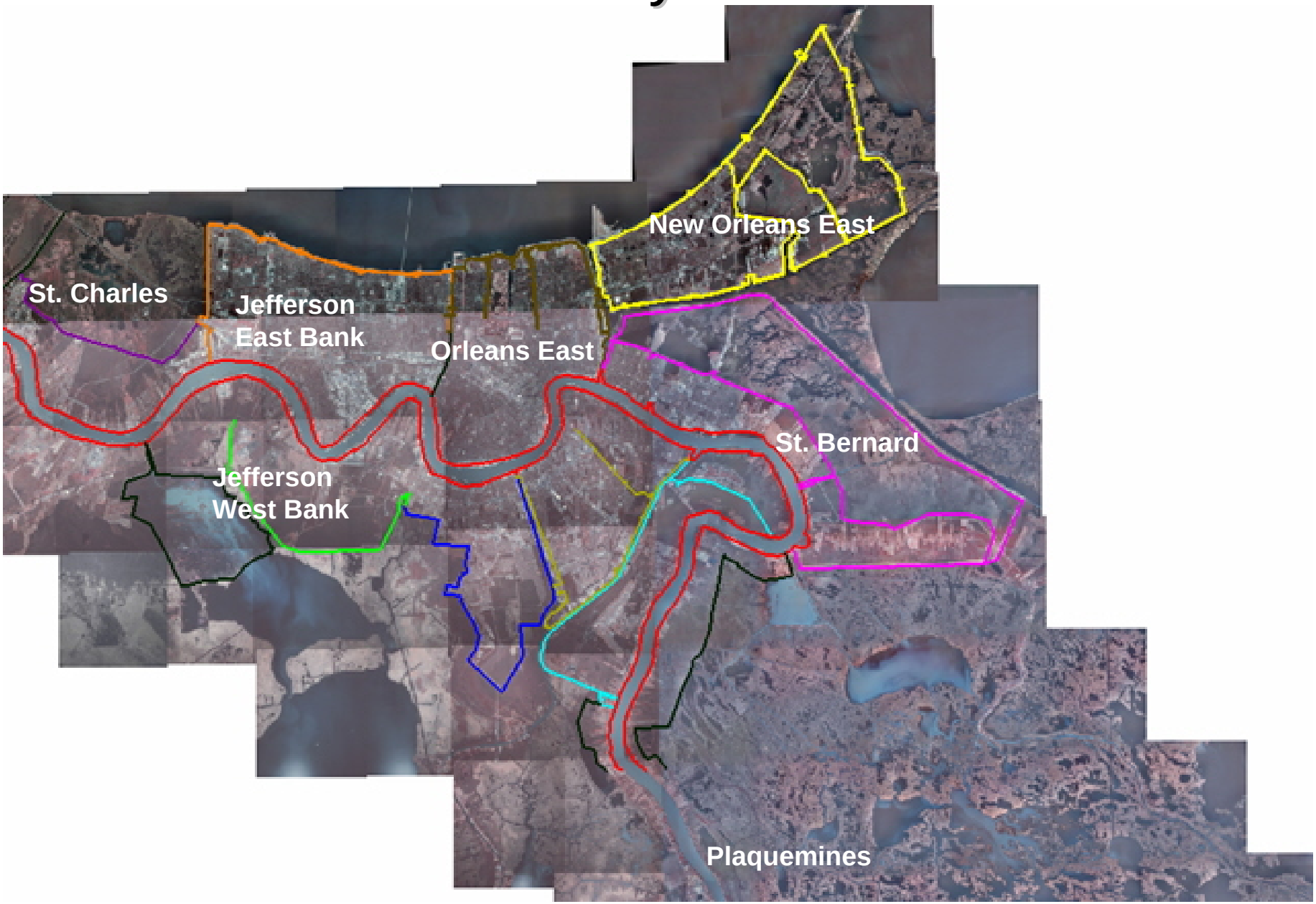
Engineering and Operational Risk and Reliability Analysis

Co-Leaders
Jerry Foster, USACE
Bruce Muller, USBR

Conditions Studied

- **Pre-Katrina Risks**
  - HPS features in-place on 28 August 2005
  - Include engineering and system knowledge gained by IPET
  - Consider range of possible hurricanes
- **1 June 2006 Risks**
  - HPS with TFG Repairs and improvements in-place on 1 June
  - Include engineering and system knowledge gained by IPET
  - Consider range of possible hurricanes
- **Risks 2006-2007**
  - Planned improvements (canal closures, etc.)

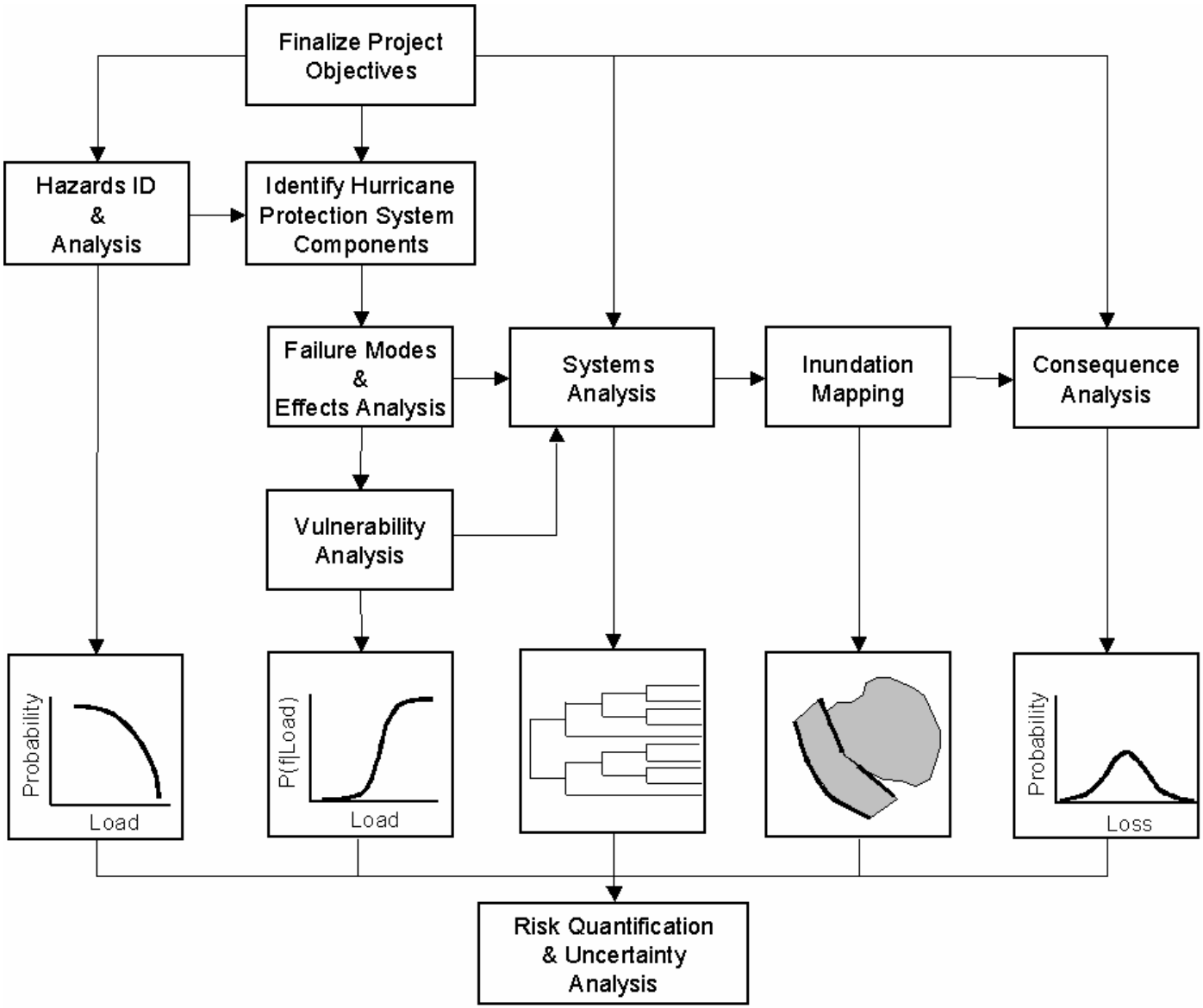
Hurricane Protection System



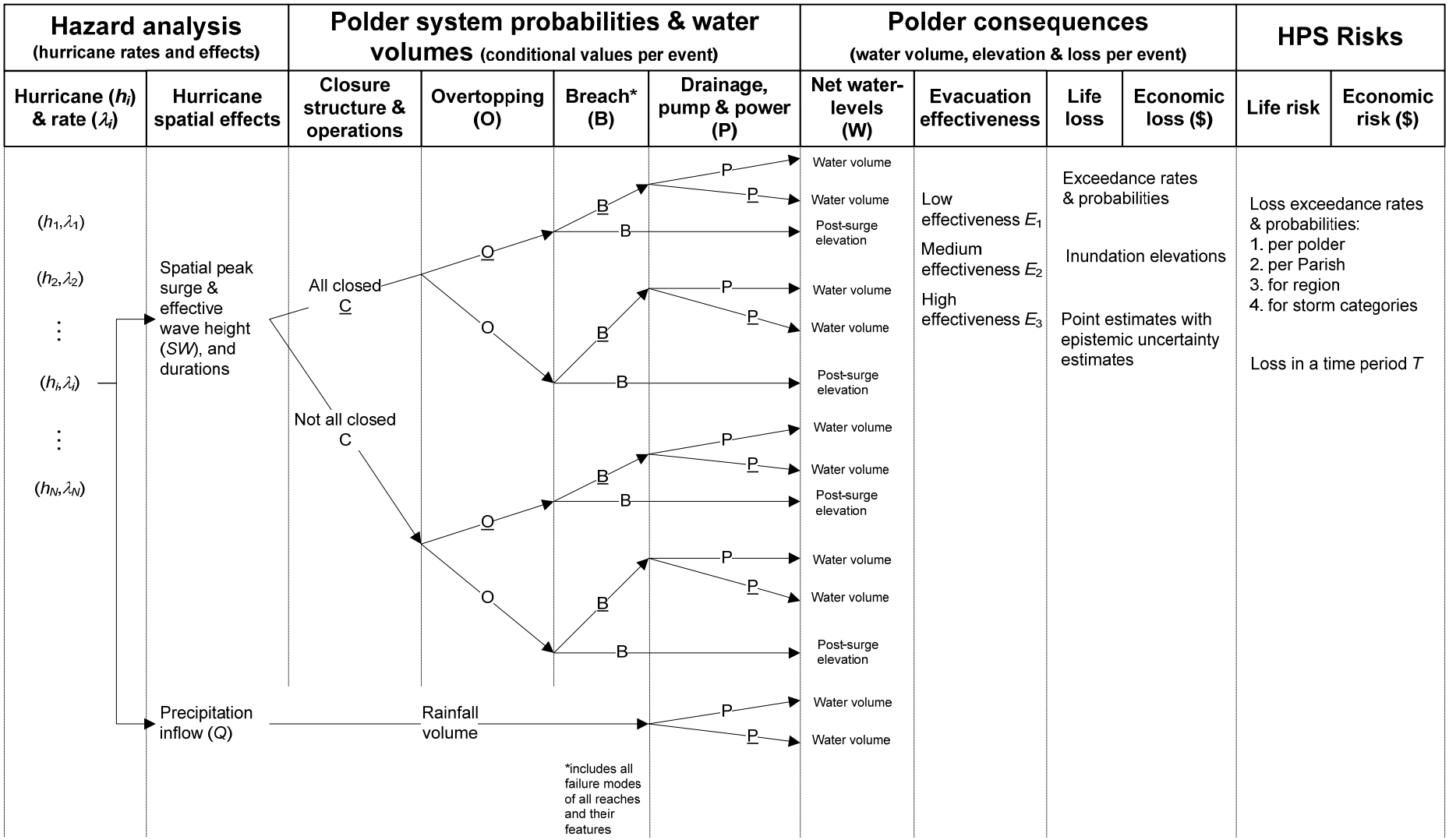
IPET Risk Model

- Detailed physical characteristics of polders modeled
- Individual polders aggregated to model system performance.
- Range of potential hurricanes considered
- Performance of physical features modeled (Reliability)
- Polder inflow volumes
  - Overtopping
  - Breaching
  - Rainfall
- Pump station performance
- Stage-storage models
- Net water levels
- Elevation-frequency mapping
- Economic and Human risks

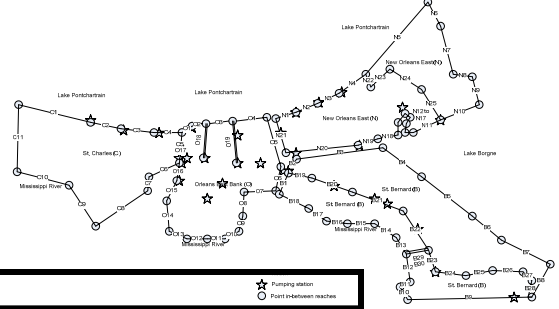
Overall Methodology



Event Tree


Hazard analysis
(hurricane rates and effects)
Polder system probabilities & water volumes (conditional values per event)
Polder consequences
(water volume, elevation & loss per event)
HPS Risks
Hurricane (h_i) & rate (λ_i)
Hurricane spatial effects
Closure structure & operations
Overtopping (O)
Breach* (B)
Drainage, pump & power (P)
Net water-levels (W)
Evacuation effectiveness
Life loss
Economic loss ($)
Life risk
Economic risk ($)
(h_1,λ_1)
(h_2,λ_2)
(h_i,λ_i)
(h_N,λ_N)
Spatial peak surge & effective wave height (SW), and durations
All closed C
Not all closed C
O
B
P
Water volume
Post-surge elevation
Precipitation inflow (Q)
Rainfall volume
*includes all failure modes of all reaches and their features
Low effectiveness E_1
Medium effectiveness E_2
High effectiveness E_3
Exceedance rates & probabilities
Inundation elevations
Point estimates with epistemic uncertainty estimates
Loss exceedance rates & probabilities:
1. per polder
2. per Parish
3. for region
4. for storm categories
Loss in a time period T

Risk Model



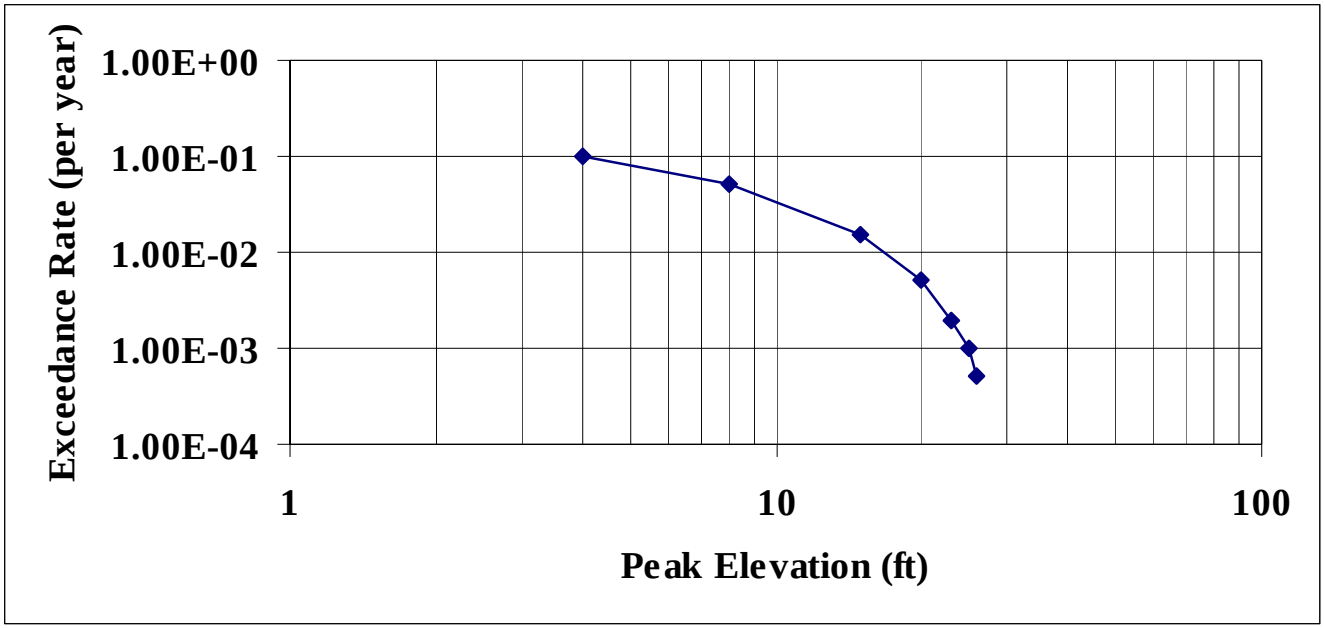
Reach Number	1
Reach start-end stations	To be provided
Reach coordinates	To be provided
Equal allocation to Sub-Polder(s)	1
Reach length (ft)	2000
Reach elevation (ft)	16
Mean (Weir Coeff.)[1]	3
COV (Weir Coeff.)	0.2

[1]Use 3.0 for floodwalls, 2.6 for levees, and 2.0 for gates

Hurricane Runs			1								
Run	Rate (R)		Surge+Waves		Duration		OT Length		OT Probability	OT Volume (Weir Eq)	
i	Mean	StD*	Hs		T		L		P(OT)	V|OT	
			Mean	StD*	Mean	StD*	Mean	StD*		Mean	StD
ID	event/yr	event/yr	ft	ft	sec	sec	ft	ft		ft^3	ft^3
1	5.00E-04	0.00E+00	25	0	5400	0	2000	0	1.00E+00	8.748E+08	1.750E+08
2	5.00E-04	0.00E+00	25	0	5400	0	2000	0	1.00E+00	8.748E+08	1.750E+08
3	7.50E-04	0.00E+00	24	0	5400	0	2000	0	1.00E+00	7.331E+08	1.466E+08
4	1.00E-03	0.00E+00	23	0	5400	0	2000	0	1.00E+00	6.001E+08	1.200E+08
5	1.00E-03	0.00E+00	22	0	5400	0	2000	0	1.00E+00	4.762E+08	9.524E+07
6	1.50E-03	0.00E+00	21	0	5400	0	2000	0	1.00E+00	3.622E+08	7.245E+07
7	2.00E-03	0.00E+00	20	0	5400	0	2000	0	1.00E+00	2.592E+08	5.184E+07
8	2.00E-03	0.00E+00	19	0	5400	0	2000	0	1.00E+00	1.684E+08	3.367E+07
9	2.00E-03	0.00E+00	18	0	5400	0	2000	0	1.00E+00	9.164E+07	1.833E+07
10	2.00E-03	0.00E+00	17	0	5400	0	2000	0	1.00E+00	3.240E+07	6.480E+06
11	3.50E-03	0.00E+00	16	0	5400	0	0	0	0.00E+00	0.000E+00	0.000E+00
12	5.00E-03	0.00E+00	15	0	4320	0	0	0	0.00E+00	0.000E+00	0.000E+00
13	5.00E-03	0.00E+00	14	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
14	5.00E-03	0.00E+00	13	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
15	5.00E-03	0.00E+00	12	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
16	5.00E-03	0.00E+00	11	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
17	5.00E-03	0.00E+00	10	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00

* Reserved for future epistemic uncertainty analysis

Hurricane Modeling



- Hurricane parameter sets developed for ADCIRC runs.
- Number of runs required was reduced by selecting parameter ranges considered possible for NO.
- Approx. 1200 runs with a medium resolution grid
- Approx. 40 runs using a high resolution grid to calibrate the medium resolution runs
- Parameter sets to include historic storms
- Add waves
- Joint probability used to determine frequencies
- Outputs: Surge plus significant wave height & durations, estimates of hurricane rates and uncertainties

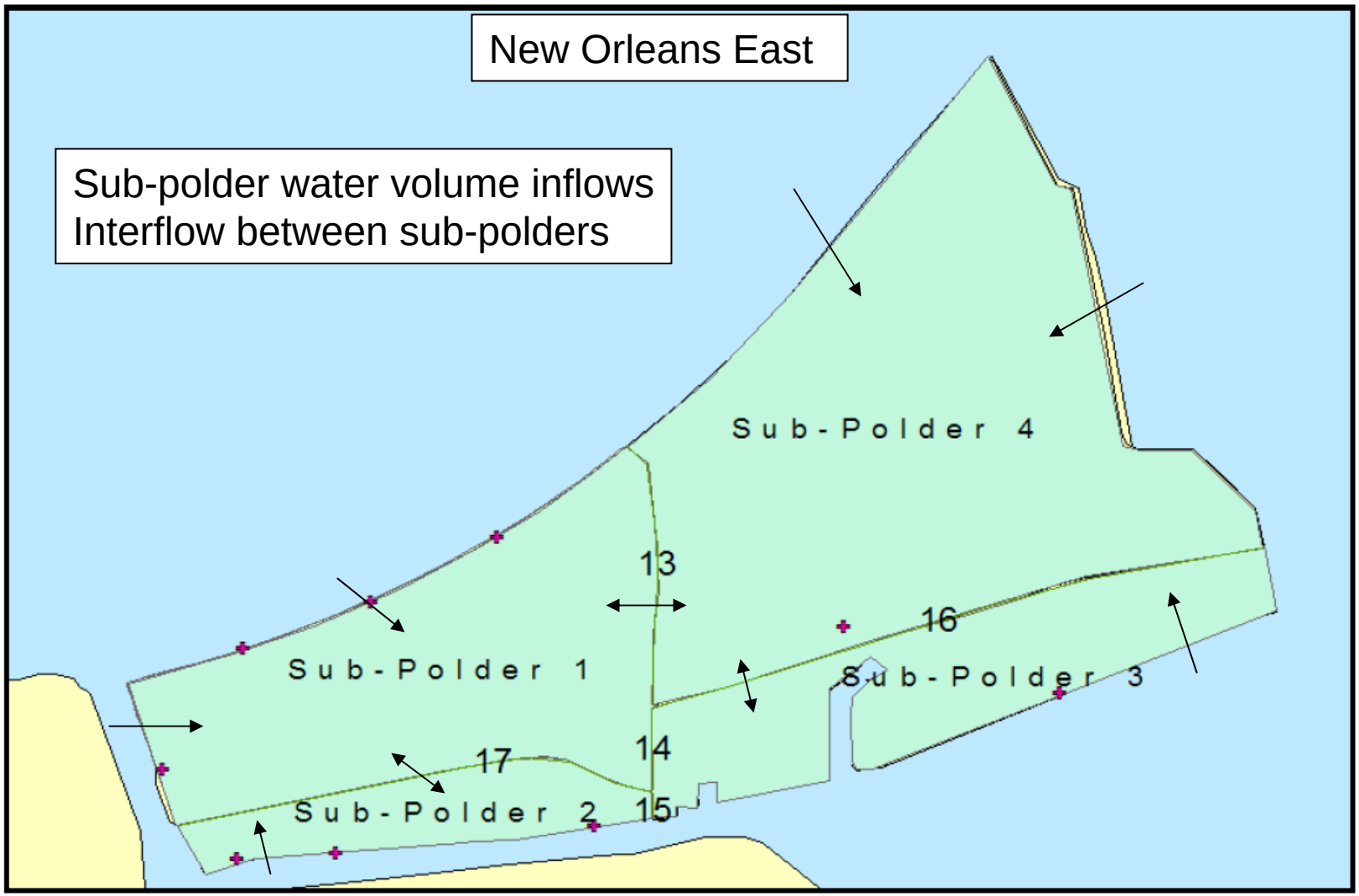
Polder Inflow Volumes

Overtopping
Breaching
Rainfall

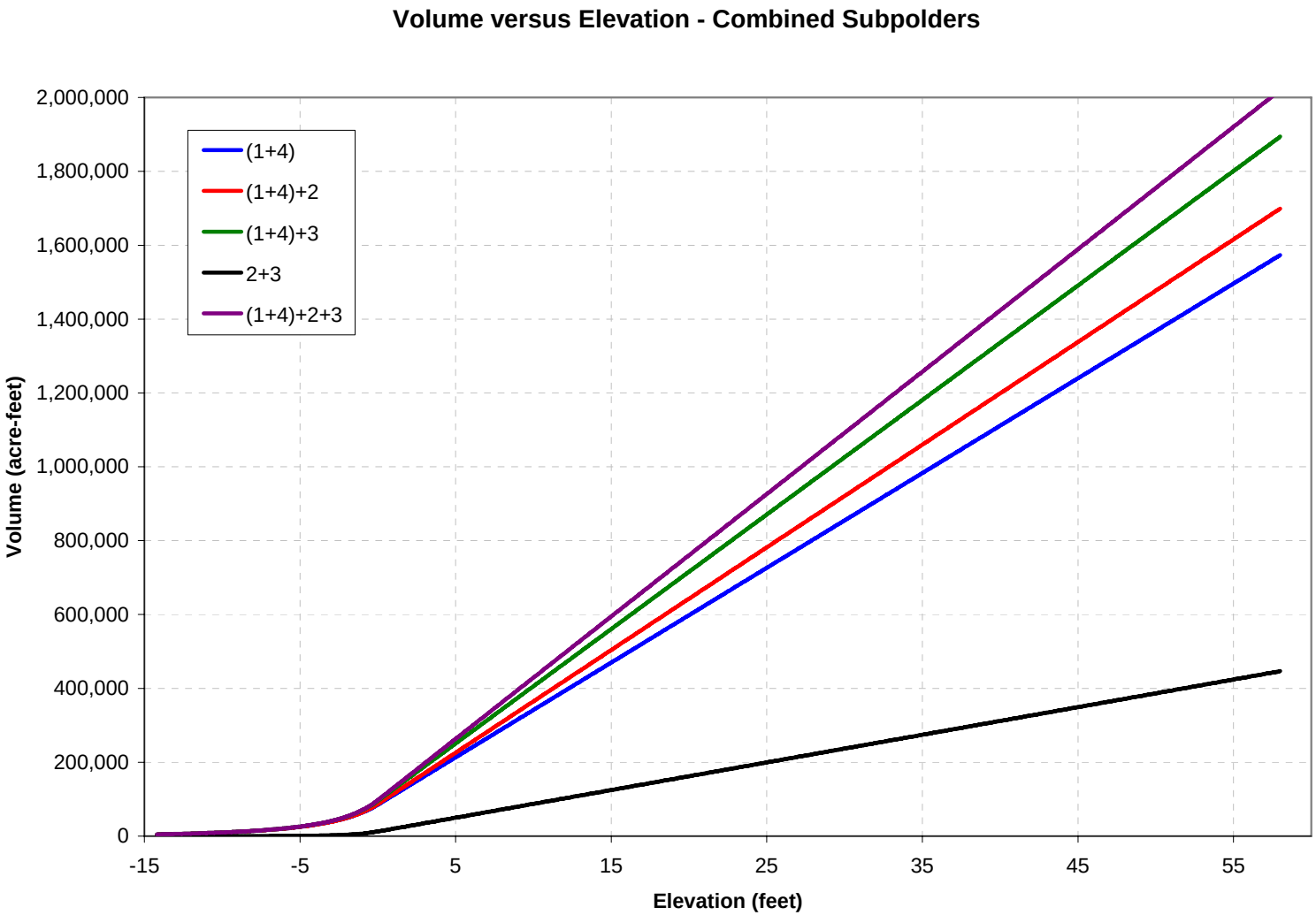
Summary by Sub-Polder		
1	2	3
To be provided	To be provided	To be provided

Sub-Polder 1				Sub-Polder 2				Sub-Polder 3			
OT Probability		OT Volume (Weir Eq)		OT Probability		OT Volume (Weir Eq)		OT Probability		OT Volume (Weir Eq)	
P(OT)		V|OT		P(OT)		V|OT		P(OT)		V|OT	
Mean	StD*	Mean	StD	Mean	StD*	Mean	StD	Mean	StD*	Mean	StD
Prob.	Prob.	ft^3	ft^3	Prob.	Prob.	ft^3	ft^3	Prob.	Prob.	ft^3	ft^3
1.00E+00	NA	1.532E+09	1.918E+08		TBD		TBD		TBD		TBD
1.00E+00	NA	1.532E+09	1.918E+08		TBD		TBD		TBD		TBD
1.00E+00	NA	1.378E+09	1.658E+08		TBD		TBD		TBD		TBD
1.00E+00	NA	1.027E+09	1.306E+08		TBD		TBD		TBD		TBD
1.00E+00	NA	9.629E+08	1.121E+08		TBD		TBD		TBD		TBD
1.00E+00	NA	7.109E+08	8.421E+07		TBD		TBD		TBD		TBD
1.00E+00	NA	4.107E+08	5.527E+07		TBD		TBD		TBD		TBD
1.00E+00	NA	2.521E+08	3.551E+07		TBD		TBD		TBD		TBD
1.00E+00	NA	1.408E+08	2.001E+07		TBD		TBD		TBD		TBD
1.00E+00	NA	4.344E+07	6.846E+06		TBD		TBD		TBD		TBD
0.00E+00	NA	0.000E+00	0.000E+00		TBD		TBD		TBD		TBD
0.00E+00	NA	0.000E+00	0.000E+00		TBD		TBD		TBD		TBD
0.00E+00	NA	0.000E+00	0.000E+00		TBD		TBD		TBD		TBD
0.00E+00	NA	0.000E+00	0.000E+00		TBD		TBD		TBD		TBD
0.00E+00	NA	0.000E+00	0.000E+00		TBD		TBD		TBD		TBD
0.00E+00	NA	0.000E+00	0.000E+00		TBD		TBD		TBD		TBD
0.00E+00	NA	0.000E+00	0.000E+00		TBD		TBD		TBD		TBD

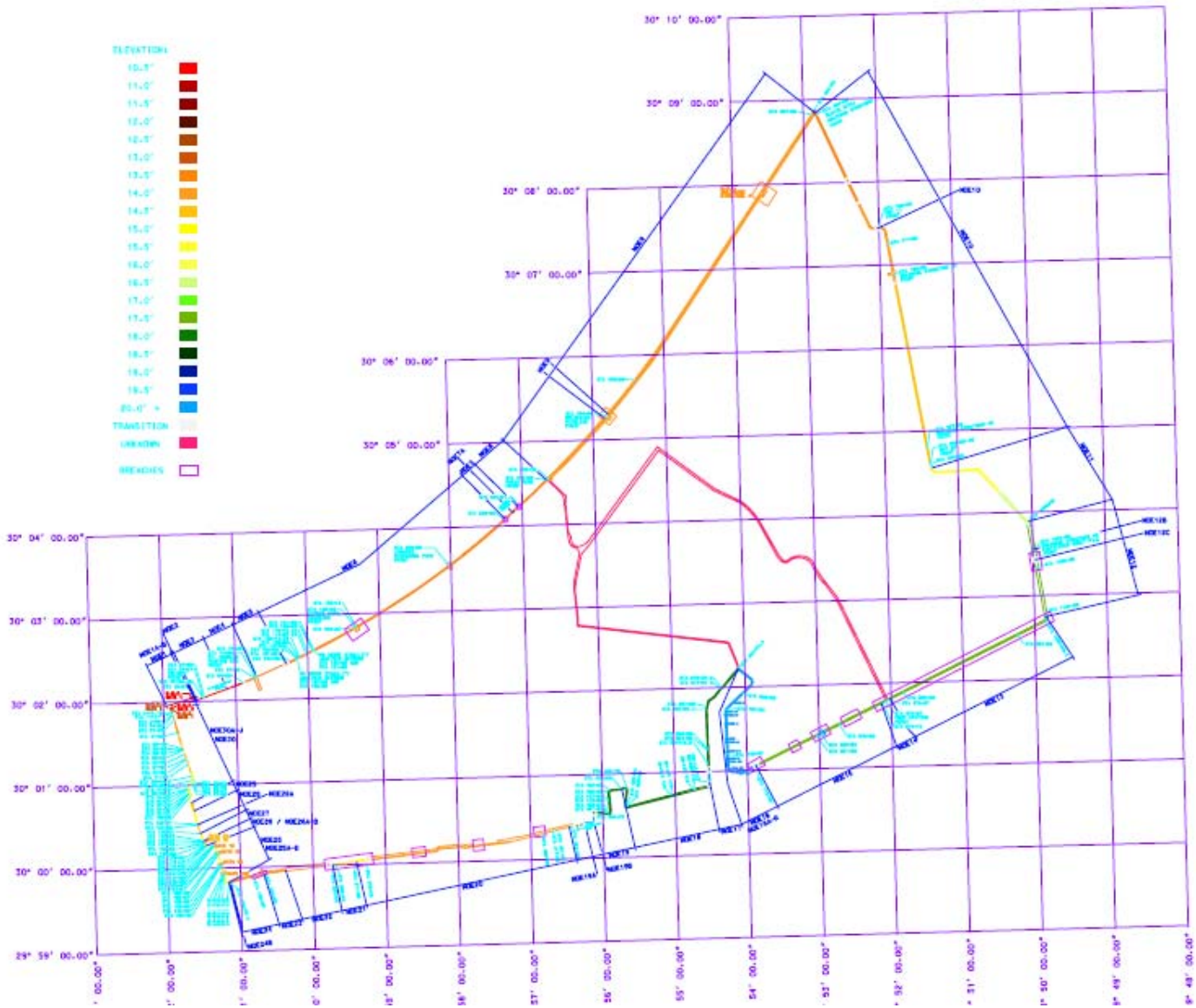
Net Water Levels



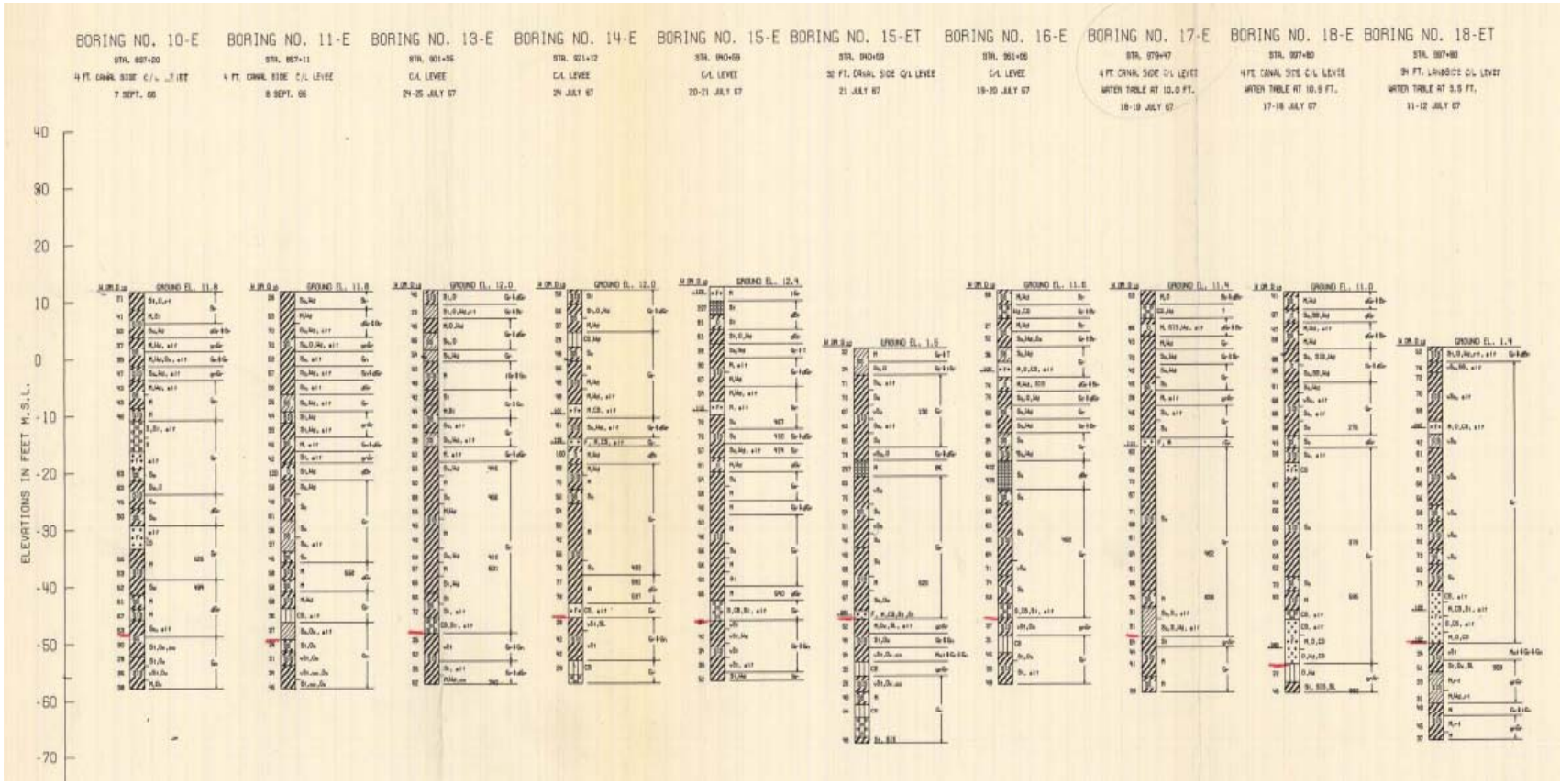
Net Water Levels



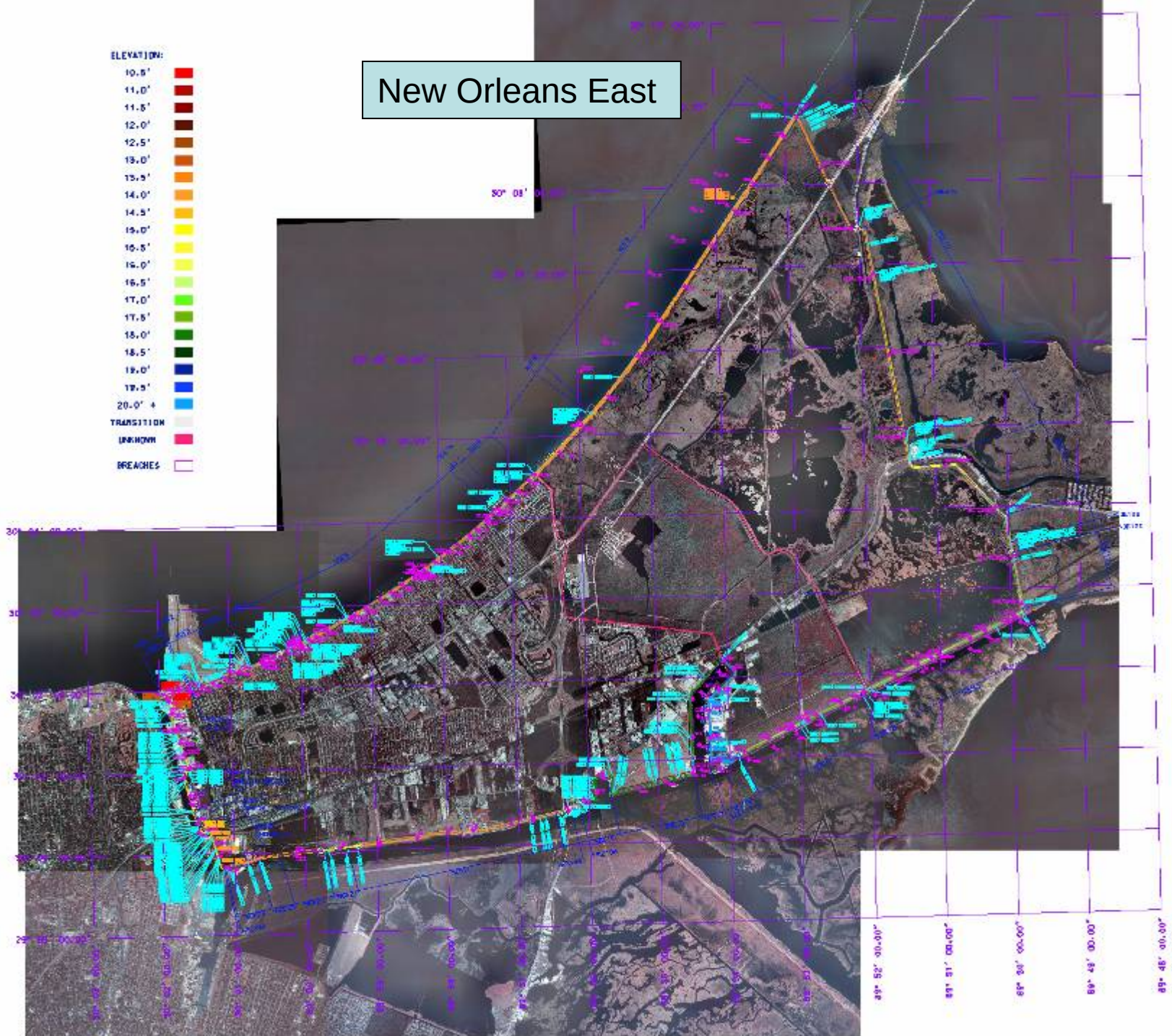
New Orleans East Polder

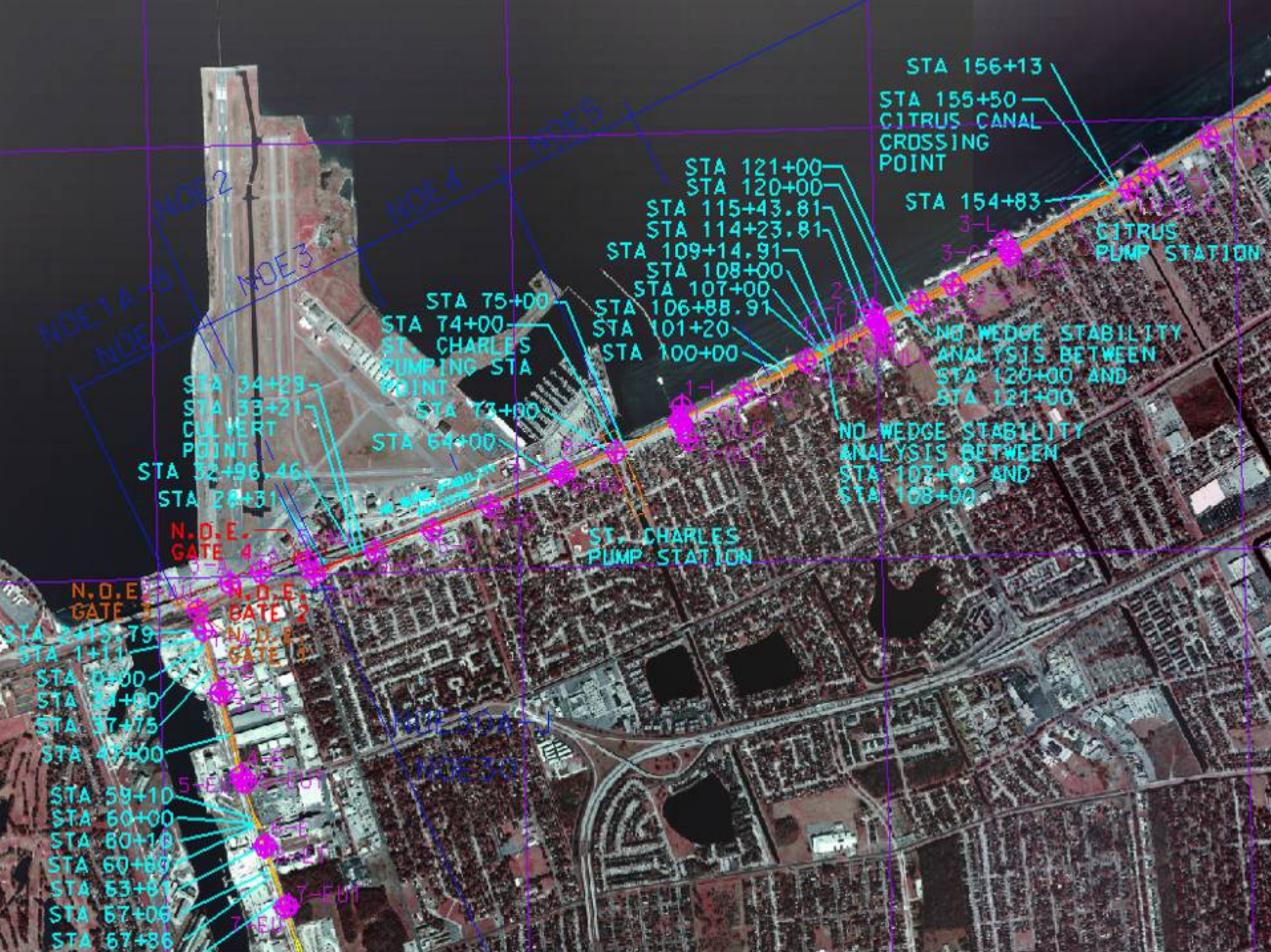


Boring Logs – NOE East Back Levee

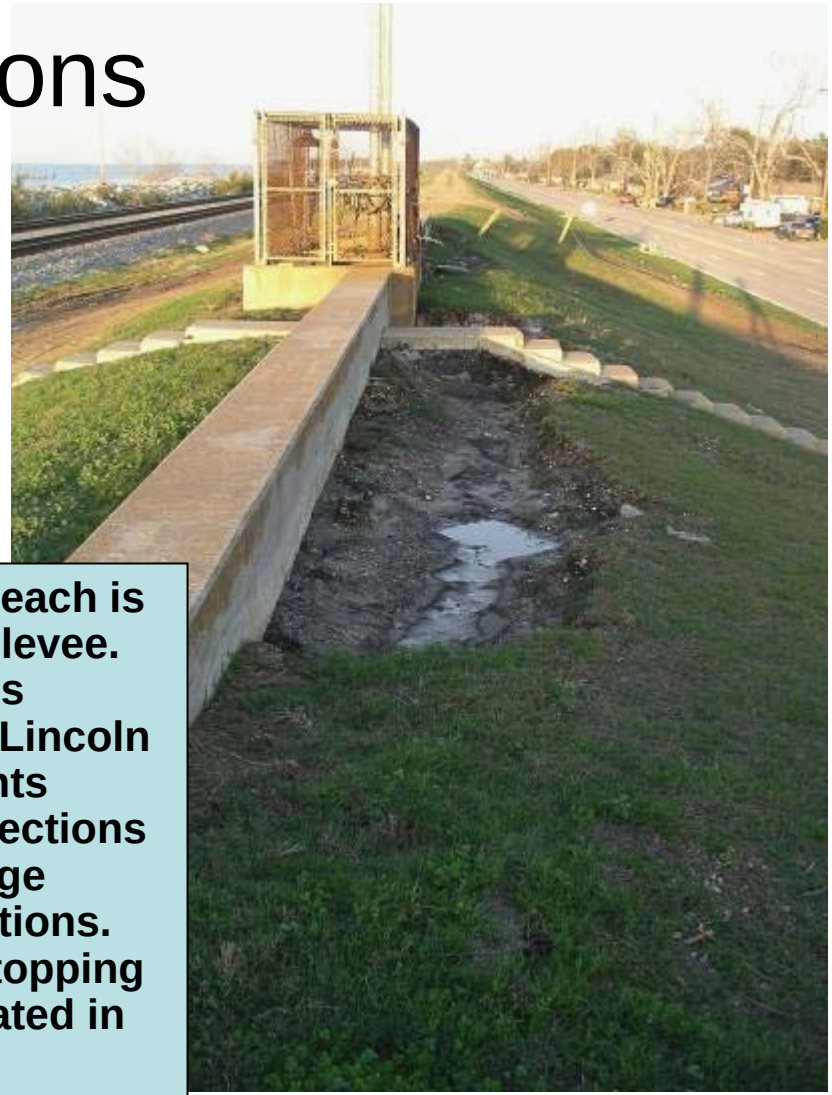


DM and IPET boring logs reviewed by geotechs to determine soil properties for reliability analyses


New Orleans East
ELEVATION:
10.5'
11.0'
11.5'
12.0'
12.5'
13.0'
13.5'
14.0'
14.5'
15.0'
15.5'
16.0'
16.5'
17.0'
17.5'
18.0'
18.5'
19.0'
19.5'
20.0' +
TRANSITION
UNKNOWN
BREACHES


STA 156+13
STA 155+50
CITRUS CANAL
CROSSING
POINT
STA 154+83
CITRUS
PUMP STATION
STA 121+00
STA 120+00
STA 115+43.81
STA 114+23.81
STA 109+14.91
STA 108+00
STA 107+00
STA 106+88.91
STA 101+20
STA 100+00
NO WEDGE STABILITY
ANALYSIS BETWEEN
STA 120+00 AND
STA 121+00
NO WEDGE STABILITY
ANALYSIS BETWEEN
STA 107+00 AND
STA 108+00
STA 75+00
STA 74+00
ST. CHARLES
PUMPING STA
POINT
STA 73+00
STA 64+00
ST. CHARLES
PUMP STATION
STA 34+29
STA 33+21
CULVERT
POINT
STA 32+96.46
STA 28+31
N.O.E.
GATE 4
N.O.E.
GATE 3
N.O.E.
GATE 2
N.O.E.
GATE 1
STA 2+15.79
STA 1+11
STA 0+00
STA 34+00
STA 37+75
STA 47+00
STA 59+10
STA 60+00
STA 60+10
STA 60+60
STA 63+81
STA 67+06
STA 67+86
NOE1A-B
NOE1
NOE2
NOE3
NOE4
NOE5
NOE30A
NOE30

Feature Definitions



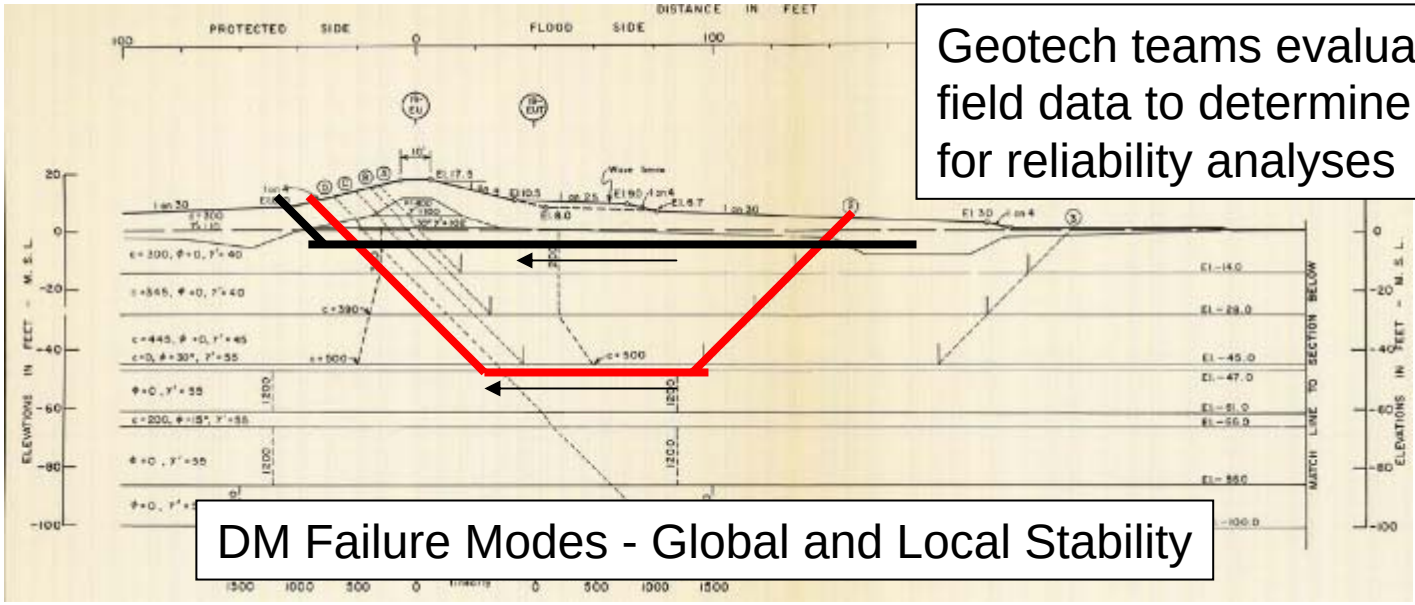
- **<u>Reach NOE6 (Citrus Lakefront DM).</u> This reach is defined by a 19,112 linear feet segment of levee. It begins at the end of the Stars and Stripes floodwall and ends at the west side of the Lincoln Beach floodwall. There are two "key" points within this segment: two small floodwall sections embedded within the levee for the discharge pipes of the Citrus and Jahncke Pump Stations. There was some minor scouring and overtopping of this levee at various locations, as indicated in Figure 4, but no failures.**

Reach Definition

- **<u>Reach NOE16 (East Back DM).</u> This reach consists of the east floodwall around the Michoud Canal. It is approximately 10,757 feet long. It starts at the GIWW and continues along the Michoud Canal where it joins with the Citrus Back floodwall. There are 18 key points along this reach for gated closures at industry and road crossings. However, from site inspections, it appears as if 5 of these gates are placed in the permanently closed position. As shown in Figure 9, the transition sheet pile floodwall at the beginning of this reach failed during Katrina.**

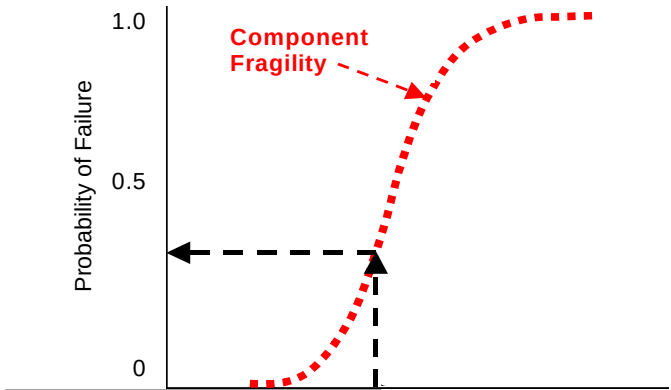
Figure 9. Floodwall Failure at East End of Michoud Canal FW

Reliability
Levees – Failure Modes

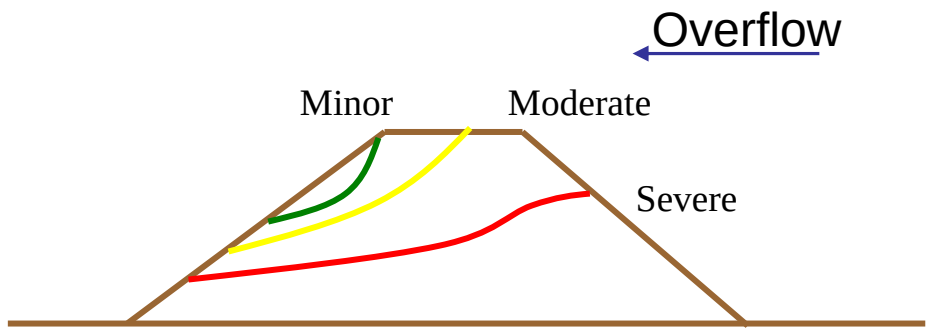


Geotech teams evaluating DM & IPET field data to determine soil properties for reliability analyses

DM Failure Modes - Global and Local Stability

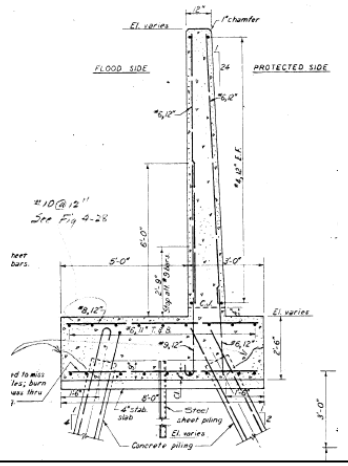


Fragility Curves



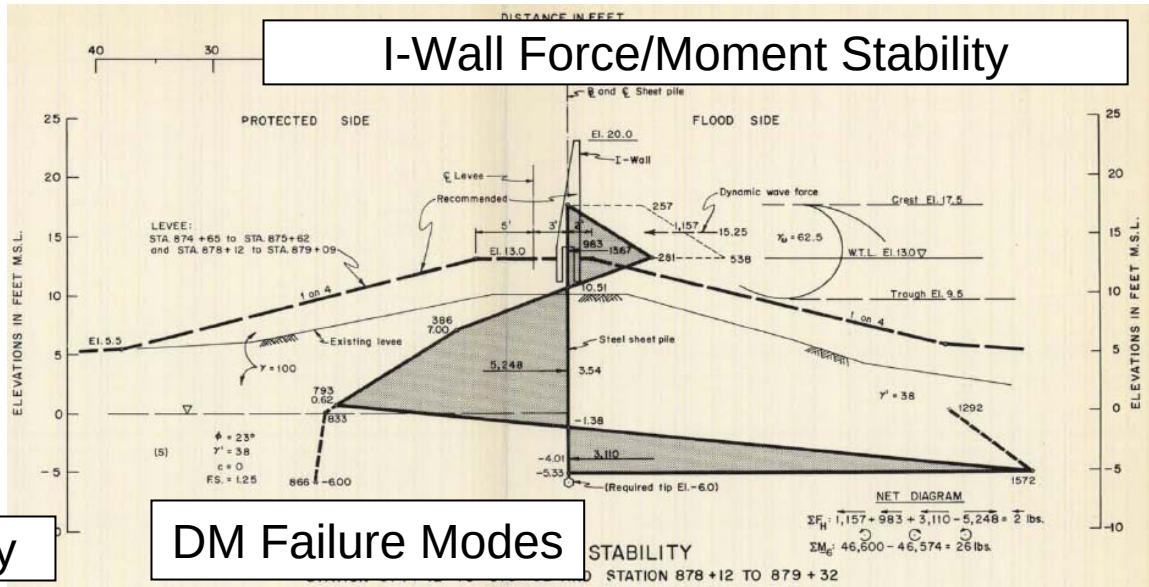
Overtopping Erosion

Walls – Failure Modes

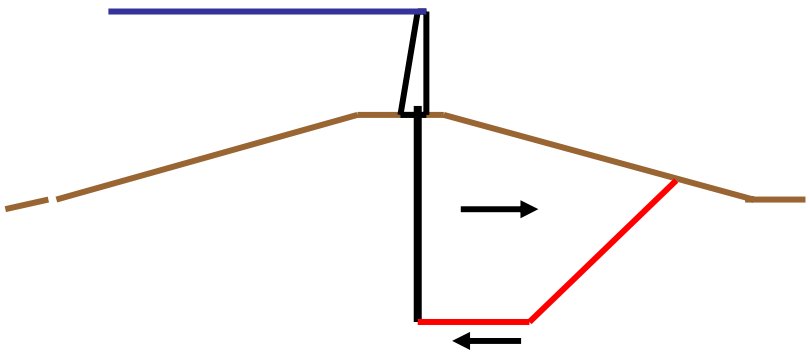


T-Wall Force/Moment Stability

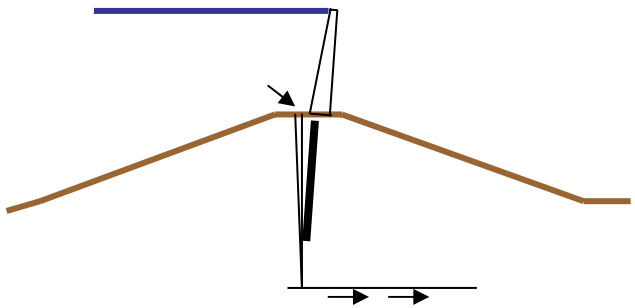
I-Wall Force/Moment Stability



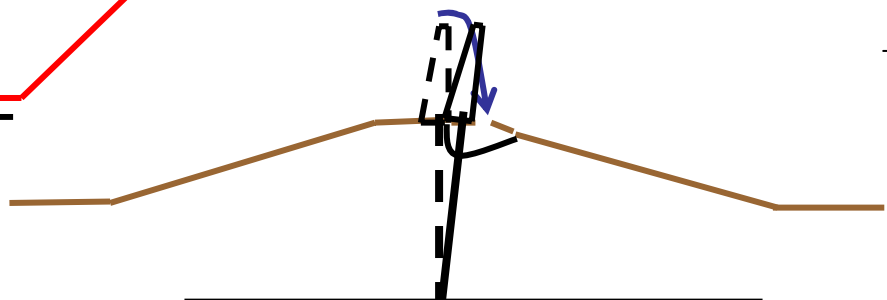
DM Failure Modes



I-Wall - Translation



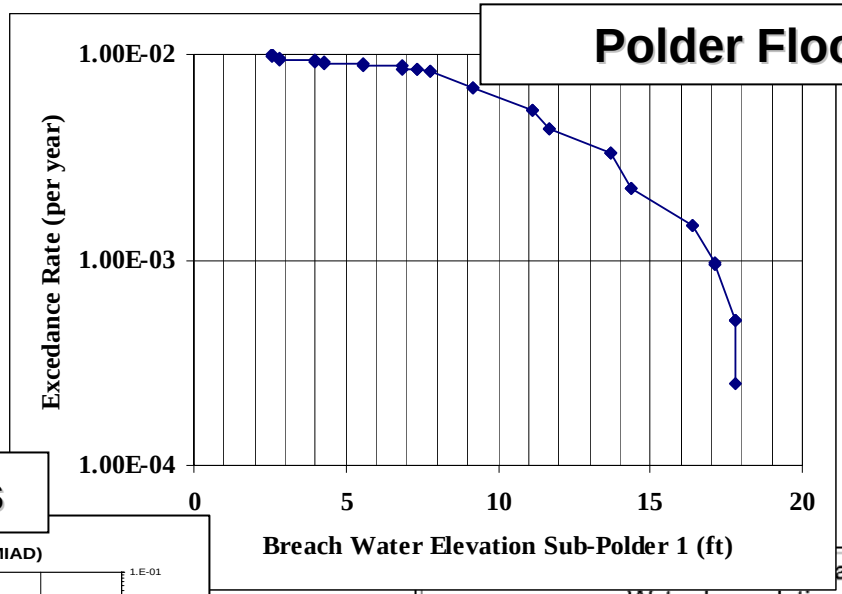
I-Wall – Rotation, Crack, Uplift



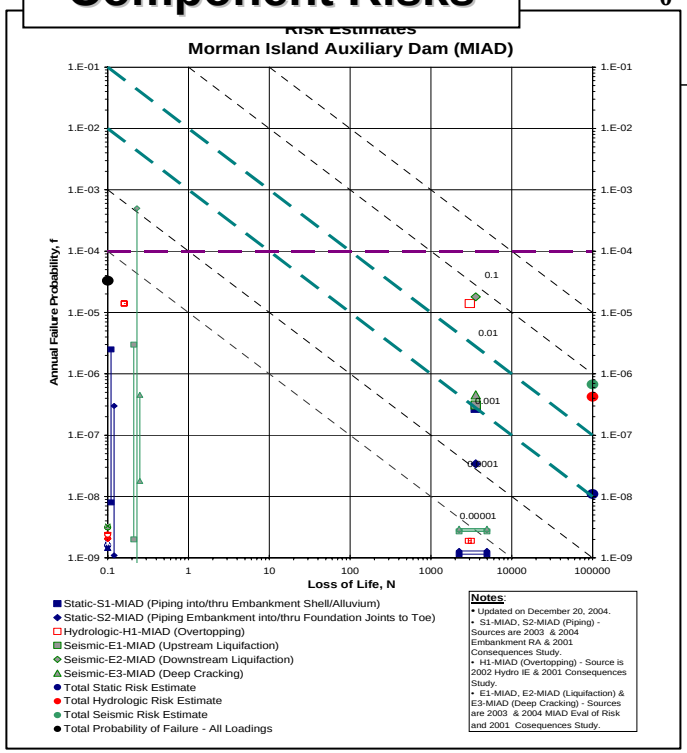
I-Wall – Erosion Stability

DISPLAY OF RESULTS

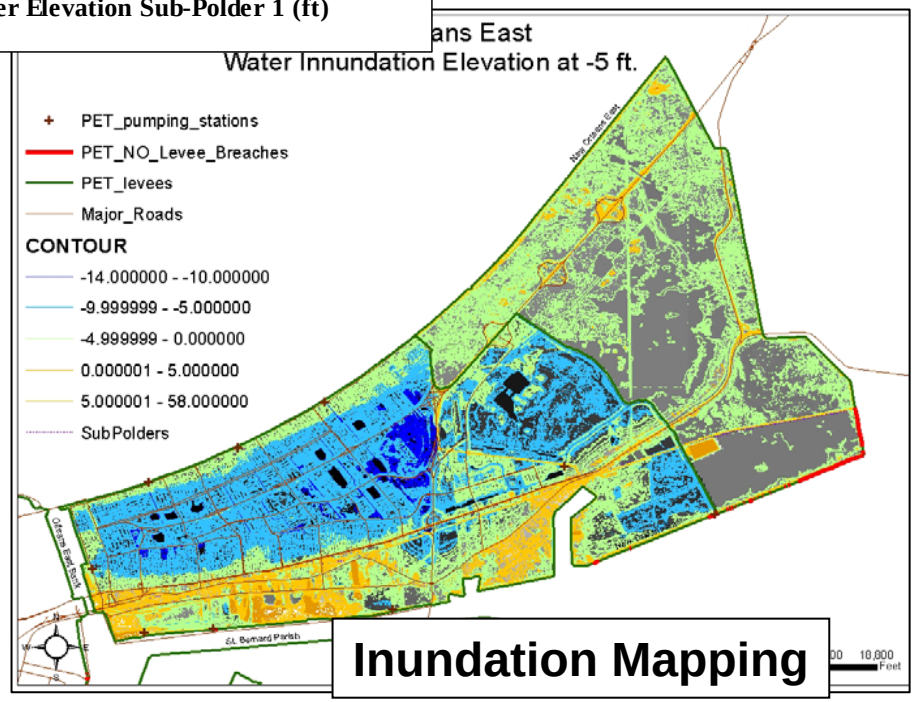
Polder Flooding Frequency



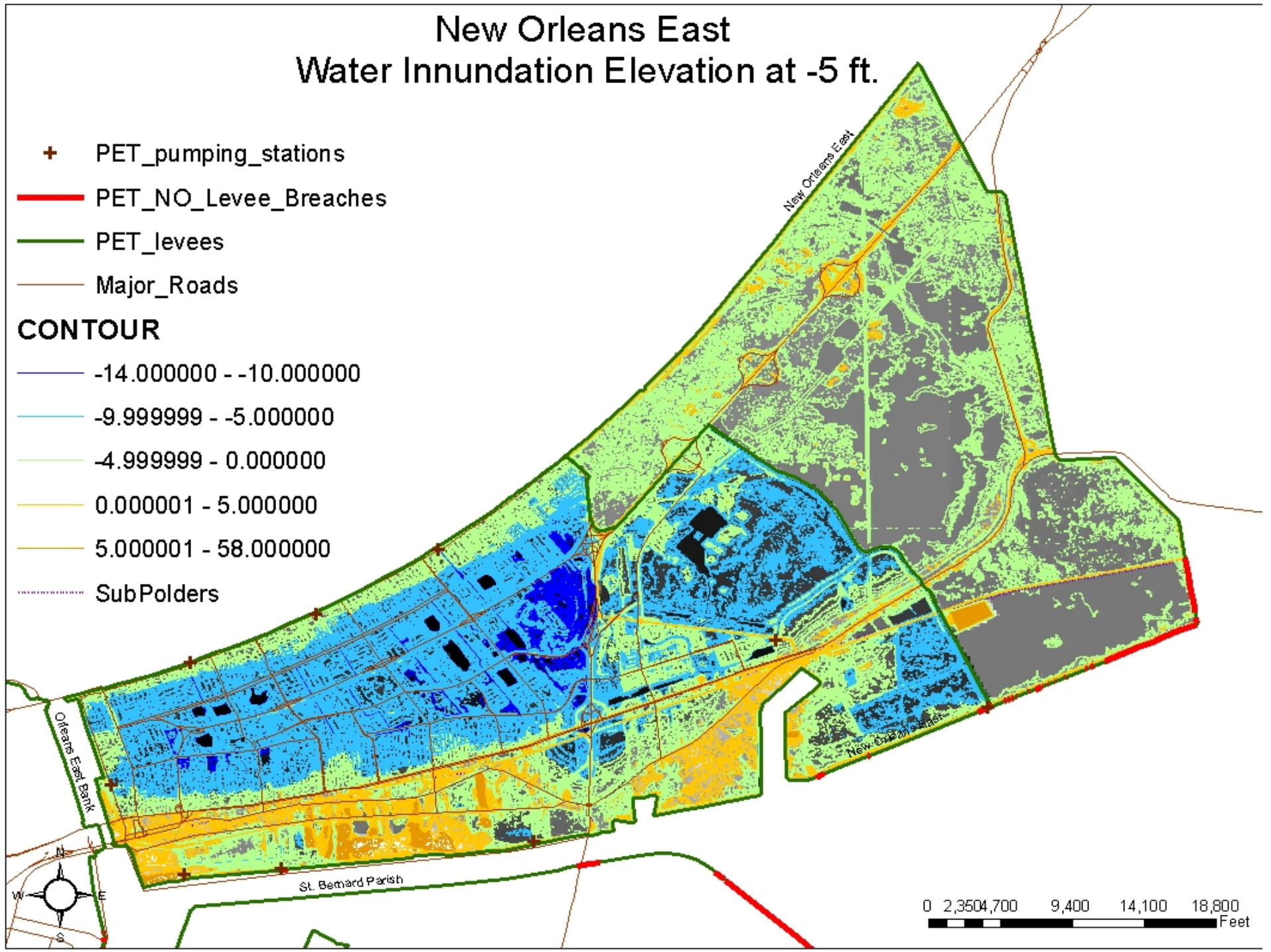
Component Risks



Inundation Mapping



New Orleans East
Water Innundation Elevation at -5 ft.



Modeling System Risks

- Individual polder results integrated into a system analysis
- Consequence team input
  - Loss of life
  - Direct economic impacts
- Deaggregate results to show feature contributions to system risks
- Risk communication plan