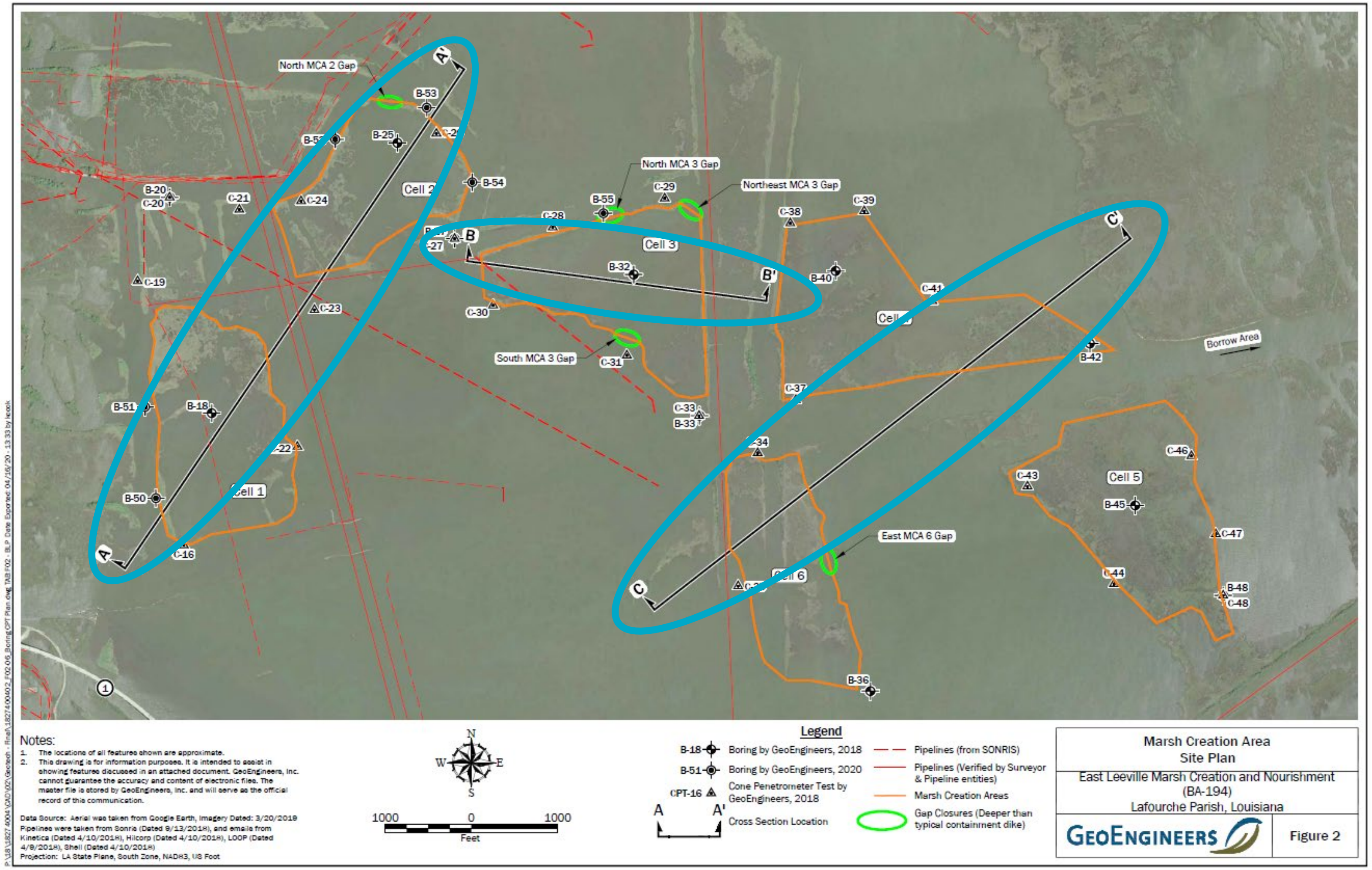
- In addition to plotting subsurface soil stratigraphy, the following soil parameters profiles are also generated to be utilized in geotechnical analysis and design:
    - Moisture content
    - Shear strength
    - Unit weight
    - Consolidation parameters

Data Synthesis and Interpretation

SUBSURFACE SOIL STRATIGRAPHY EXAMPLE

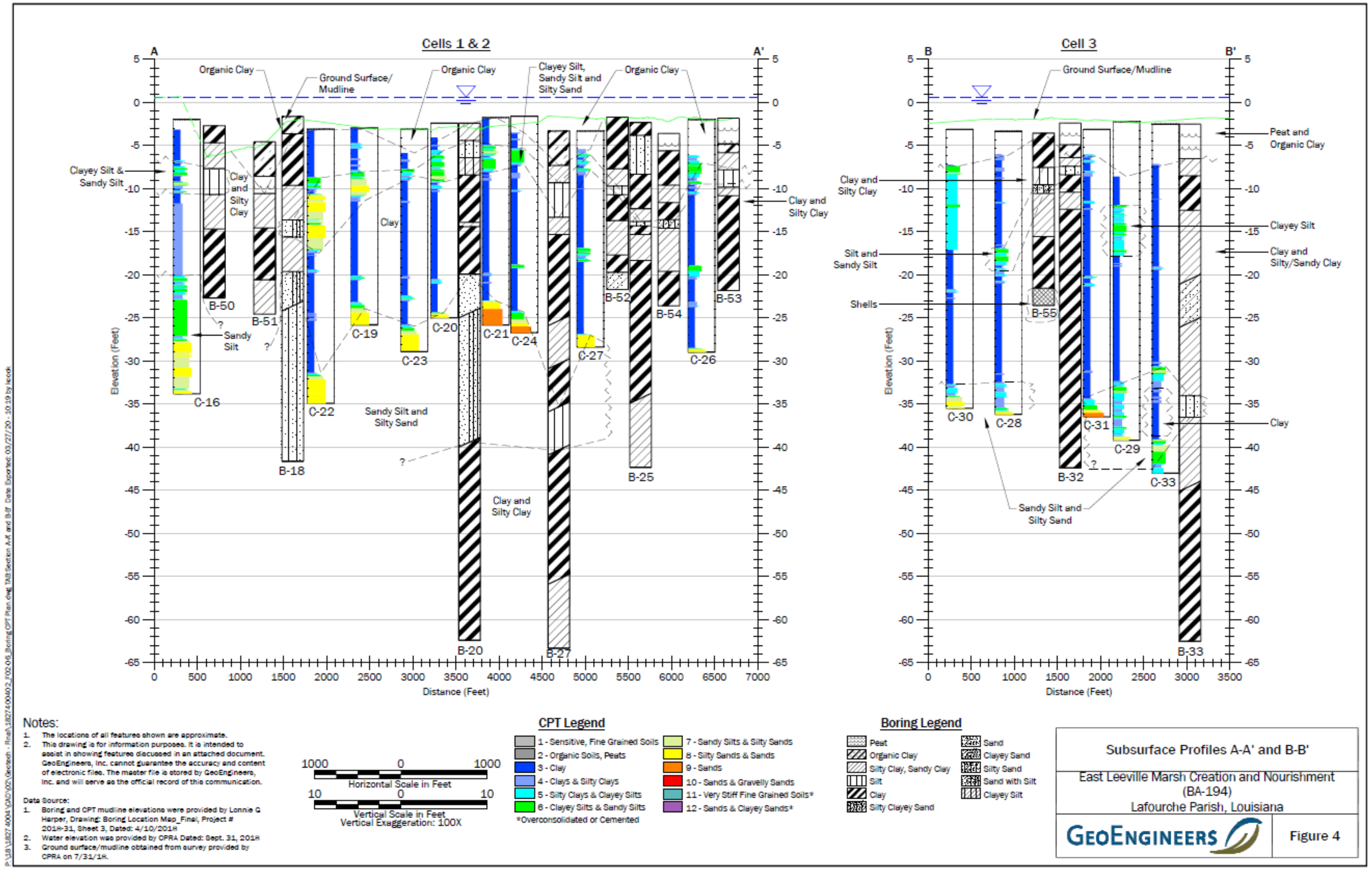
- In the example shown, the project area was divided into three reaches, based on soil subsurface stratigraphy:
  - A-A’
  - B-B’
  - C-C’

- Settlement and stability parameters were also generated for these reaches.



Data Synthesis and Interpretation

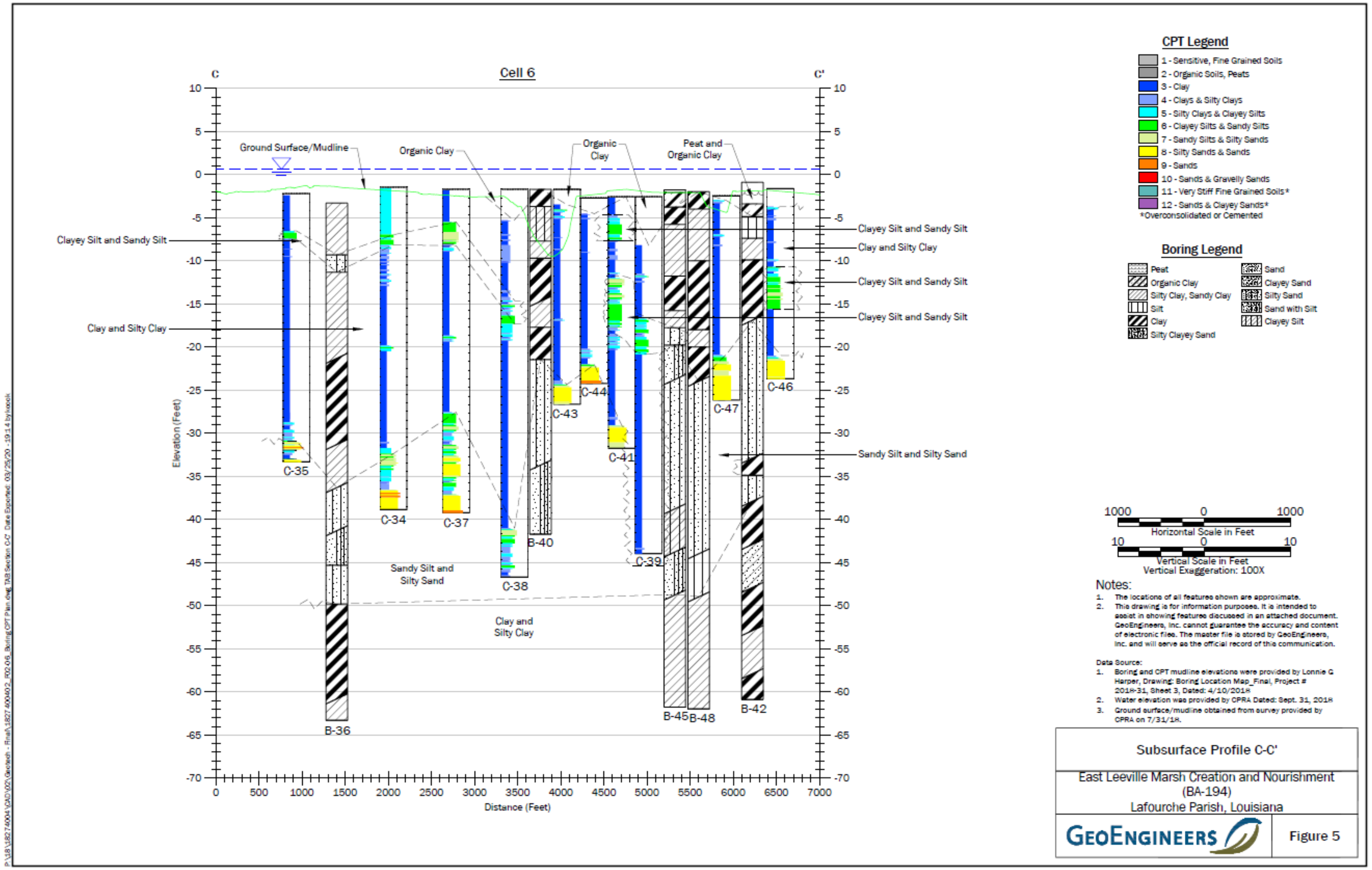
SUBSURFACE SOIL STRATIGRAPHY EXAMPLE



- This figure shows the soil stratigraphy for cross sections A-A’ and B-B’ from the plan view on the previous slide.

Data Synthesis and Interpretation

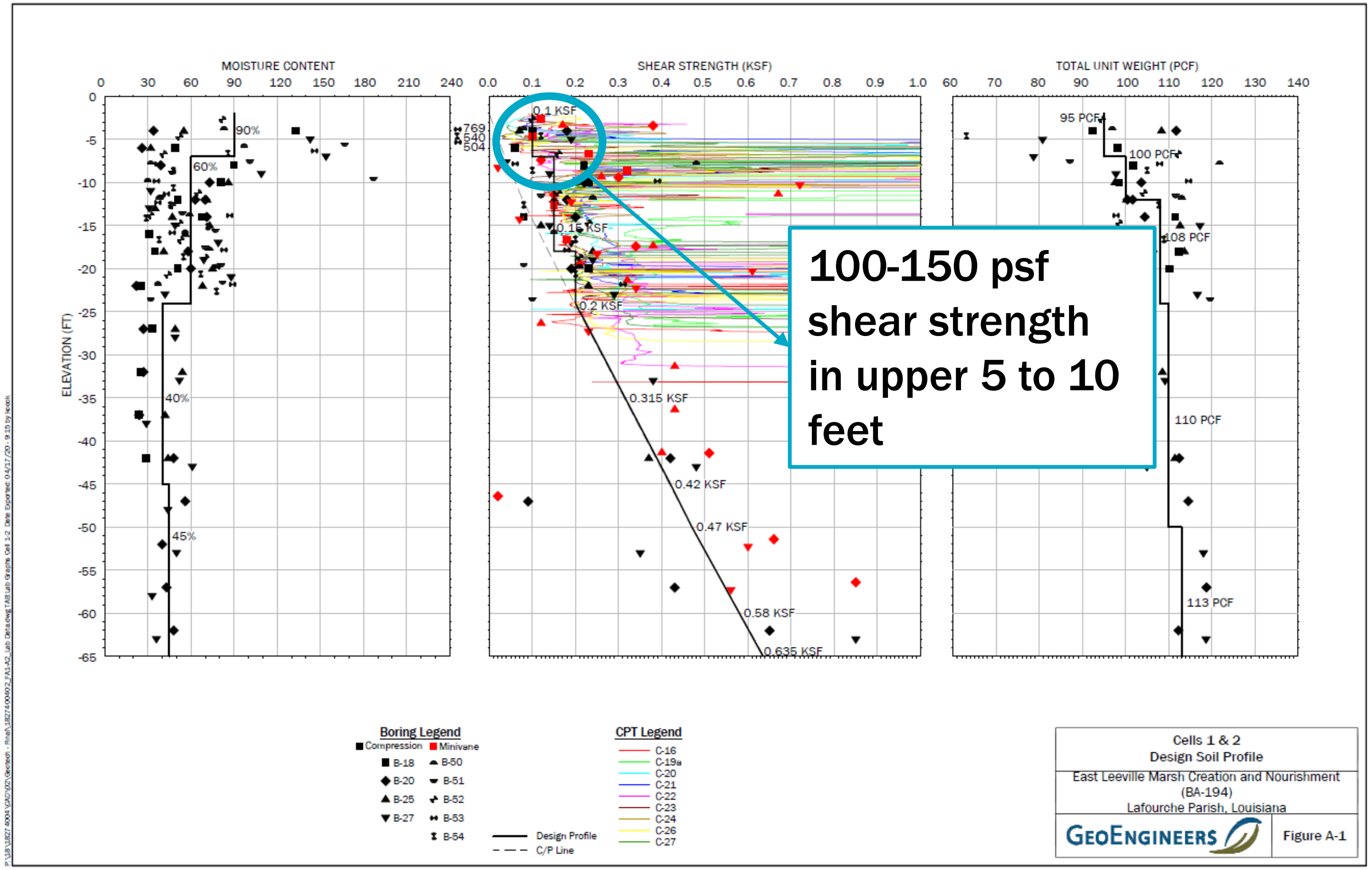
SUBSURFACE SOIL STRATIGRAPHY EXAMPLE



- Soil stratigraphy for cross sections C-C' (Slide 17). The stratigraphy of C-C' is similar to A-A', but soil parameters vary.

Data Synthesis and Interpretation

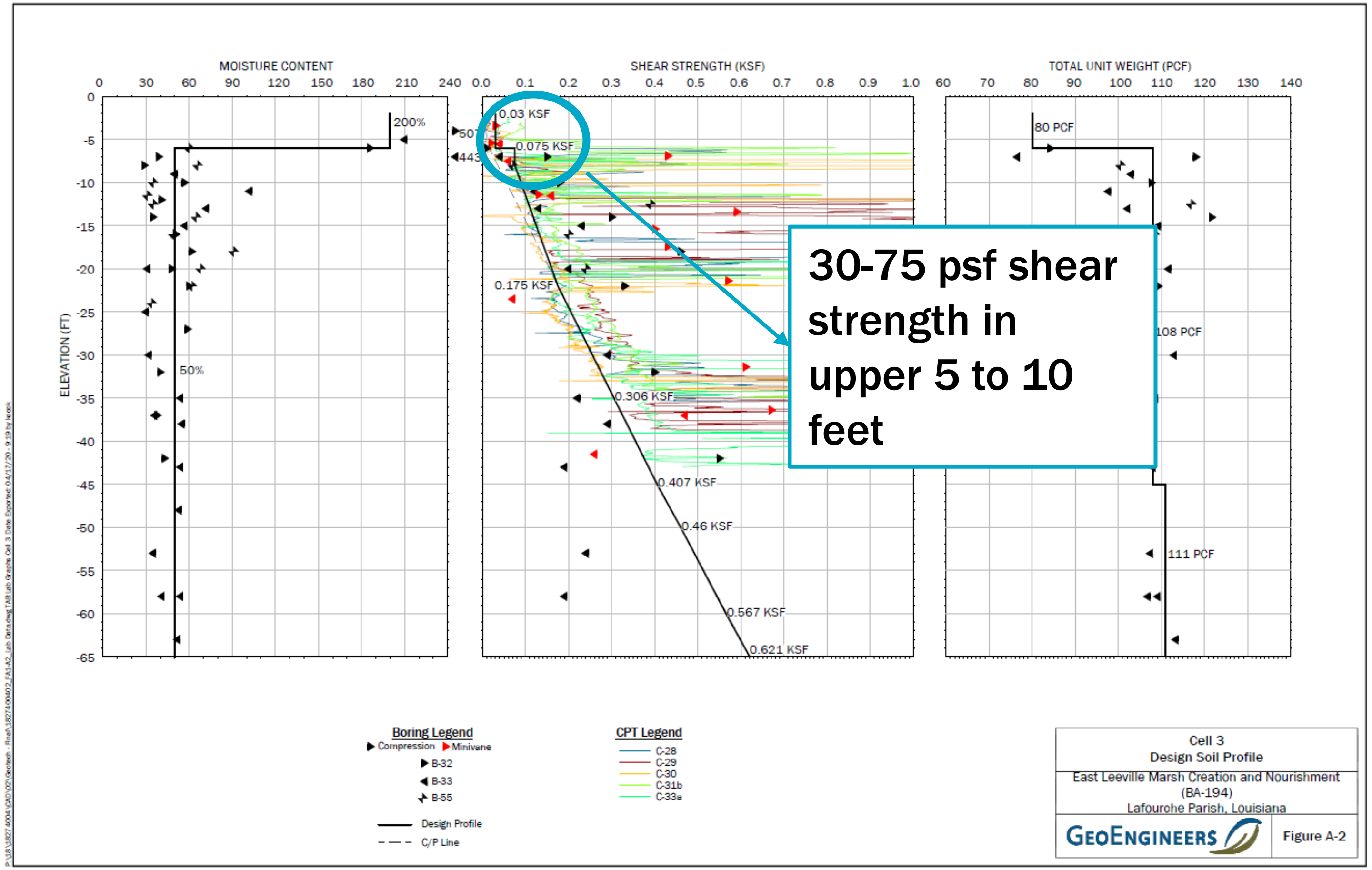
SHEAR STRENGTH / UNIT WEIGHT DESIGN PROFILE EXAMPLE



- This figure shows the moisture content, shear strength, and unit weigh profiles developed for profile A-A’ using lab testing data as well as CPT data. Shear strength and unit weight are the primary drivers of stability analyses.

Data Synthesis and Interpretation

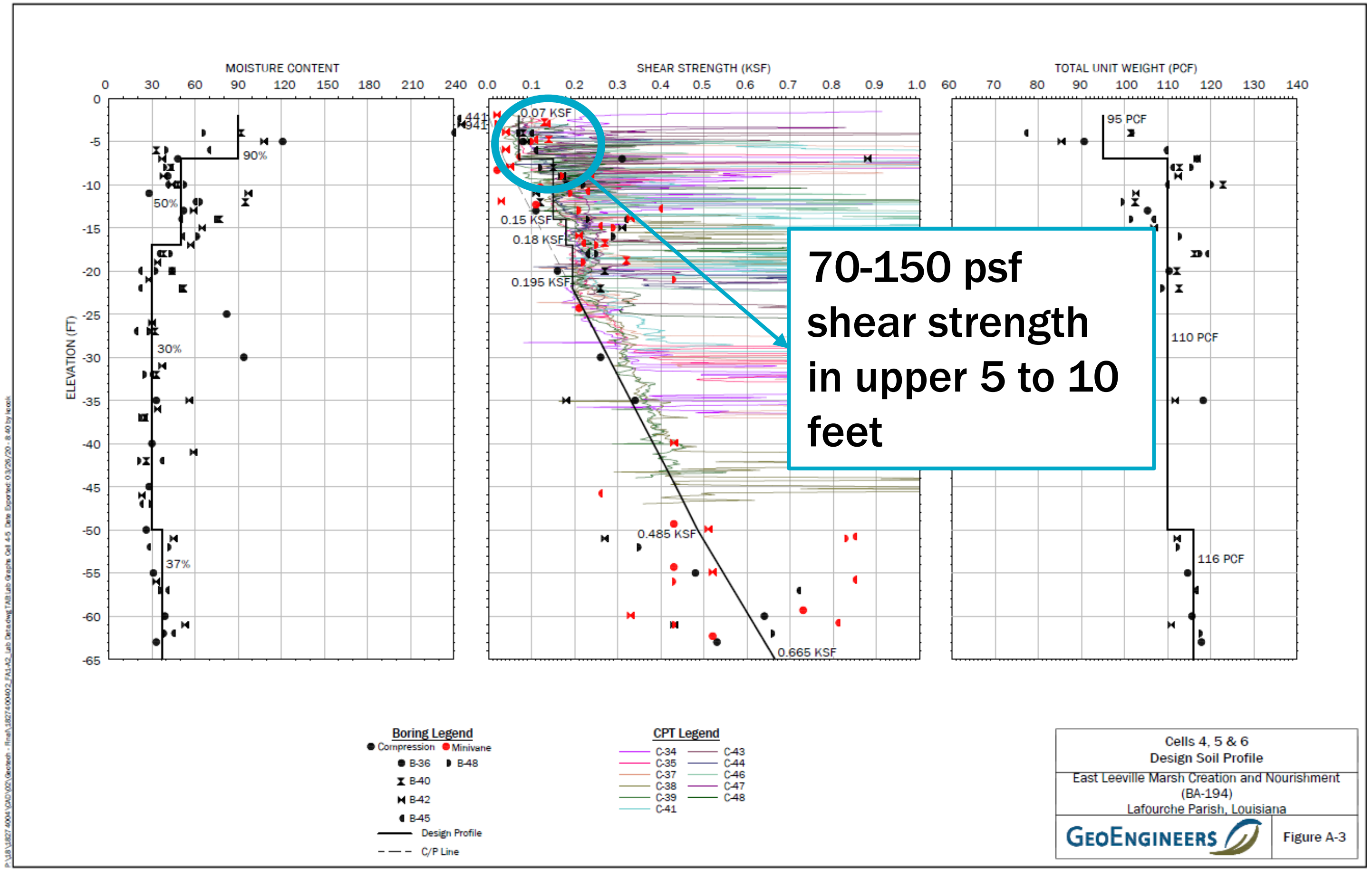
SHEAR STRENGTH / UNIT WEIGHT DESIGN PROFILE EXAMPLE



- This figure shows the moisture content, shear strength, and unit weigh profiles developed for profile B-B’ using lab testing data as well as CPT data. Shear strength and unit weight are the primary drivers of stability analyses.

Data Synthesis and Interpretation

SHEAR STRENGTH / UNIT WEIGHT DESIGN PROFILE EXAMPLE

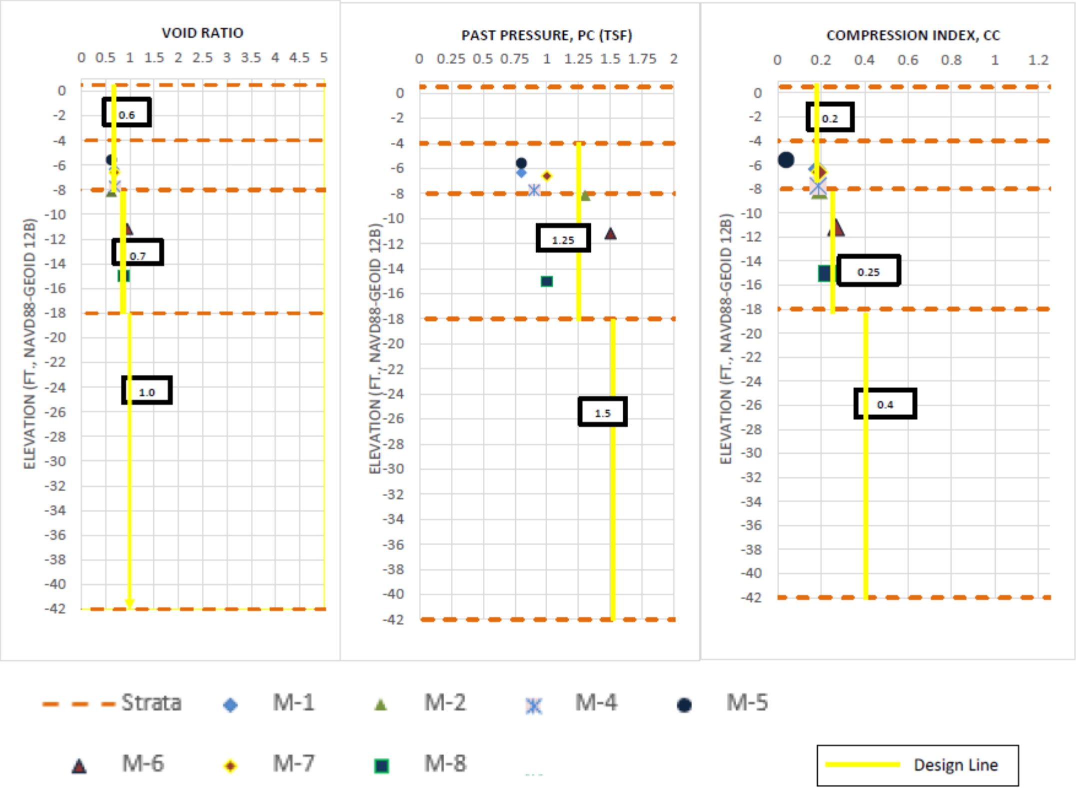


- This figure shows the moisture content, shear strength, and unit weigh profiles developed for profile B-B’ using lab testing data as well as CPT data. Shear strength and unit weight are the primary drivers of stability analyses.

Data Synthesis and Interpretation

CONSOLIDATION DESIGN PROFILE EXAMPLE

Void Ratio (e), Compression Index (CC), Past Pressure (PC) – Based on Consolidation Test



ELEVATION (ft)	0 to -4	-4 to -6	-6 to -10	-10 to -14	-14 to -18	-18 to -42
SOIL TYPE	*CH/CL/OH*	*SC*	*SP-SC*	*CH/CL*	*SP-SC/SP*	*SP*

intertek psi

dix Figure No. B-11

Marsh Creation Settlement Analysis

Marsh Creation Settlement Analysis

GENERAL PROCEDURE FOR ANALYSIS

1. Define existing site conditions, such as:
   - Hydrologic conditions (MHW, MLW, sea level rise, inundation range)
   - Subsidence rate (and accretion rate, if data is available)
   - Existing topography (mudline distribution)
   - Rainfall and evaporation rate data for the project area (NWS34) (for PSDDF)

2. Select an analysis program (influences the geotechnical parameters to be defined)
   - PSDDF, Settle3, etc.

3. Define site-specific geotechnical parameters for analysis:
   - Index properties (moisture content, unit weight)
   - Consolidation properties of dredge slurry and foundation soils

4. Estimate properties relating to dredge fill operations, such as:
   - Dredge production rate / fill period of MCAs
   - Slurry concentration (upper bound and lower bound)

Marsh Creation Settlement Analysis

GENERAL PROCEDURE FOR ANALYSIS

5. Establish the lower-bound target for marsh elevation at target year 20 (TY20).
   - Typically taken as the lower bound of the inundation range at TY20.

6. Perform settlement analysis using selected geotechnical software, aiming for the lower-bound target elevation and using the worst cast settlement parameters: upper-bound concentration and lower-bound mudline.

7. Determine the constructed marsh fill elevation (CMFE) for this TY20 elevation.

8. Increase the CMFE determined in Step 6 to provide a construction tolerance and determine the TY20 elevation.

9. Repeat for upper-bound mudline or additional mudlines of interest.

10. Repeat for selected lower-bound concentration.

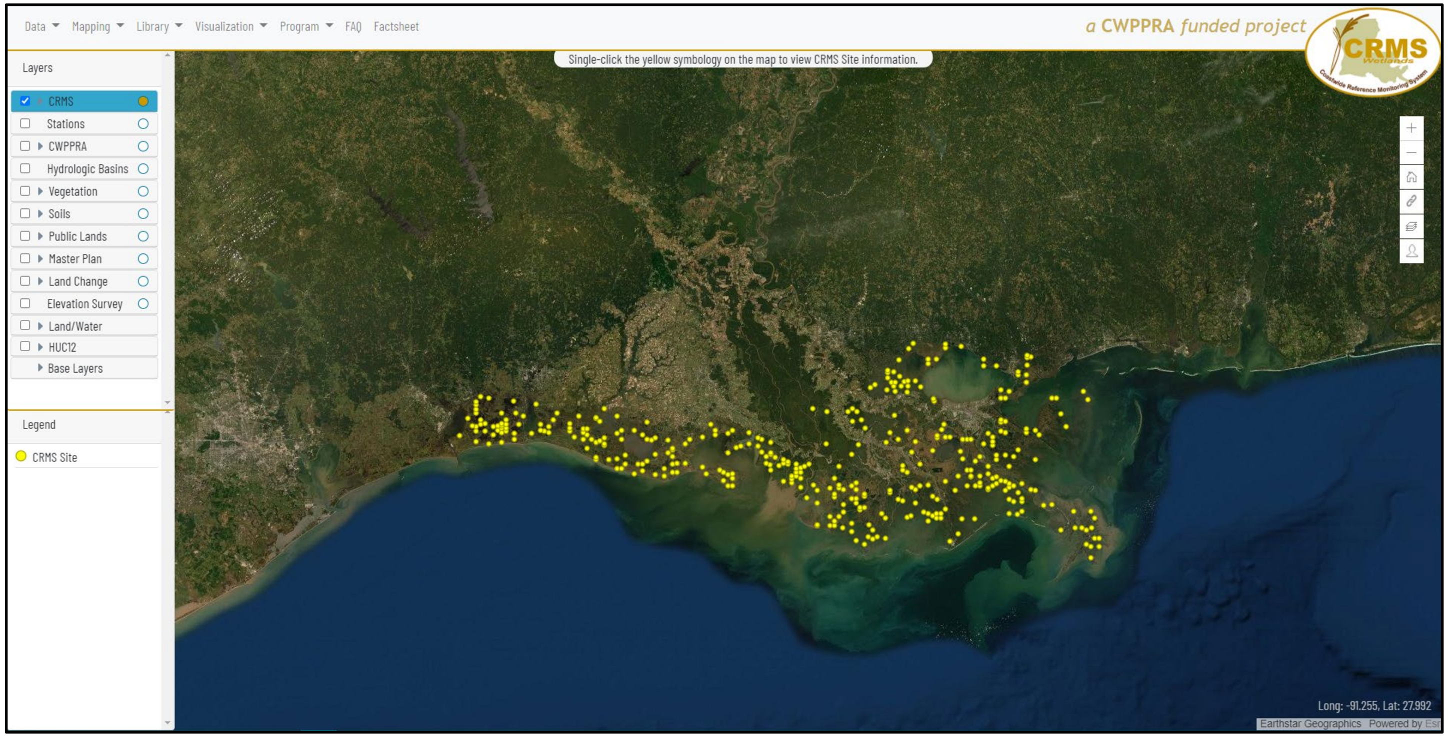
11. Perform analyses for other settlement profiles, if applicable.

Marsh Creation Settlement Analysis

DEFINING EXISTING SITE CONDITIONS – HYDROLOGIC

- Hourly hydrologic data (MHW, MLW, MTL) is typically obtained from a nearby CRMS station for the most recent 5-year period.
- CRMS stations located near a project area can be found using the Coastwide Reference Monitoring System (CRMS) Database:

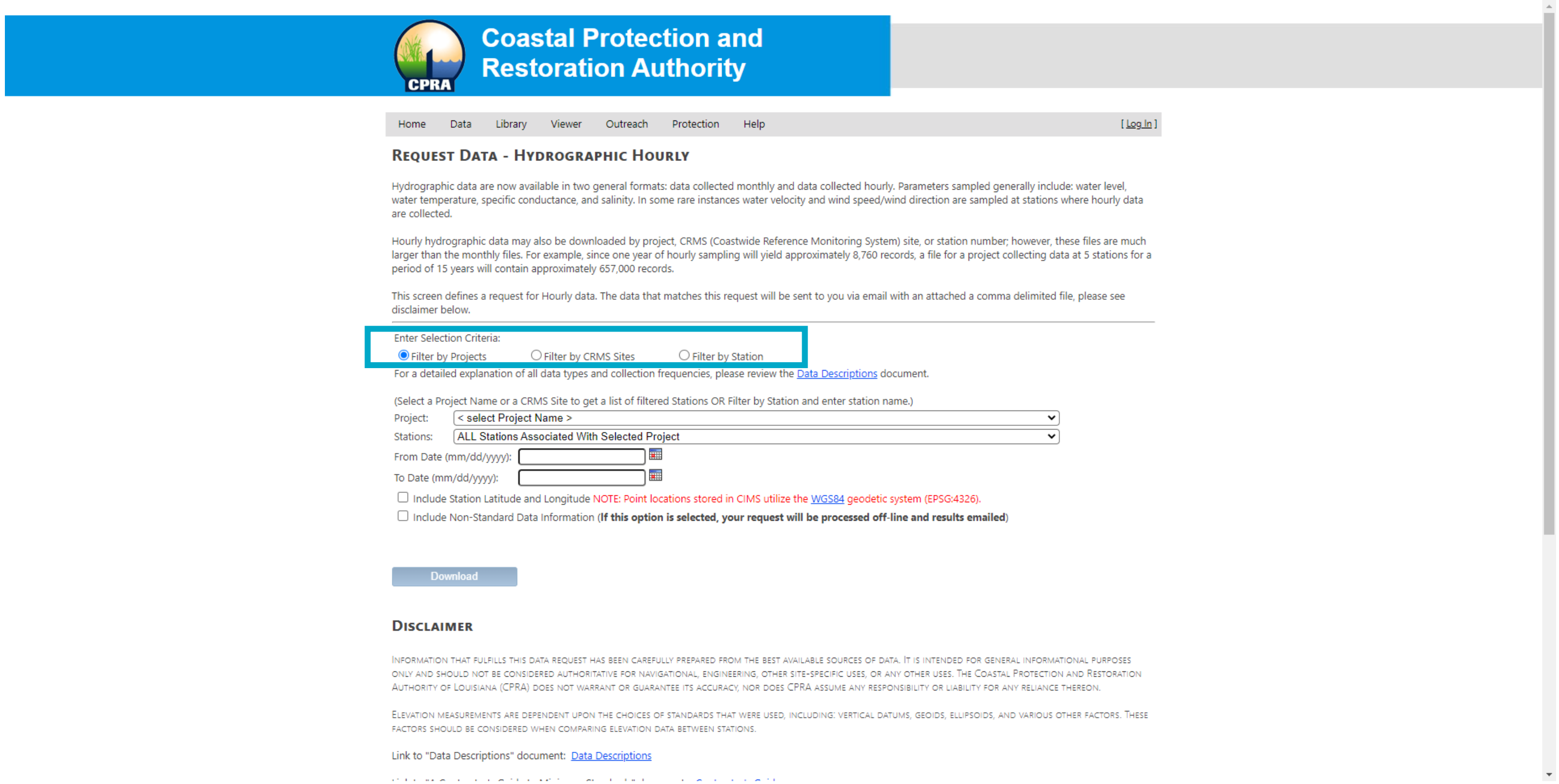
https://www.lacoast.gov/crms_viewer/Map/CRMSViewer



Marsh Creation Settlement Analysis

DEFINING EXISTING SITE CONDITIONS – HYDROLOGIC

- Once a CRMS station has been located, the CIMS database can be used to retrieve the hourly hydrologic data: https://cims.coastal.la.gov/monitoring-data/

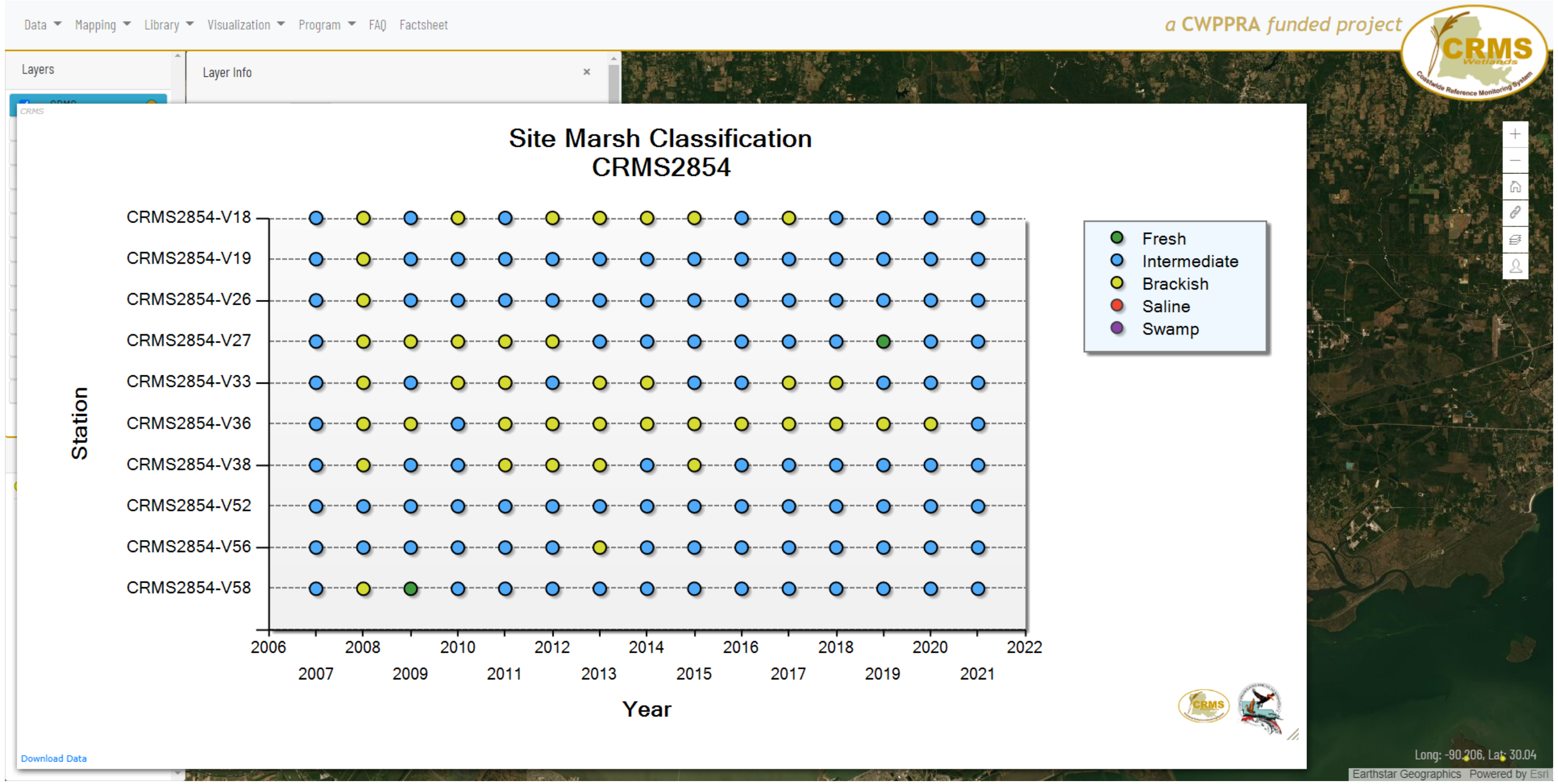


- Sea Level Rise is calculated by CPRA's Planning Division, generally using a 1.0 meter by 2100 scenario (eustatic).

Marsh Creation Settlement Analysis

DEFINING EXISTING SITE CONDITIONS - HYDROLOGIC

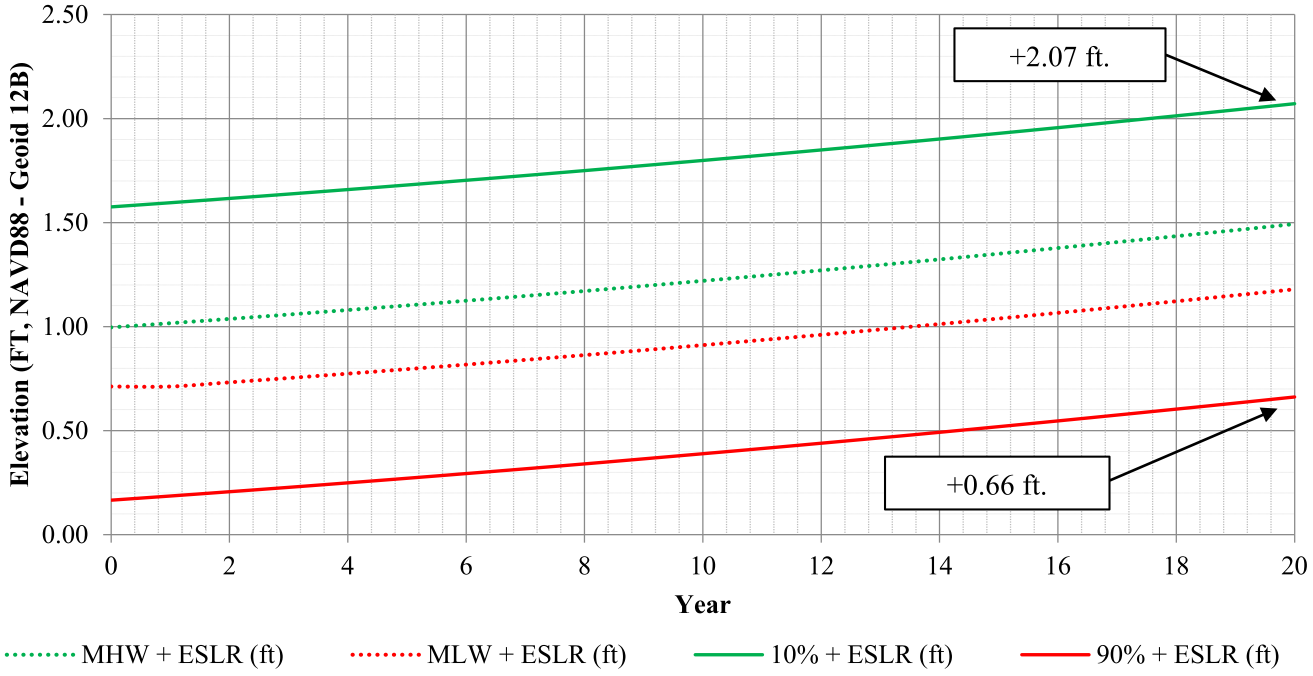
- Percent Inundation Method is used to establish the optimal inundation range of the marsh, based on information from Snedden & Swenson 2012.
- Percentiles are calculated based on the collected CIMS hydrologic data and CRMS estimates of marsh type.



Marsh Creation Settlement Analysis

DEFINING EXISTING SITE CONDITIONS – HYDROLOGIC

- Previous example showed an "intermediate" marsh type which correlates to an optimal inundation range of 10% to 90% inundated.
- "Optimal" refers to the productivity of the marsh based on salinity and vertical position of the marsh in relation to water levels.
- This range generally provides a larger area to work with when generating settlement curves versus designing to remain within MHW and MLW.

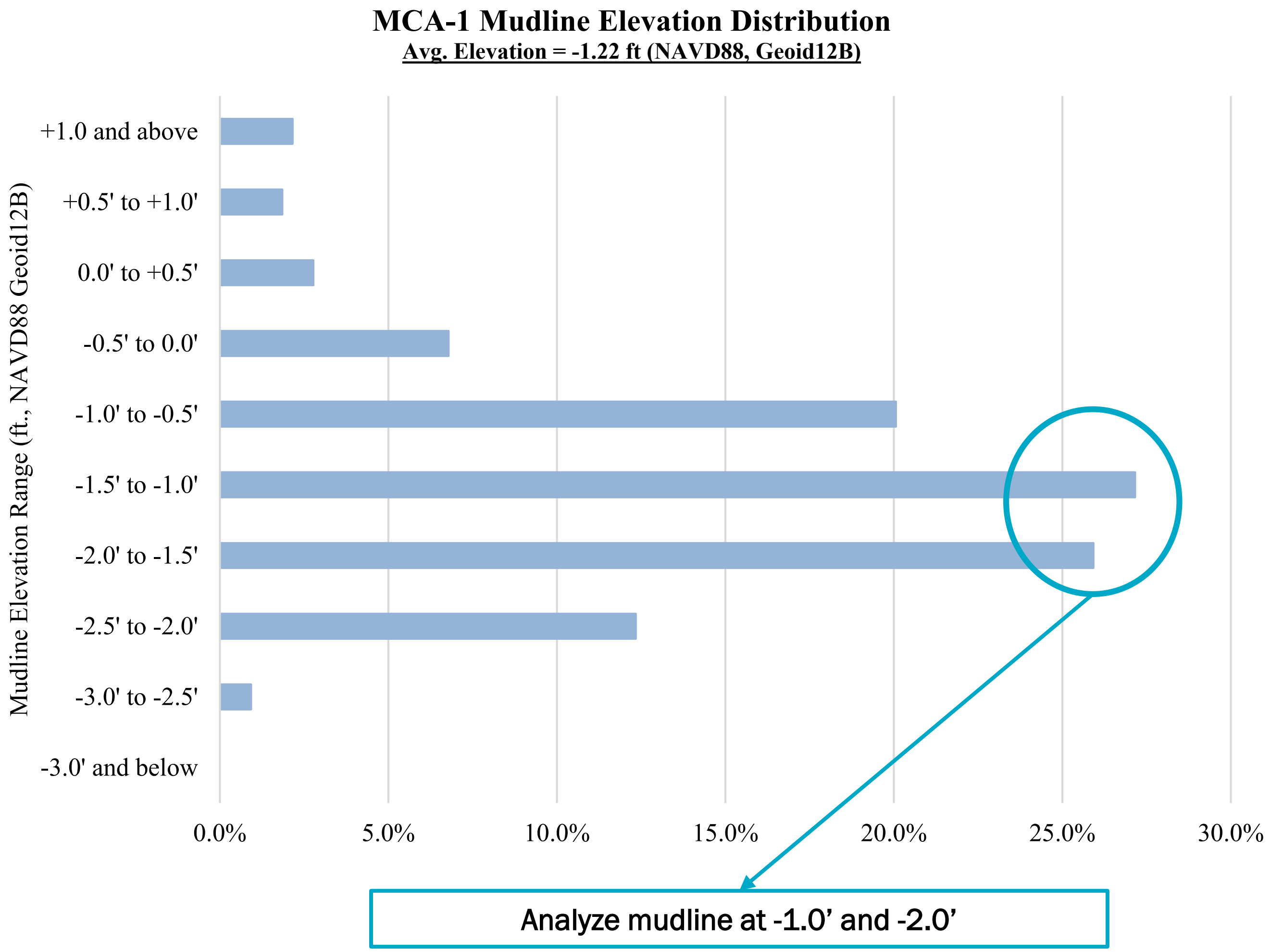


Marsh Type	Optimal Inundation Range
Fresh	10%-90%
Intermediate	10%-90%
Brackish	10%-65%
Saline	20%-80%

Marsh Creation Settlement Analysis

DEFINING EXISTING SITE CONDITIONS – SOILS

- Subsidence rate (and accretion rate, if data is available)
  - Subsidence rates have been established by CPRA's Planning division, on a per basin basis. Example, Pontchartrain basin subsidence is estimated to be approximately 5.1 mm/year (0.2 inches/year).
  - Accretion rate data is less readily available. Assumptions on accretion rates are generally made on a project-by-project basis if nearby data is available.
- Existing topography (mudline distribution)



Marsh Creation Settlement Analysis

SELECTING AN ANALYSIS PROGRAM

PRIMARY CONSOLIDATION, SECONDARY COMPRESSION, AND DESICCATION OF DREDGE FILL (PSDDF)

- Commonly used for projects with mixed sediment borrow sources to analyze settlement of dredged slurry.
- Can also be used to analyze foundation settlement.
- Can be used in conjunction with other foundation settlement programs, such as Settle3, to generate settlement curves.

SETTLE 3 (ROCSCIENCE)

- Commonly used for project with granular (sand) borrow sources.
- Can be also used to analyze foundation settlement for mixed sediment borrow projects, but still requires the use of PSDDF for slurry settlement.

Marsh Creation Settlement Analysis

DEFINING SITE-SPECIFIC GEOTECHNICAL CONDITIONS (PSDDF)

CONSOLIDATION PROPERTIES OF DREDGE SLURRY

- Specific Gravity of Soil Solids, SG
- Secondary Compression Index / Coefficient of Consolidation, C_α/C_c
- Recompression Index / Compression Index, C_r/C_c
- Effective Stress (σ') – Void Ratio (e) – Permeability (k) Relationship

Column Settling & Low Stress Consolidation Testing

- Desiccation Limit, DL
- Saturation Limit, SL
- Depth to Second Stage Drying
- Degree of Saturation at Desiccation Limit

Desiccation Parameters (PSDDF Manual)

CONSOLIDATION PROPERTIES OF MARSH CREATION AREA (FOUNDATION) SOILS

- Specific Gravity of Soil Solids (SG)
- Secondary Compression Index / Coefficient of Consolidation, C_α/C_c
- Recompression Index / Compression Index, C_r/C_c
- Effective Stress (σ') – Void Ratio (e) – Permeability (k) Relationship

1-D Consolidation Testing

Marsh Creation Settlement Analysis

DEFINING SITE-SPECIFIC GEOTECHNICAL CONDITIONS (SETTLE3)

CONSOLIDATION PROPERTIES OF MARSH CREATION AREA (FOUNDATION) SOILS

- Moisture Content, MC
- Specific Gravity, SG
- Cohesion, C
- Unit Weight, γ
- Void Ratio, e_0
- Compression Index, C_c
- Secondary Compression Index / Coefficient of Consolidation, C_α/C_c
- Recompression Index, C_r
- Coefficient of Consolidation, C_v
- Preconsolidation Pressure, P'_c
- Overburden Pressure, σ'_v
- Overconsolidation Ratio, OCR

UU or UC Test (Cohesion, Unit Weight)

1-D Consolidation Testing (Void Ratio through Overconsolidation Ratio)

*PSDDF is still necessary to compute consolidation of mixed sediment dredge slurry.

Marsh Creation Settlement Analysis

DREDGING OPERATION ASSUMPTIONS

- Generate lift schedule
  - Dependent on dredge size (production rate) and marsh creation area size
  - Past project data or USACE production rates can be used

- Establish slurry concentrations for analysis
  - <u>Upper Bound Concentration (~300 g/L)</u>: used to estimate benefits and analyze worst-case scenario settlement conditions
  - <u>Lower Bound Concentration (~150 g/L)</u>: used to determined maximum potential slurry elevation that influences the selection of the ECD crown elevation

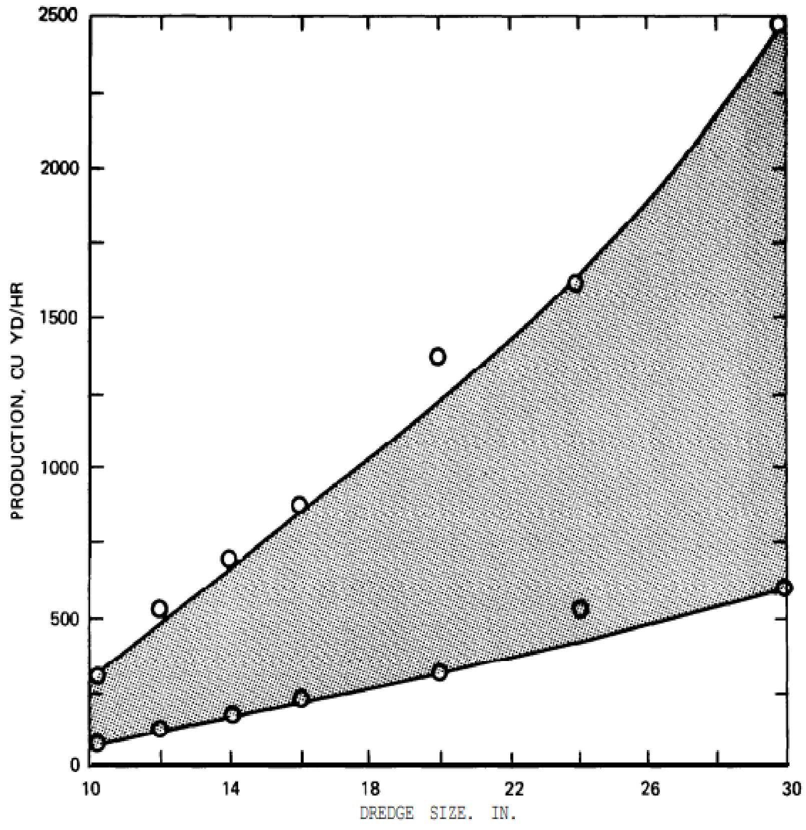
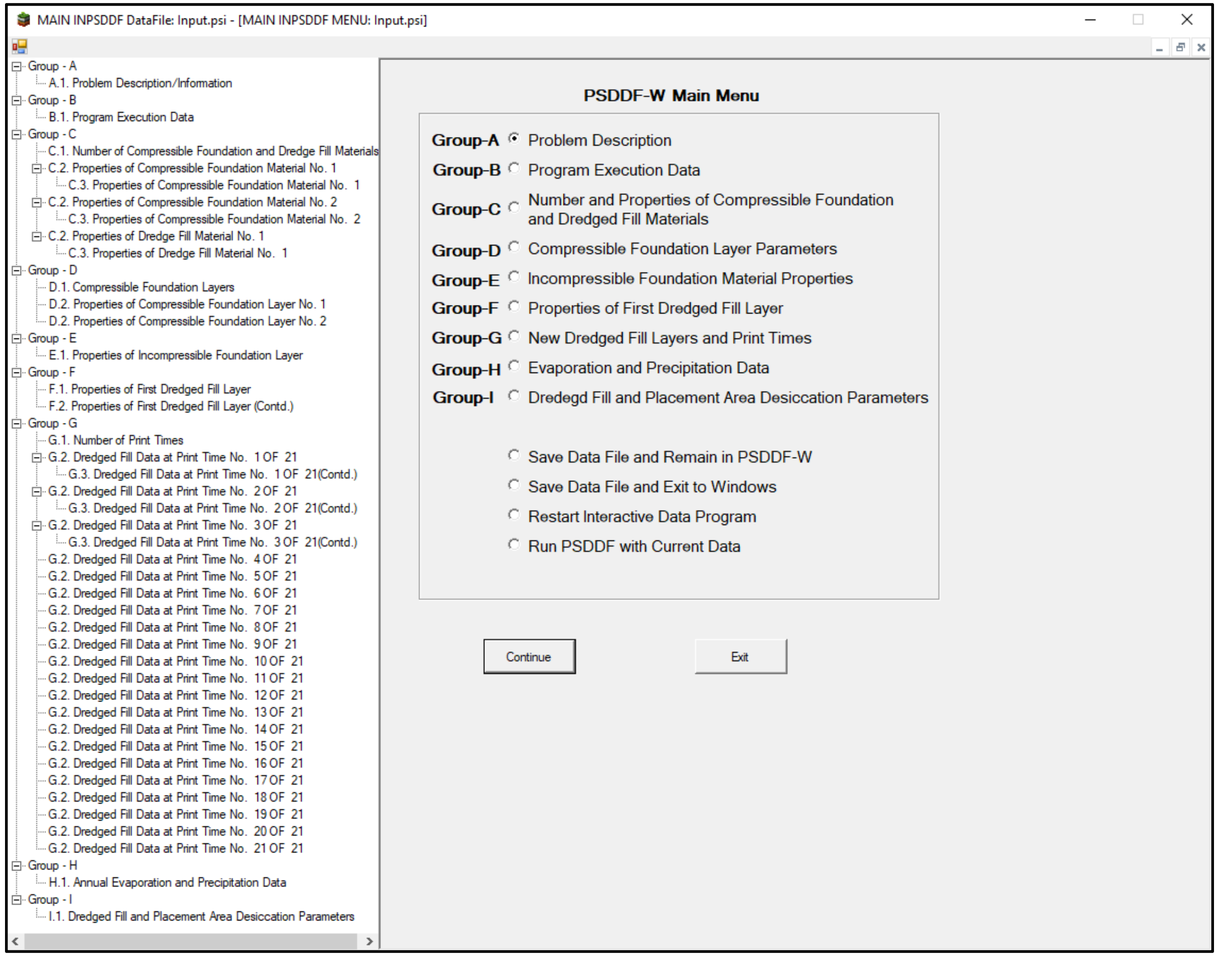


Figure 3-4. Typical cutterhead dredge production according to dredge size.

Marsh Creation Settlement Analysis

PRIMARY CONSOLIDATION, SECONDARY COMPRESSION, AND DESICCATION OF DREDGE FILL (PSDDF)

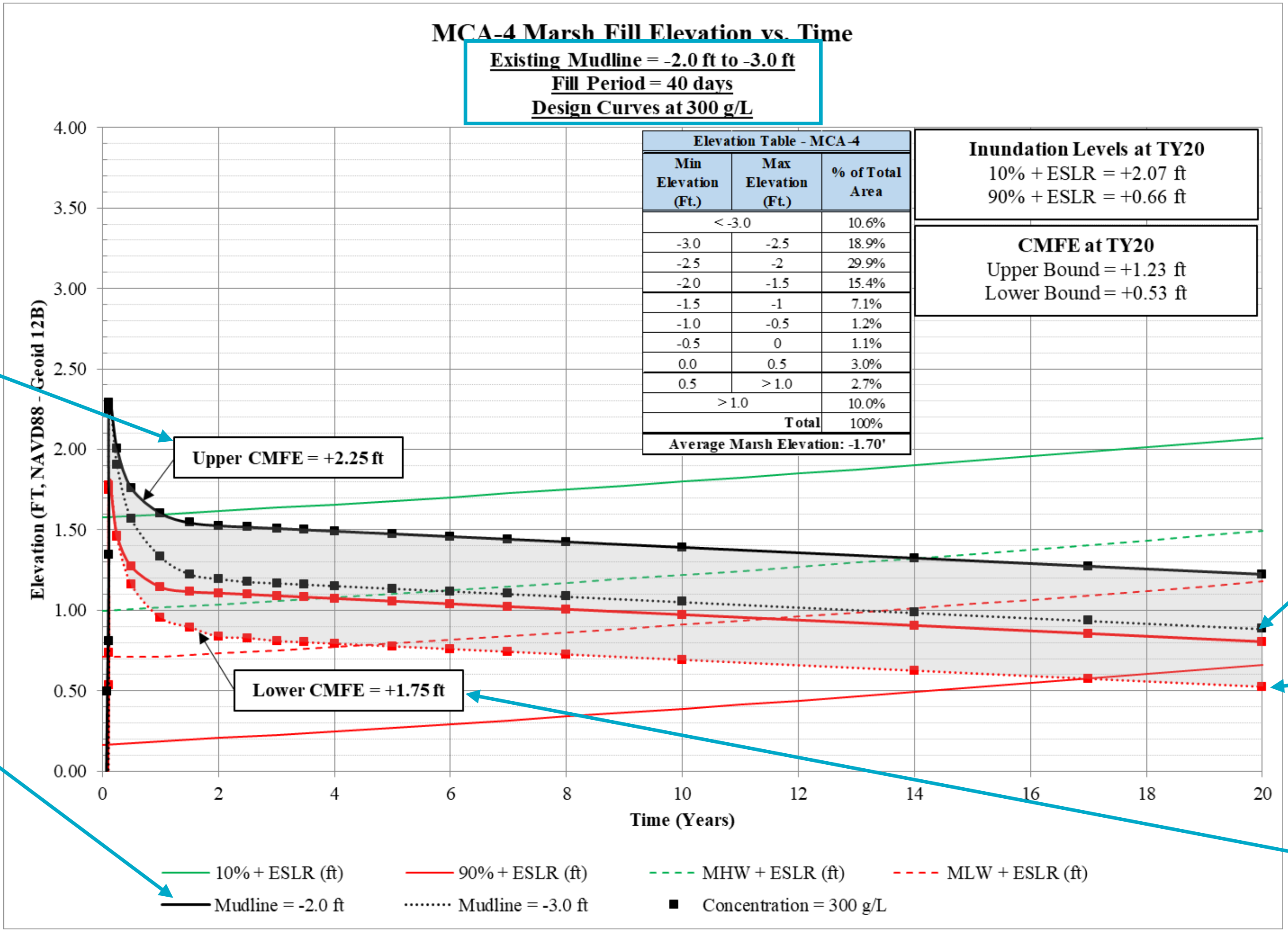


Marsh Creation Settlement Analysis

EXAMPLE SETTLEMENT ANALYSIS

3. Increase CMFE to create construction tolerance

5. Repeat for upper-bound or secondary mudline.



Elevation Table - MCA-4

Min Elevation (Ft.)	Max Elevation (Ft.)	% of Total Area
< -3.0		10.6%
-3.0	-2.5	18.9%
-2.5	-2	29.9%
-2.0	-1.5	15.4%
-1.5	-1	7.1%
-1.0	-0.5	1.2%
-0.5	0	1.1%
0.0	0.5	3.0%
0.5	> 1.0	2.7%
> 1.0		10.0%
	Total	100%

Average Marsh Elevation: -1.70'

4. Determine TY20 elevation at upper CMFE.

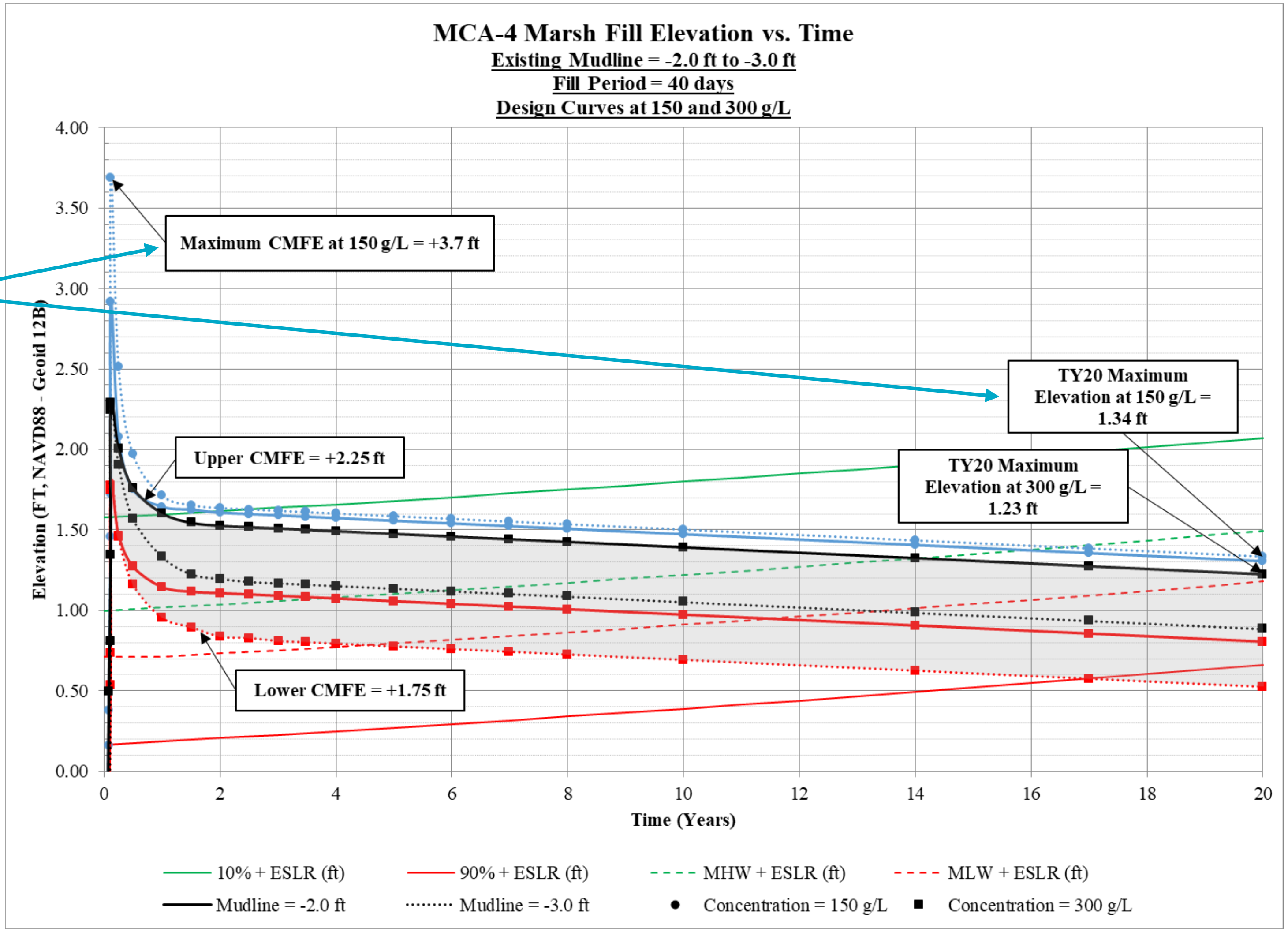
1. Analysis at lower bound mudline at upper bound concentration

2. Establish CMFE at lower-bound mudline and upper bound concentration

Marsh Creation Settlement Analysis

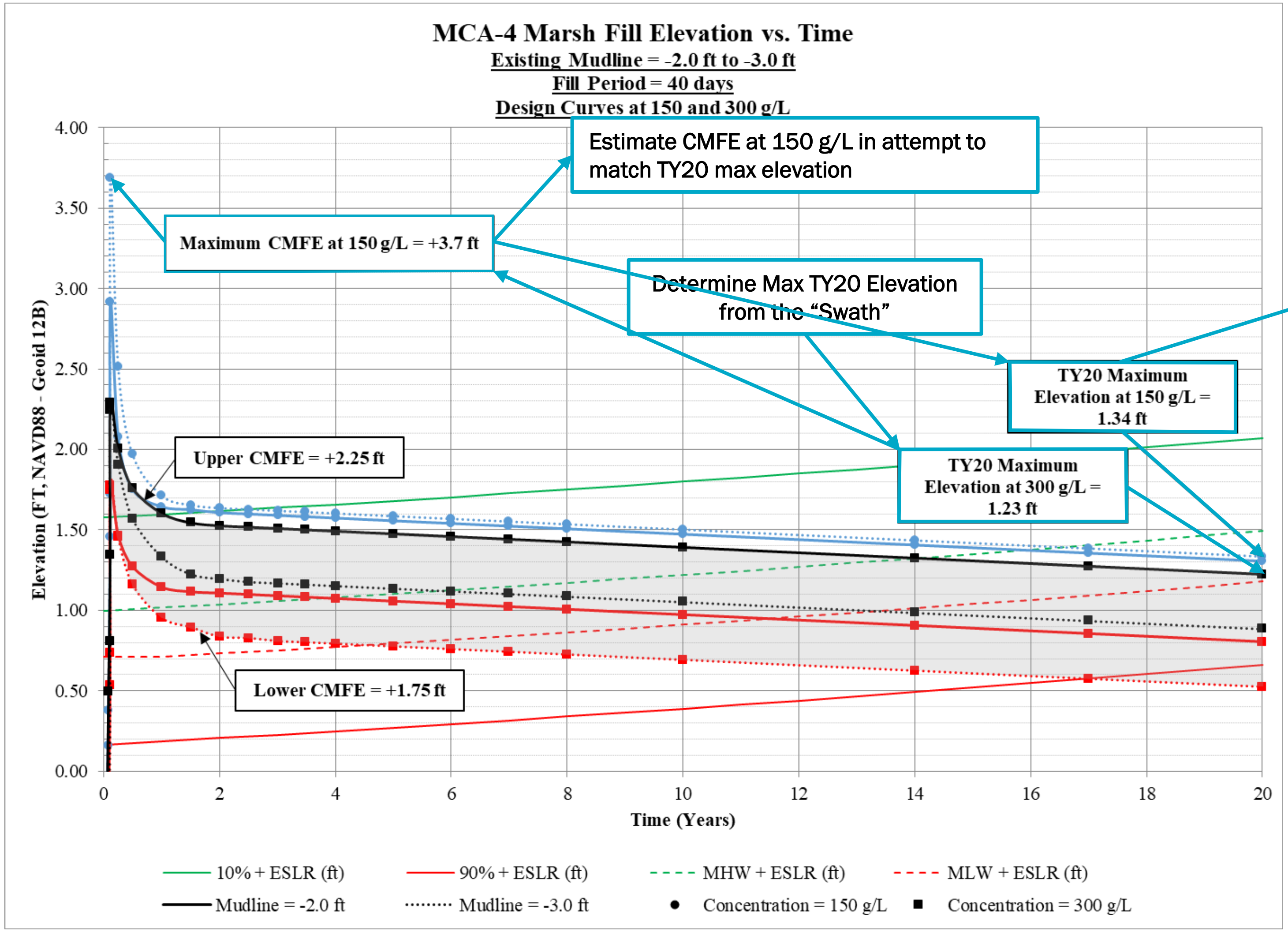
EXAMPLE SETTLEMENT ANALYSIS

6. Repeat analysis for lower-bound concentration, attempting to match TY20 elevation to determine maximum CMFE.



Marsh Creation Settlement Analysis

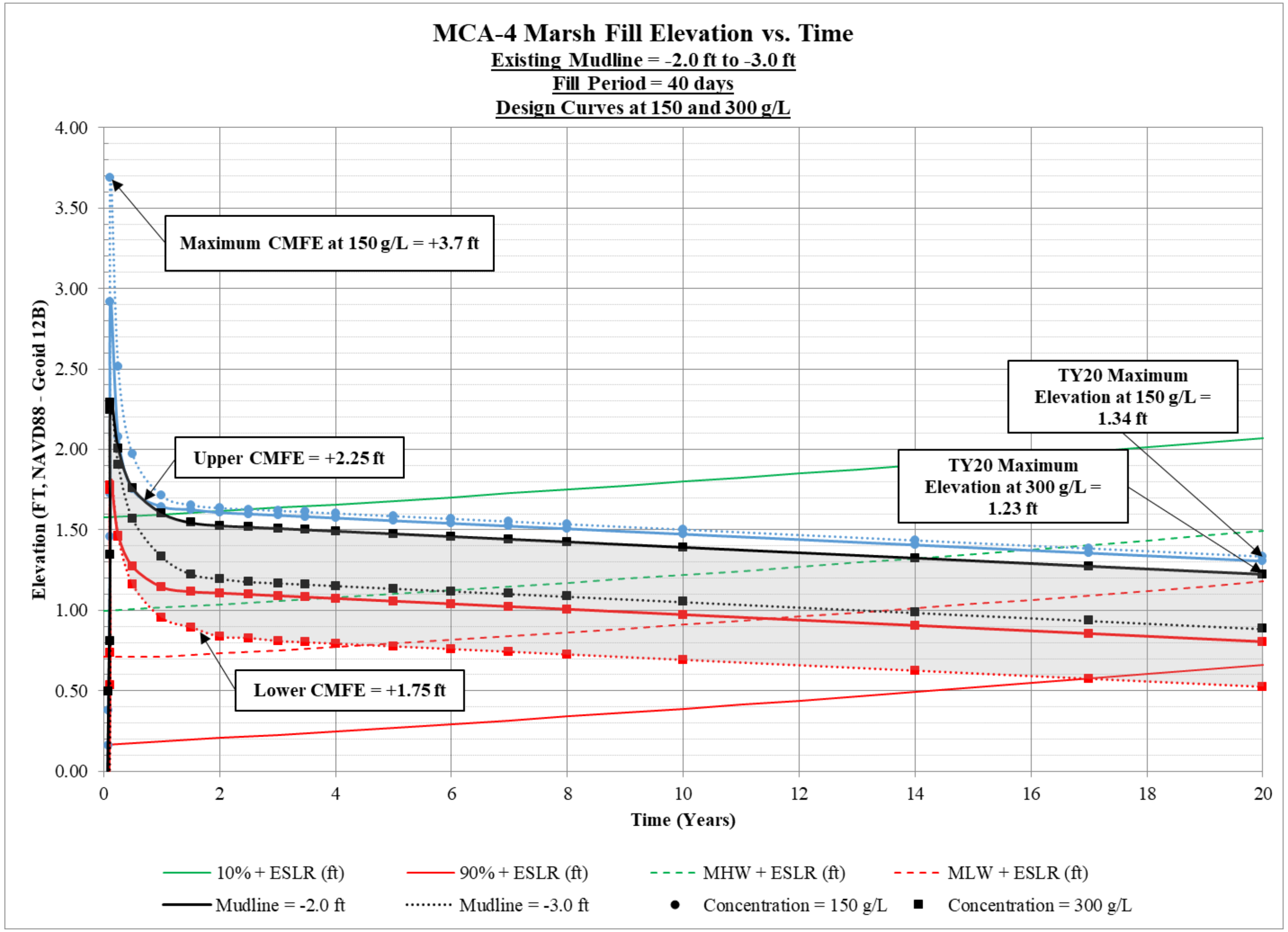
EXAMPLE SETTLEMENT ANALYSIS



Settlement analysis to compute TY20 elevation. If TY20 elevation at 150 g/L does not closely match TY20 elevation at 300 g/L, select new CMFE. Iterate as needed.

Marsh Creation Settlement Analysis

EXAMPLE SETTLEMENT ANALYSIS



Marsh Creation Settlement Analysis

A DYNAMIC PROCESS

- A slight deviation in expected soil characteristics or assumed construction conditions or practices will likely require a re-analysis of settlement.

- Construction monitoring is important to make adjustments on the fly.

- <u>It is critical for the design engineer to be in communication with the geotechnical consultant.</u>

Earthen Containment Dike Design

Earthen Containment Dike Design

GENERAL PROCEDURE FOR ANALYSIS

1. Define existing site conditions, such as:
   - Hydrologic conditions (MHW, MLW)
   - Subsidence rate (and accretion rate, if data is available)
   - Existing topography (mudline distribution)

2. Select an analysis program for:
   - Slope Stability Analysis: Slope/W, Slide, etc.
   - Settlement Analysis: Settle3, CSETT, etc.

3. Define site-specific geotechnical parameters for analysis:
   - Strength and unit weight trends of foundation soils and ECD fill materials (slope stability)
   - Drainage boundary conditions (slope stability)
   - Consolidation properties of foundation soils and ECD fill materials (settlement analysis)

Earthen Containment Dike Design

GENERAL PROCEDURE FOR ANALYSIS

4. From the results of the marsh creation area settlement analysis, determine the maximum crown elevation.
   - 1-2 feet of freeboard above the upper-bound CMFE at 300 g/L design curve or
   - 1-foot of freeboard above the upper-bound CMFE at 150 g/L design curve (Lower concentration = higher CMFE = the need for a higher ECD)

5. Perform slope stability analysis to determine an ECD section meeting the minimum F.S. requirements established in CPRA's *Marsh Creation Design Guidelines, v1 (MCDGv1.0)*.
   - Evaluate for multiple mudlines, based on the mudline distribution.
   - Evaluate for multiple soil profiles, as needed.

6. Perform settlement analysis for established ECD sections and selected mudline elevations.

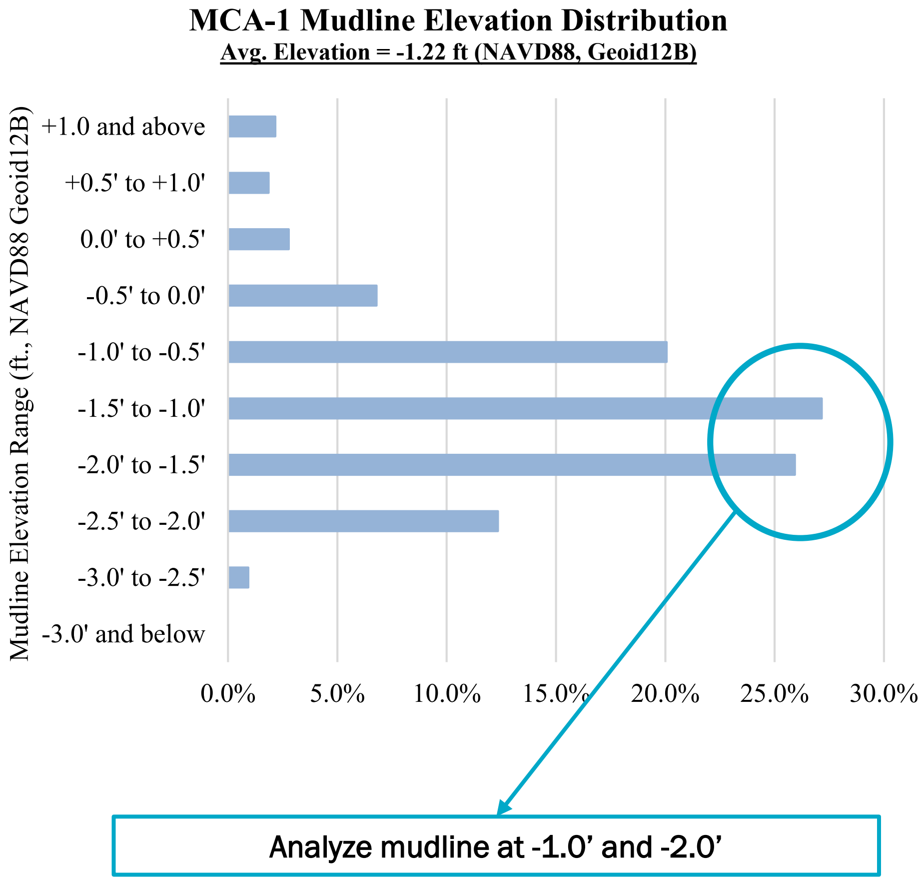
Earthen Containment Dike Design

DEFINING EXISTING SITE CONDITIONS

- Hydrologic data (MHW, MLW, MTL) is typically obtained from a nearby CRMS station for the most recent 5-year period.

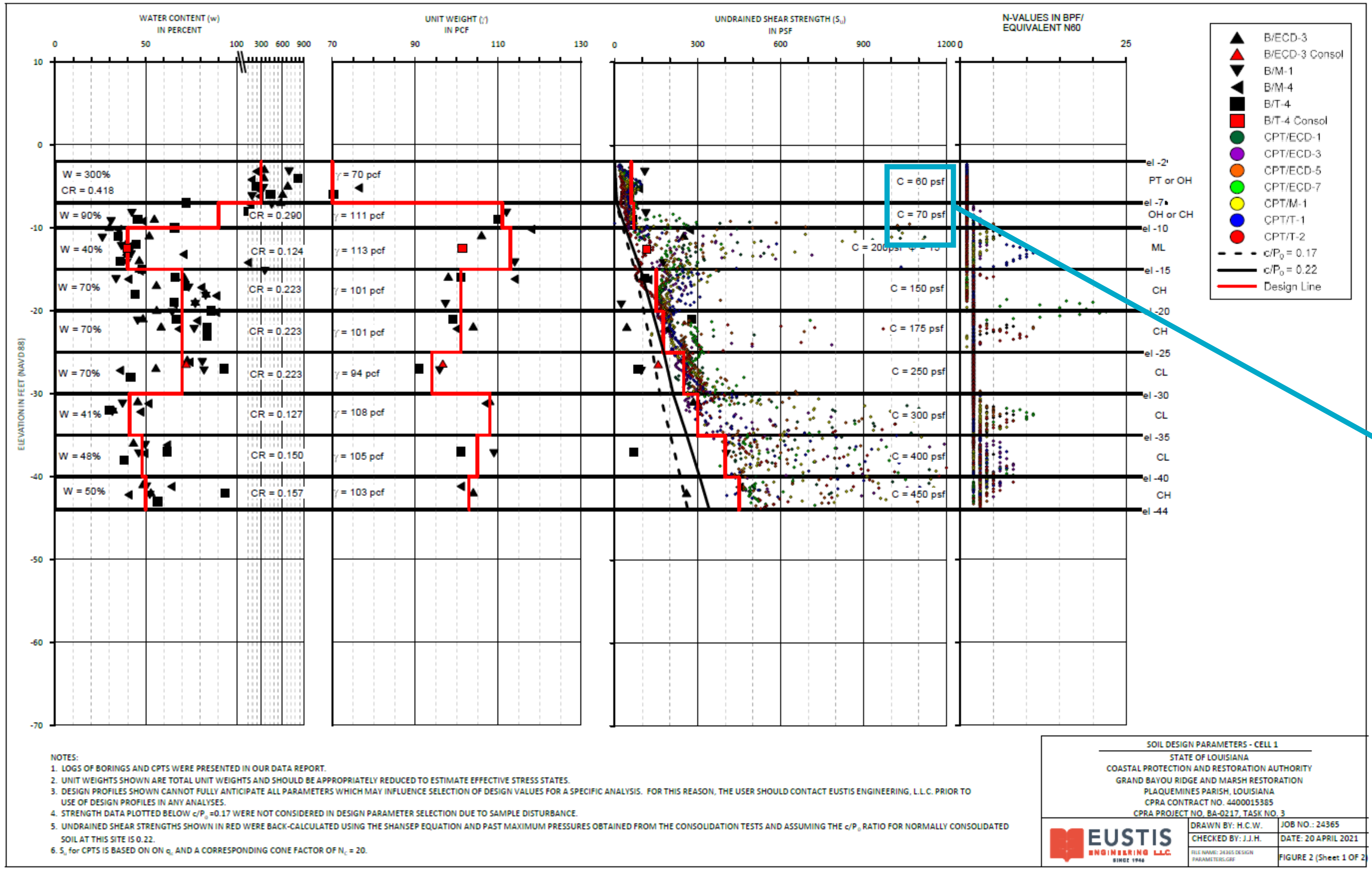
- Subsidence rate (and accretion rate, if data is available)
  - Subsidence rates have been established by CPRA's Planning division, on a per basin basis. Example, Pontchartrain basin subsidence is estimated to be approximately 5.1 mm/year (0.2 inches/year).
  - Accretion rate data is less readily available. Assumptions on accretion rates are generally made on a project-by-project basis if nearby data is available.

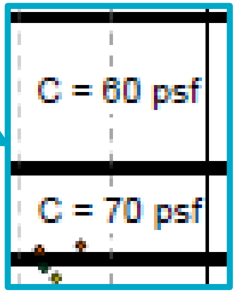
- Existing topography (mudline distribution)



Earthen Containment Dike Design

DEFINING SITE-SPECIFIC GEOTECHNICAL PARAMETERS – SLOPE STABILITY





Earthen Containment Dike Design

DEFINING SITE-SPECIFIC GEOTECHNICAL PARAMETERS – SLOPE STABILITY

3.2 Typical ECD Fill Parameters

Table B-6: Typical ECD Soil Parameters

Soil Type	Unit Weight (pcf)	Undrained Shear Strength (psf)	Friction Angle, ϕ (deg.)
*Uncompacted Clay (CH, CL))	80-100	100-200	0
*Uncompacted Organic Clay & Peat (OH, Pt)	50-80	60-100	0

*Note: The ECD Unit Weight and Cohesion are typically expressed as a percentage of the ECD Borrow Area soil parameters.

Table B-7: Typical Values for Silts, Sands, and Riprap Parameters (HSDRRSDG 2012)*.

Soil Type (per USCS)	Unit Weight (pcf)	Undrained Shear Strength (psf)	Friction Angle, ϕ (deg.)
Silt (undrained)	117	200	15
Silty Sand	122	0	30
Poorly graded Sand	122	0	33
Riprap	132	0	40

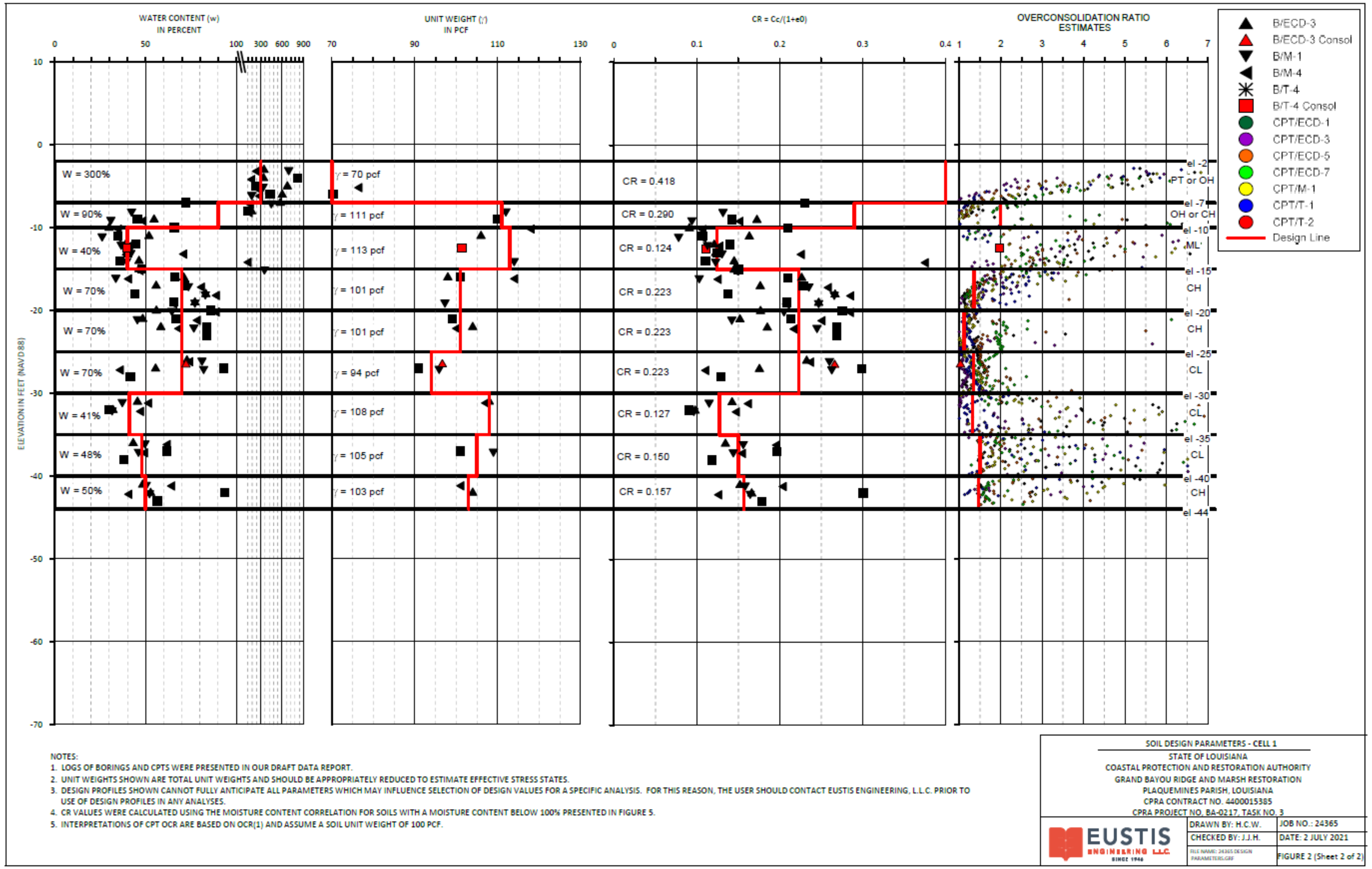
*Note: Typical values Taken from HSDRRSDG (2012) Table 3.3

Design values may vary from the typical values when site specific information is available. ECD fill properties are typically expressed as a percentage of the borrow area soils and requires engineering judgment. These values will be further refined after completion of the ongoing research.

60-70 psf shear strengths in previous example. Excavated material strength may be lower.

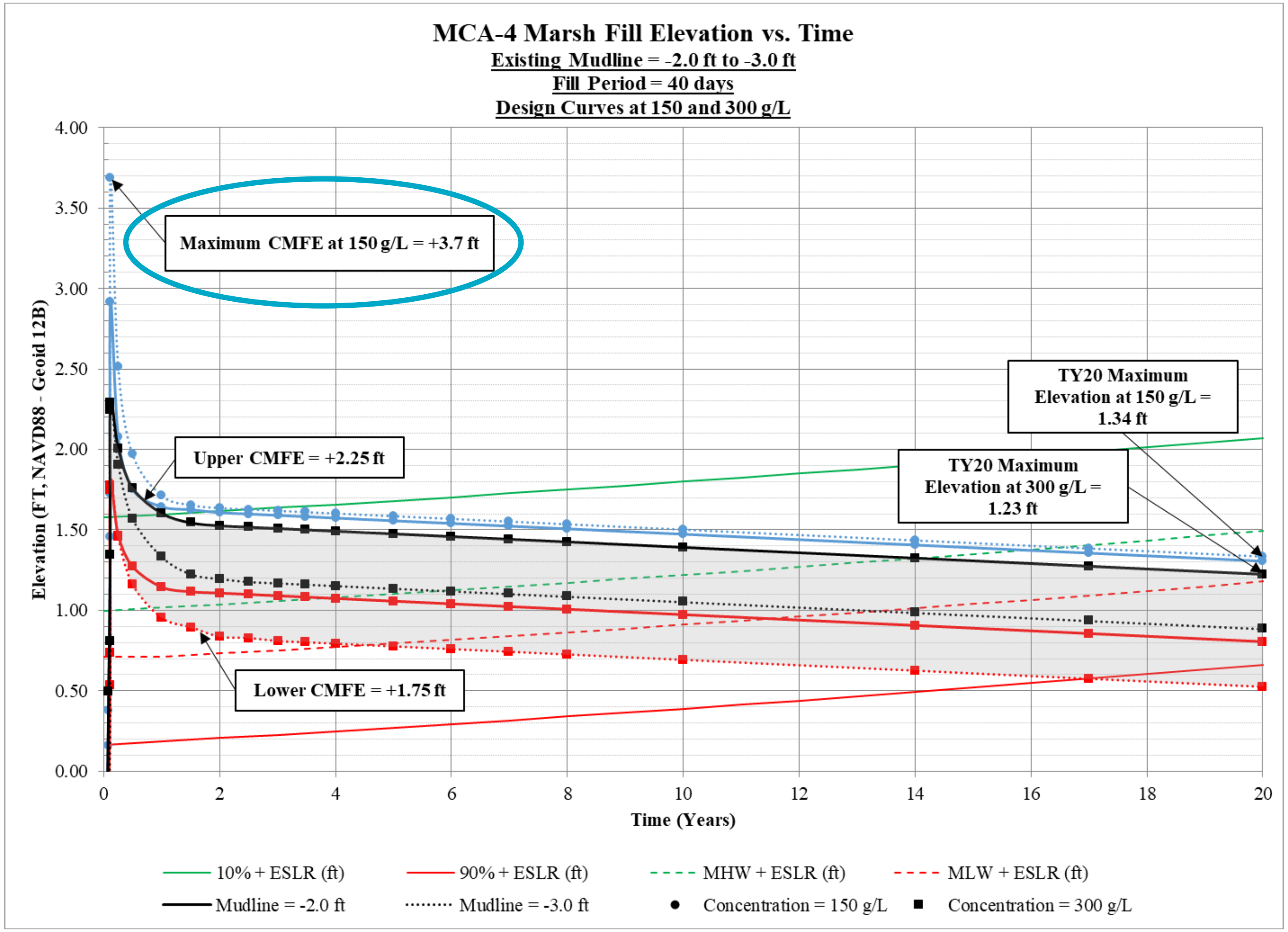
Earthen Containment Dike Design

DEFINING SITE-SPECIFIC GEOTECHNICAL PARAMETERS – SETTLEMENT



Earthen Containment Dike Design

UTILIZING MARSH CREATION AREA SETTLEMENT ANALYSIS RESULTS

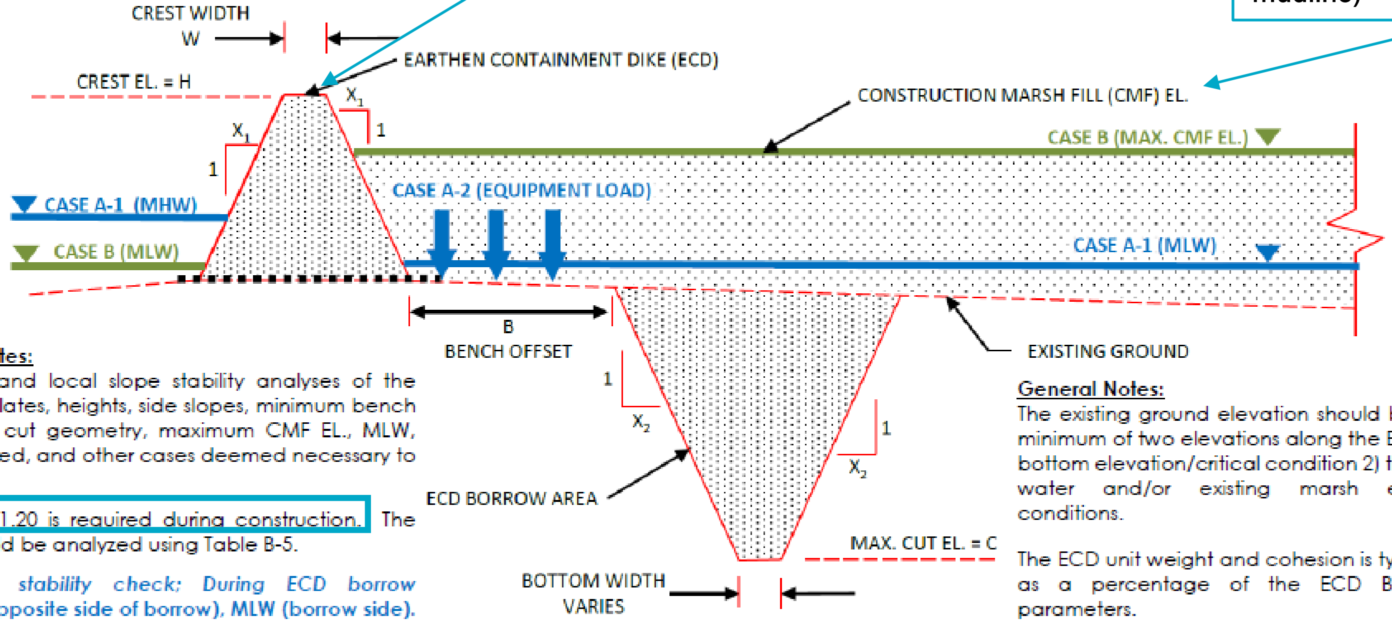


Earthen Containment Dike Design

SLOPE STABILITY ANALYSIS CASES

Maximum Scenario: set at 1-ft above maximum CMFE

Worst Case Scenario: set at maximum elevation determined from MCA settlement analysis (lower concentration, lower mudline)



Stability Analyses Notes:
Conduct a global and local slope stability analyses of the proposed ECD templates, heights, side slopes, minimum bench offset, borrow area cut geometry, maximum CMF EL., MLW, multi-lift CMF if required, and other cases deemed necessary to ensure ECD stability.

A minimum FOS of 1.20 is required during construction. The following cases should be analyzed using Table B-5.

CASE A-1: Global stability check; During ECD borrow excavation; MHW (opposite side of borrow), MLW (borrow side).

CASE A-2: Local stability check; During ECD borrow excavation; Distributed load from excavation equipment, MLW (borrow side).

CASE B: Dredged Material placed to CMF EL.; CMF (max. elevation), MLW (opposite side of borrow).

Figure B-5: Typical ECD Template.

General Notes:
The existing ground elevation should be analyzed at a minimum of two elevations along the ECD; 1) the lowest bottom elevation/critical condition 2) the average open water and/or existing marsh elevation/general conditions.

The ECD unit weight and cohesion is typically expressed as a percentage of the ECD Borrow Area soil parameters.

A distributed load of 260 psf is typically used based on large marsh hoe/marsh buggy equipment. The ECD is constructed in several lifts.

A geosynthetic reinforcement fabric may be utilized to achieve the minimum FOS.

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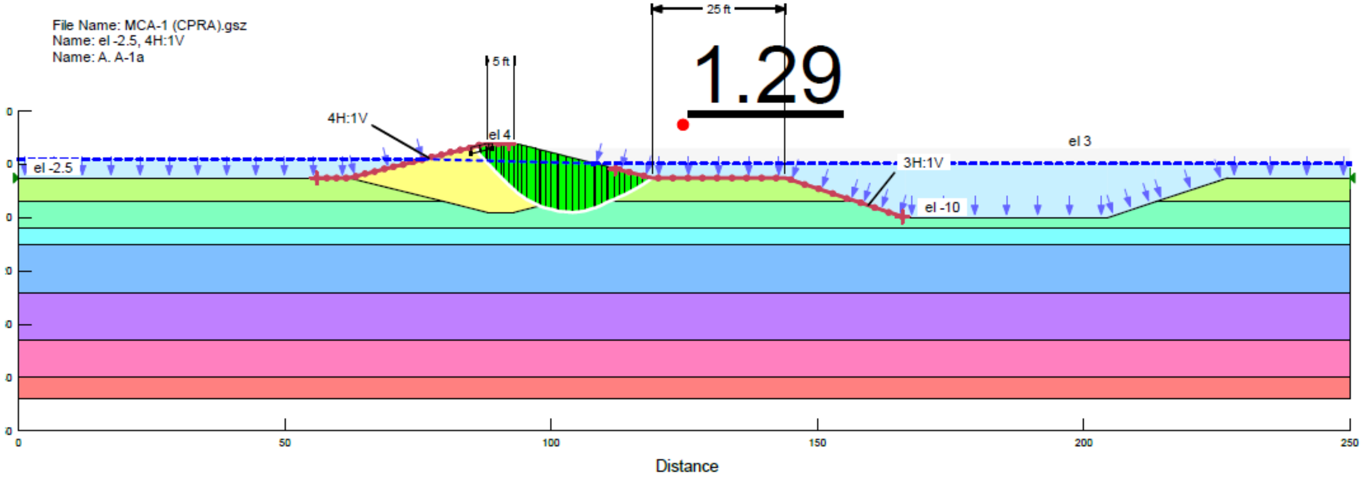
Earthen Containment Dike Design

SLOPE STABILITY ANALYSIS

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	CH el -15 to -24	Mohr-Coulomb	100	135	0	0	1
	CH el -24 to -33	Mohr-Coulomb	103	225	0	0	1
	CH el -40 to -44	Mohr-Coulomb	110	350	0	0	1
	CH el -7 to -12	Mohr-Coulomb	110	75	0	0	1
	ECD	Mohr-Coulomb	75	75	0	0	1
	ML el -12 to -15	Mohr-Coulomb	112	200	15	0	1
	ML el -33 to -40	Mohr-Coulomb	110	200	15	0	1
	PT/OH el -2 to -7	Mohr-Coulomb	70	60	0	0	1

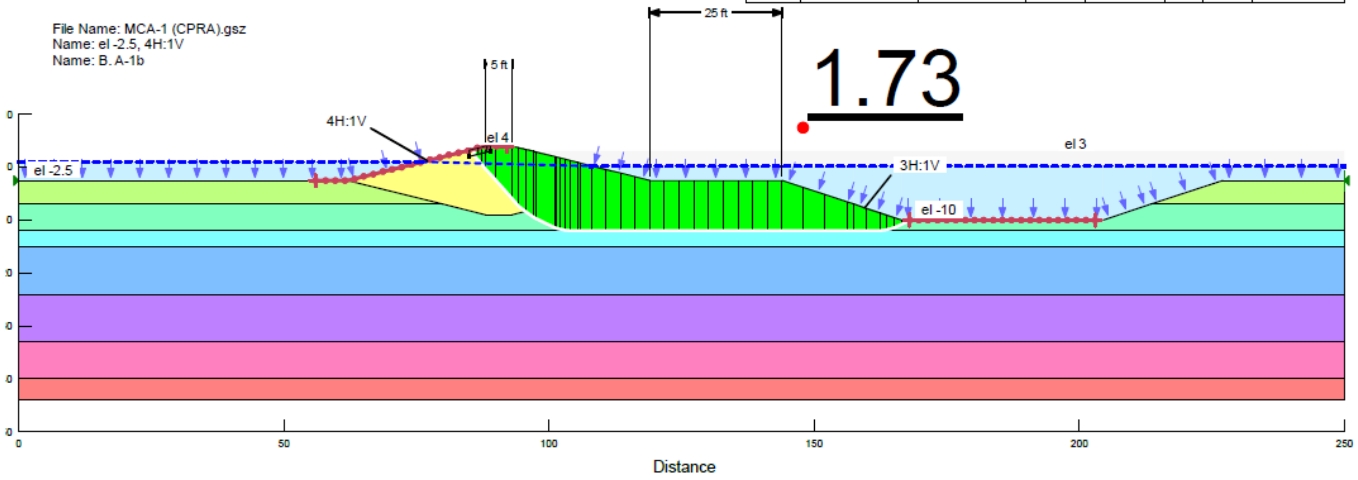


CASE A-1: GLOBAL STABILITY CHECK; DURING ECD BORROW EXCAVATION (FAILURE WITHIN THE ECD)

Earthen Containment Dike Design

SLOPE STABILITY ANALYSIS

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	CH el -15 to -24	Mohr-Coulomb	100	135	0	0	1
	CH el -24 to -33	Mohr-Coulomb	103	225	0	0	1
	CH el -40 to -44	Mohr-Coulomb	110	350	0	0	1
	CH el -7 to -12	Mohr-Coulomb	110	75	0	0	1
	ECD	Mohr-Coulomb	75	75	0	0	1
	ML el -12 to -15	Mohr-Coulomb	112	200	15	0	1
	ML el -33 to -40	Mohr-Coulomb	110	200	15	0	1
	PT/OH el -2 to -7	Mohr-Coulomb	70	60	0	0	1

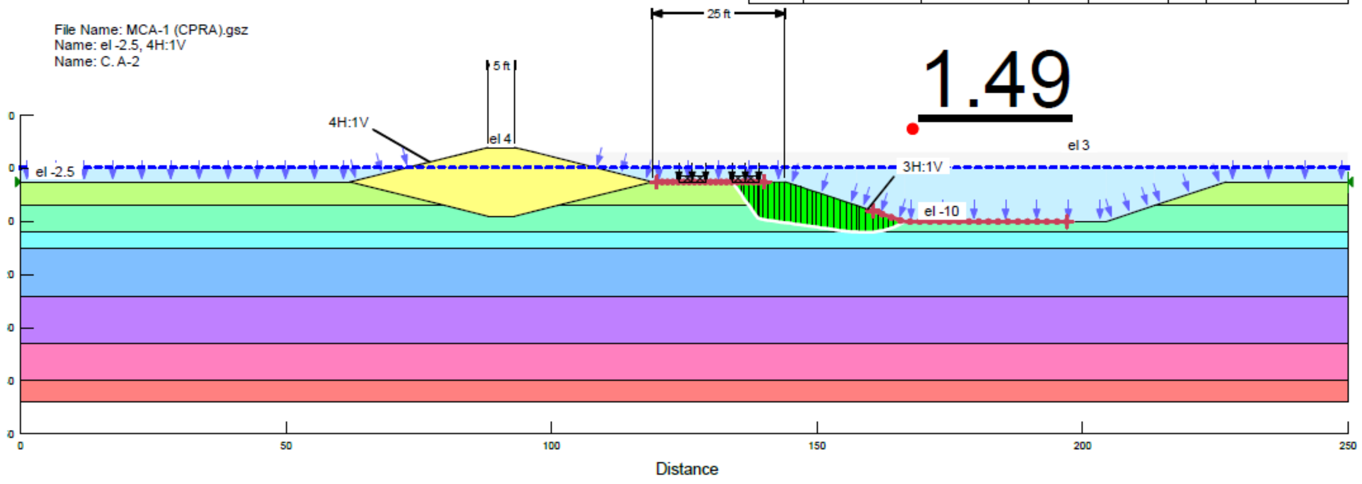


CASE A-1: GLOBAL STABILITY CHECK; DURING ECD BORROW EXCAVATION (FAILURE WITH RESPECT TO THE BORROW PIT)

Earthen Containment Dike Design

SLOPE STABILITY ANALYSIS

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	CH el -15 to -24	Mohr-Coulomb	100	135	0	0	1
	CH el -24 to -33	Mohr-Coulomb	103	225	0	0	1
	CH el -40 to -44	Mohr-Coulomb	110	350	0	0	1
	CH el -7 to -12	Mohr-Coulomb	110	75	0	0	1
	ECD	Mohr-Coulomb	75	75	0	0	1
	ML el -12 to -15	Mohr-Coulomb	112	200	15	0	1
	ML el -33 to -40	Mohr-Coulomb	110	200	15	0	1
	PT/OH el -2 to -7	Mohr-Coulomb	70	60	0	0	1

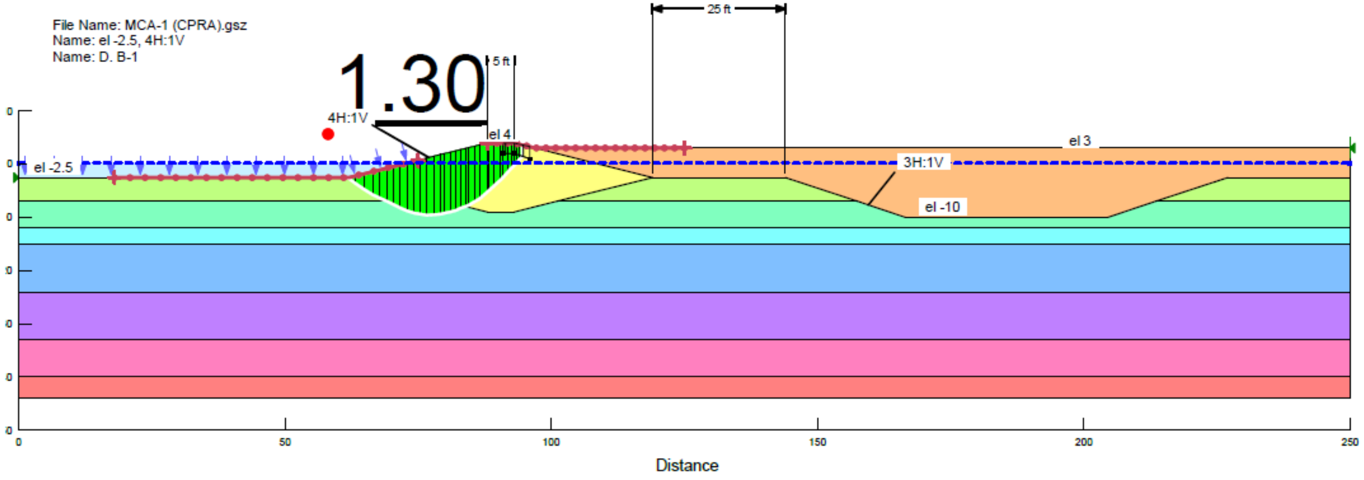


<u>CASE A-2: LOCAL STABILITY CHECK; DURING ECD BORROW EXCAVATION; DISTRIBUTED LOAD FROM EXCAVATION EQUIPMENT</u>

Earthen Containment Dike Design

SLOPE STABILITY ANALYSIS

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)	Piezometric Line
	CH el -15 to -24	Mohr-Coulomb	100	135	0	0	1
	CH el -24 to -33	Mohr-Coulomb	103	225	0	0	1
	CH el -40 to -44	Mohr-Coulomb	110	350	0	0	1
	CH el -7 to -12	Mohr-Coulomb	110	75	0	0	1
	ECD	Mohr-Coulomb	75	75	0	0	1
	ML el -12 to -15	Mohr-Coulomb	112	200	15	0	1
	ML el -33 to -40	Mohr-Coulomb	110	200	15	0	1
	PT/OH el -2 to -7	Mohr-Coulomb	70	60	0	0	1
	Sand Fill	Mohr-Coulomb	115	0	28	0	1



CASE B: DREDGE MATERIAL PLACED TO CMFE (MAXIMUM)

Earthen Containment Dike Design

CONSIDERATIONS FOR SLOPE STABILITY ANALYSIS

- There are multiple ways to model construction equipment for the settlement analysis
  - Continuous strip load (more conservative) vs. two separate strip loads to model equipment tracks
  - Accounting for buoyancy

- It is generally preferred to build ECDs larger than to include geotextile fabrics:
  - Installation of fabric is difficult.
  - Increases overall cost of the project.
  - Creates O&M concerns.

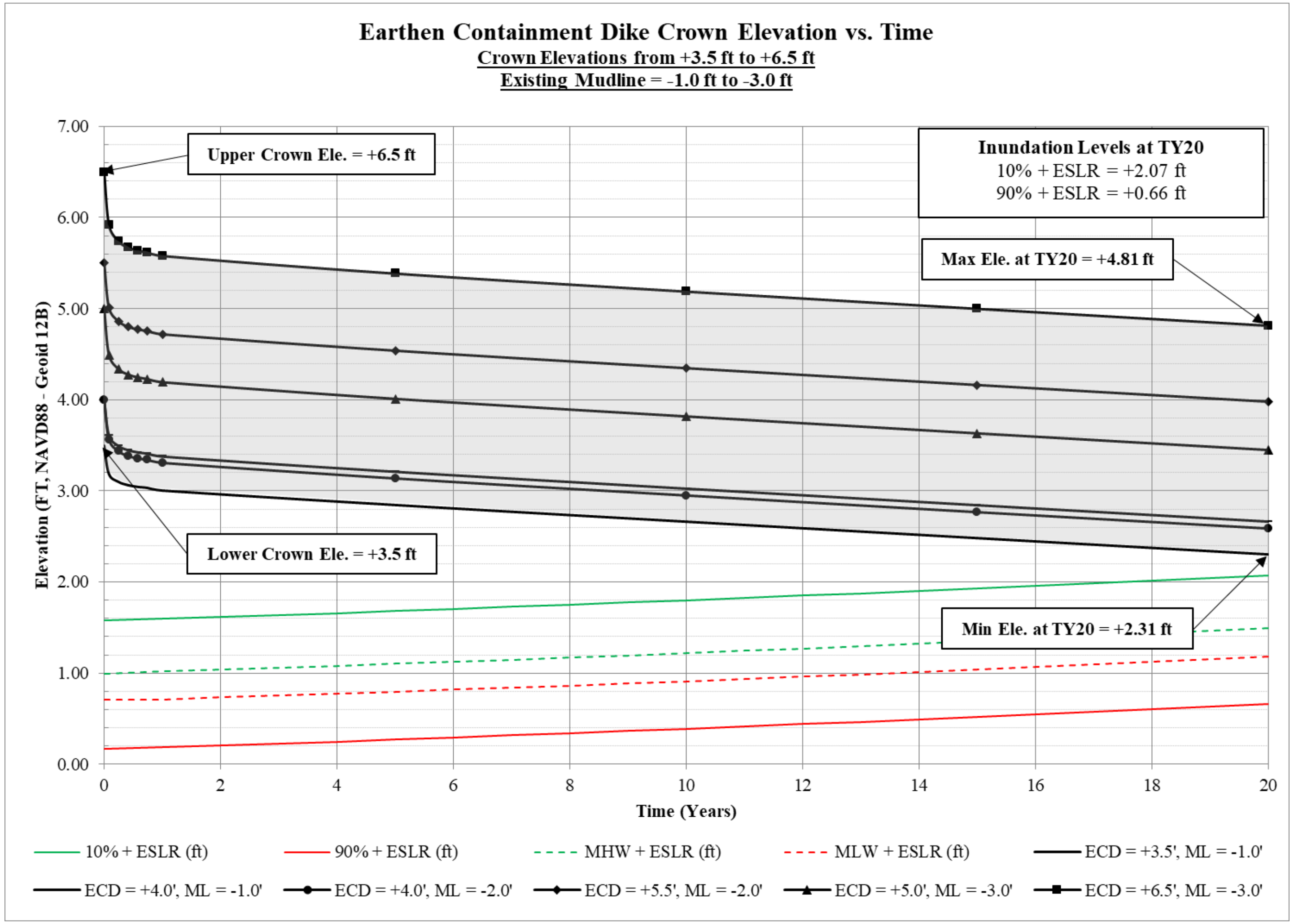
- Hay bales and/or sheet pile design may be necessary depending on geotechnical conditions and mudline elevations.

- Accounting for potential mud-waving of surficial organic layers can be analyzed in multiple ways:
  - Assume material is displaced, and the existing mudline is now deeper.
  - Include in stability analysis and estimate geotechnical properties.

- Shear strength gain between lifts can help increase factors of safety.

Earthen Containment Dike Design

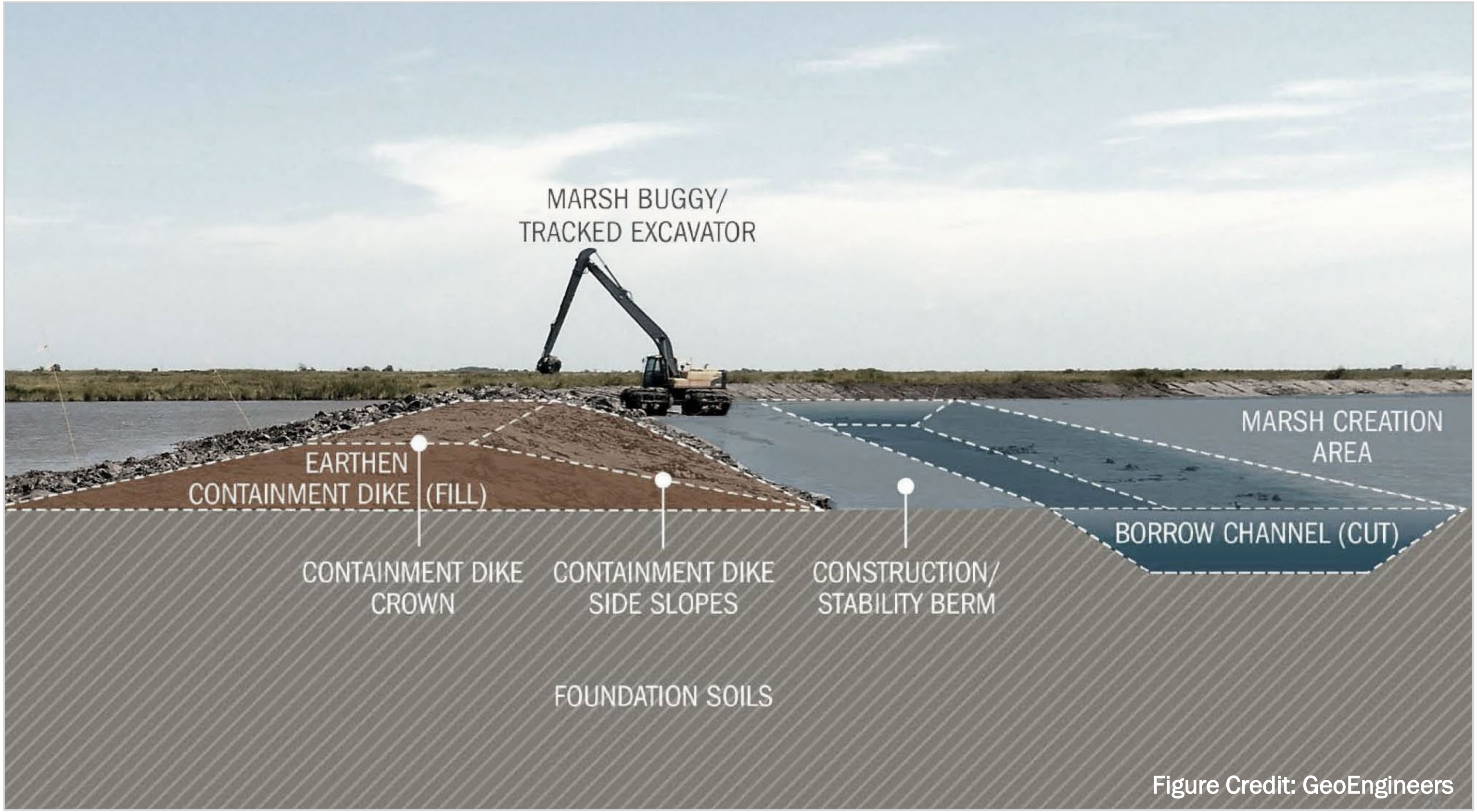
SETTLEMENT ANALYSIS RESULTS



Earthen Containment Dike Design

TAKEAWAYS

- A slight deviation in expected soil characteristics or assumed construction conditions or practices will likely require a re-analysis.
- Marsh creation and earthen containment design feed into each other.
- Modeling the mudwave is difficult.
- Construction monitoring is important to make adjustments on the fly.
- <u>It is critical for the design engineer to be in communication with the geotechnical consultant.</u>



Construction Geotech

Construction Practices

APPLYING TO CHANGING CONDITIONS

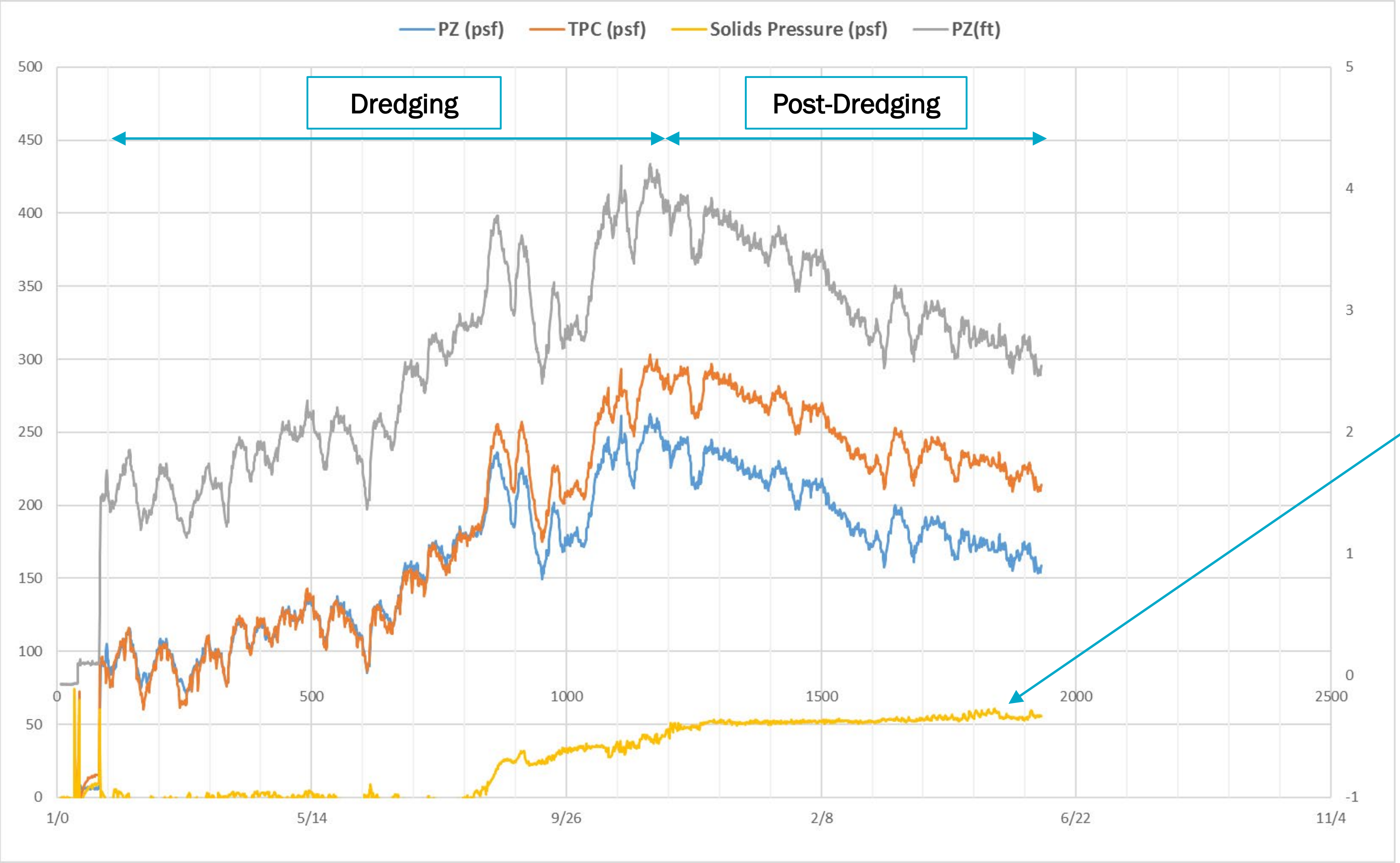
- Field sampling of dredge slurry allows for settlement curve adjustments during construction.
- Sampling of the constructed ECD may be necessary to make adjustments to slope stability or settlement analyses should issues arise.
- Instrumented settlement plates provide insight into effective and total stresses present during dredging operations that can be used to evaluate the project during construction.
- Piezometers can be used to monitor pore pressure dissipation and inform earthen containment dike lift schedules.
- Settlement plate data can be used to gain insight on potential future projects in the vicinity.

Construction Practices

ADAPTING TO CHANGING CONDITIONS – INSTRUMENTED SETTLEMENT PLATES (ISP)

Construction Practices

ADAPTING TO CHANGING CONDITIONS – INSTRUMENTED SETTLEMENT PLATES (ISP)



Solids pressure can be used to determine if enough soil solids have been placed to meet project goals

Conclusions and Takeaways

GEOTECHNICAL DESIGN OF MARSH CREATION PROJECTS

- Soft soils on marsh creation projects are softer than you may think.
  - Shear strength values less than 100-150 psf are very common in the upper 10-15 feet of marsh creation project.
  - A majority of projects contain surficial peat and organic clay layers that make design and construction challenging.

- Marsh creation settlement (and even containment design) is a dynamic process.
  - A large number of assumptions have to be made in order to generate estimates of settlement.
  - A slight deviation in expected soil characteristics or assumptions may require a re-analysis of settlement.

- Earthen containment and marsh creation design feed into each other. The analyses inform each other.

- Data collection and analysis during construction allow for adjustments on the fly.
  - ISP data can help make informed decisions on marsh elevation and quantities in real time.
  - Field sampling of slurry or ECD materials can be used to make adjustments to design analyses.

- <u>It is critical for the design engineer to remain in communication with the geotechnical consultant.</u>

Thank You

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