Intensive Management of Dredged Material to Maximize Storage Capacity of a Confined Disposal Facility in Savannah Harbor, Georgia – A Success Story

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Presentation Outline

- Project Location and Background
- Dredging-Related Infrastructure at Elba Island
- Dredging and Disposal Challenges
- Prediction of DMCAs Life
- Evaluation of Disposal Options
- **Implementation of Intensive DMCA Management**
- Conclusions & Recommendations
- Questions

Project Location

Project Background - Site History and Operations

- Elba Island - Historical Island in Savannah River, predominantly salt marsh
- Converted to a dredge material disposal area post WWII
- LNG Facility was established in 1978 and recommissioned in 2001
- 1 of 8 LNG delivery terminals in nation
  0.3 billion m^3 (11.2 billion ft^3) of LNG storage

- July 2003 - Feb 2006: Elba II Expansion Construction and in Service
- Sep 2006 - 2010: Elba III Expansion Phase A Construction and in Service
- 2014 - 2015: Elba III Expansion Phase B – Cancelled
- 2013 - 2016: Elba Liquefaction Project – Design, FERC Permitting, Construction, and in Service

Elba Liquefaction Project

Dredging-Related Infrastructure

- **Turning Basin** – Approx. 13 ha (33 ac) conforming with U.S. Coast Guard minimum (FERC Recommendation)
- **Ship Slip** – Approx. 18 ha (44 ac), berths for 2 ships simultaneously
- **DMCA 1** – Approx. 52 ha (130 ac), dike last raised 2011, current dike elevation of 15.2 m (50 ft) MLW, being used for disposal
- **DMCA 2** – Approx. 48 ha (120 ac), dike last raised 2009, being **intensively managed for drying and material harvesting** since 2011, current dike elevation of 13.4 m (44 ft) MLW

Ship Slip and Turning Basin

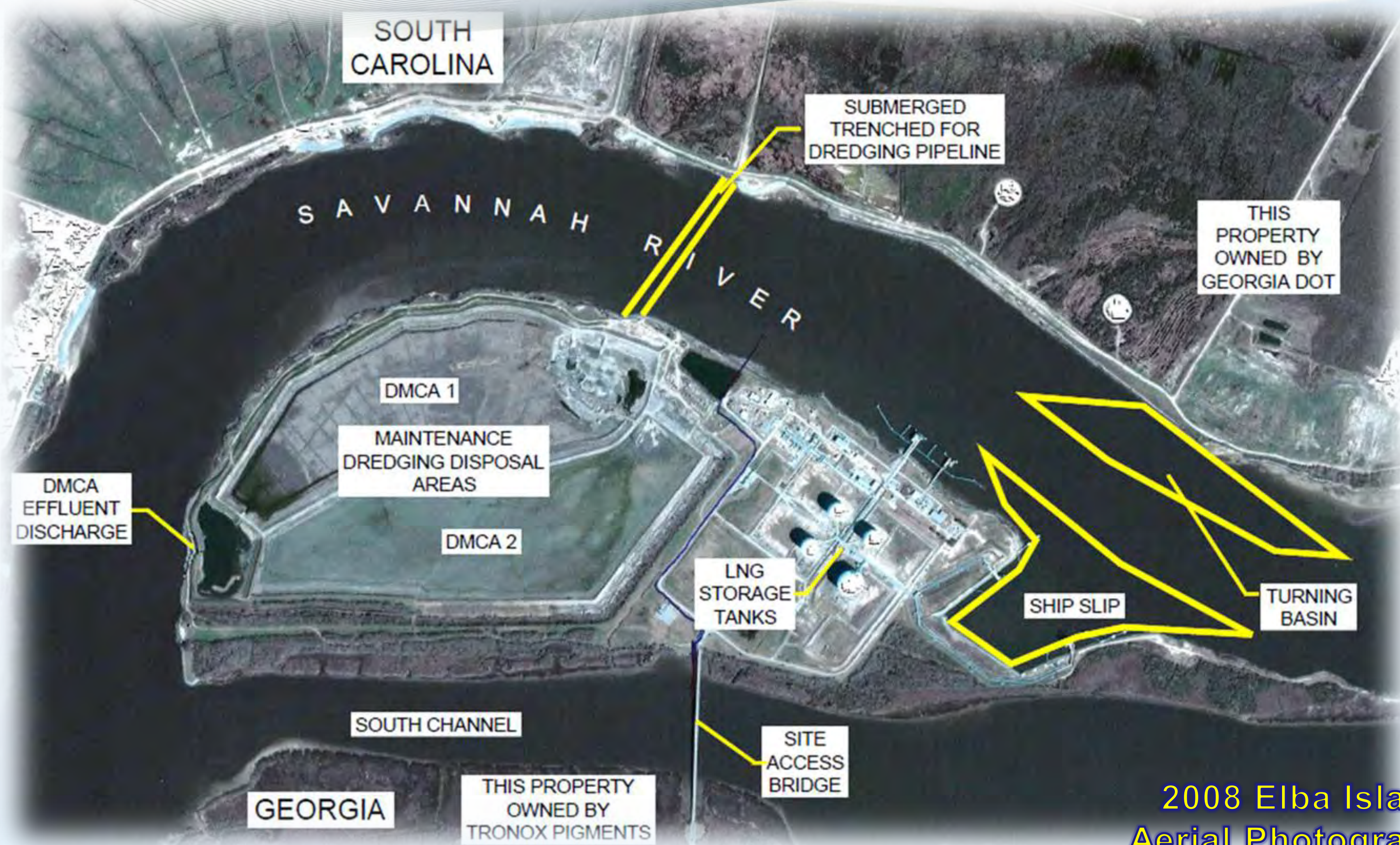
Dual Ship Off-loading

Confined Disposal Facilities (DMCAs)

Permit Requirements

- Ship Slip
  - -13.4 m (-44 ft) ***min*** to -14 m (-46 ft) ***max***, MLW dredge depth
  - 0.6 m (2 ft) allowable overdredge
  - 344,000 m^3 (450,000 yd^3) annual dredge volume
- Turning Basin
  - -12.2 m (-40 ft) ***min*** to -12.8 m (-42 ft) ***max***, MLW dredge depth
  - -0.6 m (2 ft) allowable overdredge
  - 612,000 m^3 (800,000 ft^3) annual dredge volume
- Hydraulic cutterhead dredge with upland disposal

2014 Dredging Permit



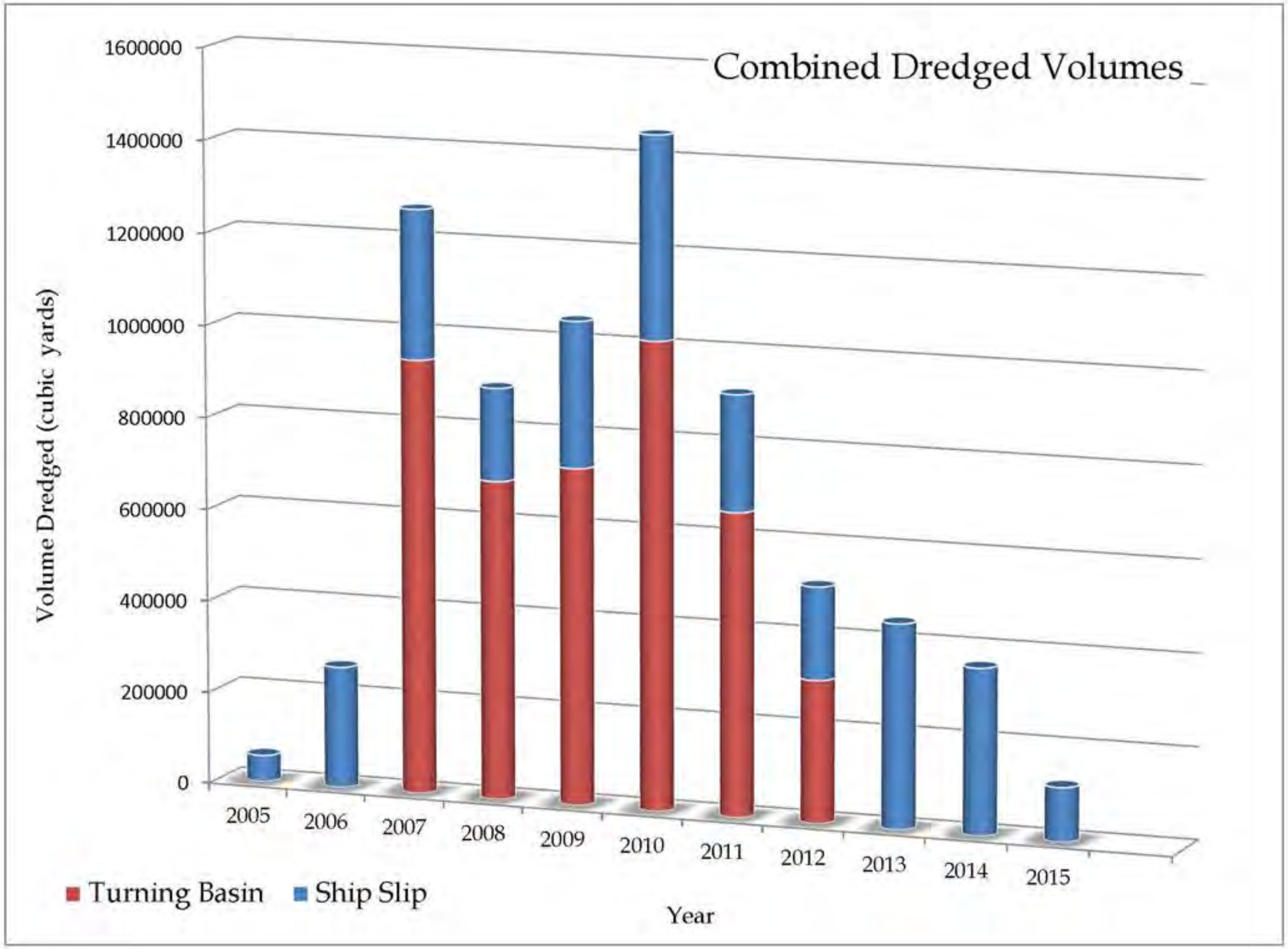
2008 Elba Island Aerial Photograph

Hydraulic Cutterhead Dredge

Contractual Obligations

- Maintain required dredged depths year round
  - -11.6 m (-38 ft) MLW minimum
  - 0.15 m (0.5 ft) under keel clearance
- Post-Panamax vessels (Q_{max} and Q_{flex})
  - -12.2 m (-40 ft) MLW drafts
  - 0.6 m (2 ft) under keel clearance
- Typical 1-month notification of LNG Tanker ship coming
- With liquefaction, ships will leave more frequently
- Huge Financial Penalty if ship cannot come or dock

Historical Maintenance Dredging Volumes



Disposal Challenges

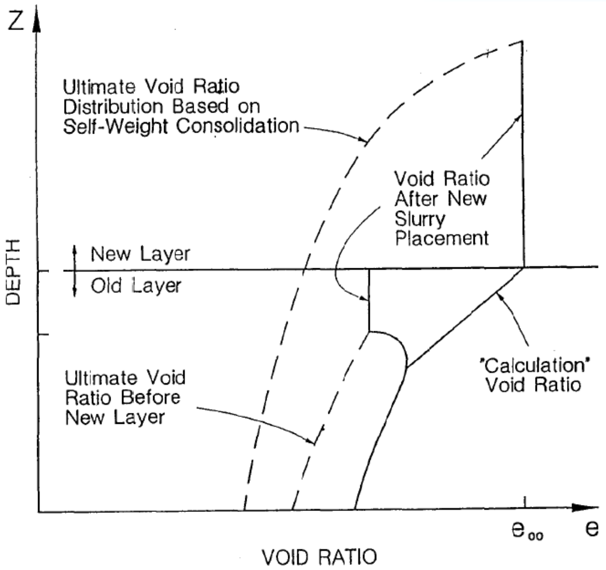
- Long-Term Dredged Material Management Plan (DMMP)
  - Prediction of DMCAs Life using PSDDF Software Program by USACE
- Impact of Increased Frequency of Dredging
  - Rapid Filling of DMCAs
  - Less Time for Consolidation and Desiccation
  - Changes to Dike Raising Schedules
- Dike Raising Constraints
  - Maximum Dike Height of 18.9 to 20.7 m (62 to 68 ft) MLW
  - Stability Constraints (marginal FS at 20.7 m (68 ft) MLW)
  - Availability of Fill Material

Prediction of Storage Capacity & Life

- Objective is to calculate how in-situ sediment volumes in river convert to in-situ dredged material volumes in DMCA over time
- Need to know:
  - Void ratios of sediment in river and dredged material after water decantation
  - Desiccation Limit of dredged material
  - Relationship between void ratio and hydraulic conductivity and between void ratio and effective stress for dredged material
- Analyze dredging disposal and drying cycles using USACE model PSDDF (*Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill*)

Prediction of DMCA Life Theoretical Background

- Primary Consolidation: governing equation
  - $$\left(\frac{\gamma_s}{\gamma_w}-1\right)\frac{d}{de}\left[\frac{k(e)}{1+e}\right]\frac{\partial e}{\partial z}+\frac{\partial}{\partial z}\left[\frac{k(e)}{\gamma_w(1+e)}\frac{d\sigma'}{de}\frac{\partial e}{\partial z}\right]+\frac{\partial e}{\partial t}=0$$
    - *k(e)* is the coefficient of soil permeability as a function of void ratio *(e)*
- Secondary Compression
  - $$S_s=\frac{C_\alpha}{(1+e_0)}(h)log\left(\frac{t}{t_p}\right)$$
- Desiccation Processes
  - $$\Delta W'=CS-(C_E'\cdot EP)+(1-C_D)RF$$
    - ΔW' is the water lost during first-stage drying,
    - CS is water supplied from lower consolidating soil,
    - C_E' is the maximum evaporation efficiency,
    - EP is Class A pan evaporation,
    - C_D is the drainage efficiency, and RF is the rainfall



Void ratio distribution immediately after placement of new lift (Cargill 1985)

Site-Specific Geotechnical Data

Measured Specific Gravity Values of Dredged Material from DMCAs

Sample ID	Measured G_s	Reference
Comp. B	2.552	June, 2011, Composite sample near weir of Samples 5 & 6
Comp. C	2.407	June, 2011, Composite sample from Pit 2 of Samples 8 & 9
P41-06	2.631	April, 2012, Jar sample 6" below desiccated crust in DMCA 2
P41-12	2.583	April, 2012, Jar sample 12" below desiccated crust in DMCA 2
P42-06	2.641	April, 2012, Jar sample 6" below desiccated crust in DMCA 2
P42-12	2.609	April, 2012, Jar sample 12" below desiccated crust in DMCA 2
P43-06	2.619	April, 2012, Jar sample 6" below desiccated crust in DMCA 2
P43-12	2.585	April, 2012, Jar sample 12" below desiccated crust in DMCA 2
P44-06	2.599	April, 2012, Jar sample 6" below desiccated crust in DMCA 2
P44-12	2.657	April, 2012, Jar sample 12" below desiccated crust in DMCA 2
A2 @ 9 ft	2.552	December 2013, Tube sample at berm outside DMCA 2
A3 @ 9 ft	2.537	December 2013, Tube sample at berm outside DMCA 2
A5 @ 3 ft	2.572	December 2013, Tube sample at berm outside DMCA 2

Average of measured: **G_s = 2.580**

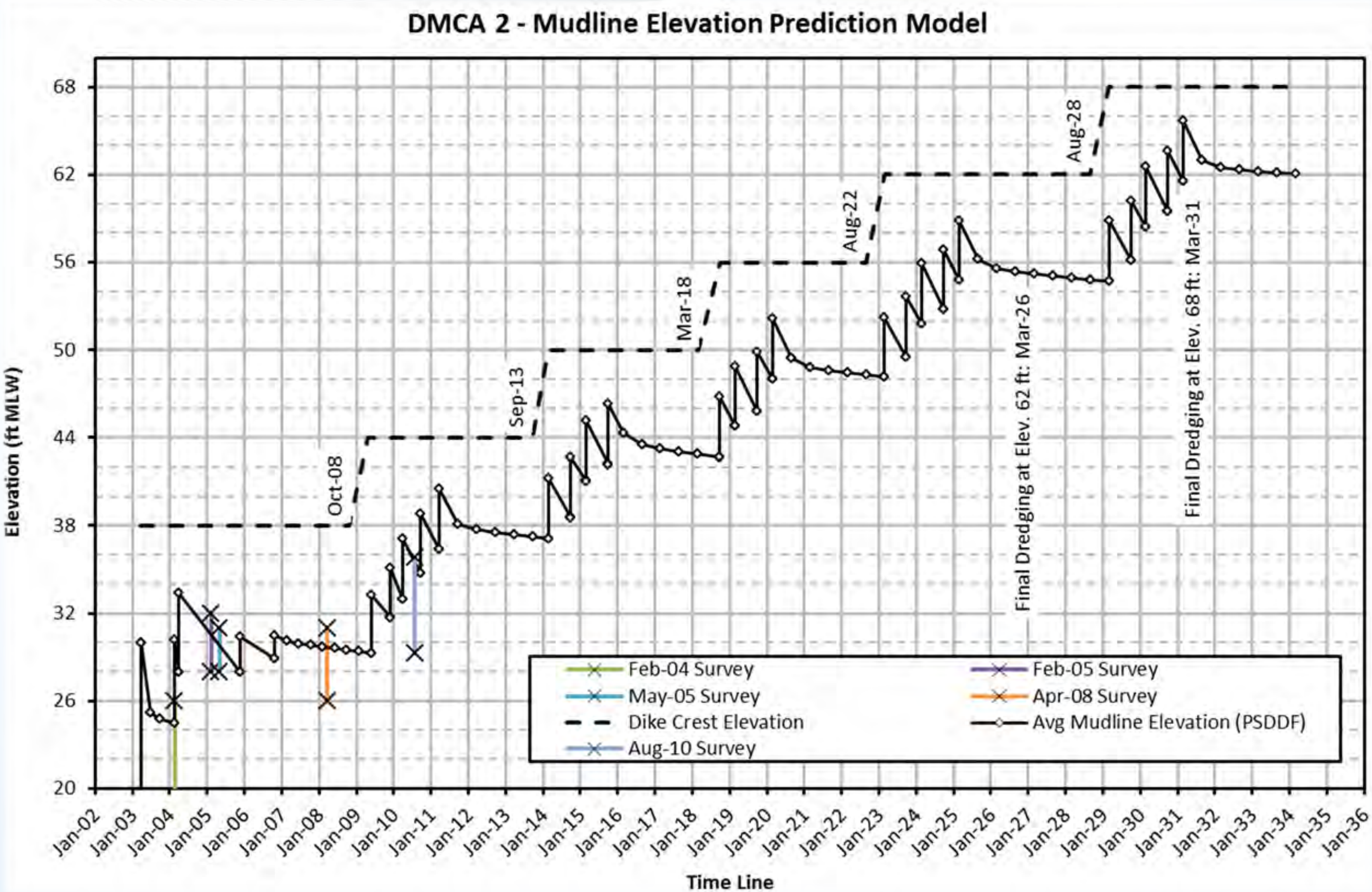
Site-Specific Geotechnical Data

Sample ID	Measured w (%)	Calculated e	Reference
TB-01	228.6	5.9	2011 Tier II Sediment Investigation
TB-02	294.9	7.6	2011 Tier II Sediment Investigation
TB-03	279.9	7.2	2011 Tier II Sediment Investigation
TB-04	248.9	6.4	2011 Tier II Sediment Investigation
TB-05	231.8	6.0	2011 Tier II Sediment Investigation
SS-09	250.0	6.4	2011 Tier II Sediment Investigation
SS-10	265.0	6.8	2011 Tier II Sediment Investigation
SS-11	317.3	8.2	2011 Tier II Sediment Investigation
SS-12	331.5	8.6	2011 Tier II Sediment Investigation
L1D1	405.7	10.5	2013 Bed-Leveling Research
L1D2	415.2	10.7	2013 Bed-Leveling Research
L2D1	375.6	9.7	2013 Bed-Leveling Research
Average of calculated:		e = 7.8	

Calculated Void Ratios of Sediments and Dredged Material

Sample ID	Measured Water Content, w	Calculated, e	Reference
Weir-5	399.2	10.3	Sample near the weir end of DMCA 1
Weir-6	422.2	10.9	Sample near the weir end of DMCA 1
Pit 2-7	391.7	10.1	Sample ¼ DMCA length from dredge pipe
Pit 2-8	429.8	11.1	Sample ¼ DMCA length from dredge pipe
Pit 2-9	440.9	11.4	Sample ¼ DMCA length from dredge pipe
Pit 2-10	400.1	10.3	Sample ¼ DMCA length from dredge pipe
Average of calculated:		e = 10.7	

DMCAs Life Prediction Using PSDDF Model



DMCAs Life Prediction Using PSDDF Model

<table>
<tr><th rowspan="3">Cases</th><th rowspan="3">Comments</th><th rowspan="3" colspan="2">Dredging Event</th><th rowspan="2" colspan="2">Thickness Deposited (ft)</th><th colspan="2">Estimated Life Expectancy</th></tr>
<tr><th>DMCA 1</th><th>DMCA 2</th></tr>
<tr><th>DMCA 1</th><th>DMCA 2</th><th>El. 62 ft</th><th>El. 62 ft</th></tr>
<tr><td rowspan="2">Case 1</td><td rowspan="2">2 dredging events per year: SS and TB</td><td>1</td><td>April</td><td>3.94</td><td>4.22</td><td rowspan="2">Apr-25</td><td rowspan="2">Oct-24</td></tr>
<tr><td>2</td><td>October</td><td>3.94</td><td>4.22</td></tr>
<tr><td rowspan="3">Case 2</td><td rowspan="3">3 dredging events per year: SS and TB</td><td>1</td><td>March</td><td>2.63</td><td>2.82</td><td rowspan="3">Jul-25</td><td rowspan="3">Nov-24</td></tr>
<tr><td>2</td><td>July</td><td>2.63</td><td>2.82</td></tr>
<tr><td>3</td><td>November</td><td>2.63</td><td>2.82</td></tr>
<tr><td rowspan="3">Case 3</td><td rowspan="3">3 dredging events per year: SS</td><td>1</td><td>March</td><td>1.07</td><td>1.15</td><td rowspan="3">Mar-49</td><td rowspan="3">Jul-50</td></tr>
<tr><td>2</td><td>July</td><td>1.07</td><td>1.15</td></tr>
<tr><td>3</td><td>November</td><td>1.07</td><td>1.15</td></tr>
<tr><td rowspan="3">Case 4</td><td rowspan="3">3 dredging events per year: SS
2 dredging events per year: TB</td><td>1</td><td>March</td><td>3.4</td><td>3.65</td><td rowspan="3">Mar-25</td><td rowspan="3">Mar-27</td></tr>
<tr><td>2</td><td>July</td><td>3.4</td><td>3.65</td></tr>
<tr><td>3</td><td>November</td><td>1.07</td><td>1.15</td></tr>
<tr><td colspan="8">Notes: SS = Ship Slip; TB = Turning Basin</td></tr>
</table>

Evaluation of Disposal Options

- **Bed leveling (agitation dredging) in ship slip**
  - Research (NW 5) Permit issued in January 2012
  - Study Period: April 2012 thru May 2013
  - Allow more drying time in DMCA by increasing time between dredging events
- **Negotiations with USACE & GDOT**
  - Use of SC DMCAs for dredged material disposal
  - Ship Slip and Turning Basin are for a single user
- **Ocean Disposal**
- **Intensive management of DMCA drainage and dredged material harvesting**
  - Concepts developed during last DMCA 1 dike raising in 2011
  - Concepts currently being implemented in DMCA 2 since 2011
  - Final objective is system steady state where volume capacity of DMCA is perpetually restored between dredging

Concept of Intensive DMCA Management

- Rapid removal of decanted water and constant removal of rainfall and drainage water
- Use of specialty equipment to remove dredged material at perimeter to promote more rapid development of interior desiccated crust
- Continued removal of desiccated crust within approximately 60 m (200 ft) DMCA perimeter
- Development of interior borrow pits for material mining as possible
- Hauling desiccated and consolidated material to stockpile areas outside DMCAs for further drying and processing

Construction Equipment Being Used

- Marsh (Swamp) Buggies – 2
- Long-Reach Excavators – 4
- Trackhoe Excavator – 1
- 25-ton Off-Road Trucks – 2 to 4
- Track Harrow (for disking) – 2
- Bulldozers – 2

Implementation – Decanted Water

Implementation – Marsh Buggy

Implementation – Long-Reach Excavators

Implementation – Marsh Buggy

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Implementation – Marsh Buggy

Implementation – Track Harrow

Implementation – Dozer

Tracking Consolidation and Settlement

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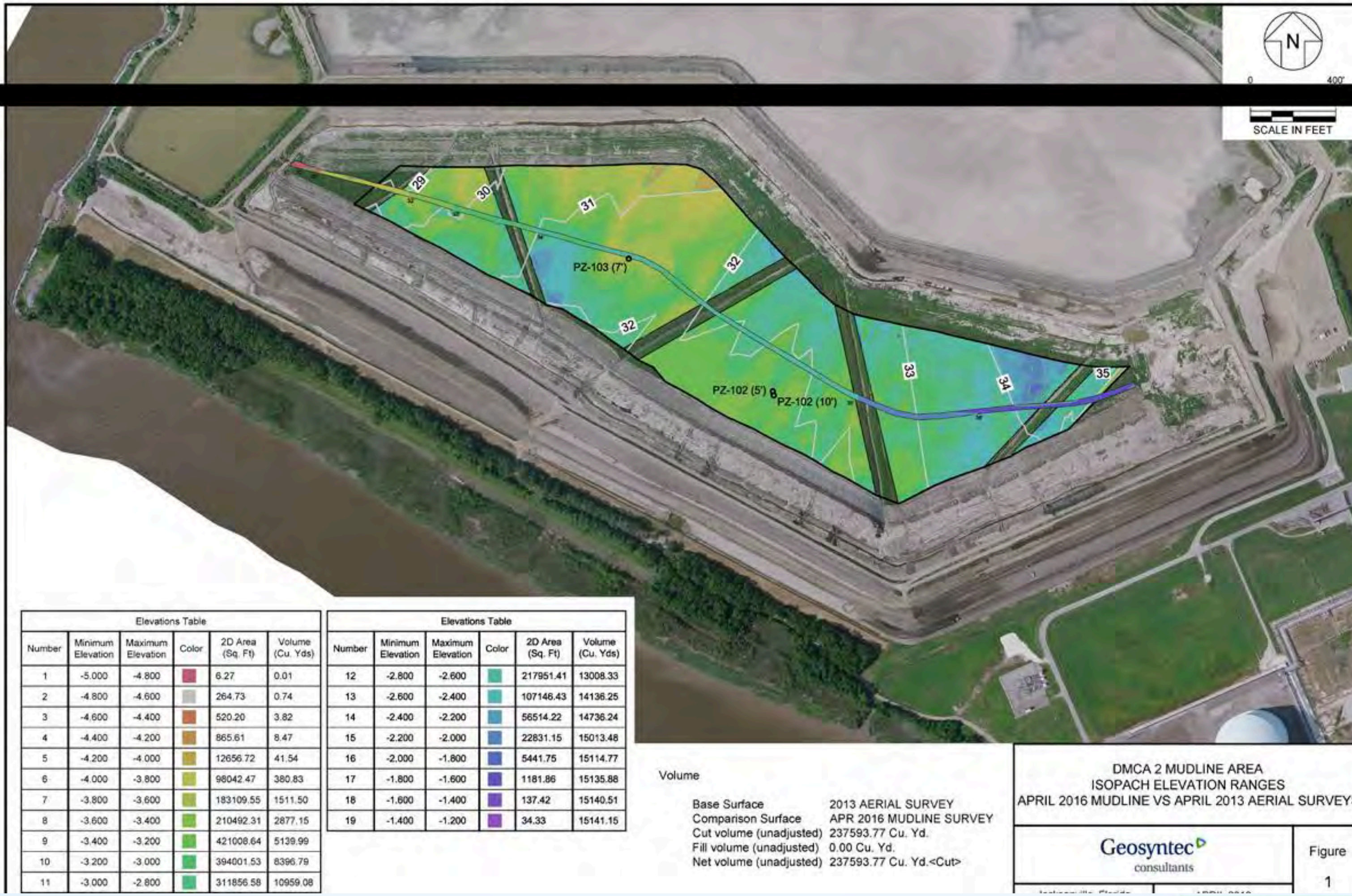

Elevations Table					
Number	Minimum Elevation	Maximum Elevation	Color	2D Area (Sq. Ft)	Volume (Cu. Yds)
1	-5.000	-4.800		6.27	0.01
2	-4.800	-4.600		264.73	0.74
3	-4.600	-4.400		520.20	3.82
4	-4.400	-4.200		865.61	8.47
5	-4.200	-4.000		12656.72	41.54
6	-4.000	-3.800		98042.47	380.83
7	-3.800	-3.600		183109.55	1511.50
8	-3.600	-3.400		210492.31	2877.15
9	-3.400	-3.200		421008.64	5139.99
10	-3.200	-3.000		394001.53	8396.79
11	-3.000	-2.800		311856.58	10959.08

Elevations Table					
Number	Minimum Elevation	Maximum Elevation	Color	2D Area (Sq. Ft)	Volume (Cu. Yds)
12	-2.800	-2.600		217951.41	13008.33
13	-2.600	-2.400		107146.43	14136.25
14	-2.400	-2.200		56514.22	14736.24
15	-2.200	-2.000		22831.15	15013.48
16	-2.000	-1.800		5441.75	15114.77
17	-1.800	-1.600		1181.86	15135.88
18	-1.600	-1.400		137.42	15140.51
19	-1.400	-1.200		34.33	15141.15

Volume

Base Surface	2013 AERIAL SURVEY
Comparison Surface	APR 2016 MUDLINE SURVEY
Cut volume (unadjusted)	237593.77 Cu. Yd.
Fill volume (unadjusted)	0.00 Cu. Yd.
Net volume (unadjusted)	237593.77 Cu. Yd.<Cut>

DMCA 2 MUDLINE AREA
ISOPACH ELEVATION RANGES
APRIL 2016 MUDLINE VS APRIL 2013 AERIAL SURVEYS

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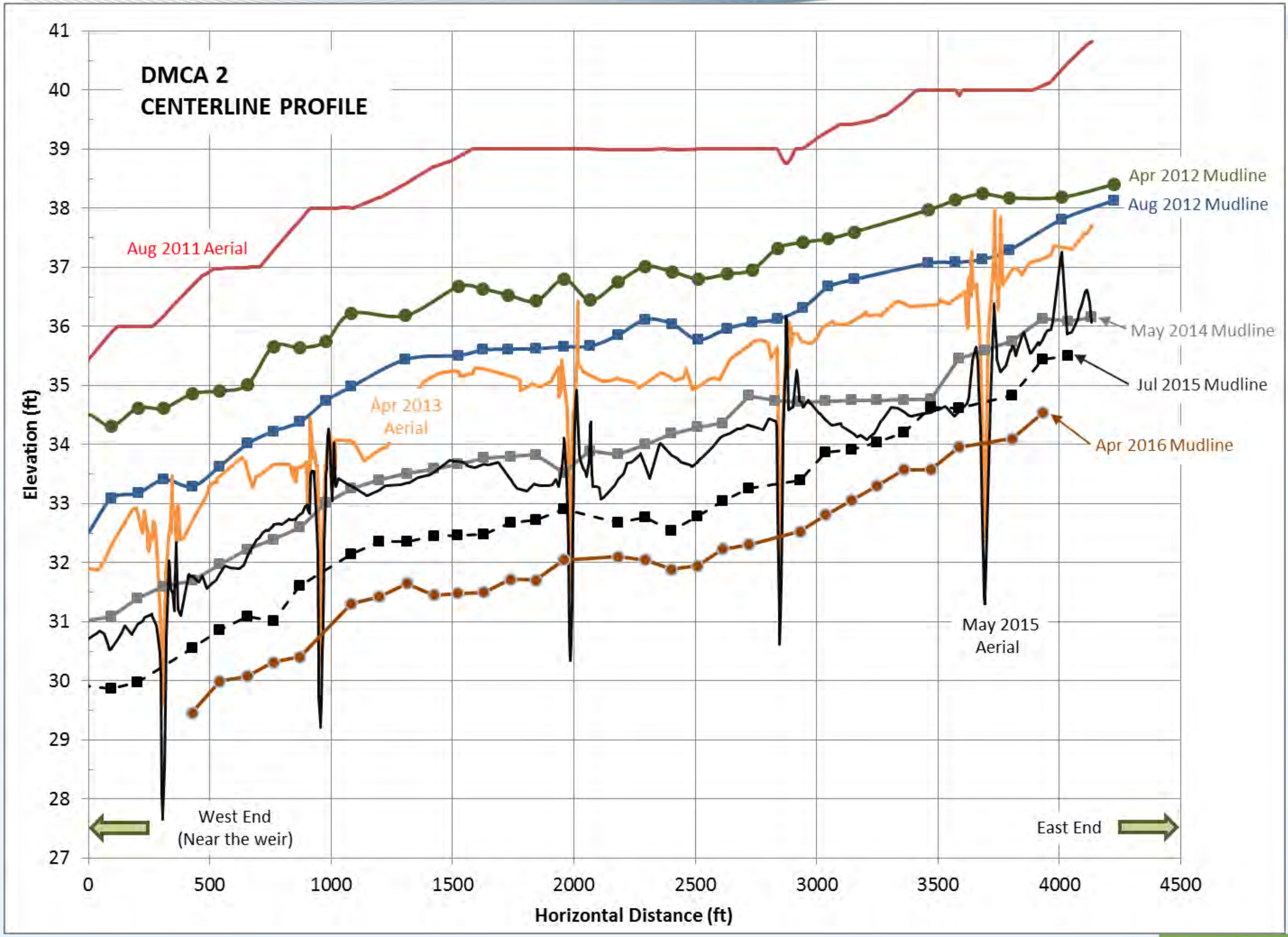
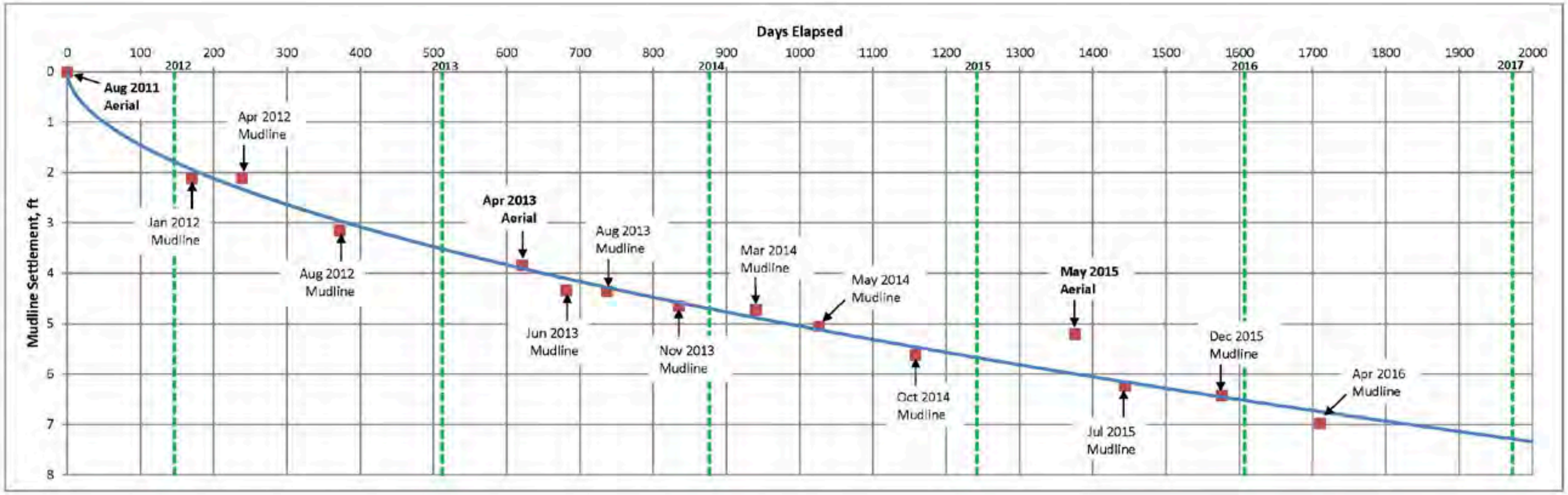
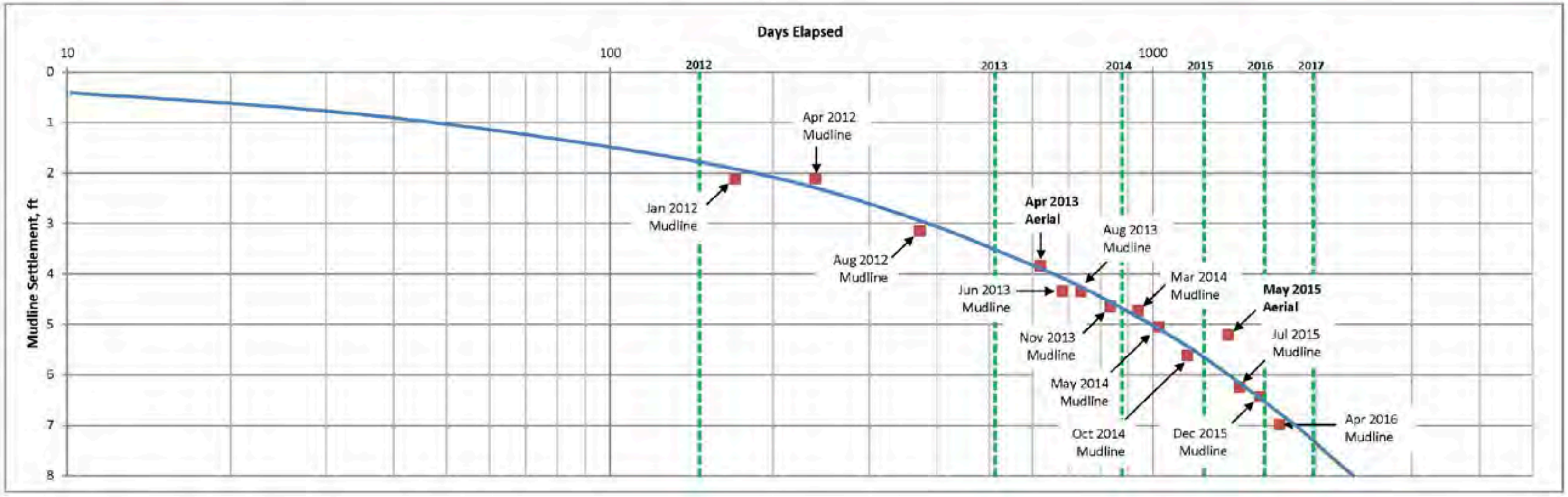
Figure 1

On-going Settlement in DMCA 2



Consolidation/Desiccation Settlement in DMCA 2





Material Harvesting Efforts in DMCA 2

Survey Date	DMCA 2 Capacity to El. 40 ft MLW (CY)	Net Capacity Increased (CY)	Cost	$/CY of Capacity Gained	Dike Raising Equivalent to Capacity Gained (ft)
August 2011	316,279	N/A	N/A	N/A	N/A
April 2013	1,285,361	969,082	$ 2,546,936	$ 2.63	4.8
May 2015	1,946,142	660,781	$ 5,180,006	$ 7.84	3.3
TOTAL	**N/A**	**1,629,863**	**$ 7,726,942**	**$ 4.74**	**8.0**

Survey Date	Material Harvested (CY)	Material Stockpiled (CY)	Material Recovery (%)	$/CY of Material Harvested	$/CY of Material Generated
August 2011	N/A	N/A	N/A	N/A	N/A
April 2013	405,399	NM(2)	NM(2)	$ 6.28	NM(2)
May 2015	459,862	253,930	55%	$ 11.26	$ 20.40
TOTAL	**865,262**	**NM(2)**	**NM(2)**	**$ 8.93**	**NM(2)**

Conclusions & Recommendations

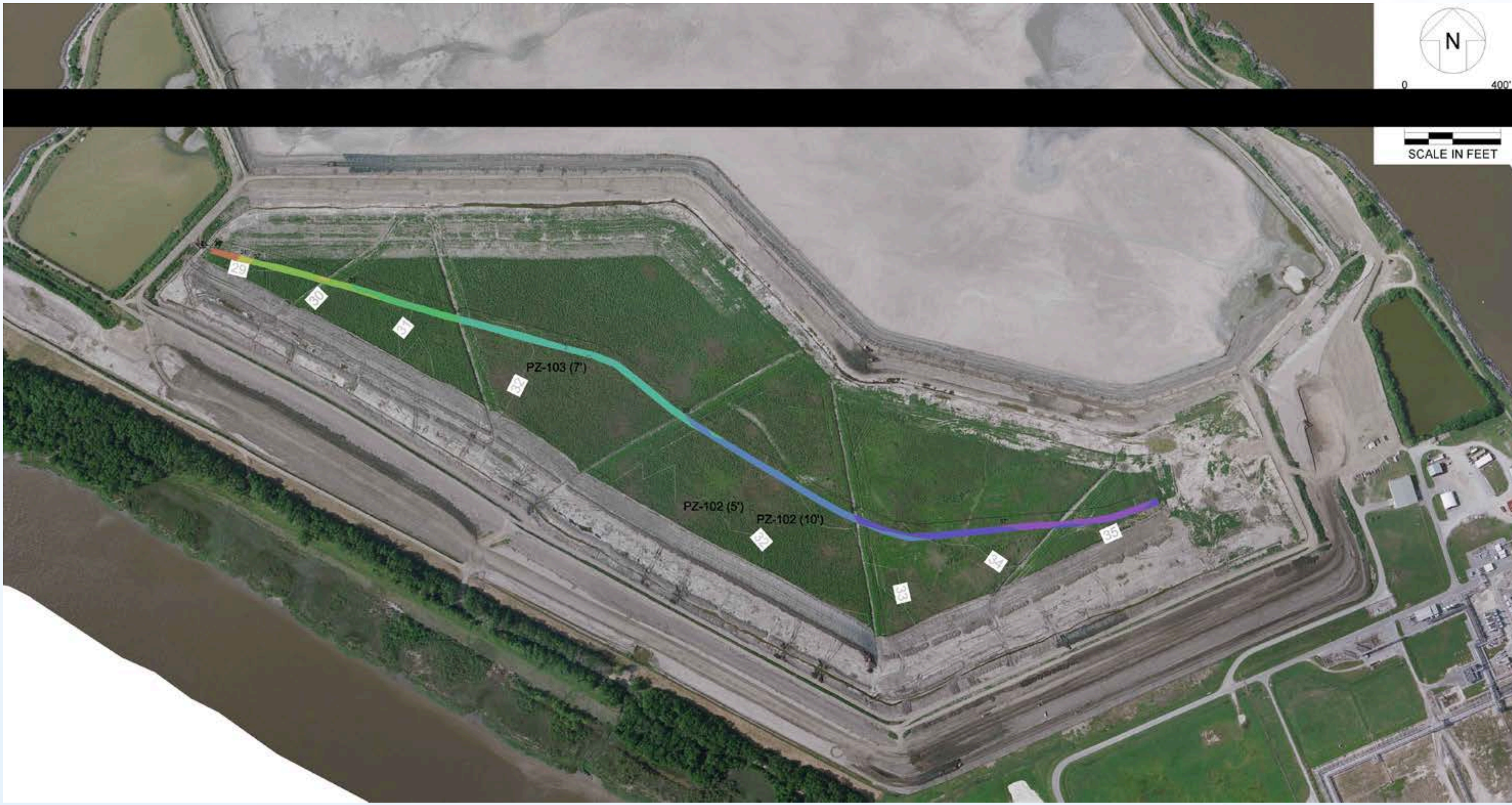
Conclusions

- Increase in available disposal capacity
- Potential increase in anticipated life of DMCA 2
- Generation of fill material for dike raising
  - Beneficial reuse of dredged sediments

Recommendations

- Duplicate effort in DMCA 1
- Subdivide DMCA 2 to facilitate ditching within the interior portion of the DMCA
  - Provides additional opportunity to achieve system steady state where volume capacity of DMCA is perpetually restored between dredging

Subdivide DMCA 2



Questions

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