Underwater Noise Level Study during Impact Pile Driving

FDOT Project No. BDV34 985-03, Katasha Cornwell, Office of Environmental Management, Project Manager

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Motivation

- Pile driving may make enough noise to kill/injure fish and other marine animals

- Florida does not have reliable local guidelines to predict anthropogenic noise during pile driving and it has been using CalTrans' "Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish" (Buehler et al. 2015)

Project Objectives

- Main Objective – Characterize underwater noise levels during impact pile driving throughout the State of Florida
  - Sample noise data at several bridges throughout the state and use data to develop correlations between noise and other variables
  - Determine transmission loss coefficients and use to data to develop statistics between noise and other variables
  - Develop technical guidance in collaboration with NMFS and USFWS

Specific Variables of Interest

- Decibels
  - $dB = 10\log_{10}\left[\left(\frac{P}{P_{ref}}\right)^2\right]$
  - $P = \text{sound pressure (Pa)}$
  - $P_{ref} = 1\mu\text{Pa}$
- Sound Attenuation Coefficient
  - $TL = F \times \log_{10}\frac{R}{R_0}$
  - *R* = Range from sound source
  - R_0 = Reference range
  - *F* = Transmission loss coefficient
  - *TL* = Transmission loss (in dB)
- Sound Statistics
  - *Peak* = peak sound-level
  - *RMS* = root-mean-square sound-level
  - *SEL* = sound exposure level

$$SEL = 10\log_{10}\int \left(P/P_{ref}\right)^2 dt$$

Current Noise Guidelines – Interim Criteria (CalTrans 2015)

Effect	Metric	Fish Mass (g)	Threshold (dB relative to 1 μPa)
Onset of physical injury	Peak Pressure	N/A	206
	Accumulated SEL	$>$ 2g	187
		$\leq$ 2g	183
Adverse behavior effects	RMS Pressure	N/A	150

New Data for Possibly Updating Guidelines (Popper et al. 2019)

Type of Animal	Mortality and potential mortal injury	Impairment			
		Recoverable injury	Temporary threshold shift (TTS)	Masking	Behavior
Fish: no swim bladder (particle motion detection)	> 219 dB SEL_{cum} or > 213 dB peak	> 216 dB SEL_{cum} > 213 dB Peak	>> 186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or > 207 dB peak	203 dB SEL_{cum} or > 207 dB peak	> 186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or > 207 dB peak	203 dB SEL_{cum} or > 207 dB peak	186 dB SEL_{cum}	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea Turtles	210 dB SEL_{cum} or > 207 dB peak	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Eggs and larvae	> 210 dB SEL_{cum} or > 207 dB peak	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

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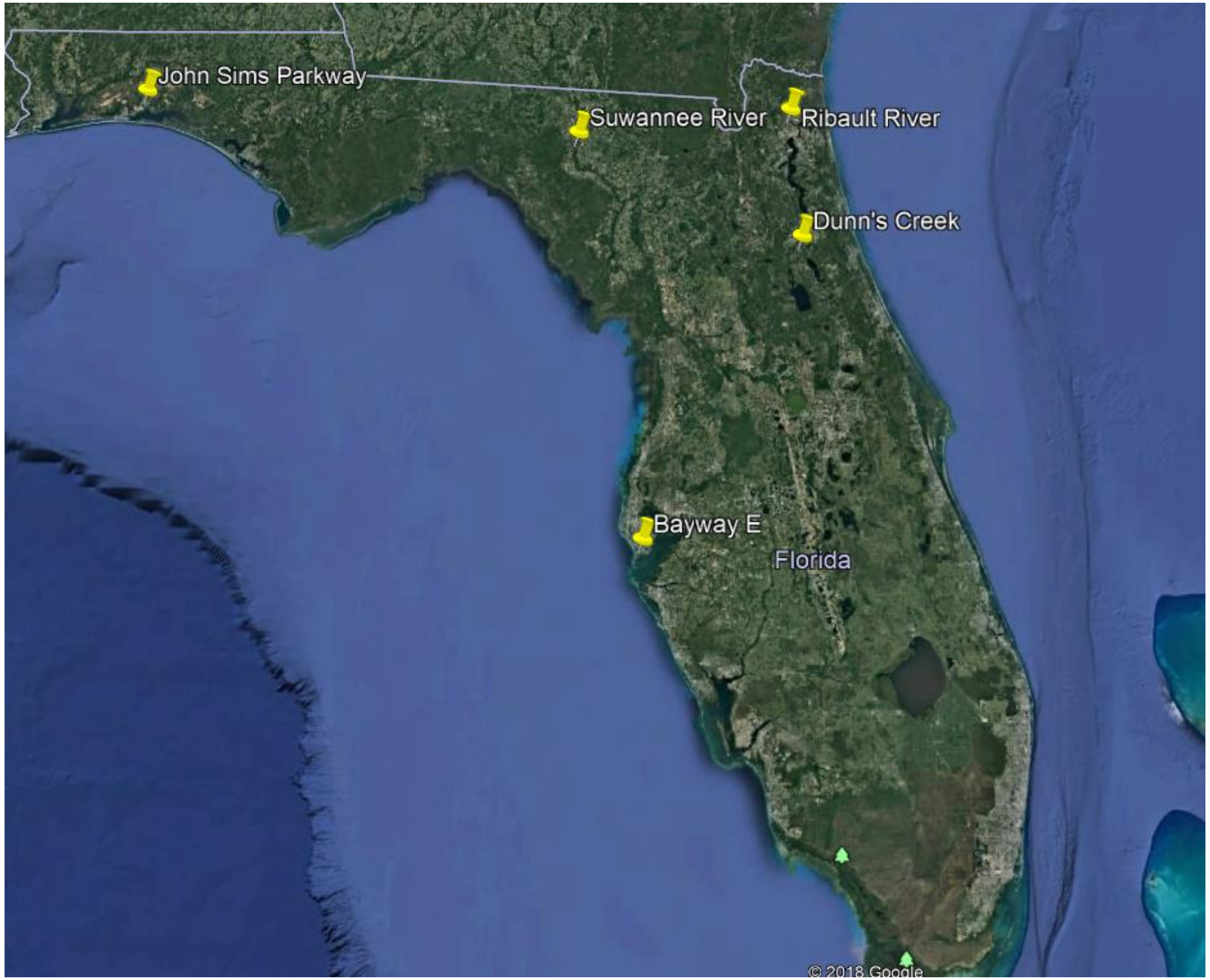
Data Collection



Data Collection Location Map

Site Name	Latitude (N)	Longitude (W)	Date(s) of Visit	Number of Piles	Drive Type
Bayway E	27°41'41.06”	82°43'0.84"	6/3/19 6/4/19	1 steel pile	Steel trestle vibrating
Dunn’s Creek	29°34'38.95"	81°37'34.73"	3/14/19 3/15/19	2 sheet pile pairs	Sheet pile vibrating
John Sims Pkwy	30°30'9.73"	86°29'38.51"	6/24/19 6/26/19	1 concrete pile	Concrete production piles percussion hammer
Ribault River	30°23'43.99"	81°42'52.21"	5/7/19 6/10/19	1 concrete test pile and 3 production piles	Percussion hammer
Suwannee River	30°14'40.86"	83°15'0.34"W	4/18/19	3 concrete piles	Percussion hammer

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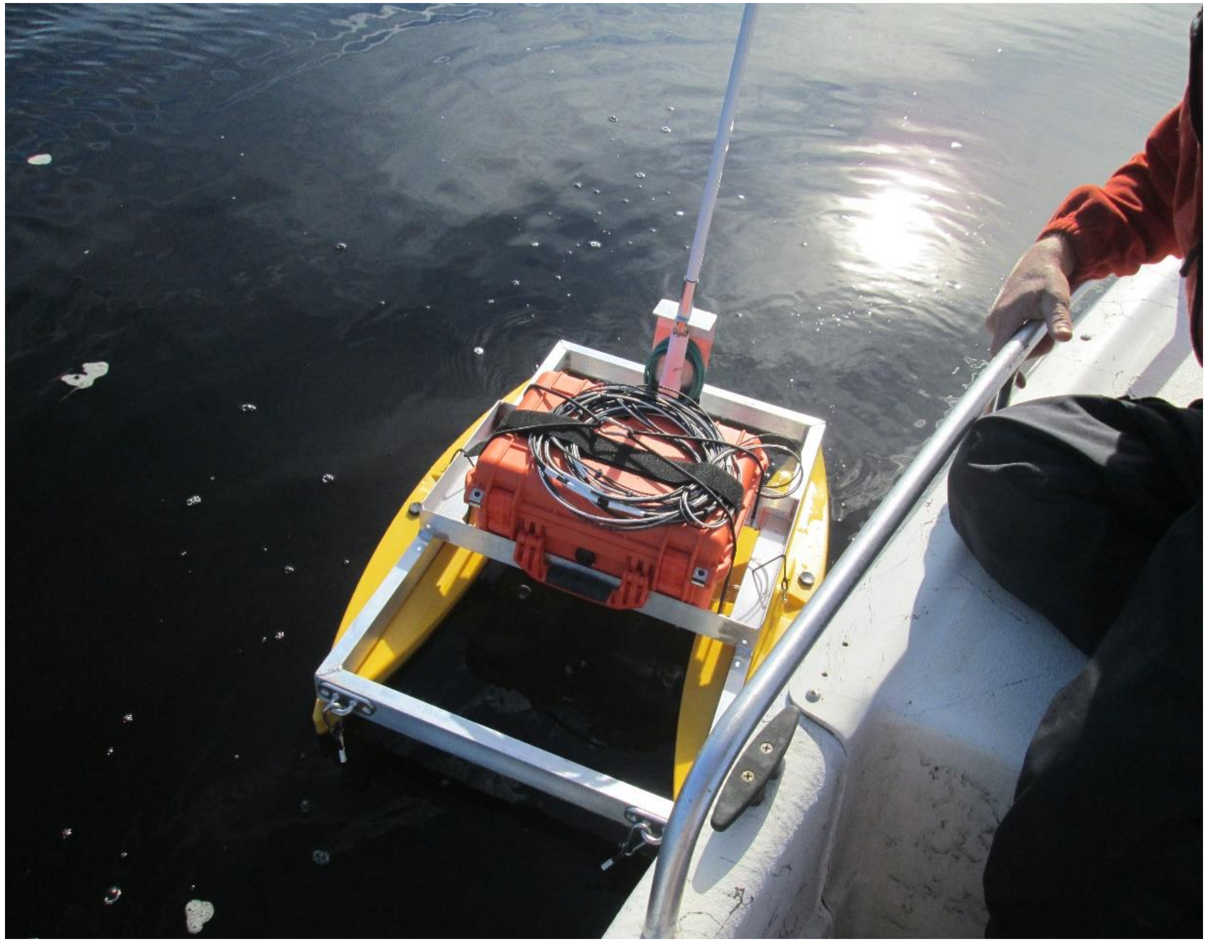
Data Collection – Buoy System



Data Collection Buoy

Deploying the Data Collection System

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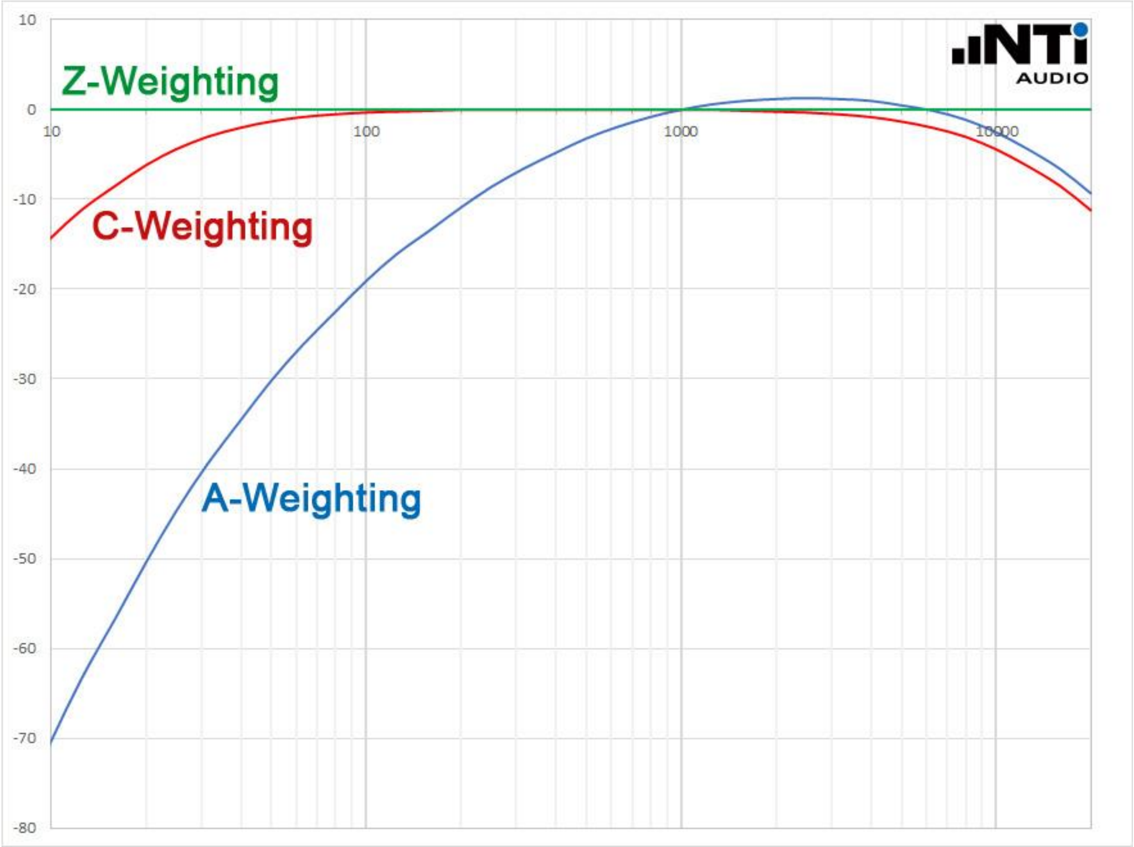
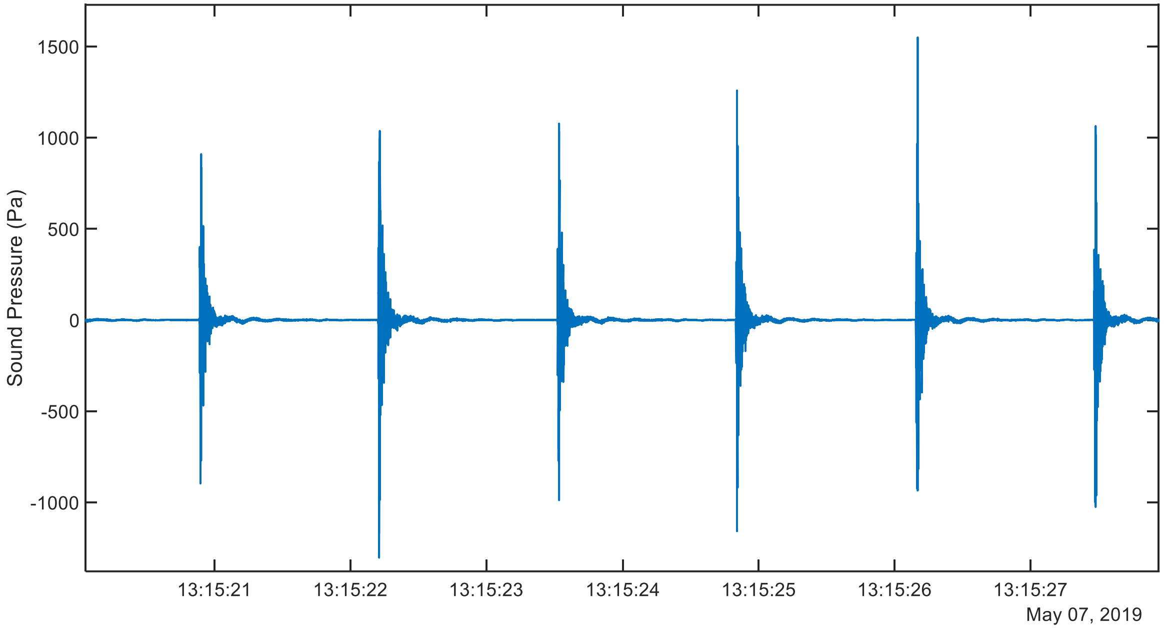
Data Collection – Built-in Methods

- LZ_{peak} @ rate of 1 Hz
- LAF @ rate of 100 Hz
- L_{min} @ rate of 1 Hz
- L_{max} @ rate of 1 Hz
- .wav data

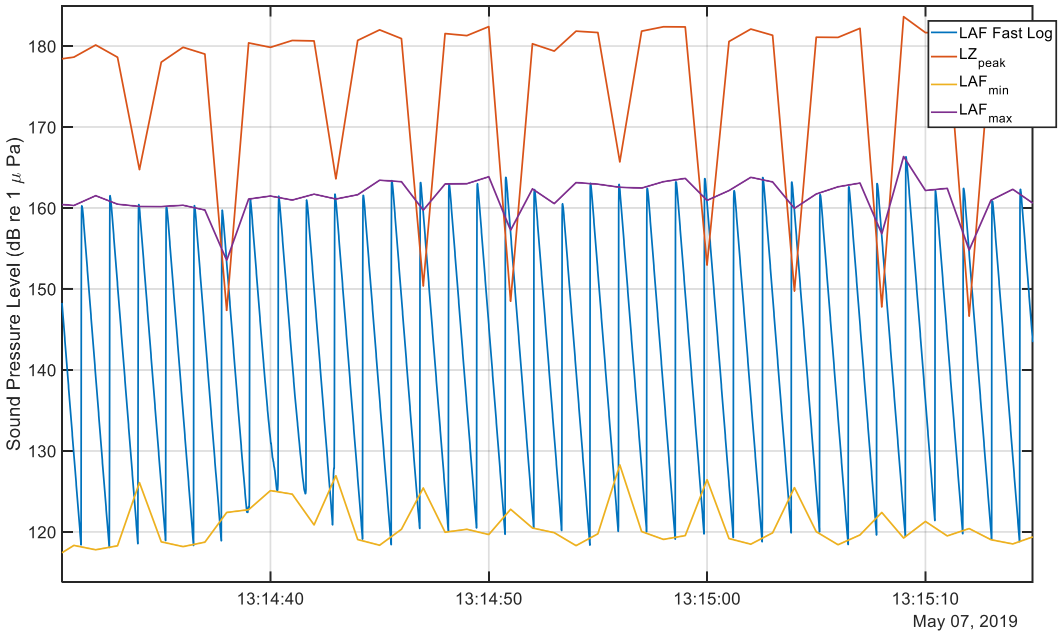


Sound weighting methods

Built-In Data Collection vs. Actual Sound Signal

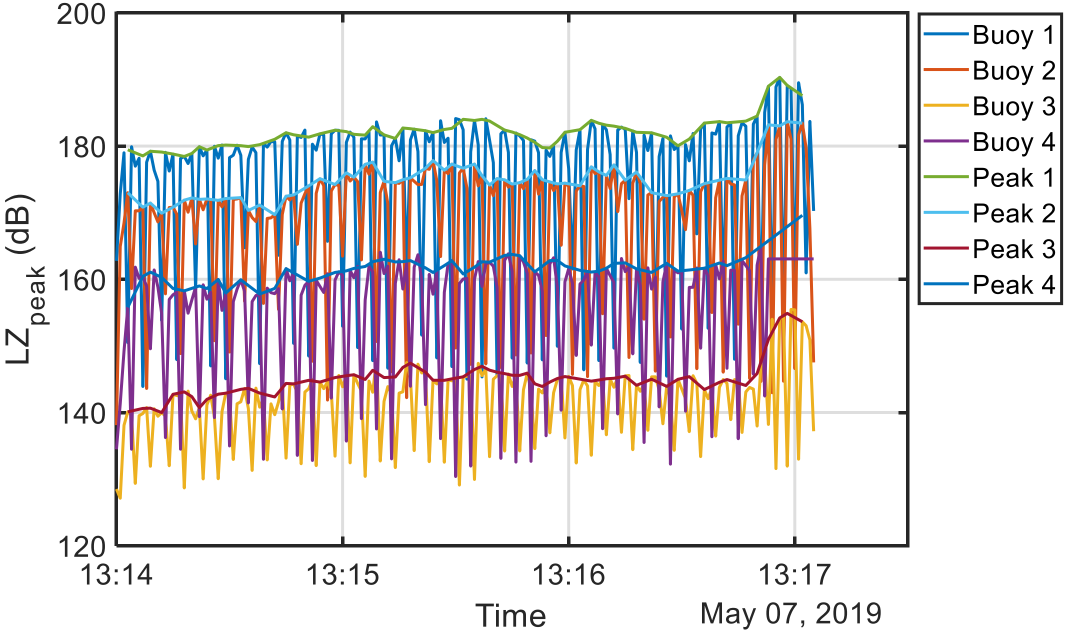


Actual Sound Signal

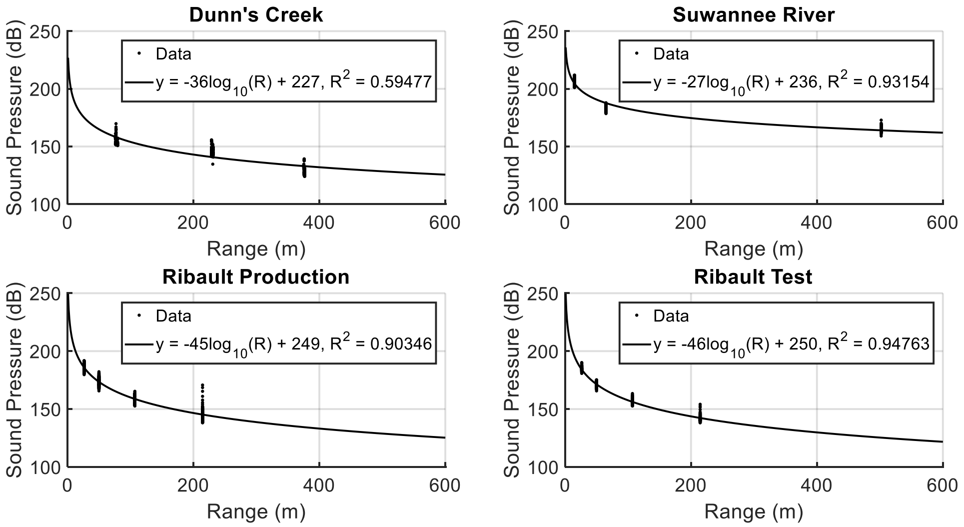


Built-in Data Collection Methods

Updated Data Analysis – Old Methodology

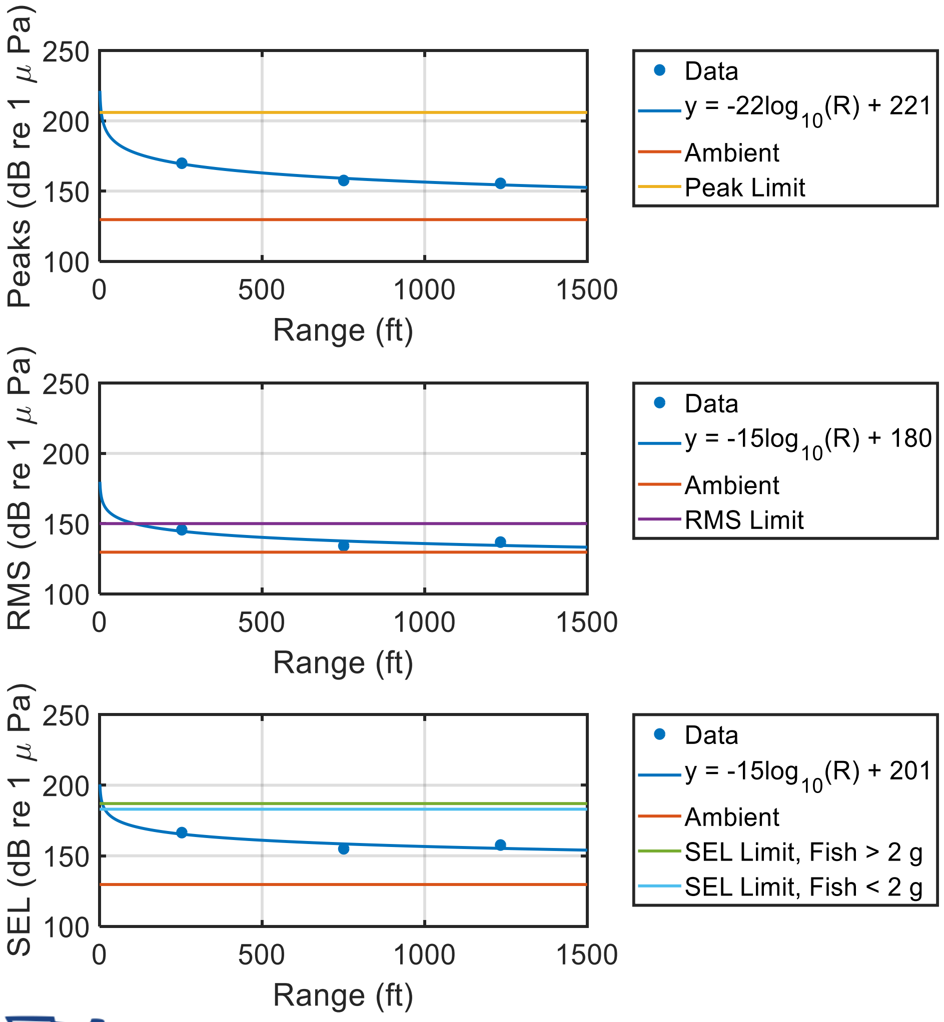


Sample LZ_{peak} results (Ribault test pile shown)

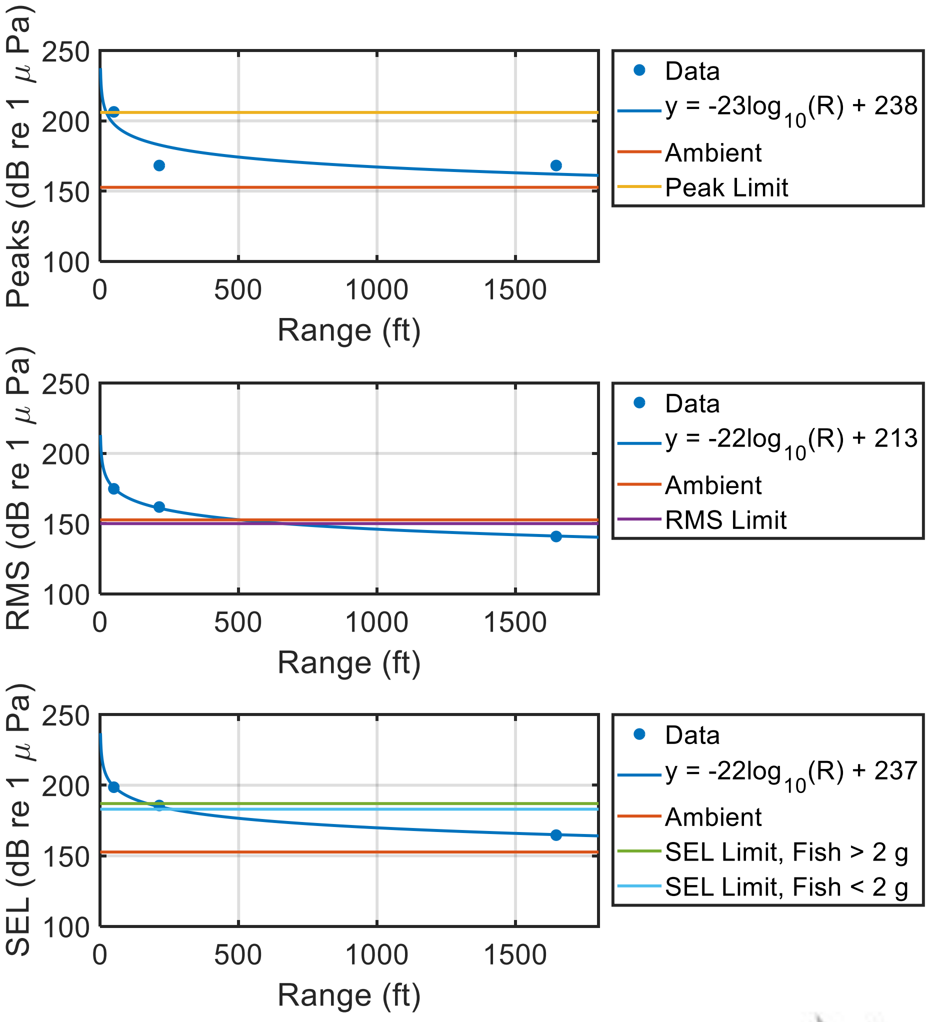


Peak sound pressure LZ_{peak} sample results

Results – New Methodology



.wav results from Dunn's Creek, Sheet 1



.wav results from Suwannee R., pile 1

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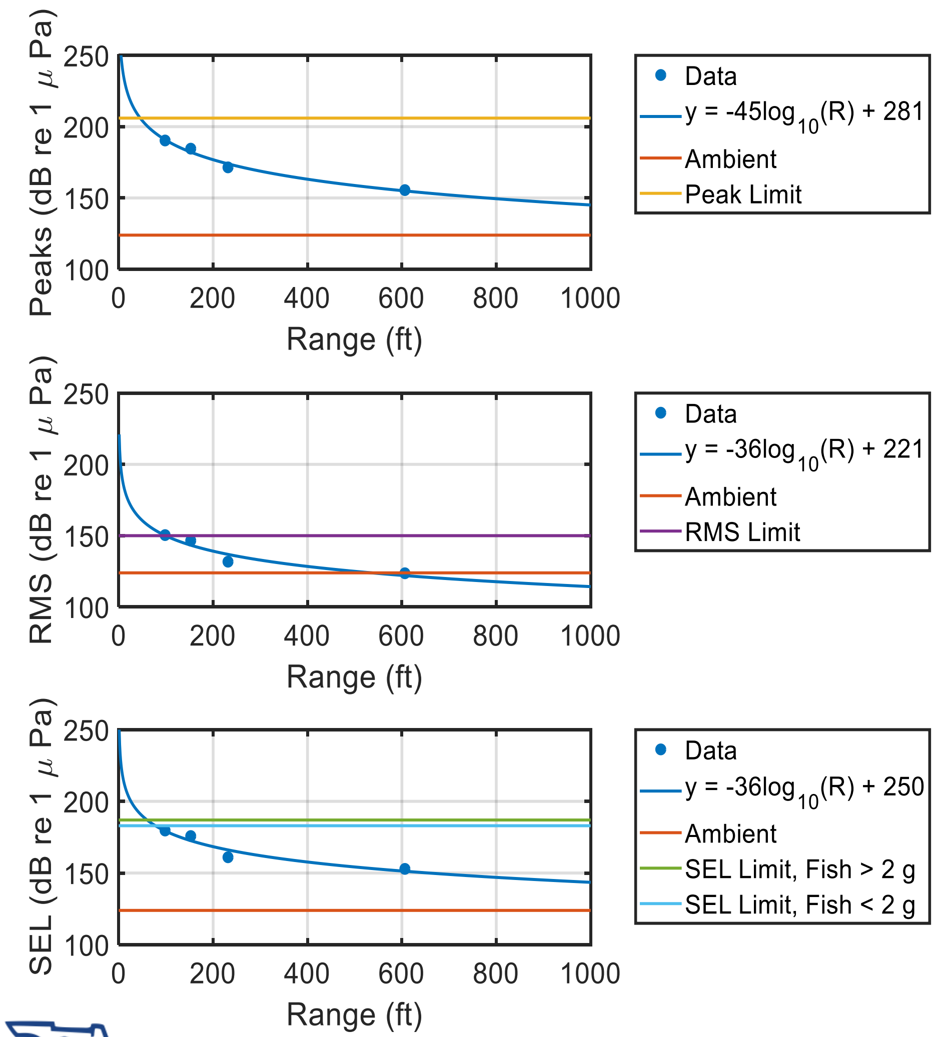
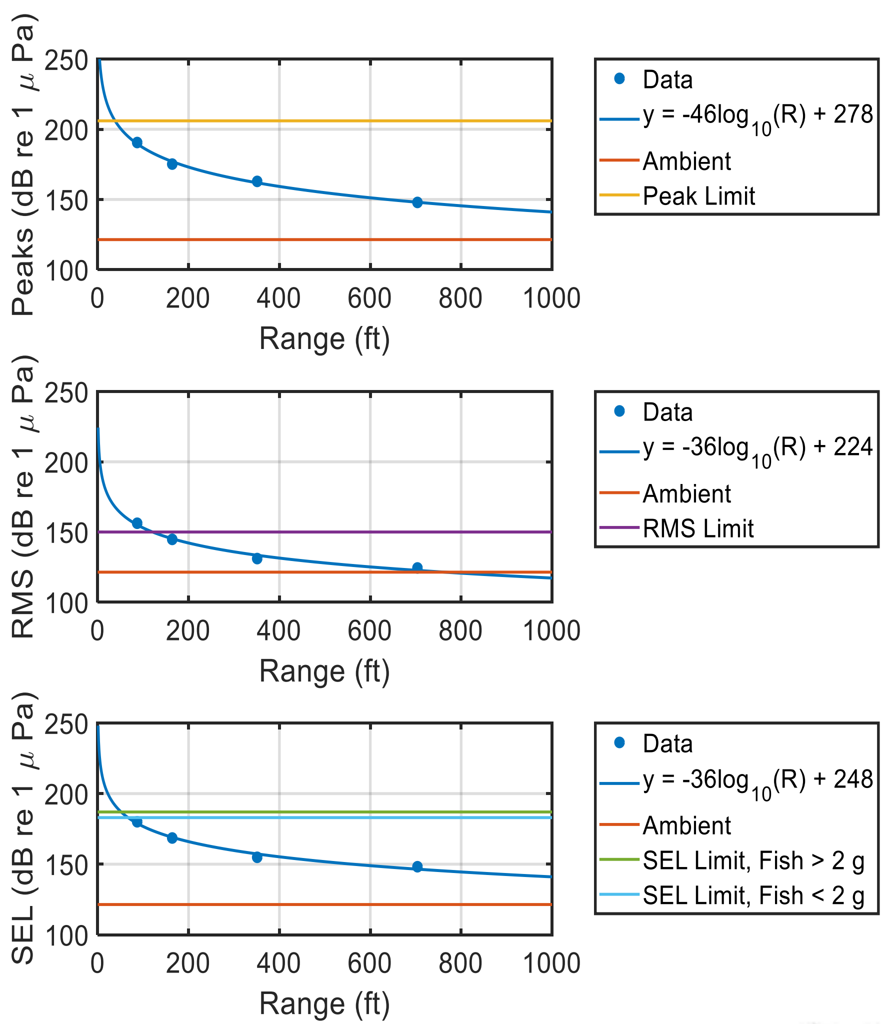
Results – New Methodology



.wav results from Ribault test pile



.wav results from Ribault production pile 1

SEL Results Summary

TL/SEL Results Using LZ_{peak} Data

Site Name	Noise Event	TL Coefficient	Extrapolated SEL (dB)
Suwannee River	Pile 1	25	258
	Pile 2	28	268
	Pile 3	27	261
Ribault River	Test Pile	47	272
	Pile 1	46	272
	Pile 2	46	277
	Pile 3	43	267
Bayway E	Trestle Vibrating	7	201
Dunn's Creek	Sheet Pile Pair 1	37	251
	Sheet Pile Pair 2	36	247

TL/SEL Results Using Raw Sound Data

Site Name	Noise Event	TL Coefficient	Extrapolated SEL (dB)
Suwannee River	Pile 1	22	237
	Pile 2	24	245
	Pile 3	25	243
Ribault River	Test Pile	36	250
	Pile 1	36	248
	Pile 2	35	250
	Pile 3	23	225
Bayway E	Trestle Vibrating	13	198
Dunn's Creek	Sheet Pile Pair 1	15	199
	Sheet Pile Pair 2	14	195

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RMS Results Summary

TL/RMS Results Using LZ_{peak} Data

Site Name	Noise Event	TL Coefficient	Extrapolated RMS (dB)
Suwannee River	Pile 1	24	227
	Pile 2	25	230
	Pile 3	25	234
Ribault River	Test Pile	43	237
	Pile 1	42	237
	Pile 2	41	240
	Pile 3	39	234
Bayway E	Trestle Vibrating	5	155
Dunn's Creek	Sheet Pile Pair 1	35	224
	Sheet Pile Pair 2	36	225

TL/RMS Results Using Raw Sound Data

Site Name	Noise Event	TL Coefficient	Extrapolated RMS (dB)
Suwannee River	Pile 1	22	213
	Pile 2	24	218
	Pile 3	25	222
Ribault River	Test Pile	36	221
	Pile 1	36	224
	Pile 2	35	226
	Pile 3	23	194
Bayway E	Trestle Vibrating	13	168
Dunn's Creek	Sheet Pile Pair 1	15	180
	Sheet Pile Pair 2	14	176

Peaks Results Summary

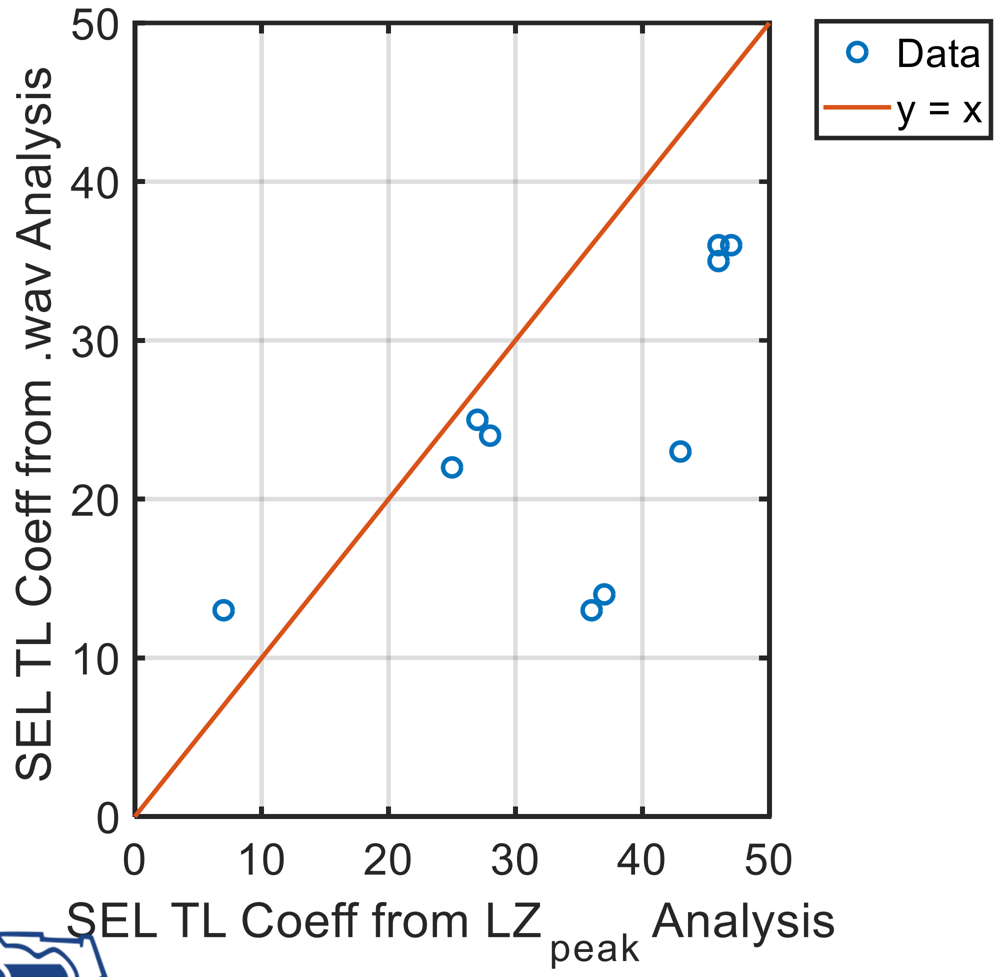
TL/Peaks Results Using LZ_{peak} Data

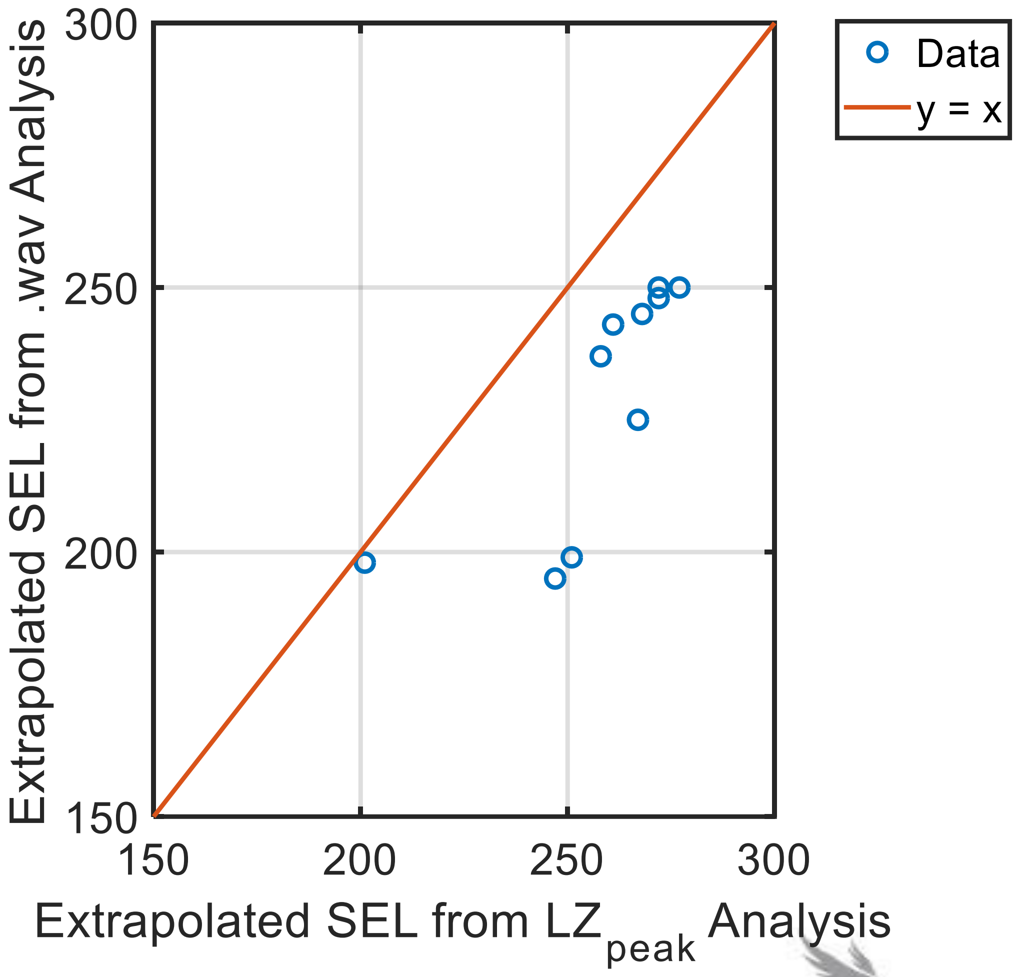
Site Name	Noise Event	TL Coefficient	Extrapolated RMS (dB)
Suwannee River	Pile 1	22	229
	Pile 2	26	238
	Pile 3	27	241
Ribault River	Test Pile	46	258
	Pile 1	39	244
	Pile 2	45	258
	Pile 3	22	217
Bayway E	Trestle Vibrating	15	200
Dunn’s Creek	Sheet Pile Pair 1	42	250
	Sheet Pile Pair 2	35	229

TL/Peaks Results Using Raw Sound Data

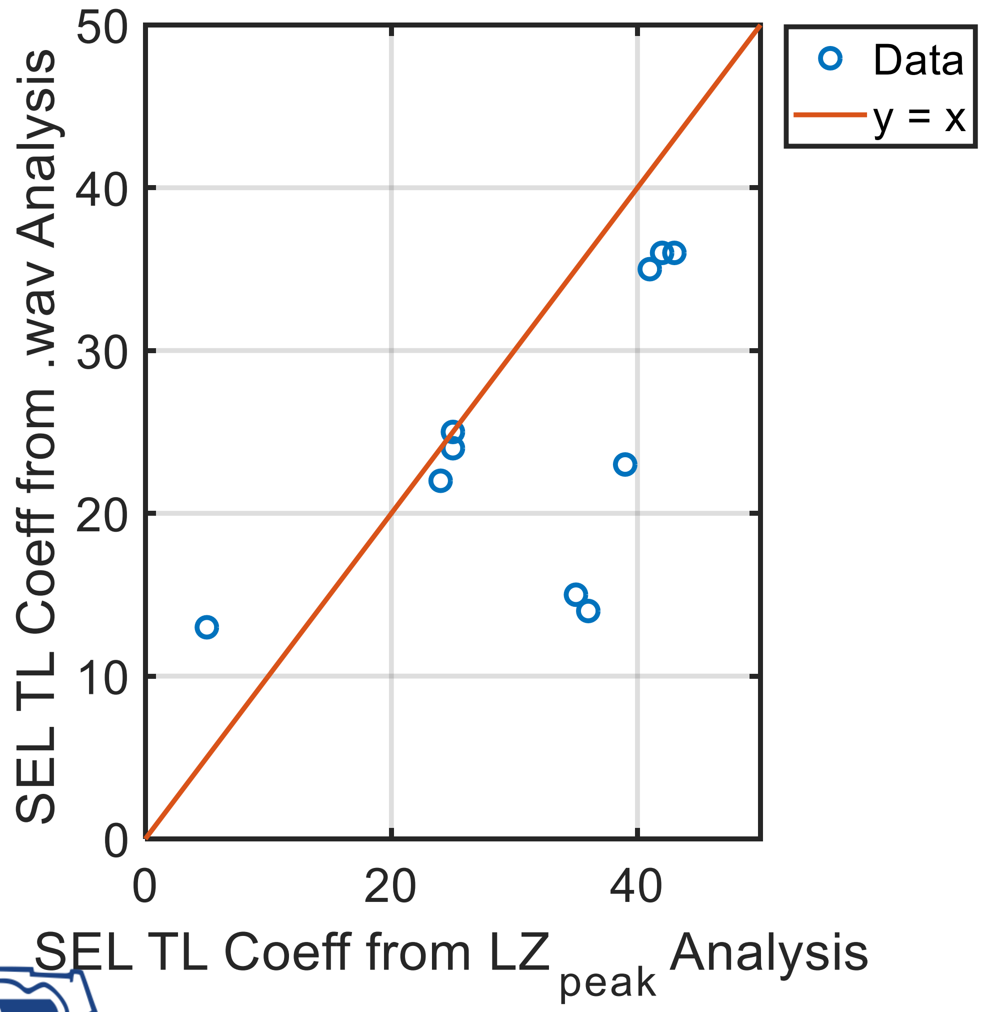
Site Name	Noise Event	TL Coefficient	Extrapolated RMS (dB)
Suwannee River	Pile 1	23	238
	Pile 2	25	242
	Pile 3	26	246
Ribault River	Test Pile	45	281
	Pile 1	46	278
	Pile 2	47	285
	Pile 3	40	266
Bayway E	Trestle Vibrating	13	201
Dunn’s Creek	Sheet Pile Pair 1	22	221
	Sheet Pile Pair 2	9	183

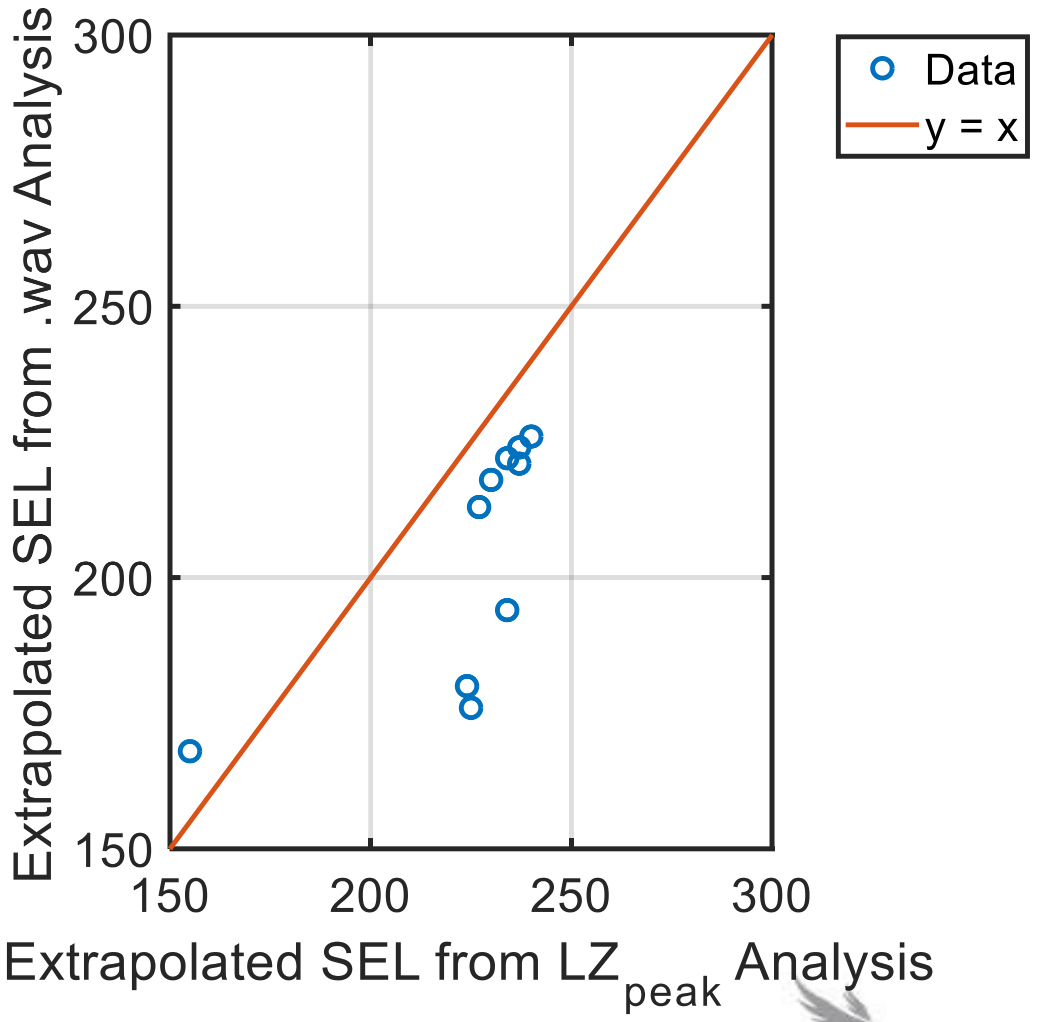
Graphical Results Summary (SEL)



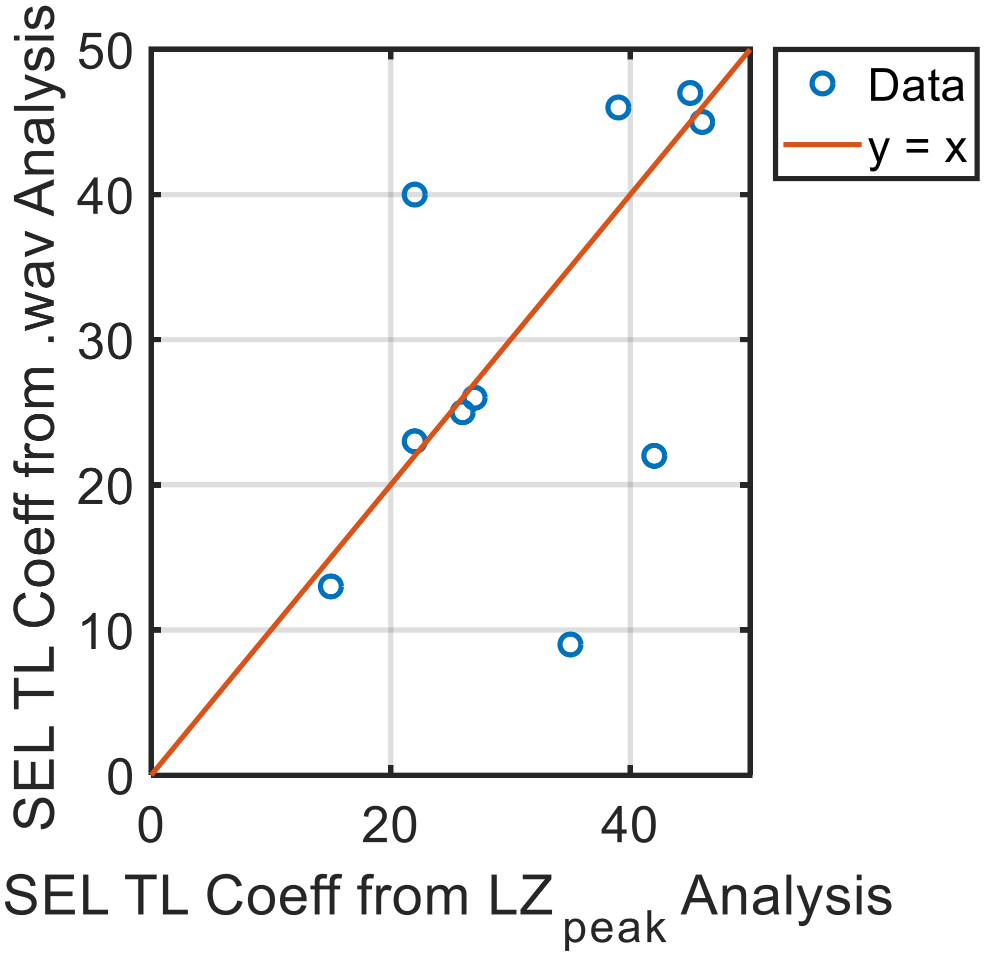


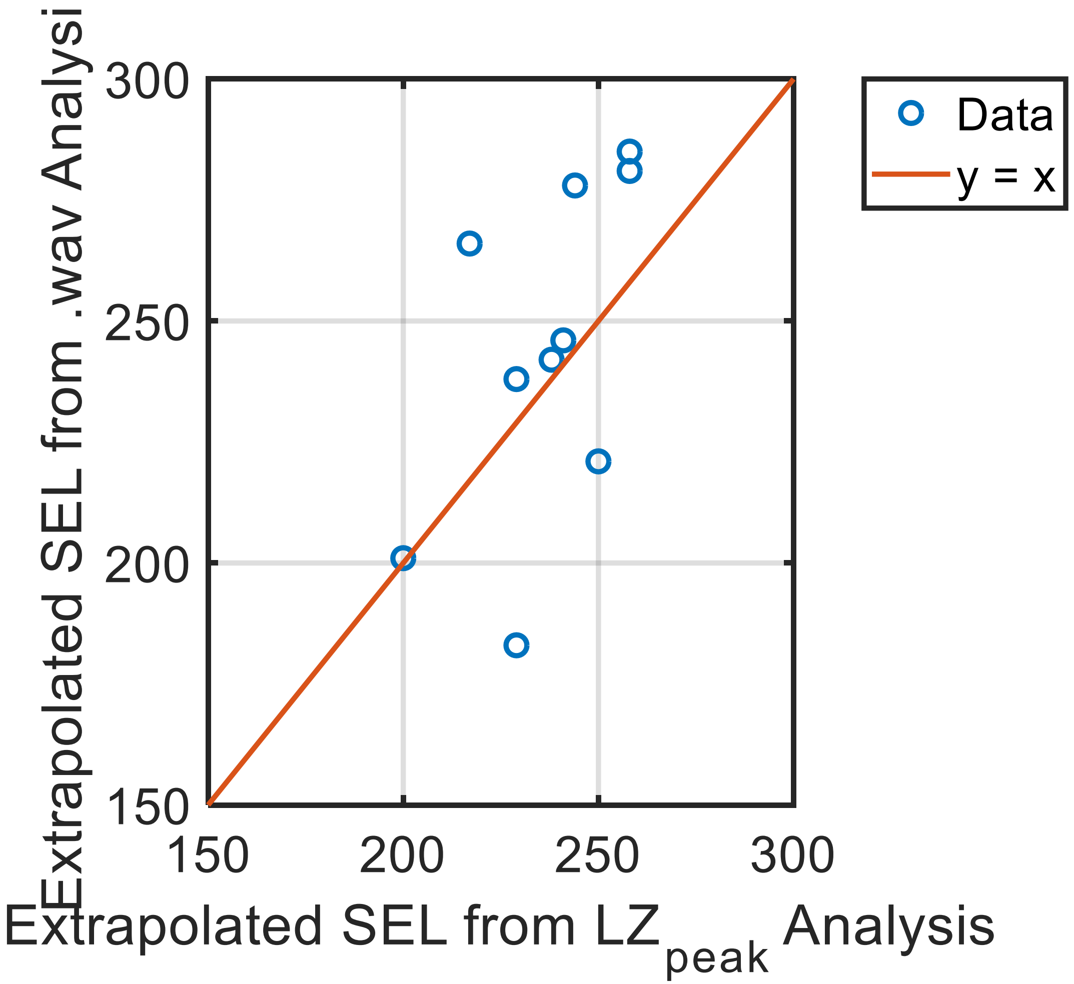
Graphical Results Summary (RMS)



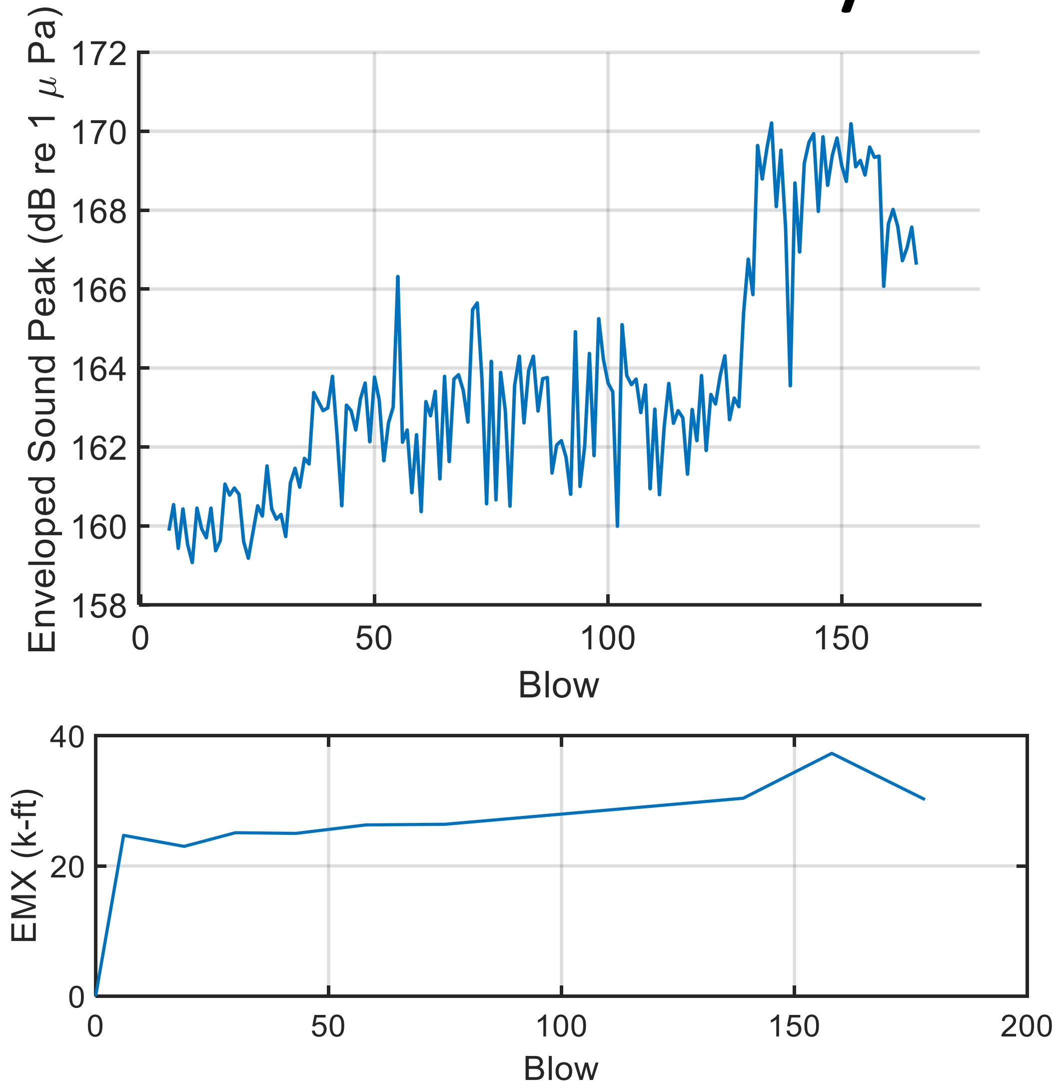


Graphical Results Summary (Peaks)

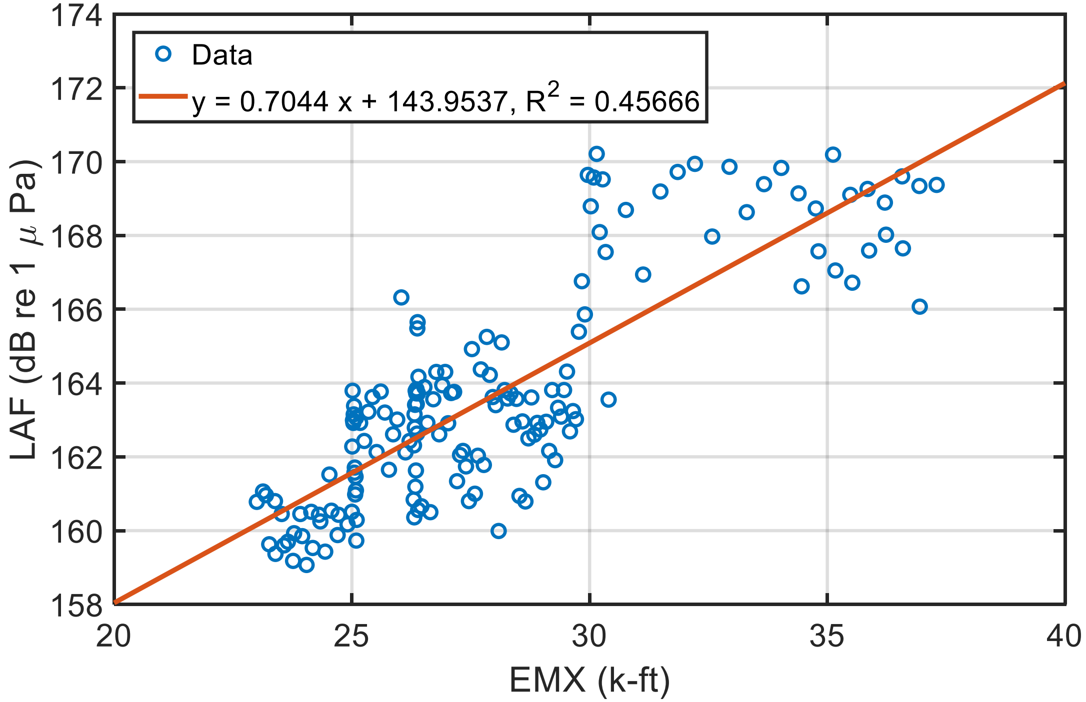




EMX/Noise Correlation

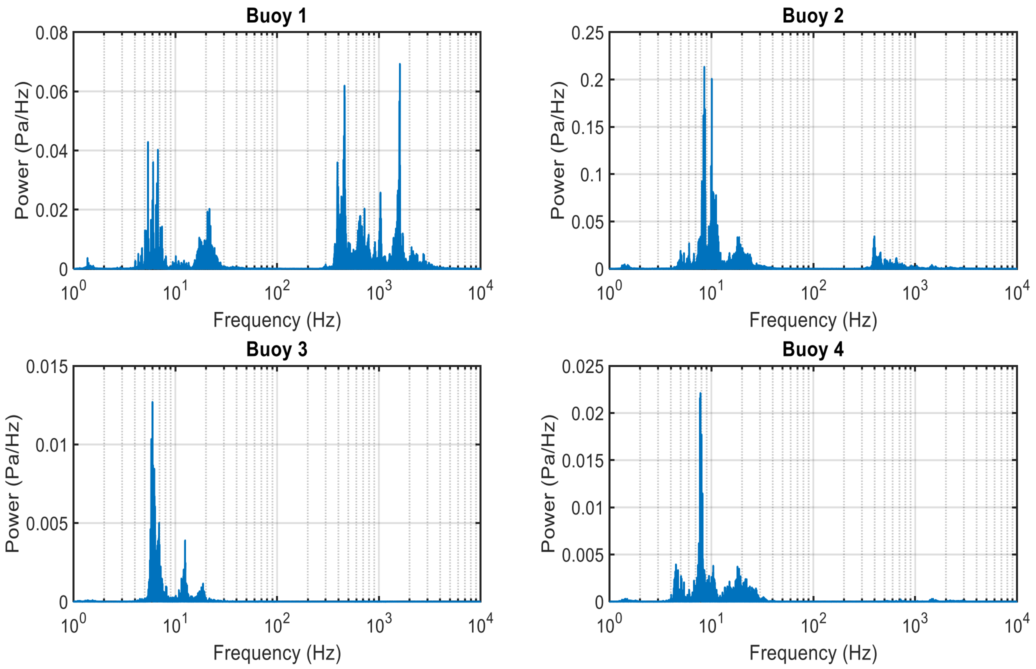


Peak sound versus blow-number (top); and EMX versus blow-number (bottom); from Ribault test pile

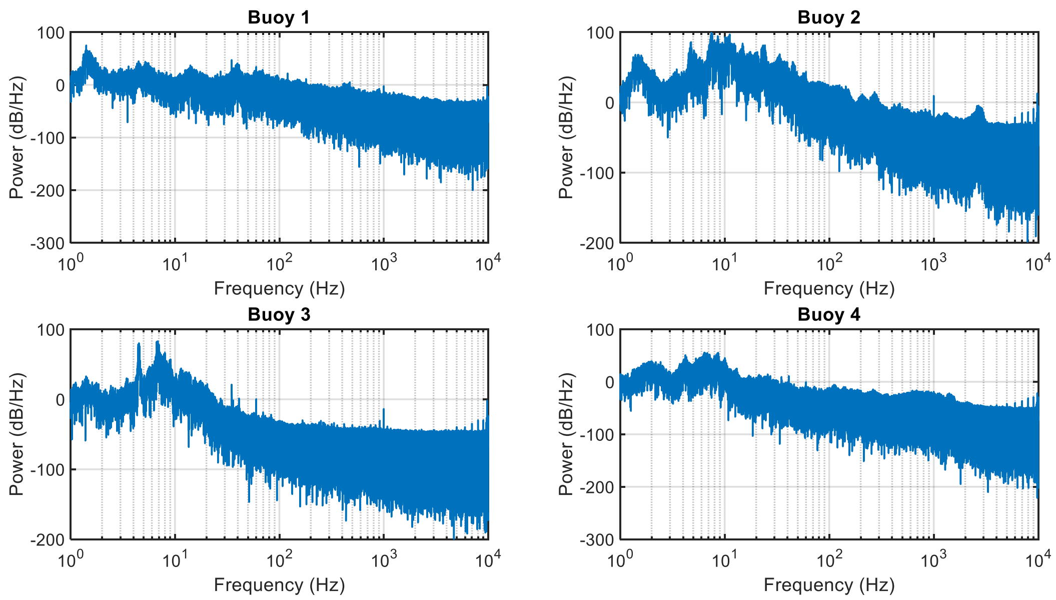


Correlation between peak sound and EMX; from Ribault test pile

Frequency Domain Analysis

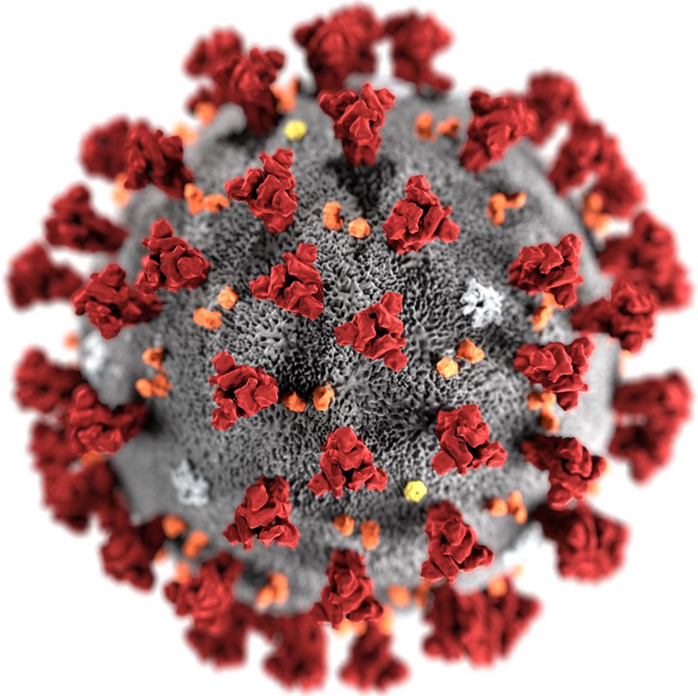


Spectral results from Ribault test pile (in Pa)



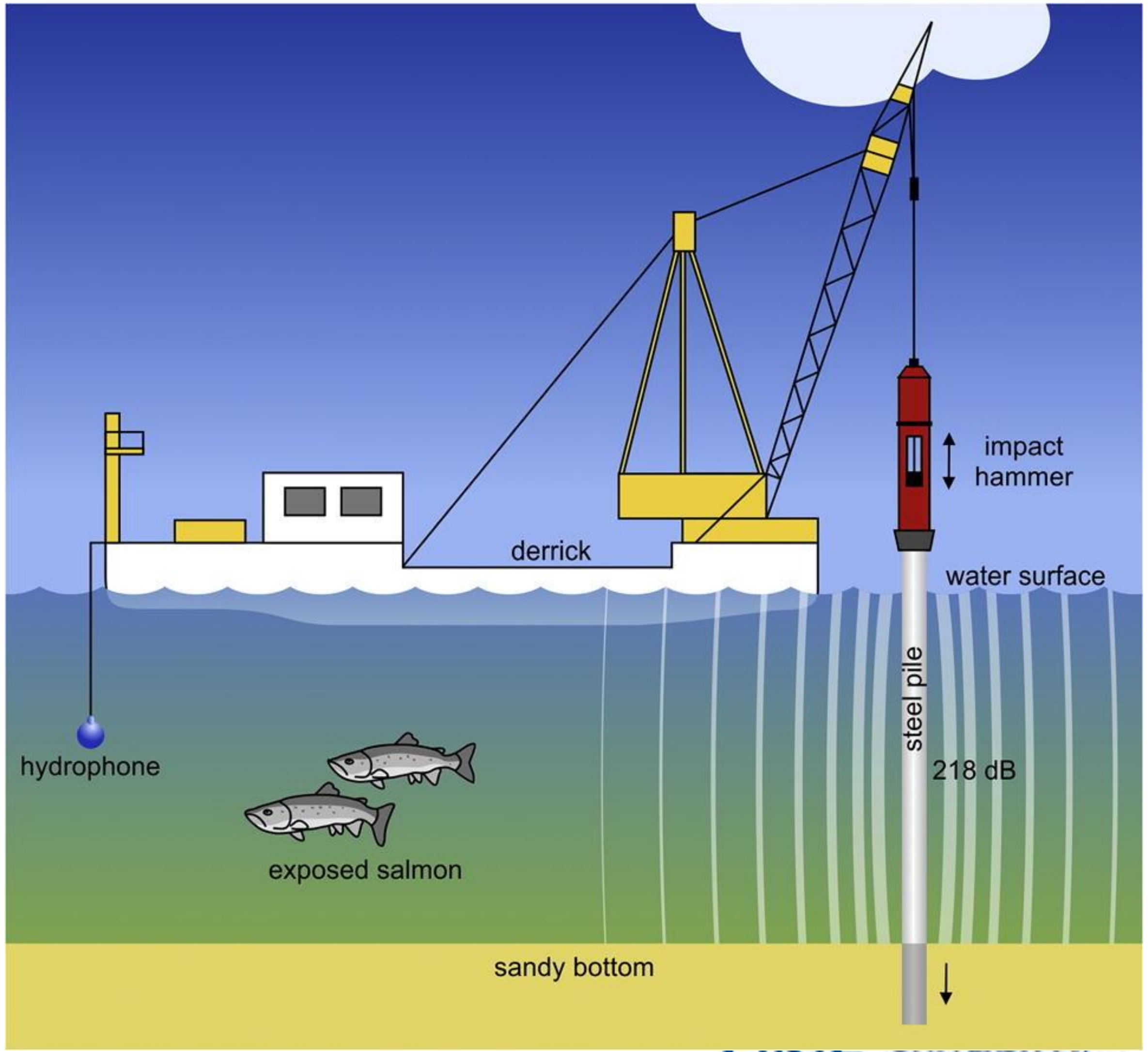
Spectral results from Ribault test pile (rescaled in dB)

What to Do?



What Causes Sound Decay?

- Geometrical effects
- Absorption at the water surface
- Geotechnical absorption

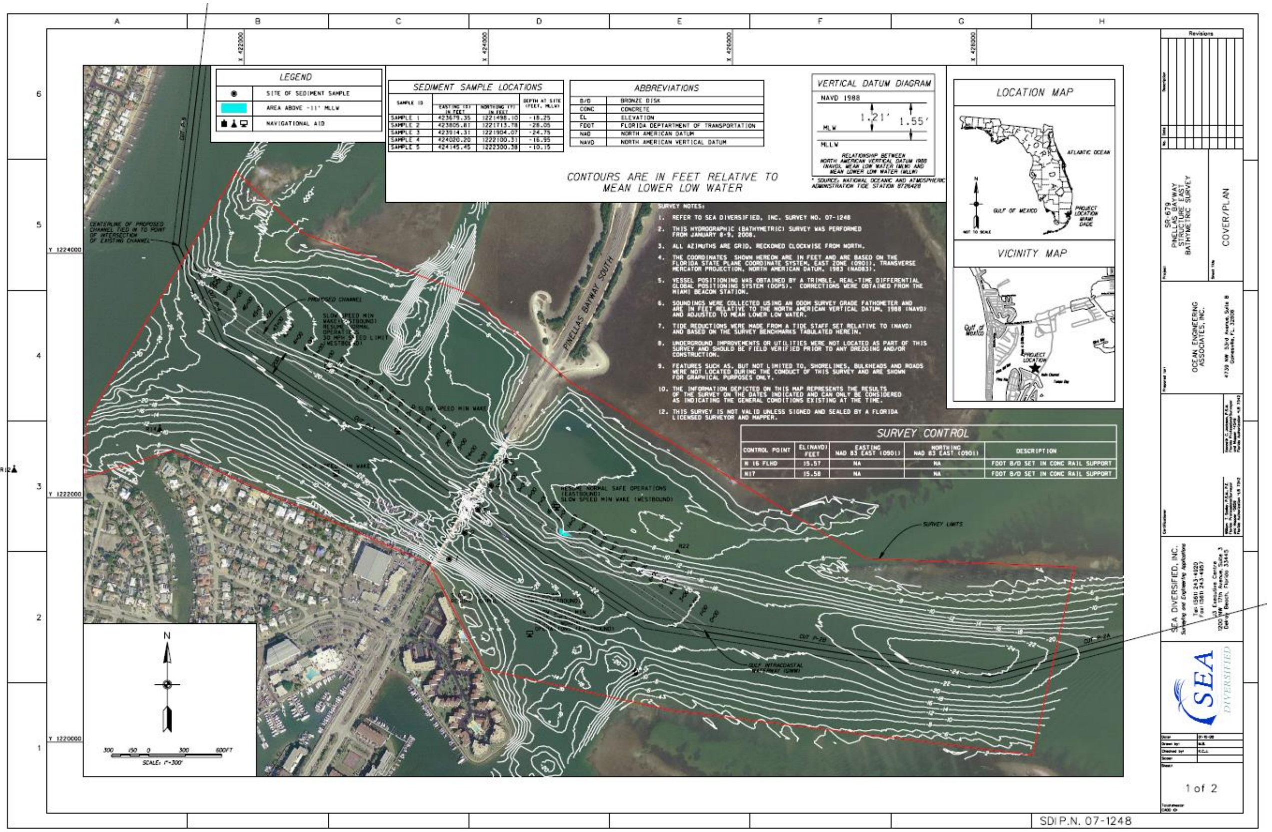


Computational Fluid Dynamics (CFD)

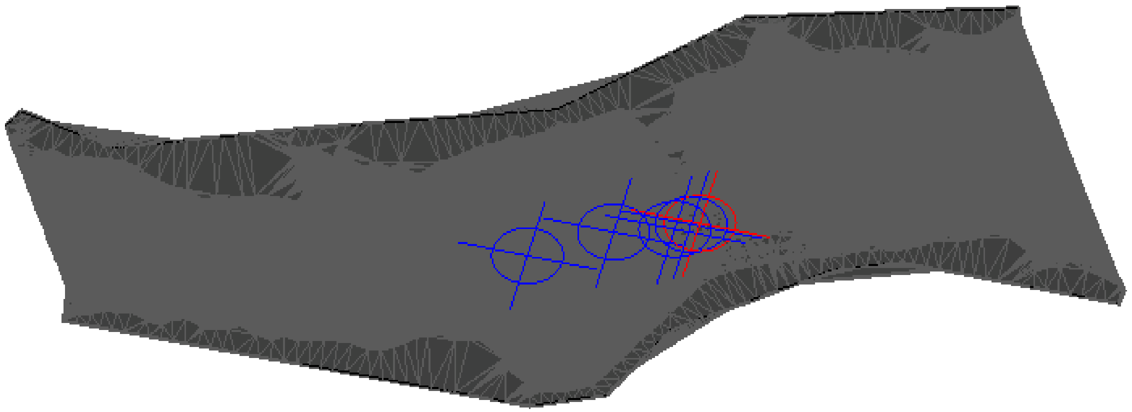
$$\frac{1}{c^2}\frac{\partial^2 p^a}{\partial t^2} + \frac{2\overline{v}}{c^2}\cdot\frac{\nabla\partial p^a}{\partial t} + \frac{\overline{v}\cdot\nabla}{c^2}(\nabla\cdot\overline{v}p^a) - \nabla^2\left(p^a + \tau\frac{\partial p^a}{\partial t}\right) = -\left[\frac{1}{c^2}\frac{\partial^2\Phi_p}{\partial t^2} + \frac{2\overline{v}\cdot\nabla}{c^2}\frac{\partial p'}{\partial t} + \frac{\overline{v}\cdot\nabla}{c^2}(\nabla\cdot\overline{v}p')\right]$$

- p' = perturbation pressure
- $p^a = sound\ pressure$
- $\overline{v}$ = time-averaged (i.e., mean) velocity;
- $\tau =$ damping term
- c = speed of sound;
- Φ_p = the noise source function.

Mapping Local Bathymetry



Bayway E Bathymetry Map



Bayway E Three-Dimensional Bathymetry

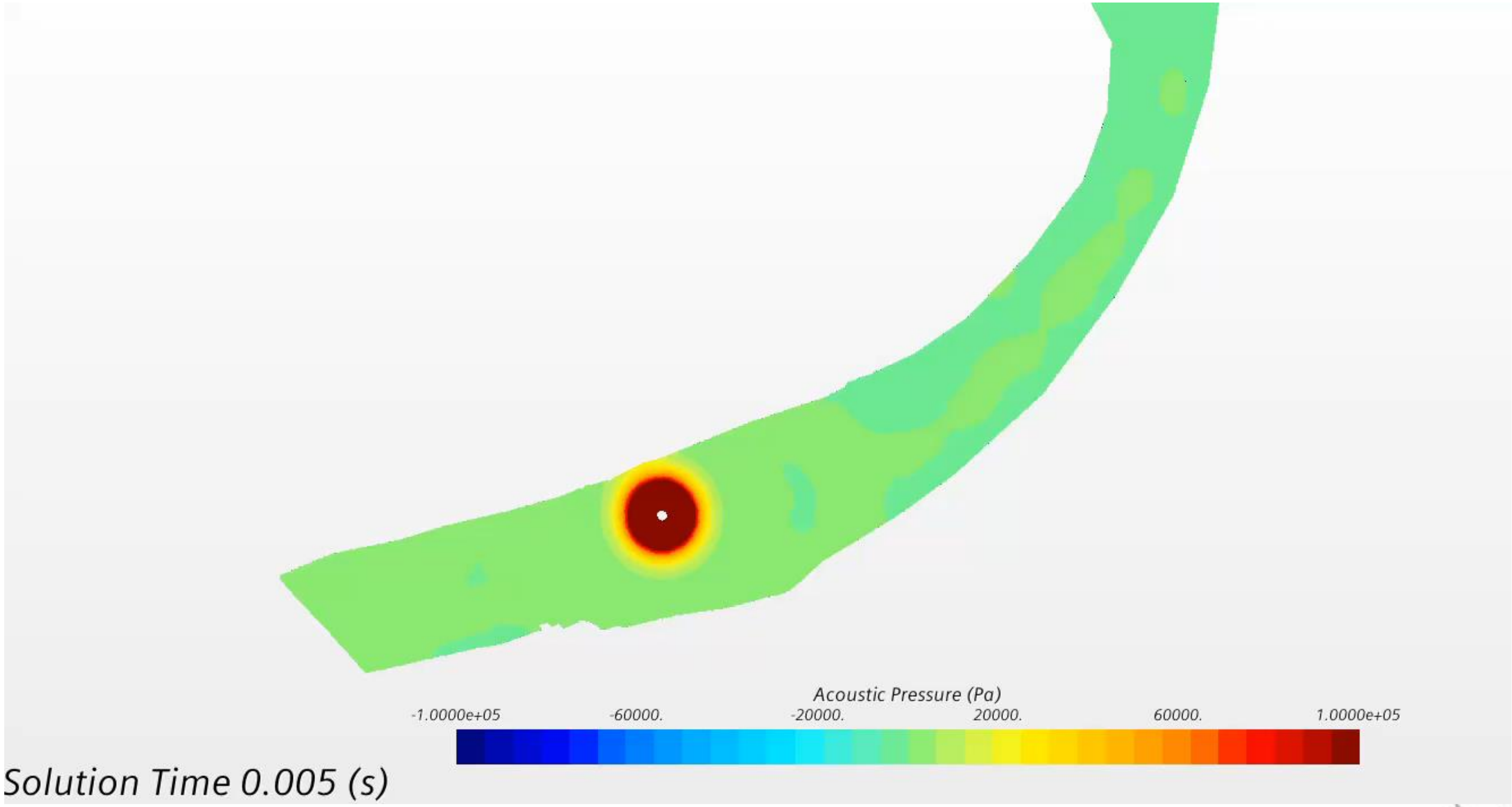
Meshing Local Bathymetry

Ribault River Mesh

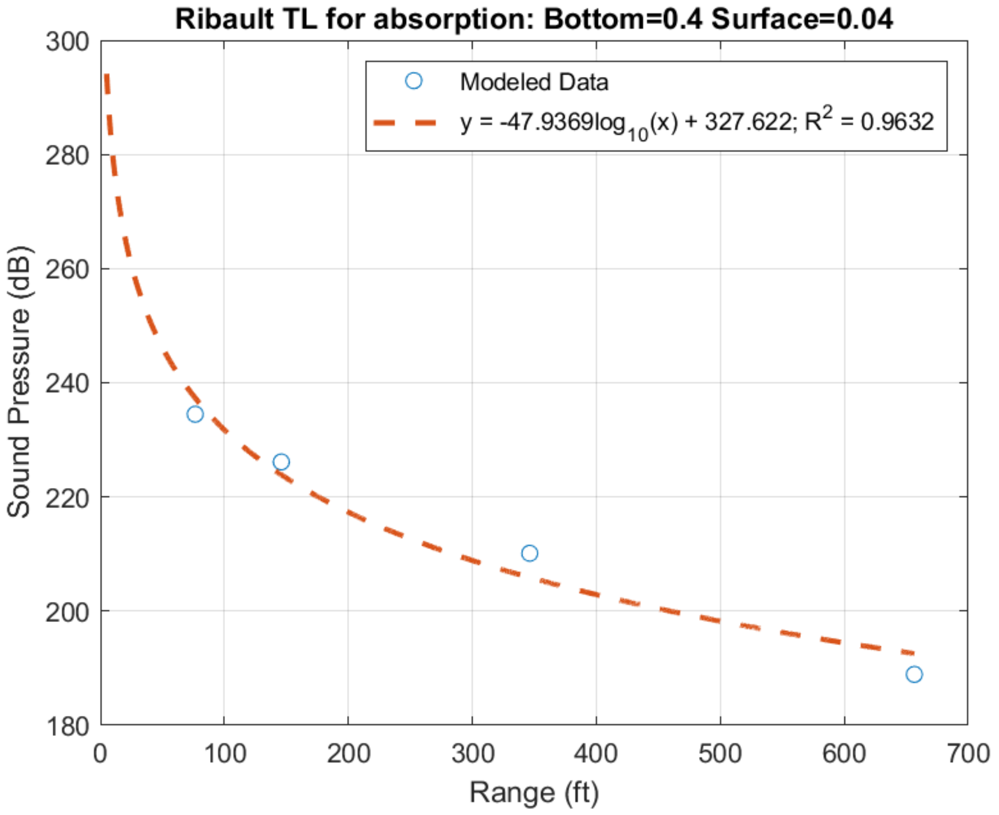
Testing Matrix

- Water surface absorption coefficient – vary from 0% to 60%
- Bottom absorption coefficient – vary from 0% to 100%
- Approximately 70 models/site

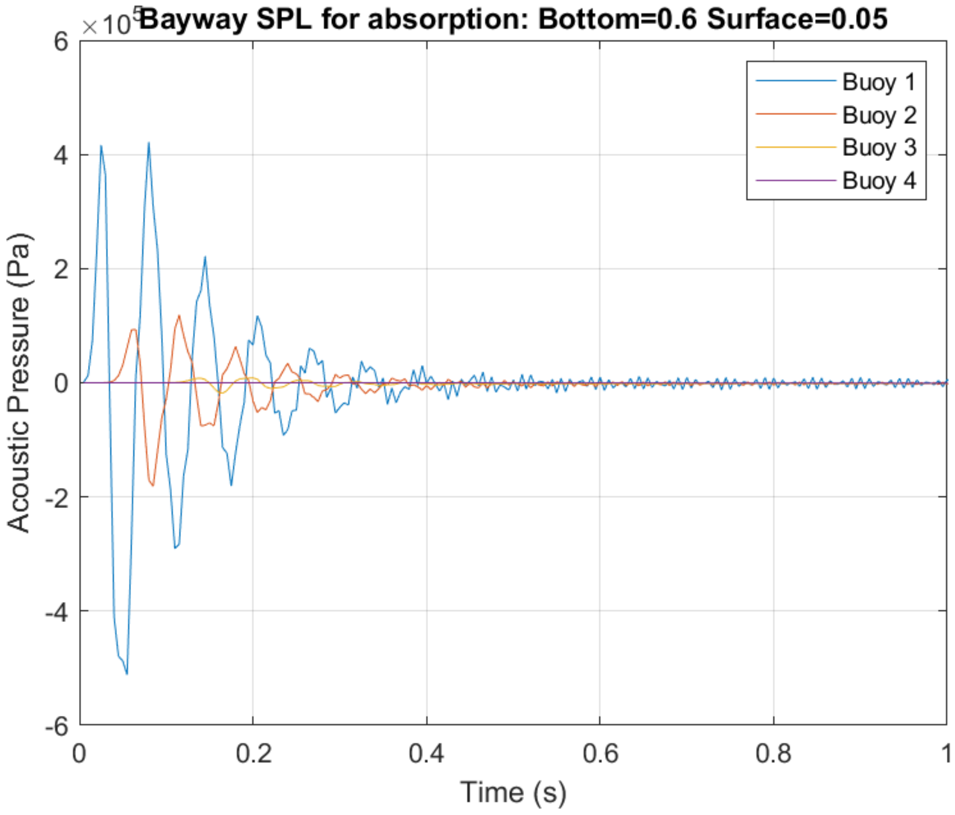
Results


Acoustic Pressure (Pa)
-1.0000e+05
-60000.
-20000.
20000.
60000.
1.0000e+05
Solution Time 0.005 (s)

Sample Results

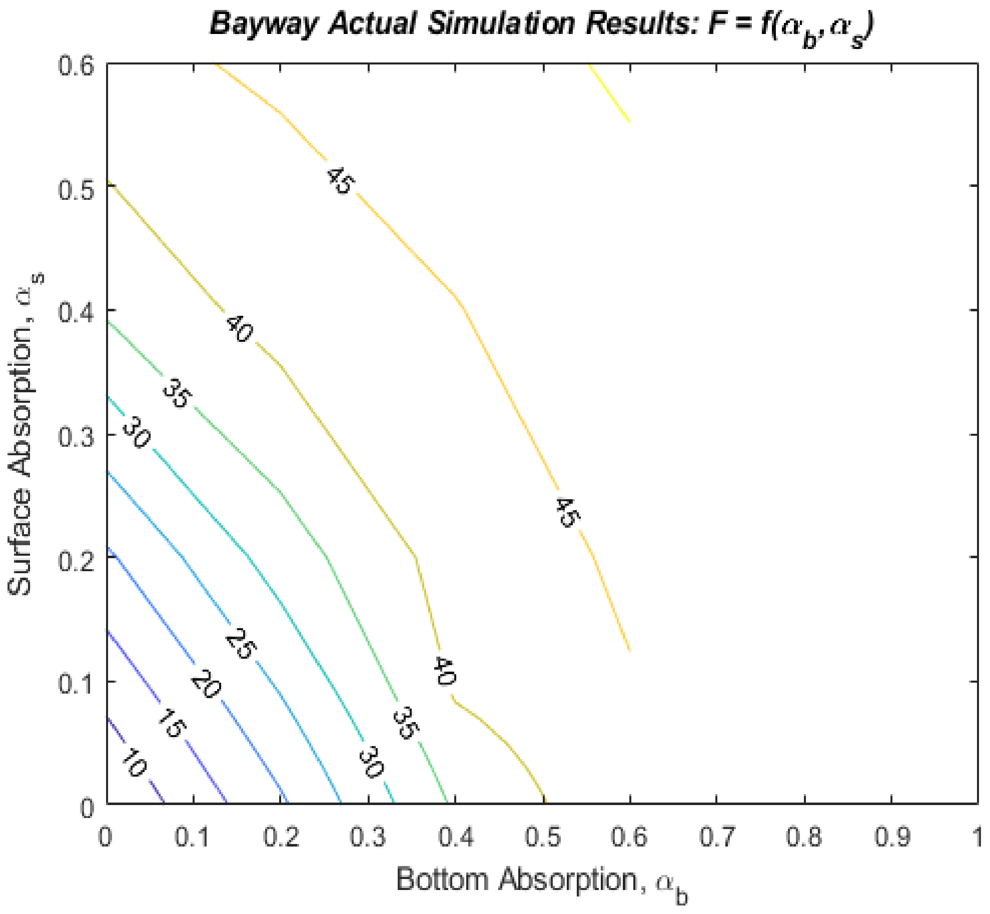


Sample Results from Ribault

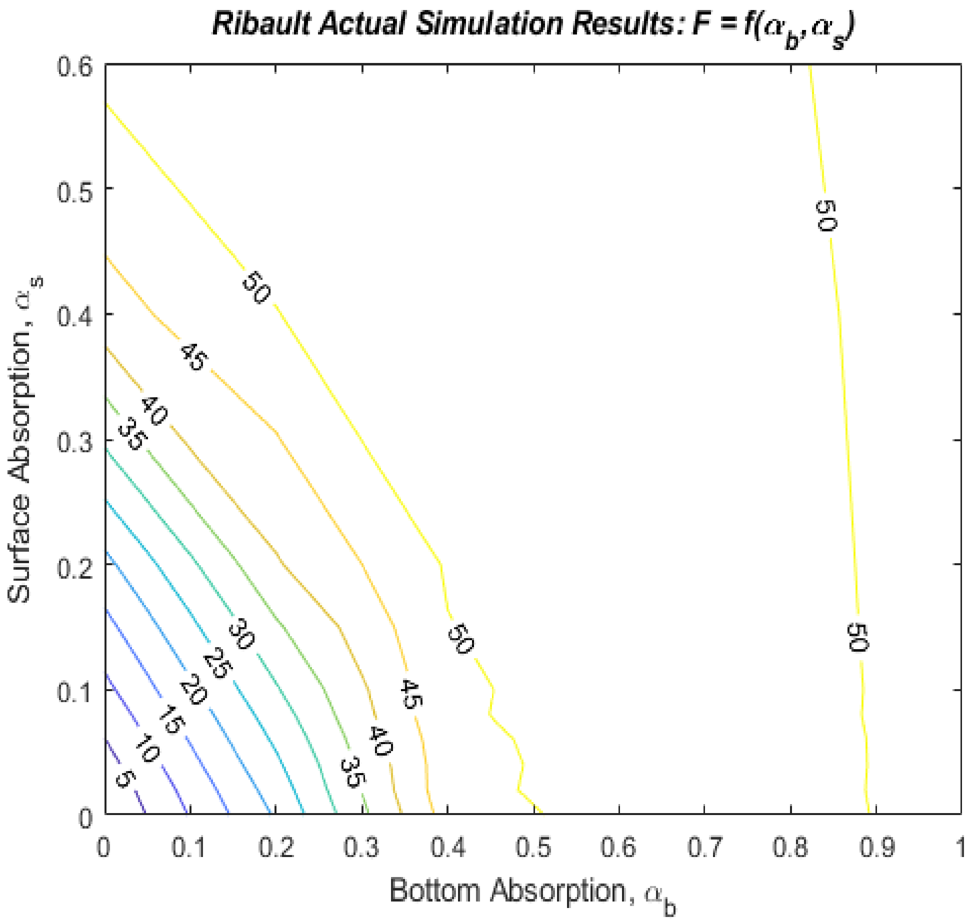


Sample Results from Bayway

Results Contours



Contour Results from Bayway
(actual TL coefficient = 18)



Contour Results from Ribault
(actual TL coefficient = 44)

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Conclusions from Modeling

- Assume low surface absorption
- Bayway – between 15% and 20% of sound energy absorbed by soil
- Ribault – between 35% and 40% of sound energy absorbed by soil
- Results appear to show that geotechnical conditions influence TL coefficient

Modeling Caveats/Upcoming Work

- Currents, turbulence, viscosity neglected; these updated runs are ongoing
- More sites needed; moving on to Suwannee River, John Sims Parkway, Dunn's Creek
- Correlations between bottom absorption coefficient and traditional geotech properties

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Other Upcoming Work

- Continue with frequency-based data analysis; may be appropriate to define TL coefficient and SEL/Peak sound as a function of both amplitude and frequency

- Signal-based data/frequency domain data analysis at new sites

Upcoming Sites

- Driving ongoing
  - John Sims Parkway (D3)
  - Cedar Key C Street (D2)
  - St. Joe's Bay Inlet Bridge test piles (D3)

- Driving scheduled in 2020
  - Blackwater River (D3)
  - Choctawhatchee Bay Bridge Fender Replacement (D3)
  - Manatee River Bridge (D1)
  - St. Joe's Bay Inlet Bridge production piles (D3)
  - New River Bridge (D2)
  - Howard Frankland Bridge (D7)
  - Simpson Creek Bridge (D2)
  - Myrtle Creek Bridge (D2)

Thank you!