Appendix A

Table 1A. Mesh and Nodal Attributes Applied in Final Storm Run (from the FEMA report)

Storm	Track	Mesh Description	SCC	ESL	MN
1	JPM_30001018	base	CCAP	v2	base
2	JPM_30001019	base	CCAP	v2	base
3	JPM_30001020	base	CCAP	v2	base
4	JPM_30001021	base	CCAP	v2	base
5	JPM_30001022	base	CCAP	v2	base
6	JPM_30001023	base	CCAP	v2	base
7	JPM_30001024	base	CCAP	v2	base
8	JPM_30001025	canal filled	v3	v5	canal filled edit
9	JPM_30001026	canal filled	v3	v5	canal filled edit
10	JPM_30001027	canal filled	v3	v5	canal filled edit
11	JPM_30001028	canal filled	v3	v5	canal filled edit
12	JPM_30001029	canal filled	v3	v5	canal filled edit
13	JPM_30001030	canal filled	v3	v5	canal filled edit
14	JPM_30001031	canal filled	v3	v5	canal filled edit
15	JPM_30001032	canal filled	v3	v5	canal filled edit
16	JPM_30001033	canal filled	v3	v5	canal filled edit
17	JPM_30001034	base	CCAP	none	base
18	JPM_30001035	base	CCAP	v2	base
19	JPM_30001036	base	CCAP	v2	base
20	JPM_30002006	canal filled	v3	v5	canal filled edit
21	JPM_30002007	canal filled	v3	v5	canal filled edit
22	JPM_30002008	canal filled	v3	v6	canal filled edit
23	JPM_30002009	canal filled	v3	v5	canal filled edit
24	JPM_30002010	canal filled+ deepened_Carib_v2	v3	v6	canal filled edit
25	JPM_30002011	canal filled+ deepened_Carib_v2	v3+Everglades+ CoralGables	v9	canal filled edit
26	JPM_30002012	canal filled+ deepened_Carib_v2	v3+Everglades	v7	canal filled edit
27	JPM_30002013	canal filled+ deepened_Carib_v2	v3+Everglades	v7	canal filled edit
28	JPM_30002014	canal filled	v3+Everglades	v6	canal filled edit
29	JPM_30002015	canal filled	v3+Everglades	v6	canal filled edit
30	JPM_30002016	canal filled	v3+Everglades	v5	canal filled edit
31	JPM_30002017	base	CCAP	v2	base
32	JPM_30002018	base	CCAP	none	base
33	JPM_30002019	base	CCAP	v2	base

34	JPM_30002020	base	CCAP	v2	base
35	JPM_30002021	base	CCAP	v2	base
36	JPM_30002022	base	CCAP	v2	base
37	JPM_30002023	base	CCAP	none	base
38	JPM_30002024	base	CCAP	v2	base
39	JPM_30003025	base	CCAP	v2	base
40	JPM_30003026	base	CCAP	v2	base
41	JPM_30003027	base	CCAP	v2	base
42	JPM_30003028	base	CCAP	v2	base
43	JPM_30003029	base	CCAP	v2	base
44	JPM_30003030	base	CCAP	v2	base
45	JPM_30003031	base	CCAP	v2	base
46	JPM_30003032	base	CCAP	v2	base
47	JPM_30003033	base	CCAP	v2	base
48	JPM_30003034	base	CCAP	v2	base
49	JPM_30003035	base	CCAP	v2	base
50	JPM_30003036	base	CCAP	v2	base
51	JPM_30003037	base	CCAP	v2	base
52	JPM_30003038	canal filled	v3	v5	canal filled edit
53	JPM_30003039	canal filled	v3	v5	canal filled edit
54	JPM_30003040	canal filled	v3	v5	canal filled edit
55	JPM_30003041	canal filled	v3	v5	canal filled edit
56	JPM_30003042	canal filled	v3	v5	canal filled edit
57	JPM_30003043	canal filled	v3+Caribbean	v5	canal filled edit
58	JPM_30003044	canal filled	v3	v5	canal filled edit
59	JPM_30003045	canal filled	v3	v5	canal filled edit
60	JPM_30003046	canal filled	v3	v5	canal filled edit
61	JPM_30003047	canal filled	v3	v5	canal filled edit
62	JPM_30003048	canal filled	v3	v6	canal filled edit
63	JPM_30003049	canal filled	v3	v6	canal filled edit
64	JPM_30003050	canal filled	v3	v5	canal filled edit
65	JPM_30003051	canal filled	v3	v5	canal filled edit
66	JPM_30003052	canal filled	v3	v5	canal filled edit
67	JPM_30003053	base	CCAP	v2	base
68	JPM_30003054	canal filled	v3	v5	canal filled edit
69	JPM_30003055	base	CCAP	v2	base
70	JPM_30004003	base	CCAP	none	base
71	JPM_30004004	base	Caribbean	v5	base
72	JPM_30004005	canal filled	v3	v5	canal filled edit
73	JPM_30004006	canal filled	v3	v5	canal filled edit
74	JPM_30004007	canal filled+ deepened_C arib_v2	v3+Everglades+ CoralGables	v11	canal filled edit

75	JPM_30004008	canal filled+ deepened_Carib_v2	v3	v5	canal filled edit
76	JPM_30004009	canal filled+ deepened_Carib_v2	v3	v5	canal filled edit
77	JPM_30004010	canal filled	v3+Everglades	v5	canal filled edit
78	JPM_30004011	canal filled	v3+Everglades	v5	canal filled edit
79	JPM_30004012	base	CCAP	v2	base
80	JPM_30004013	base	CCAP	v2	base
81	JPM_30004014	canal filled+ deepened_Carib	v3	v5	canal filled edit
82	JPM_30004015	canal filled+ deepened_Carib	v3	v5	canal filled edit
83	JPM_30005005	base	CCAP	v2	base
84	JPM_30005006	canal filled	v3	v5	canal filled edit
85	JPM_30005007	canal filled	v3	v5	canal filled edit
86	JPM_30005008	canal filled	v3	v6	canal filled edit
87	JPM_30005009	base	v3	v5	base
88	JPM_30005010	canal filled	v3	v5	canal filled edit
89	JPM_30005011	canal filled	v3	v5	canal filled edit
90	JPM_30005012	canal filled	v3	v5	canal filled edit
91	JPM_30005013	canal filled	v3+Everglades+ Pinecrest	v9	canal filled edit
92	JPM_30005014	base	CCAP	v2	base
93	JPM_30005015	base	CCAP	v2	base
94	JPM_30005016	base	CCAP	v2	base
95	JPM_30005017	base	CCAP	v2	base
96	JPM_30005018	base	CCAP	none	base
97	JPM_30005019	base	CCAP	v2	base
98	JPM_30005020	base	CCAP	v2	base
99	JPM_30005021	base	CCAP	v2	base
100	JPM_30005022	base	CCAP	v2	base
101	JPM_30005023	base	CCAP	v2	base
102	JPM_30005024	base	CCAP	v2	base
103	JPM_30006003	canal filled+ deepened_Carib	v3	v5	canal filled edit
104	JPM_30006004	canal filled+ deepened_Carib	v3	v5	canal filled edit
105	JPM_30006005	canal filled	v3+Everglades	v5	canal filled edit
106	JPM_30006006	canal filled	v3	v6	canal filled edit

107	JPM_30006007	canal filled+ deepened_Carib_v2	v3+Everglades+ CoralGables	v10	canal filled edit
108	JPM_30006008	canal filled+ deepened_Carib_v2	v3	v7	canal filled edit
109	JPM_30006009	canal filled+ deepened_Carib_v4	v3	v5	canal filled edit
110	JPM_30006010	canal filled+ deepened_Carib_v2	v3	v6	canal filled edit
111	JPM_30006011	canal filled+ deepened_Carib_v4	v3	v5	canal filled edit
112	JPM_30006012	canal filled+ deepened_Carib_v2	v3	v5	canal filled edit
113	JPM_30006013	base	CCAP	v2	base
114	JPM_30006014	canal filled+ deepened_Carib_v4	v3+Everglades	v5	canal filled edit
115	JPM_30006015	canal filled+ deepened_Carib	v3	v5	canal filled edit
116	JPM_30007008	base	CCAP	v2	base
117	JPM_30007009	canal filled	v3	v5	canal filled edit
118	JPM_30007010	canal filled	v3	v5	canal filled edit
119	JPM_30007011	canal filled	v3	v5	canal filled edit
120	JPM_30007012	canal filled	v3	v6	canal filled edit
121	JPM_30007013	canal filled	v3	v5	canal filled edit
122	JPM_30007014	canal filled	v3	v5	canal filled edit
123	JPM_30007015	canal filled	v3	v6	canal filled edit
124	JPM_30007016	canal filled	v3	v5	canal filled edit
125	JPM_30007017	canal filled	v3	v5	canal filled edit
126	JPM_30007018	base	CCAP	v2	base
127	JPM_30007019	base	CCAP	none	base
128	JPM_30007020	base	CCAP	v2	base
129	JPM_30008006	base	CCAP	v2	base
130	JPM_30008007	base	CCAP	v2	base
131	JPM_30008008	base	CCAP	v2	base
132	JPM_30008009	canal filled	v3	v5	canal filled edit
133	JPM_30008010	base	CCAP	v2	base
134	JPM_30008011	canal filled	v3	v5	canal filled edit
135	JPM_30008012	canal filled	v3	v5	canal filled edit

136	JPM_30008013	base	CCAP	v2	base
137	JPM_30008014	base	CCAP	v2	base
138	JPM_30008015	base	CCAP	v2	base
139	JPM_30009009	base	CCAP	none	base
140	JPM_30009010	base	CCAP	v2	base
141	JPM_30009011	base	CCAP	v2	base
142	JPM_30009012	base	CCAP	v2	base
143	JPM_30009013	base	CCAP	v2	base
144	JPM_30009014	canal filled	v3	v5	canal filled edit
145	JPM_30009015	base	CCAP	v2	base
146	JPM_30009016	base	CCAP	v2	base
147	JPM_30009017	base	CCAP	v2	base
148	JPM_30009018	base	CCAP	v2	base
149	JPM_30009019	canal filled	v3	v5	canal filled edit
150	JPM_30009020	base	CCAP	v2	base
151	JPM_30009021	base	CCAP	v2	base
152	JPM_30009022	base	CCAP	v2	base
153	JPM_30009023	base	CCAP	v2	base
154	JPM_30009024	base	CCAP	v2	base
155	JPM_30009025	base	CCAP	v2	base
156	JPM_30009027	base	CCAP	v2	base
157	JPM_30009028	base	CCAP	v2	base
158	JPM_30009031	base	CCAP	v2	base
159	JPM_30009032	base	CCAP	v2	base
160	JPM_30010014	base	CCAP	v2	base
161	JPM_30010015	base	CCAP	v2	base
162	JPM_30010016	base	CCAP	v2	base
163	JPM_30010017	base	CCAP	v2	base
164	JPM_30010018	base	CCAP	v2	base
165	JPM_30010019	base	CCAP	v2	base
166	JPM_30010020	base	CCAP	v2	base
167	JPM_30010021	base	CCAP	v2	base
168	JPM_30010022	canal filled	v3	v5	canal filled edit
169	JPM_30010023	base	CCAP	v2	base
170	JPM_30010024	base	CCAP	v2	base
171	JPM_30010025	base	CCAP	v2	base
172	JPM_30010027	base	CCAP	v2	base
173	JPM_30010028	canal filled	v3	v5	canal filled edit
174	JPM_30010029	canal filled	v3	v5	canal filled edit
175	JPM_30010030	base	CCAP	v2	base
176	JPM_30010031	base	CCAP	v2	base
177	JPM_30010032	base	CCAP	v2	base
178	JPM_30010033	base	CCAP	v2	base

179	JPM_30010034	base	CCAP	v2	base
180	JPM_30010037	base	CCAP	v2	base
181	JPM_30010048	base	CCAP	v2	base
182	JPM_30010049	base	CCAP	v2	base
183	JPM_30011016	base	CCAP	v2	base
184	JPM_30011017	base	CCAP	v2	base
185	JPM_30011019	base	CCAP	v2	base
186	JPM_30011020	base	CCAP	v2	base
187	JPM_30011021	canal filled	v3	v5	canal filled edit
188	JPM_30011022	base	CCAP	v2	base
189	JPM_30011023	base	CCAP	none	base
190	JPM_30011024	base	CCAP	none	base
191	JPM_30011025	base	CCAP	v2	base
192	JPM_30011026	base	CCAP	v2	base
193	JPM_30011027	base	CCAP	v2	base
194	JPM_30012005	base	CCAP	v2	base
195	JPM_30012006	base	CCAP	v2	base
196	JPM_30012007	base	CCAP	v2	base
197	JPM_30012008	canal filled	v3	v5	canal filled edit
198	JPM_30012009	canal filled	v3	v5	canal filled edit
199	JPM_30012010	canal filled	v3	v5	canal filled edit
200	JPM_30012011	canal filled+ deepened_C arib_v4	v3+Everglades	v5	canal filled edit
201	JPM_30012012	canal filled	v3	v5	canal filled edit
202	JPM_30012013	canal filled	v3	v5	canal filled edit
203	JPM_30012014	base	CCAP	v2	base
204	JPM_30012015	base	CCAP	v2	base
205	JPM_30012016	base	CCAP	none	base
206	JPM_30012017	base	CCAP	v2	base
207	JPM_30012018	base	CCAP	v2	base
208	JPM_30013016	base	CCAP	v2	base
209	JPM_30013017	base	CCAP	none	base
210	JPM_30013018	base	CCAP	v2	base
211	JPM_30013019	base	CCAP	v2	base
212	JPM_30013020	base	CCAP	v2	base
213	JPM_30013021	base	CCAP	v2	base
214	JPM_30013022	base	CCAP	v2	base
215	JPM_30013023	base	CCAP	v2	base
216	JPM_30013024	base	CCAP	v2	base
217	JPM_30013025	base	CCAP	v2	base
218	JPM_30013026	canal filled	v3	v5	canal filled edit
219	JPM_30013027	canal filled	v3	v5	canal filled edit
220	JPM_30013028	canal filled	v3	v5	canal filled edit

221	JPM_30013029	canal filled	v3	v5	canal filled edit
222	JPM_30013030	base	CCAP	v2	base
223	JPM_30013031	canal filled	v3	v5	canal filled edit
224	JPM_30013032	canal filled	v3	v5	canal filled edit
225	JPM_30013033	canal filled	v3	v5	canal filled edit
226	JPM_30013034	base	CCAP	v2	base
227	JPM_30013035	base	CCAP	v2	base
228	JPM_30013036	base	CCAP	v2	base
229	JPM_30014004	base	CCAP	v2	base
230	JPM_30014005	base	CCAP	v2	base
231	JPM_30014006	base	CCAP	v2	base
232	JPM_30014007	base	CCAP	v2	base
233	JPM_30014008	base	CCAP	v2	base
234	JPM_30014009	base	CCAP	v2	base
235	JPM_30014010	base	CCAP	v2	base
236	JPM_30014011	base	CCAP	v2	base
237	JPM_30014012	base	CCAP	v2	base
238	JPM_30015005	base	CCAP	v2	base
239	JPM_30015006	base	CCAP	v2	base
240	JPM_30015007	base	CCAP	v2	base
241	JPM_30015008	canal filled	v3	v5	canal filled edit
242	JPM_30015009	base	CCAP	v2	base
243	JPM_30015010	base	CCAP	v2	base
244	JPM_30015011	base	CCAP	v2	base
245	JPM_30015012	canal filled	v3	v5	canal filled edit
246	JPM_30015013	base	CCAP	v2	base
247	JPM_30015014	base	CCAP	v2	base
248	JPM_30015015	base	CCAP	v2	base
249	JPM_30015016	base	CCAP	v2	base
250	JPM_30015017	base	CCAP	v2	base
251	JPM_30015018	base	CCAP	v2	base
252	JPM_30015019	base	CCAP	v2	base
253	JPM_30016002	base	CCAP	v2	base
254	JPM_30016003	base	CCAP	v2	base
255	JPM_30016004	base	CCAP	v2	base
256	JPM_30016005	base	CCAP	none	base
257	JPM_30016006	base	v3	v5	base
258	JPM_30016007	canal filled	v3	v5	canal filled edit
259	JPM_30016008	base	CCAP	v2	base
260	JPM_30016009	base	CCAP	v2	base
261	JPM_30016010	base	CCAP	v2	base
262	JPM_30016011	base	CCAP	v2	base
263	JPM_30016012	base	CCAP	v2	base

264	JPM_30017005	base	CCAP	v2	base
265	JPM_30017006	base	CCAP	v2	base
266	JPM_30017007	base	CCAP	v2	base
267	JPM_30017008	base	CCAP	v2	base
268	JPM_30017009	base	CCAP	v2	base
269	JPM_30017010	base	CCAP	v2	base
270	JPM_30017011	base	CCAP	v2	base
271	JPM_30017012	base	CCAP	v2	base
272	JPM_30017013	base	CCAP	v2	base
273	JPM_30018005	base	CCAP	v2	base
274	JPM_30018006	base	CCAP	v2	base
275	JPM_30018007	base	CCAP	v2	base
276	JPM_30018008	base	CCAP	v2	base
277	JPM_30018009	base	CCAP	v2	base
278	JPM_30018010	base	CCAP	v2	base
279	JPM_30018011	base	CCAP	v2	base
280	JPM_30020011	base	CCAP	v2	base
281	JPM_30020012	base	CCAP	v2	base
282	JPM_30020013	base	CCAP	v2	base
283	JPM_30020014	base	CCAP	v2	base
284	JPM_30020015	base	CCAP	v2	base
285	JPM_30020016	base	CCAP	v2	base
286	JPM_30020017	base	CCAP	v2	base
287	JPM_30020018	base	CCAP	v2	base
288	JPM_30020021	base	CCAP	v2	base
289	JPM_30020022	base	CCAP	v2	base
290	JPM_30020023	base	CCAP	v2	base
291	JPM_30020024	base	CCAP	v2	base
292	JPM_50001006	canal filled	v3+Everglades	v5	canal filled edit
293	JPM_50001007	base	Everglades	v5	base
294	JPM_50001008	base	Everglades	v5	base
295	JPM_50001009	base	Everglades	v2	base
296	JPM_50001010	base	CCAP	v2	base
297	JPM_50002005	base	CCAP	v2	base
298	JPM_50002006	canal filled	v3	v5	canal filled edit
299	JPM_50002007	canal filled	v3	v5	canal filled edit
300	JPM_50002008	base	CCAP	none	base
301	JPM_50002009	base	CCAP	v2	base
302	JPM_50002010	base	CCAP	v2	base
303	JPM_50002011	base	CCAP	v2	base
304	JPM_50002012	base	CCAP	v2	base
305	JPM_50004005	base	CCAP	v2	base
306	JPM_50004006	base	CCAP	v2	base

307	JPM_50006007	base	CCAP	v2	base
308	JPM_50006008	base	CCAP	v2	base
309	JPM_50006009	base	CCAP	none	base
310	JPM_50006010	base	CCAP	v2	base
311	JPM_50007007	canal filled	v3	v5	canal filled edit
312	JPM_50007008	canal filled	v3	v5	canal filled edit
313	JPM_50007009	canal filled	v3	v5	canal filled edit
314	JPM_50007010	base	CCAP	v2	base
315	JPM_50007011	base	CCAP	none	base
316	JPM_50007012	base	CCAP	v2	base
317	JPM_50007013	base	CCAP	v2	base
318	JPM_50007014	base	CCAP	v2	base
319	JPM_50008003	canal filled+ deepened_Carib_v4	v3+Everglades	v5	canal filled edit
320	JPM_50008004	canal filled	v3+Everglades	v5	canal filled edit
321	JPM_50008005	canal filled	v3+Everglades	v5	canal filled edit
322	JPM_50008006	base	Everglades	v5	base
323	JPM_50008007	canal filled+ deepened_Carib_v4	v3+Everglades	v5	canal filled edit
324	JPM_50009004	canal filled	v3	v6	canal filled edit
325	JPM_50009005	canal filled+ deepened_Carib_v4	v3+Everglades	v5	canal filled edit
326	JPM_50009006	canal filled+ deepened_Carib_v4	v3	v5	canal filled edit
327	JPM_50009007	canal filled+ deepened_Carib_v4	v3+Everglades	v5	canal filled edit
328	JPM_50009008	base	CCAP	v2	base
329	JPM_50009009	canal filled+ deepened_Carib_v4	v3	v5	canal filled edit
330	JPM_50010006	base	CCAP	v2	base
331	JPM_50010007	base	CCAP	v2	base
332	JPM_50010008	base	CCAP	v2	base
333	JPM_50010009	base	CCAP	v2	base
334	JPM_50011005	base	Everglades	v5	base
335	JPM_50011006	base	Everglades	v5	base
336	JPM_50011007	base	CCAP	v2	base
337	JPM_50011008	base	CCAP	v2	base
338	JPM_50011009	base	CCAP	v2	base
339	JPM_50011010	base	CCAP	v2	base

340	JPM_50012004	base	CCAP	v2	base
341	JPM_50012005	base	CCAP	v2	base
342	JPM_50012006	base	CCAP	v2	base
343	JPM_50012007	base	CCAP	v2	base
344	JPM_50012008	base	CCAP	v2	base
345	JPM_50012009	base	CCAP	v2	base
346	JPM_50012010	base	CCAP	v2	base
347	JPM_50012011	base	CCAP	v2	base
348	JPM_50013011	base	CCAP	v2	base
349	JPM_50014001	base	CCAP	v2	base
350	JPM_50014002	base	CCAP	v2	base
351	JPM_50014003	base	CCAP	v2	base
352	JPM_50014004	base	CCAP	v2	base
353	JPM_50014005	base	CCAP	v2	base
354	JPM_50014006	base	CCAP	v2	base
355	JPM_50015008	base	CCAP	v2	base
356	JPM_50015009	base	CCAP	v2	base
357	JPM_50015010	base	CCAP	v2	base
358	JPM_50015011	base	CCAP	v2	base
359	JPM_50015012	base	CCAP	v2	base
360	JPM_50015013	base	CCAP	v2	base
361	JPM_50015014	base	CCAP	v2	base
362	JPM_50016005	base	CCAP	v2	base
363	JPM_50016006	base	CCAP	v2	base
364	JPM_50016007	base	CCAP	v2	base
365	JPM_50016008	base	CCAP	v2	base
366	JPM_50016009	base	CCAP	v2	base
367	JPM_50016010	base	CCAP	v2	base
368	JPM_50016011	base	CCAP	v2	base
369	JPM_50017004	base	CCAP	v2	base
370	JPM_50017005	base	CCAP	v2	base
371	JPM_50017006	canal filled	v3	v5	canal filled edit
372	JPM_50017007	canal filled	v3	v5	canal filled edit
373	JPM_50017008	base	CCAP	v2	base
374	JPM_50017009	base	CCAP	v2	base
375	JPM_50017010	base	CCAP	v2	base
376	JPM_50017011	base	CCAP	v2	base
377	JPM_50017012	base	CCAP	v2	base
378	JPM_50018002	base	CCAP	v2	base
379	JPM_50018003	base	CCAP	v2	base
380	JPM_50018004	base	CCAP	v2	base
381	JPM_50018005	base	CCAP	v2	base
382	JPM_50018006	base	CCAP	v2	base

383	JPM_50019003	hybrid	v3	v5	canal filled edit
384	JPM_50019004	canal filled+ deepened_Carib_v4	v3+Everglades	v5	canal filled edit
385	JPM_50019005	base	CCAP	v2	base
386	JPM_50019006	base	CCAP	none	base
387	JPM_50019007	base	CCAP	v2	base
388	JPM_50020003	base	CCAP	v2	base
389	JPM_50020004	base	CCAP	v2	base
390	JPM_50020005	base	CCAP	v2	base
391	JPM_50020006	base	CCAP	v2	base
392	JPM_50020007	base	CCAP	v2	base

Appendix B

Review & Evaluation of FEMA's Coastal Flood Risk Study

Topographic Elevation Data Technical Memorandum (Deliverable 2.1)
Task Order #1778-01

September 3, 2020 | 13134.201.R2.Rev0

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Review & Evaluation of FEMA's Coastal Flood Risk Study

Topographic Elevation Data Technical Memorandum (Deliverable 2.1)
Task Order #1778-01

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Moffatt & Nichol

13134.201.R2.Rev0

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Revision	Date	Status	Comments	Prepared	Reviewed	Approved
Rev # A	04/22/2020	DRAFT	County Review	AEW	LC	DS
Rev # B	08/20/2020	DRAFT	County Comments	AEW	LC	DS
Rev # 0	09/03/2020	FINAL		DS	GT	DS

Executive Summary

In fiscal year 2013, the Federal Emergency Management Agency (FEMA) initiated the Coastal Risk Flood Study Project for the South Florida Study Area (Coastal Study). The Coastal Study was intended to better define flood risks within South Florida by utilizing updated coastal storm surge models, erosion and hazard analyses, digital elevation models, and geographic information systems technologies data to update the digital Flood Insurance Rate Maps and Flood Insurance Study reports for Broward, Miami-Dade, Monroe, and Palm Beach Counties. BakerAECOM was contracted by FEMA to undertake the Coastal Study.

The topographic data, used by BakerAECOM for Palm Beach County, in the development of the digital elevation model (DEM) for the Coastal Study was compiled from various datasets. The data collection dates ranged from 2001 to 2007. The resulting DEM had a 10-foot grid and is herein referred to as Southwest Florida Topo-Bathy (SWFLTB) DEM. In 2016, the U.S. Army Corps of Engineers (USACE) produced a 10-foot grid Light Detection and Ranging (LiDAR) model for portions of the barrier islands within Palm Beach County, which was later used in the creation of the USACE DEM, along with the SWFLTB DEM data for the creation of the updated Flood Insurance Rate Maps (FIRM)s. During the same timeframe, the U.S. Geological Survey conducted an extensive LiDAR survey for all of Palm Beach County based on a 2-foot grid; herein referred to as PBC DEM.

- Coastal Study – SWFLTB DEM
- Updated FIRMs – USACE DEM
- 2016/2017 Palm Beach County LiDAR for comparison – PBC DEM

The purpose of Task 2.1 *Topographic Elevation Data Evaluation* is to evaluate the difference in elevations for the DEMs used for the Coastal Study and the FIRM mapping with that of the 2016/2017 Palm Beach County LiDAR and to assess the appropriateness of the methods used by FEMA to stitch together data from multiple sources when creating the Coastal Study DEM. This task only considers the area overlap among the datasets that fall within the boundaries of Palm Beach County, and more specifically within the updated coastal FIRM panels. The methods used by FEMA to stitch together or compile the various datasets within the study area of this task appears to be acceptable. For elevation comparison, the three DEMs were converted to the same horizontal and vertical datums prior to analysis.

There is a total of approximately 92,935 acres contained within the Palm Beach County coastal FIRM panels, not including the surface water area. Within the coastal FIRM panels, areas were examined for elevation differences of 0.5 feet or greater and 1 foot or greater between the PBC DEM and SWFLTB DEM and between the PBC DEM and USACE DEM. Based on the accuracy of FEMA FIRMs and survey tolerances of the data used in this analysis, a deviation of 0.5 feet or greater was deemed to be large enough to possibly affect mappings of flood zone of the updated FIRMs.

- Differences of less than +/-0.5 feet between the DEM's were documented for 73.6% of the coastal FIRM panel area when comparing the PBC DEM to the SWFLTB DEM; 59.0% within incorporated boundaries and 14.6% within unincorporated boundaries. Similar trends were identified when comparing the PBC DEM to the USACE DEM.
- The USACE DEM, which incorporated more recent survey data, exhibited better agreement with PBC DEM.

Elevation differences outside of FEMA's special flood hazard areas (SFHA) have limited, if any, influence on the updated FIRM maps. Elevation differences between the PBC DEM and the SWFLTB DEM as well as the PBC DEM and the USACE DEM were compared within the footprints of the FEMA's mapped Changes Since Last FIRM (CSLF). The footprints of the CSLF were estimated at 11,509 acres as compared to 92,934 acres within the coastal FIRM panels. Within the CSLF footprints (Table E.1), the following was determined:

- Incorporated boundaries represented 83.9% (9,659 acres) of the area included in the CSLF footprints; unincorporated boundaries represented 16.1% (1,850 acres) of the area.
- Differences of less than +/-0.5 feet between the DEM's were documented for 78% of the CSLF footprints when comparing the PBC DEM to the SWFLTB DEM; 65.0% within incorporated boundaries and 12.9% within unincorporated boundaries. Similar trends but with increased agreement for differences less than +/-0.5 feet (as noted above) were identified when comparing the PBC DEM to the USACE DEM.
- Difference of greater than 0.5 feet between DEM's were documented for 22.0% of the CSLF footprints when comparing the PBC DEM to the SWFLTB DEM; with the PBC DEM being above the SWFLTB DEM for 15.0% (1,732 acres) of the area and below for 7.0% (804 acres) of the area.

Table E.1: PBC DEM minus SWFLTB DEM within CSLF Footprints

PBC DEM minus SWFLTB DEM	Incorporated (acre)	Unicorporated (acre)	Total (acre)	Incorporated (%)	Unincorporated (%)	Total (%)
PBC ≥ 1.0 foot above	509	112	621	4.4%	1.0%	5.4%
PBC 0.5 to 1.0 feet above	964	147	1,111	8.4%	1.3%	9.7%
PBC < 0.5 feet above/below	7,486	1,487	8,973	65.0%	12.9%	78.0%
PBC 0.5 to 1.0 feet below	473	66	539	4.1%	0.6%	4.7%
PBC ≥ 1.0 feet below	227	38	265	2.0%	0.3%	2.3%
Total	9,659	1,850	11,509	83.9%	16.1%	100.0%
PBC above	1,473	259	1,732	12.8%	2.3%	15.0%
PBC below	700	104	804	6.1%	0.9%	7.0%

Based on the DEM comparisons, inclusion of the PBC DEM in FEMA's coastal study would help address the following:

- Differences may have expanded (overestimated) the inland extents of the SFHA mapped by FEMA in the central portion of the County. The DEM comparisons indicated that the PBC DEM was approximately 0.5 to 1.0 feet above the SWFLTB DEM west of the Lake Worth Lagoon. The differences (FIRM panels 0393, 0581, 05983, 0591, 0593, 0781, 0783, 0791, and 0793) extended approximately 15.5 miles between 45th Street, West Palm Beach and East Ocean Avenue, Boynton Beach. The differences appear to be inherent to the 2007 Florida Department of Emergency Management LiDAR data used by FEMA to generate the DEM in this area and therefore may be attributed to data collection techniques (e.g. flight lines, airframes, sensors, equipment).
- Differences may have limited (reduced) the inland extents of the SFHA mapped by FEMA in the southern portion of the County. The data used by FEMA in the creation of the SWFLTB DEM changed from the 2007 Florida Department of Emergency Management to the 2001 Palm Beach County LiDAR and resulted in an apparent vertical offset. The differences (FIRM panels 1159, 1178, and 1179) indicated that the PBC DEM was approximately 0.5 to 1 foot below the SWFLTB DEM.
- Larger differences (e.g. greater than 1 foot) appear to be due in part to the occurrence of construction and development during the time between the capture of the SWFLTB DEM in 2007 and the PBC DEM in 2016/17. Differences identified by the DEM comparisons may also be attributed in part to post-processing of the survey data and gridding methods. LiDAR survey data is processed to eliminate buildings, trees, and other obstructions to represent "bare earth" (i.e. ground elevations). Post-processing techniques, gridding methods, and technological advances in data collection since 2007 may account for some of the differences identified herein. A location-by-location analysis (which was beyond the scope of work) is necessary to evaluate whether these differences with respect to updated base flood elevations (BFEs) would affect/alter the mapping of flood zones shown in FEMA's preliminary FIRM panels.

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Tables

Figures

1. Background

In fiscal year 2013, the Federal Emergency Management Agency (FEMA) initiated the Coastal Risk Flood Study Project for the South Florida Study Area (Coastal Study). The results of the Coastal Study were overlaid onto an updated DEM created using the 2016 USACE LiDAR to create updated digital Flood Insurance Rate Maps and Flood Insurance Study (FIS) reports for Broward, Miami-Dade, Monroe, and Palm Beach Counties. The Coastal Study was intended to better define flood risks within South Florida by utilizing updated ground elevation and topographic data, new climatological data, improved computing resources, coastal storm surge models, erosion and hazard analyses, and improvements in geographic information systems (GIS) technologies to improve coastal mapping accuracy. BakerAECOM was contracted by FEMA to undertake the Coastal Study.

The topographic dataset used by FEMA for the development of the Coastal Study utilized Two Florida Department of Emergency Management LiDAR Models from 2007, along with various other sources. The updated LiDAR from the USACE was not completed in time to be included in the Coastal Study Analysis but was included in the mapping. Additional LiDAR from the U.S. Geological Survey (USGS) was conducted for the full limits of Palm Beach County during late 2016 and early 2017. This data was not used for the Coastal Study nor the creation of the updated FIRMs and FISs. The differences between these three datasets are discussed herein.

2. Introduction

The purpose of this task is to evaluate the difference in elevations for the actual digital elevation model (DEM) used for the Coastal Study and the DEM used for the creation of the FIRMs and FISs with that of the 2016/2017 Palm Beach County LiDAR. The topographic data used for the creation of the Coastal Study was not the same topographic data used in the mapping of the new FIRMs. This task only considers the area of overlap between the three datasets that fall within the boundaries of Palm Beach County, and more specifically within the updated Coastal FIRM Panels.

3. Data Files

3.1 BakerAECOM Southwest Florida Topo-Bathy DEM

The DEM used in the Coastal Study, compiled by BakerAECOM, is represented by the Southwest Florida Topo-Bathy (SWFLTB) DEM. The SWFLTB DEM is labeled "FINAL_DEMS_01202016 (Received 2020-03-02)" in tiled ASCII Raster Text files. It covers the entire coastal area of southern Florida (Figure 3.1). The data, as received from BakerAECOM, have a horizontal resolution of 10 ft with elevations measured in meters. The DEM was compiled from several different input datasets with varying ranges of accuracy, resolution, and dates of collection. The input data and process used to derive this DEM are detailed in the BakerAECOM Report *Technical Approach – Topographic/Bathymetric Digital Elevation Model, Task Order 99 – South Florida Insurance Study,* Version 4.0 (March 2016).

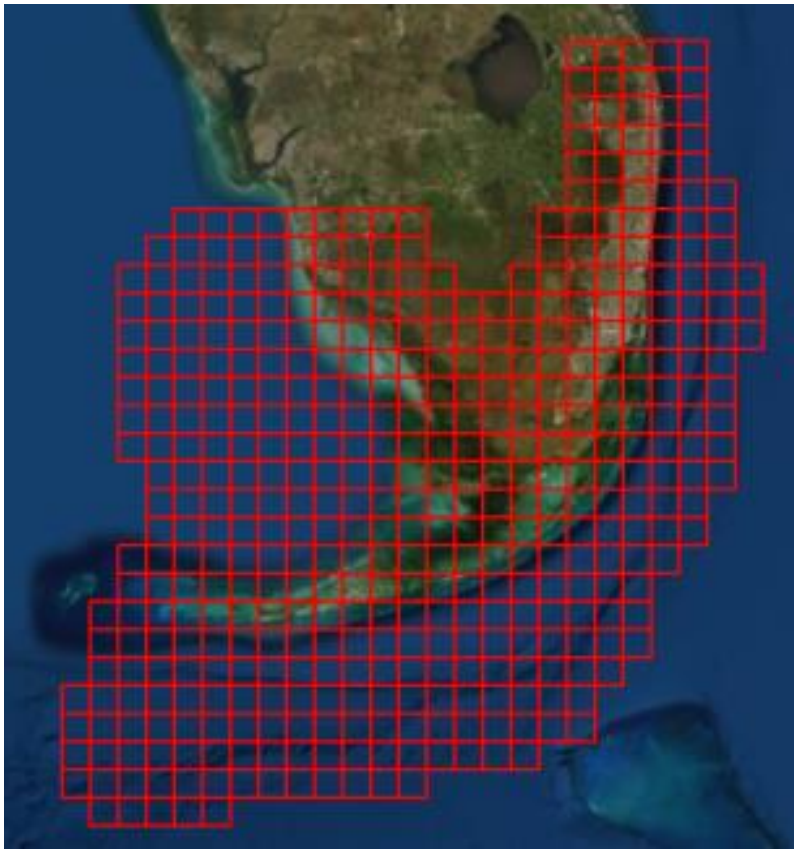


Figure 3.1: Extent of SWFLTB DEM Tiles

Several primary sources were compiled to create the Palm Beach County portion of the SWFLTB DEM. They are as follows:

- Two Florida Department of Emergency Management LiDAR Models
  - 2007 Palm Beach County, FL LiDAR (Figure 3.2) – collected between July 2007 and January 2008 with a vertical accuracy of .29 feet at a 95% confidence interval (CI).
  - 2007 Herbert Hoover Dike Project, FL LiDAR (Figure 3.3) – collected between September 2007 and January 2008 with a vertical accuracy of .6 feet at a 95% CI.

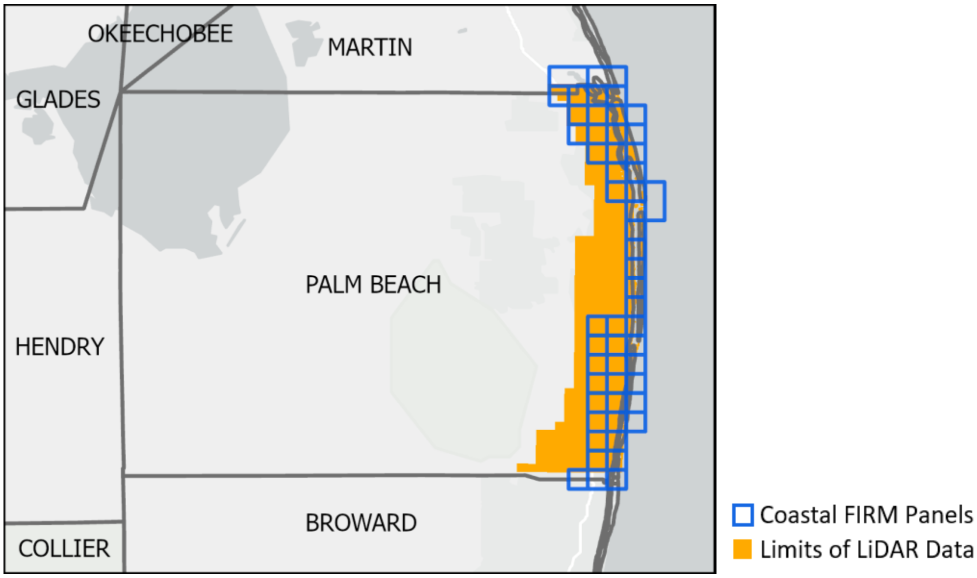


Figure 3.2: Extent of 2007 Palm Beach County, FL LiDAR with Coastal FIRM Outlines

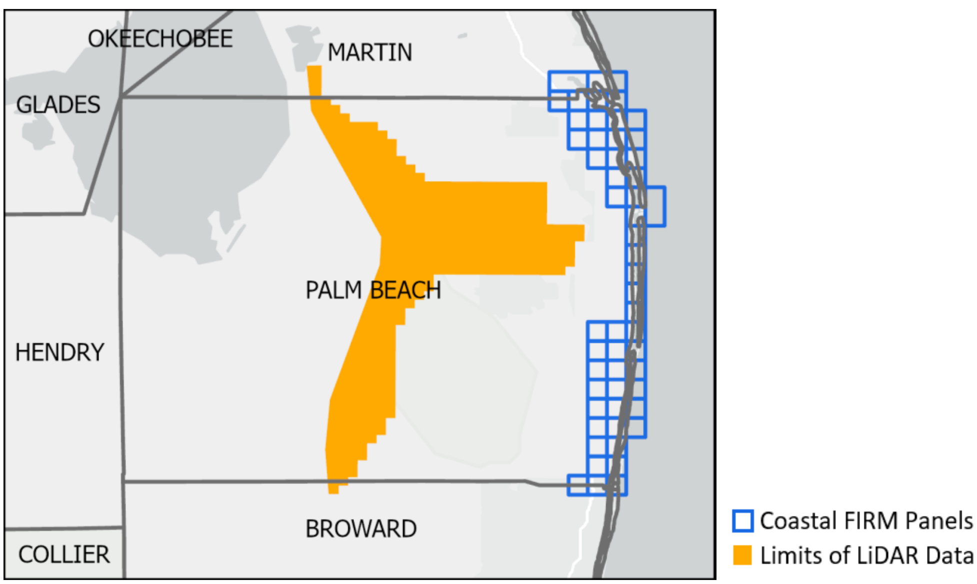


Figure 3.3: Extent of 2007 Herbert Hoover Dike Project, FL LiDAR with Coastal FIRM Outlines

- The 2001 Palm Beach County, Florida LiDAR (Figure 3.4) – referred to as “supplemental data” in the report.
  - Has a calendar date of 2001
  - Is comprised of three separate datasets

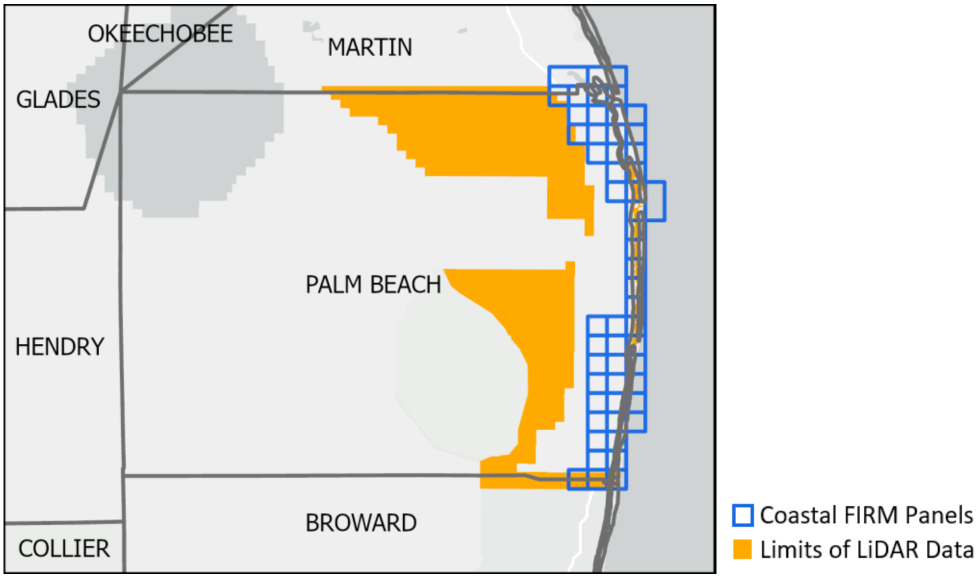


Figure 3.4: Extent of 2001 Palm Beach County, Florida LiDAR with Coastal FIRM Outlines

The data for the remaining area covered by the SWFLTB DEM are as follows, but they are outside of the FIRM Panels and have no impact on this analysis.

- USGS National Elevation Data 10 Meter DEMs
- South Florida Composite Topography 50-foot DEM
  - The bulk of this area appears to be comprised of the Loxahatchee National Wildlife Refuge area.
  - Both of these datasets were used as a “last resort” when other datasets were unavailable.

At the boundaries of the individual datasets used to create the SWFLTB DEM, there are apparent break lines due to the varying capture dates of the data (Figure 3.5). The capture dates of the input datasets range from 2001 to January 2008. The highest accuracy LiDAR input data that comprises most of the area closest to the coastline were flown in 2007. It is important to note the data for the SWFLTB DEM included bathymetric data.

In Figure 3.5, highlights an example of development between capture dates and its influence on the SWFLTB DEM. Only a portion of a newer residential development is represented in the DEM due to the time between capture dates of the constituent datsetsets. The red polygon represents an area of the development not included in the DEM. Many of the larger differences identified in the DEM analysis (Section 5), are the due to development and construction that has taken place since the capture of the older input elevation models.

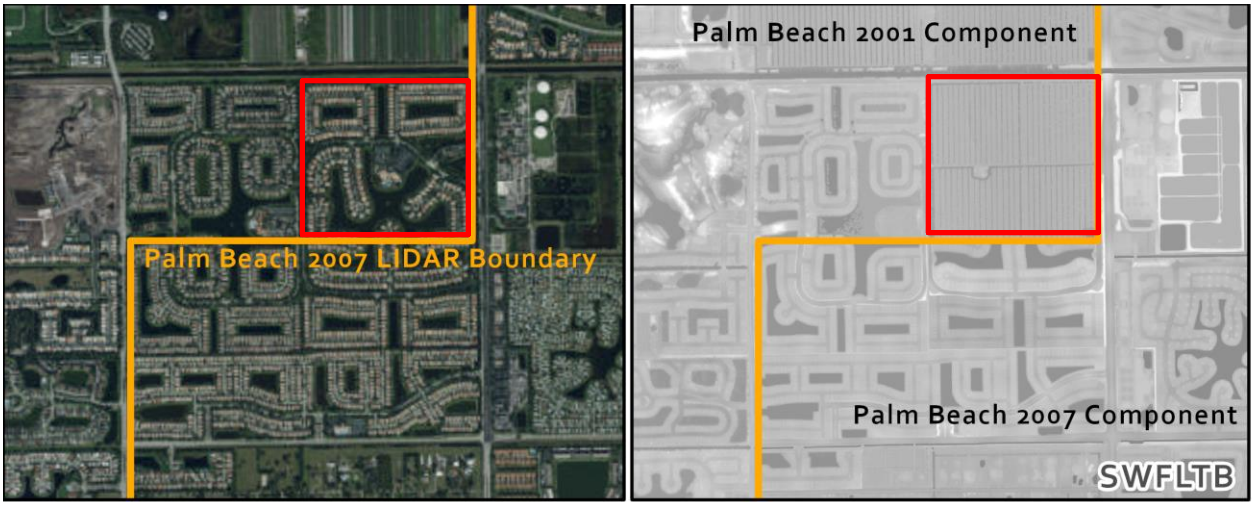


Figure 3.5: Pictorial Representation of SWFLTB DEM Data Variance (Left panel – Aerial Image; Right Panel – SWFLTB DEM)

3.1.1 Appropriateness of Data Compilation

No gaps between datasets were found within the area being assessed in this task within the SWFLTB DEM compiled or "stitched together" by BakerAECOM. Based on our analysis of the information contained within the BakerAECOM Report *Technical Approach,* no obvious errors were found in the horizontal reprojections/ transformations or vertical transformations. Transformations are conversions between datums and necessarily introduce some amount of error, the magnitude of which are dependent upon the input and output datum, the specific location, and the transformation equation used. Vertical transformation errors tend to be relatively small, in the range of a few centimeters.

The only direct manipulation of input data done by BakerAECOM appears to be where breaklines were created between the DEM and the Bathymetry portions of the surface. These break lines occur at the shore and around some of the inland waterways, not along the edges of varying datasets. Breaklines are used to define interpolation of data sets in order to more accurately reflect actual conditions. For example, the vertical face of a bulkhead or seawall may not be represented in a DEM without a breakline to help define the top of the structure and the bottom of the structure.

The differences at the edges are common in comparing elevation surfaces done over different areas due to different survey controls and varying degrees of resolution and accuracy requirements. Even within the same data collection project, calculating a surface solution for different coverage areas will result in edge mismatches, when all the input data is the same. Therefore, the data compilation within the study area of this task appears to be acceptable.

3.1.2 Coordinate Reference Systems

The horizontal datum for the data is HARN Florida East, Ft, NAD 83. The Vertical datum for the data is the North American Vertical Datum of 1988 (NAVD88). Note: though the BakerAECOM report states that the vertical data is referenced in feet; however, inspection of the dataset delivered to Moffatt & Nichol suggested that the vertical data was in meters. The vertical units were converted to feet assuming a conversion of 3.28084 feet per meter for the analysis presented herein.

3.2 USACE LiDAR DEM

The 2016 USACE LiDAR (Figure 3.6), delivered as “Final_PB_Topo.gdb”, was used to create the USACE DEM used in the development of the updated FIRMs and FISs. The USACE DEM, developed by FEMA, is the 2007 Florida Department of Emergency Management LiDAR used by BakerAECOM supplemented with the 2016 USACE LiDAR along the barrier islands. The 2016 USACE LiDAR was roughly used to represent the barrier islands east of state road A1A and the 2007 Florida Department of Emergency Management LiDAR was used to represent elevations to the west. Figure 3.6 shows the extents of the 2016 USACE LiDAR information. The remainder of the project area matches the SWFLTB DEM. The USACE LiDAR data has a vertical accuracy of 0.31 feet (9.5 cm) and a horizontal accuracy of 3.28 feet (1 meter) at a 95% CI. Appendix A highlights the change in elevation from the SWFLTB DEM used in the modeling to the USACE DEM used for mapping.

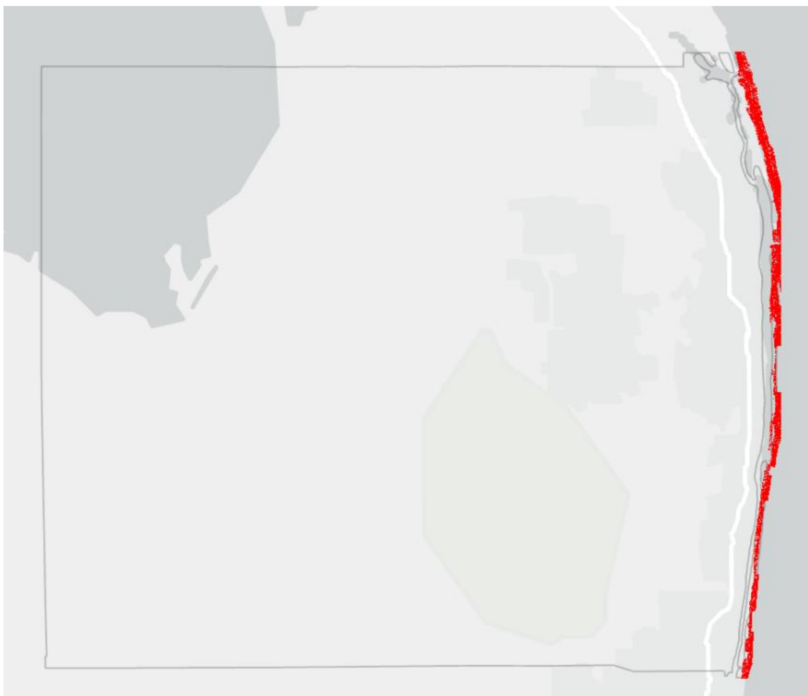


Figure 3.6: Pictorial Representation of Limits of 2016 USACE LiDAR

3.2.1 Coordinate Reference Systems

The horizontal datum for the data is State Plane Florida East FIPS 0901, Ft, NAD 83. The Vertical datum for the data is NAVD88 in feet.

3.3 Palm Beach County LiDAR DEM

The 2016/2017 USGS topography LiDAR, represented herein by the Palm Beach County (PBC) DEM, was developed by Dewberry. The data were collected between December 20, 2016 and March 10, 2017 and cover the entire county except for Lake Okeechobee in the northwest corner of the County (Figure 3.7). The DEM has a 2-foot horizontal resolution. The data are seamless and derived from measurements taken during a 3-month time period from a single source, providing more uniform accuracy than when multiple sources are used. The LiDAR measures water surface elevations but does not include any bathymetric data. For additional information regarding the DEM creation, refer to *Palm Beach County Lidar Report – Report Produced for the U.S. Geological Survey* by Dewberry, dated June 14, 2018.

Figure 3.7: Limits of PBC DEM

Per the Dewberry Report, the LiDAR vertical accuracy is as follows:

> *For the Palm Beach County LiDAR Project, the tested root mean square error in the z direction (RMSEz) of the classified lidar data for checkpoints in non-vegetated terrain equaled 0.16 ft (4.9 cm) compared with the 10 cm specification; and the NVA [Non-vegetated Vertical Accuracy] of the classified lidar data computed using RMSEz x 1.9600 was equal to 0.31 ft (9.4 cm), compared with the 19.6 cm specification. For the Palm Beach County LiDAR Project, the tested VVA [Vegetated Vertical Accuracy] of the classified lidar data computed using the 95th percentile was equal to 0.59 ft (18 cm) compared with the 29.4 cm specification*.

3.3.1 Coordinate Reference Systems

The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment NAD 83 (2011) Florida State Plane East. The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88). Horizontal units are in U.S. Survey Feet, vertical units are in U.S. Survey Feet. Geoid 12B was used to convert ellipsoid heights to orthometric heights.

4. Process

4.1 DEM Conversions

To limit the analysis to Palm Beach County and to limit the working data, the tiles that fell within the boundary of Palm Beach County were extracted from the SWFLTB DEM dataset. The USACE DEM was already limited to Palm Beach County. Finally, the PBC DEM files that overlapped the selected SWFLTB and USACE DEM tiles previously identified were selected and included in the initial analysis (Figure 4.1 and Figure 4.2). This ensured that the area of analysis included all areas of overlap between the three datasets within Palm Beach County. The datasets were further pared down to show only the DEM files within the limits of the coastal FIRM panels of Palm Beach County (Figure 4.3).

Data were then pre-processed using the Geospatial Data Abstraction Library (GDAL). GDAL is a command line open source raster and vector translator library to allow for easier handling of large datasets. Additional information on the process can be found at https://gdal.org/.

The SWFLTB DEM tiles were mosaicked into a single raster and transformed into the NAD 1983 HARN State Plane Florida East FIPS 0901 (US Feet). GDAL was used to perform all these functions in one step utilizing the Warp command. Transformation was necessary to ensure the data from the SWFLTB DEM was compatible with the USACE and PBC DEMs since it was in a different coordinate system in its native form.

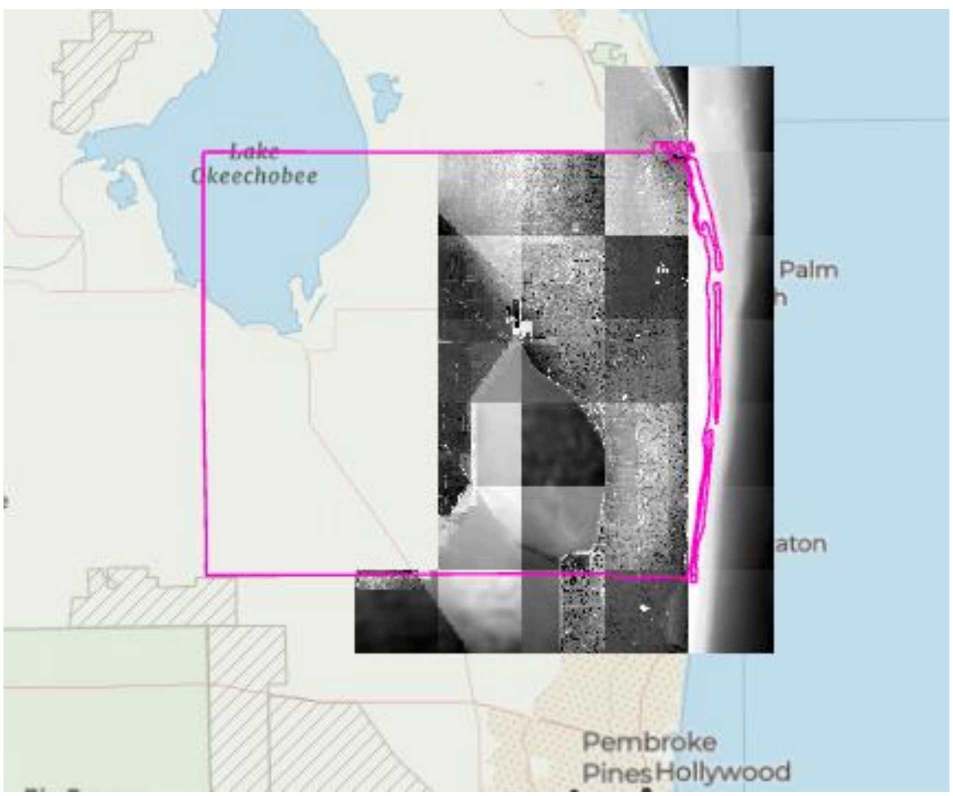


Figure 4.1: Limits of Palm Beach County with SWFLTB DEM Tiles

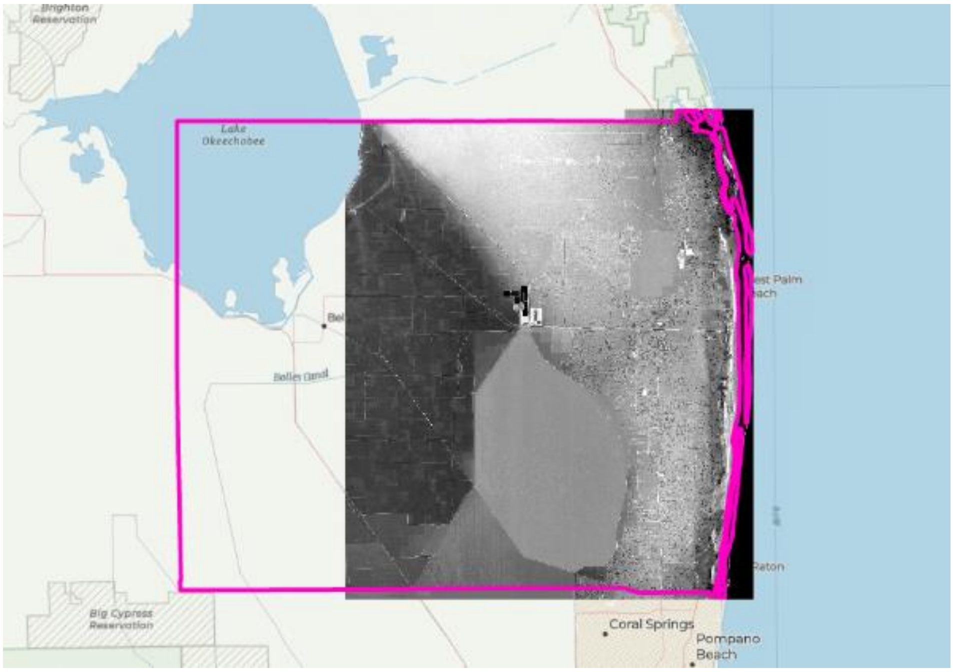


Figure 4.2: Limits of Palm Beach County with PBC DEM Tiles

Figure 4.3: Outline of Palm Beach County Coastal FIRM Panels

The PBC DEM files were then further refined for comparison with the other DEMs by resampling. The 2-foot grid cell resolution of the PBC DEM was resampled at a 10-foot grid to match the resolution of the SWFLTB and USACE files using the Lanczos resampling algorithm included with GDAL. The translated files were re-projected to the NAD 1983 HARN State Plane Florida East FIPS 0901 (US Feet) coordinate reference system and mosaicked into a single raster and elevation units were converted from meters to feet. All these functions were performed in one step using the GDAL Warp command.

The re-projected and resampled data were spot checked for horizontal accuracy. Both the mosaics lined up well with each other, with the USACE DEM, and with the reference orthophotography and when checked against linear features like road and canal intersections, there was no perceptible shift or offset that resulted from the resampling.

4.2 DEM Analysis

The process of comparing the SWFLTB DEM with the PBC DEM was performed utilizing the ArcGIS Pro Spatial Analyst module using a simple raster math operation that subtracted the value of SWFLTB DEM mosaic from the PBC DEM mosaic value on a cell-by-cell basis. The operation was performed a second time subtracting the USACE DEM from the PBC DEM utilizing the same approach. The resulting rasters contain only areas of overlap between the compared datasets within the Palm Beach County FIRM boundaries.

Zonal statistic tools were used to perform a detailed comparison look at elevation differences for areas that overlap the FIRM panels. In addition, the comparison tool was used to compare the difference between incorporated and unincorporated areas. Figure 4.4 shows the elevation differences between the PBC DEM and SWFLTB DEM, as well as shows the boundaries of the Coastal FIRM limits within Palm Beach County. The "white" shaded areas on the map represent differences of 0.5 feet or less. The varying shades of "teal" show where the PBC DEM is above than the SWFLTB DEM, while the "tan" shades show where it is below. It should be noted that darker "teal" shaded areas are shown within interior water bodies (i.e. Loxahatchee River, Lake Worth Lagoon, Intracoastal Waterway, canals, etc.) because the PBC DEM did contain limited bathymetric survey data and the DEM within the water bodies was not representative of actual elevations. Appendix B shows FIRM panel by FIRM panel results of the PBC DEM and SWFLTB DEM comparison, while Appendix C shows the FIRM panel by FIRM panel results of the PBC DEM minus the USACE DEM.

The figures in Appendix B and C also show the Primary Frontal Dune (PFD) line as provided by FEMA. Per FEMA, "the primary frontal dune zone is defined in 44 CFR Section 59.1 of the NFIP [National Flood Insurance Program] regulations. The primary frontal dune represents a continuous or nearly continuous mound or ridge of sand with relatively steep seaward and landward slopes that occur immediately landward and adjacent to the beach. The primary frontal dune zone is subject to erosion and overtopping from high tides and waves during major coastal storms. The inland limit of the primary frontal dune zone occurs at the point where there is a distinct change from a relatively steep slope to a relatively mild slope." PFDs establish the minimum landward limit of the Coastal High Hazard Area (CHHA) or V zones on the FIRMS. PFDs are not required to be continuous along the length of the studied shoreline. The PFDs shown herein were included in BakerAECOM's FIRM database submission to FEMA as part of the Coastal Study. A review of the primary frontal dune and how it was defined will be evaluated as part of Task 5 – *Storm Surge, Wave Model, and Flood Map Evaluation*.

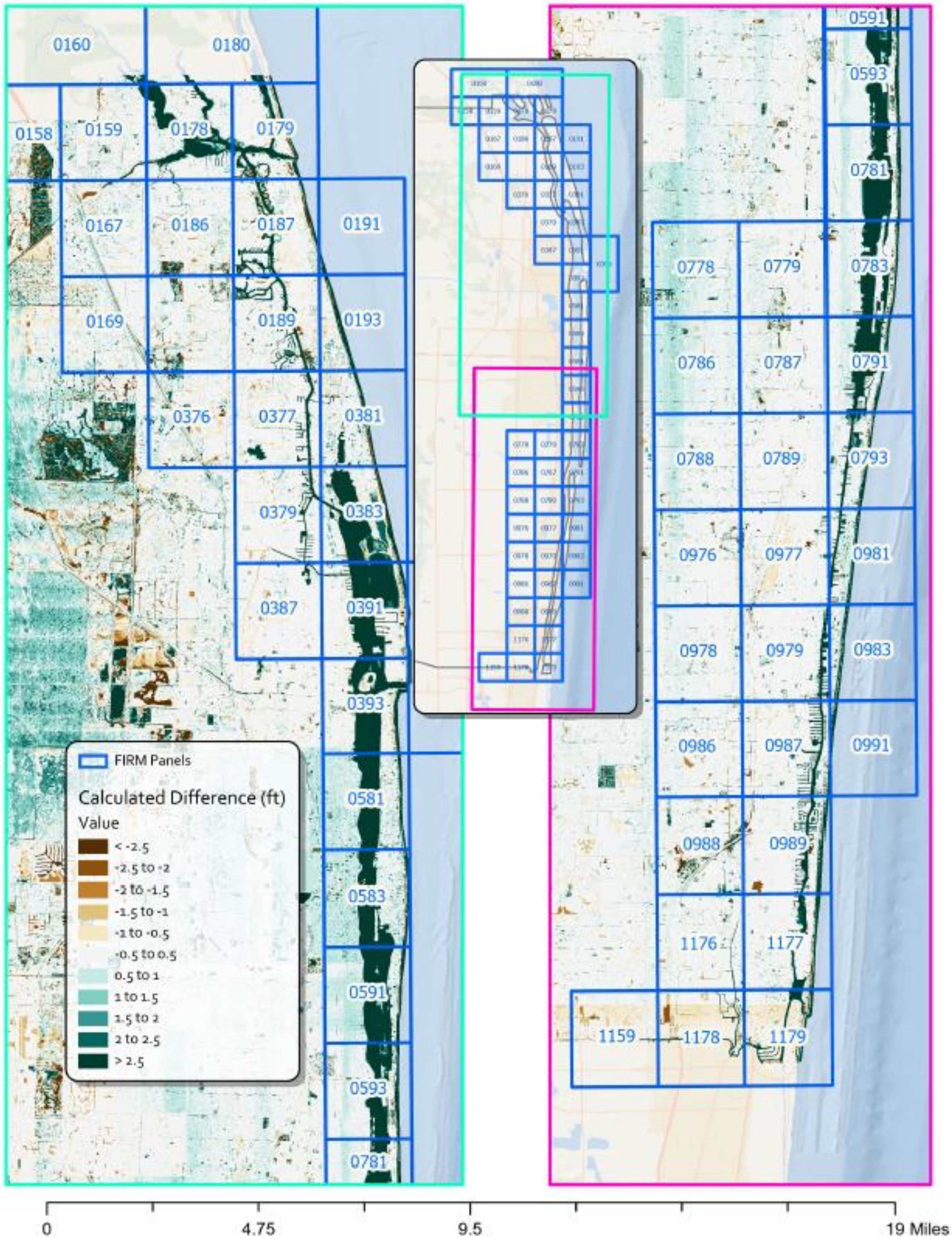


Figure 4.4: DEM Comparison with FIRM Panels: PBC DEM minus SWFLTB DEM

5. Results

5.1 DEM Comparisons

The PBC DEM was compared to the DEM's developed by FEMA (SWFLTB and USACE DEM's) to quantify the differences between them both within (incorporated boundaries) and outside (unincorporated boundaries) municipal boundaries of the County. The differences are presented in terms of acreage for four elevations ranges with respect to each of FEMA DEM's being compared.

- PBC DEM ≥ 1.0 feet above FEMA's DEM
- PBC DEM 0.5 to 1.0 feet above FEMA's DEM
- PBC DEM < 0.5 feet above/below FEMA's DEM (assumed vertical tolerance of survey data)
- PBC DEM 0.5 to 1.0 feet below FEMA's DEM
- PBC DEM ≥ 1.0 feet below FEMA's DEM

There is a total of 92,934 acres contained within the Palm Beach County Coastal FIRM panels, not including the surface water area. Comparison of the PBC DEM and the SWFLTB DEM are shown with overlays of FEMA's coastal FIRM panels (Figure 4.4) and municipal boundaries (Figure 5.1). Comparison of the DEM's resulted in the following.

- **PBC DEM minus SWFLTB DEM** (Table 5.1):
  - Incorporated boundaries represented 78.5% (72,918 acres) of the area included in the Coastal FIRM panels; unincorporated boundaries represented 21.5% (20,016 acres) of the area.
  - Differences of less than +/-0.5 feet between the DEM's were documented for 73.6% of the Coastal FIRM panel area; 59.0% within incorporated boundaries and 14.6% within unincorporated boundaries.
  - Differences of greater than 0.5 feet between DEM's were documented for 26.3% (24,501) of the coastal FIRM panel areas; with the PBC DEM being above the SWFLTB DEM for 18.6% (17,319 acres) of the area and below for 7.7% (7,182 acres) of the area.
  - In the central portion of the County, differences indicated that the PBC DEM was approximately 0.5 to 1.0 feet above the SWFLTB DEM west of the Lake Worth Lagoon. The differences (FIRM panels 0393, 0581, 05983, 0591, 0593, 0781, 0783, 0791, and 0793) extended approximately 15.5 miles between 45th Street, West Palm Beach and East Ocean Avenue, Boynton Beach. The differences appear to be inherent to the 2007 Florida Department of Emergency Management LiDAR data used by FEMA to generate the DEM in this area and therefore may be attributed to data collection techniques (e.g. flight lines, airframes, sensors, equipment). These differences may have expanded (overestimated) the inland extents of the SFHA mapped by FEMA.
  - In the southern portion of the County, the data used by FEMA in the creation of the SWFLTB DEM changed from the 2007 Florida Department of Emergency Management to the 2001 Palm Beach County LiDAR and resulted in an apparent vertical offset. The differences (FIRM panels 1159, 1178, and 1179) indicated that the PBC DEM was approximately 0.5 to 1 foot below the SWFLTB DEM. These differences may have limited (reduced) the inland extents of the SFHA mapped by FEMA.
  - Larger differences (greater than 1 foot) appear to be due in part to the occurrence of construction and development during the time between the capture of the SWFLTB DEM in 2007 and the PBC DEM in 2016/17.
  - Differences may also be attributed to post-processing of the survey data and gridding methods. LiDAR survey data is processed to eliminate buildings, trees, and other obstructions to represent "bare earth" (i.e. ground elevations). Post-processing techniques, gridding methods, and technological advances in data collection since 2007 may account for some of the differences shown herein.

- **PBC DEM minus USACE DEM** (Table 5.2):
  - Similar trends were identified when comparing the PBC DEM to the USACE DEM.
  - As discussed in Section 3.2, the USACE DEM was updated with USACE data collected in 2016. The updated USACE data was roughly used to represent the barrier islands east of state road A1A, while the data to the west was consistent with the data used to generate the SWFLTB DEM. The barrier islands are mostly contained by incorporated boundaries.
  - The differences of less than +/-0.5 feet between the DEM's increased to 59.5% within incorporated boundaries for the USACE DEM from 59.0% for the SWFLTB DEM. The improved agreement with the USACE DEM is attributed to the inclusion of updated USACE data to represent the barrier islands.

Table 5.1: PBC DEM minus SWFLTB DEM within Coastal FIRM panels

PBC DEM minus SWFLTB DEM	Incorporated (acre)	Unincorporated (acre)	Total (acre)	Incorporated (%)	Unincorporated (%)	Total (%)
PBC ≥ 1.0 foot above	4,488	1,353	5,841	4.8%	1.5%	6.3%
PBC 0.5 to 1.0 feet above	7,914	3,564	11,478	8.5%	3.8%	12.4%
PBC < 0.5 feet above/below	54,872	13,561	68,433	59.0%	14.6%	73.6%
PBC 0.5 to 1.0 feet below	3,544	968	4,512	3.8%	1.0%	4.9%
PBC ≥ 1.0 feet below	2,100	570	2,670	2.3%	0.6%	2.9%
Total	72,918	20,016	92,934	78.5%	21.5%	100.0%
PBC above	12,402	4,917	17,319	13.3%	5.3%	18.6%
PBC below	5,644	1,538	7,182	6.1%	1.7%	7.7%

Table 5.2: PBC DEM minus USACE DEM within Coastal FIRM panels

PBC DEM minus USACE DEM	Incorporated (acre)	Unincorporated (acre)	Total (acre)	Incorporated (%)	Unincorporated (%)	Total (%)
PBC ≥ 1.0 foot above	4,172	1,331	5,503	4.5%	1.4%	5.9%
PBC 0.5 to 1.0 feet above	7,340	3,560	10,900	7.9%	3.8%	11.7%
PBC < 0.5 feet above/below	55,334	13,595	68,929	59.5%	14.6%	74.2%
PBC 0.5 to 1.0 feet below	3,915	971	4,886	4.2%	1.0%	5.3%
PBC ≥ 1.0 feet below	2,157	559	2,716	2.3%	0.6%	2.9%
Total	72,918	20,016	92,934	78.5%	21.5%	100.0%
PBC above	11,512	4,891	16,403	12.4%	5.3%	17.7%
PBC below	6,072	1,530	7,602	6.5%	1.6%	8.2%

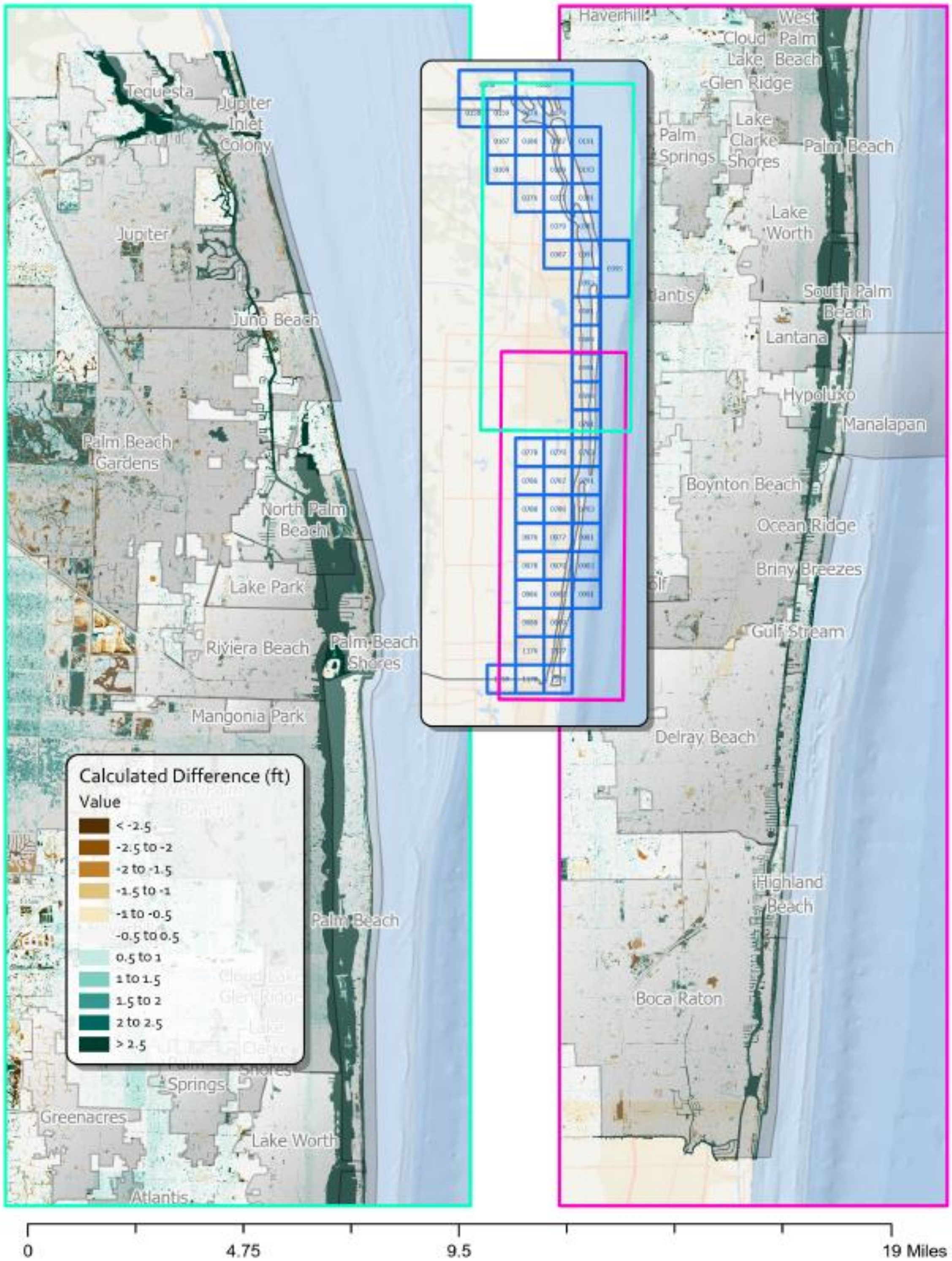


Figure 5.1: DEM Comparison with Municipal Boundaries: PBC DEM minus SWFLTB DEM

Elevations differences outside of FEMA's special flood hazard areas (SFHA) have limited, if any, influence on the updated FIRM Maps. As an additional method of comparison, elevation differences between the PBC DEM and the SWFLTB DEM as well as the PBC DEM and the USACE DEM were compared within the footprints of the FEMA's mapped Changes Since Last FIRM (CSLF). The footprints of CSLF was estimated at 11,509 acres as compared to 92,934 acres within the coastal FIRM panels.

Figure 5.2 shows the mapped CSLF for Palm Beach County as reported by FEMA. Note the gray areas designate no change in zone; however, this map does not specify if any Base Flood Elevations (BFEs) were updated within an existing zone. Appendix D contains enlarged views of the elevation differences along the Palm Beach County coastline for the PBC DEM minus the SWFLTB DEM, as well as the PBC DEM minus the USACE DEM, with a comparison to the CSLF map. Comparison of the DEM's within the footprints of the CSLF resulted in the following.

- **PBC DEM minus SWFLTB DEM** (Table 5.3):
    - Incorporated boundaries represented 83.9% (9,659 acres) of the area included in the CSLF footprints; unincorporated boundaries represented 16.1% (1,850 acres) of the area.
    - Differences of less than +/-0.5 feet between the DEM's were documented for 78% of the CSLF footprints; 65.0% within incorporated boundaries and 12.9% within unincorporated boundaries.
    - Difference of greater than 0.5 feet between DEM's were documented for 22.0% of the CSLF footprints; with the PBC DEM being above the SWFLTB DEM for 15.0% of the area and below for 7.0% of the area.
- **PBC DEM minus USACE DEM** (Table 5.4):
    - Similar trends were identified when comparing the PBC DEM to the USACE DEM.
    - The differences of less than +/-0.5 feet between the DEM's increased to 65.6% within incorporated boundaries for the USACE DEM from 65.0% for the SWFLTB DEM. The improved agreement with the USACE DEM is a direct reflection of the limits of the updated USACE data for the County's barrier islands used in creating the USACE DEM.

Table 5.3: PBC DEM minus SWFLTB DEM within CSLF Footprints

PBC DEM minus SWFLTB DEM	Incorporated (acre)	Unicorporated (acre)	Total (acre)	Incorporated (%)	Unincorporated (%)	Total (%)
PBC ≥ 1.0 foot above	509	112	621	4.4%	1.0%	5.4%
PBC 0.5 to 1.0 feet above	964	147	1,111	8.4%	1.3%	9.7%
PBC < 0.5 feet above/below	7,486	1,487	8,973	65.0%	12.9%	78.0%
PBC 0.5 to 1.0 feet below	473	66	539	4.1%	0.6%	4.7%
PBC ≥ 1.0 feet below	227	38	265	2.0%	0.3%	2.3%
Total	9,659	1,850	11,509	83.9%	16.1%	100.0%
PBC above	1,473	259	1,732	12.8%	2.3%	15.0%
PBC below	700	104	804	6.1%	0.9%	7.0%

Table 5.4: PBC DEM minus USACE DEM within CSLF Footprints

PBC DEM minus USACE DEM	Incorporated (acre)	Unicorporated (acre)	Total (acre)	Incorporated (%)	Unincorporated (%)	Total (%)
PBC ≥ 1.0 foot above	484	108	592	4.2%	0.9%	5.1%
PBC 0.5 to 1.0 feet above	887	144	1,031	7.7%	1.3%	9.0%
PBC < 0.5 feet above/below	7,552	1,495	9,047	65.6%	13.0%	78.6%
PBC 0.5 to 1.0 feet below	515	66	581	4.5%	0.6%	5.0%
PBC ≥ 1.0 feet below	221	37	258	1.9%	0.3%	2.2%
Total	9,659	1,850	11,509	83.9%	16.1%	100.0%
PBC above	1,371	252	1,623	11.9%	2.2%	14.1%
PBC below	736	103	839	6.4%	0.9%	7.3%

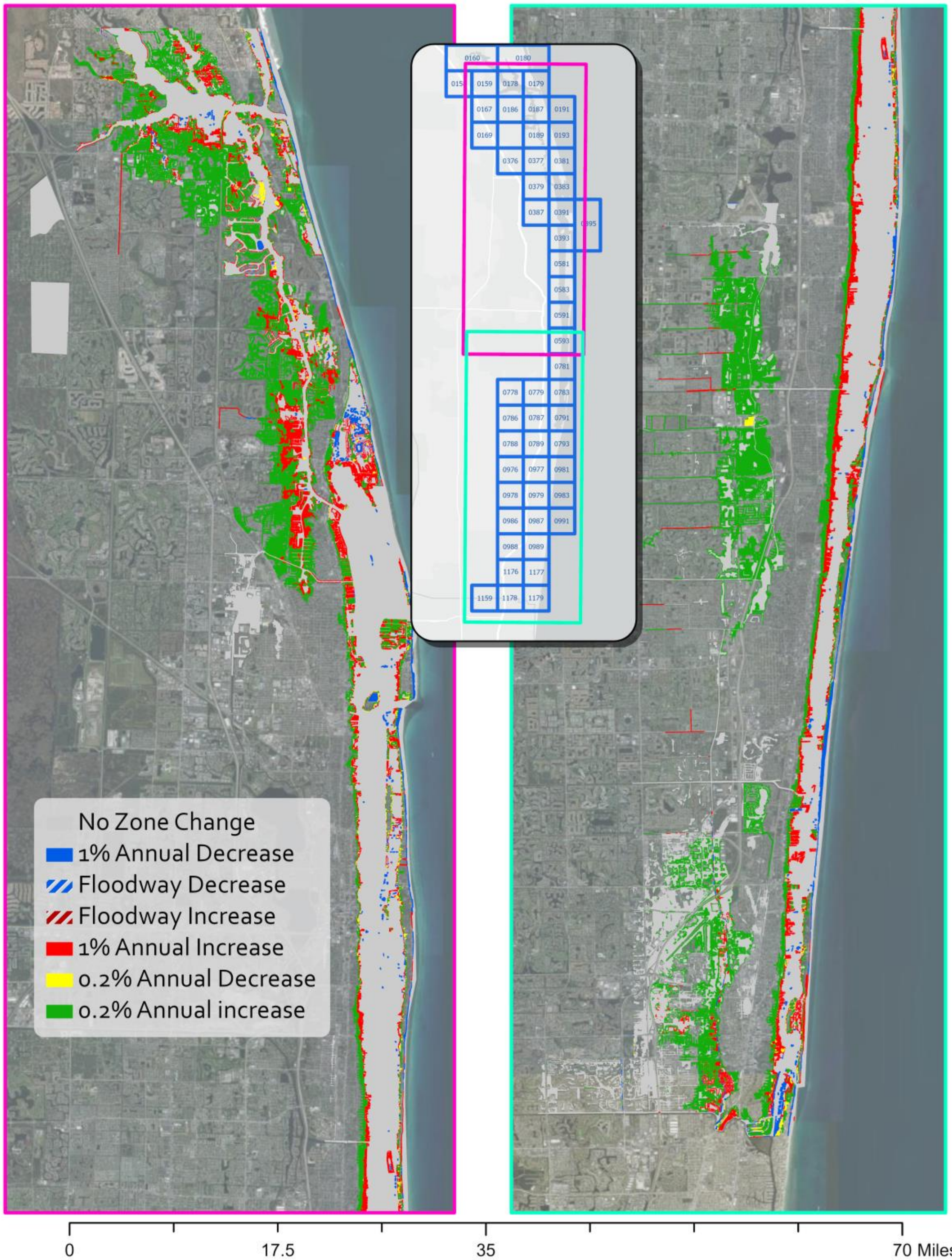


Figure 5.2: FEMA's mapped CSLF: Palm Beach County

The BFEs, not accounted for in the mapped CSLF, are estimated by FEMA at 1-foot increments and are determined based on the storm surge (stillwater and wave setup), erosion, runup, and overland wave propagation. During large storm surge events, surge and waves push inland from the natural coastline. The overland wave heights are determined based on the stillwater elevations, starting wave conditions, ground elevation, and obstructions in the inland area. This information is generally determined utilizing data from FEMA's Wave Height Analysis for Flood Insurance Studies (WHAFIS) transects. Figure 5.3 shows the WHAFIS transect lines within Palm Beach County used in FEMA's mapping overlain on the DEM comparison of the PBC DEM and SWFLTB DEM. Appendix D also provides enlarged views of the elevation differences along the WHAFIS transect lines.

After review of the DEM comparisons, the mapped CSLF, and the WHAFIS transect lines, transect 148 was selected for further analysis to convey differences between the DEM's and how they may relate to FEMA's preliminary FIRM panels.

- It was found that areas had undergone significant redevelopment between the data collection times of the two DEMs (SWFLTB DEM and PBC DEM) as can be seen in Figure 5.4 and Figure 5.5.
- Figure 5.6 shows the profile cut along the entire length of the Transect 148. Except for the areas of development and the lack of bathymetry data in the PBC DEM, the two profiles are in acceptable agreement given that the difference in elevations are less than the accuracy tolerances for the DEM's. In the areas of development, the PBC DEM was above the SWFLTB DEM but FEMA's mapped CSLF indicated an increased flood hazard.
- Review of preliminary FIRM panel (Figure 5.7) for FEMA's updated study and the effective (current) FIRM panel indicated that the flood risk increased in the areas of development as the BFE increased to +7 feet, NAVD88 from +4 feet, NAVD88. FEMA's mapping of the flood zones in this instance appears to correctly reflect the defined BFE with respect of the DEM's as well as the mapped CSLF.

This type of analysis would be necessary on a location-by-location (e.g. parcels and individual structures) basis to evaluate whether differences identified by DEM comparisons with respect to updated BFE would affect/alter the mapping of flood zones shown in FEMA's preliminary FIRM panels. Location specific differences, if documented to be above FEMA's defined BFE by a flood elevation certificate signed by a Florida professional land surveyor, could be addressed as a letter of map revision (LOMR) issued by FEMA.

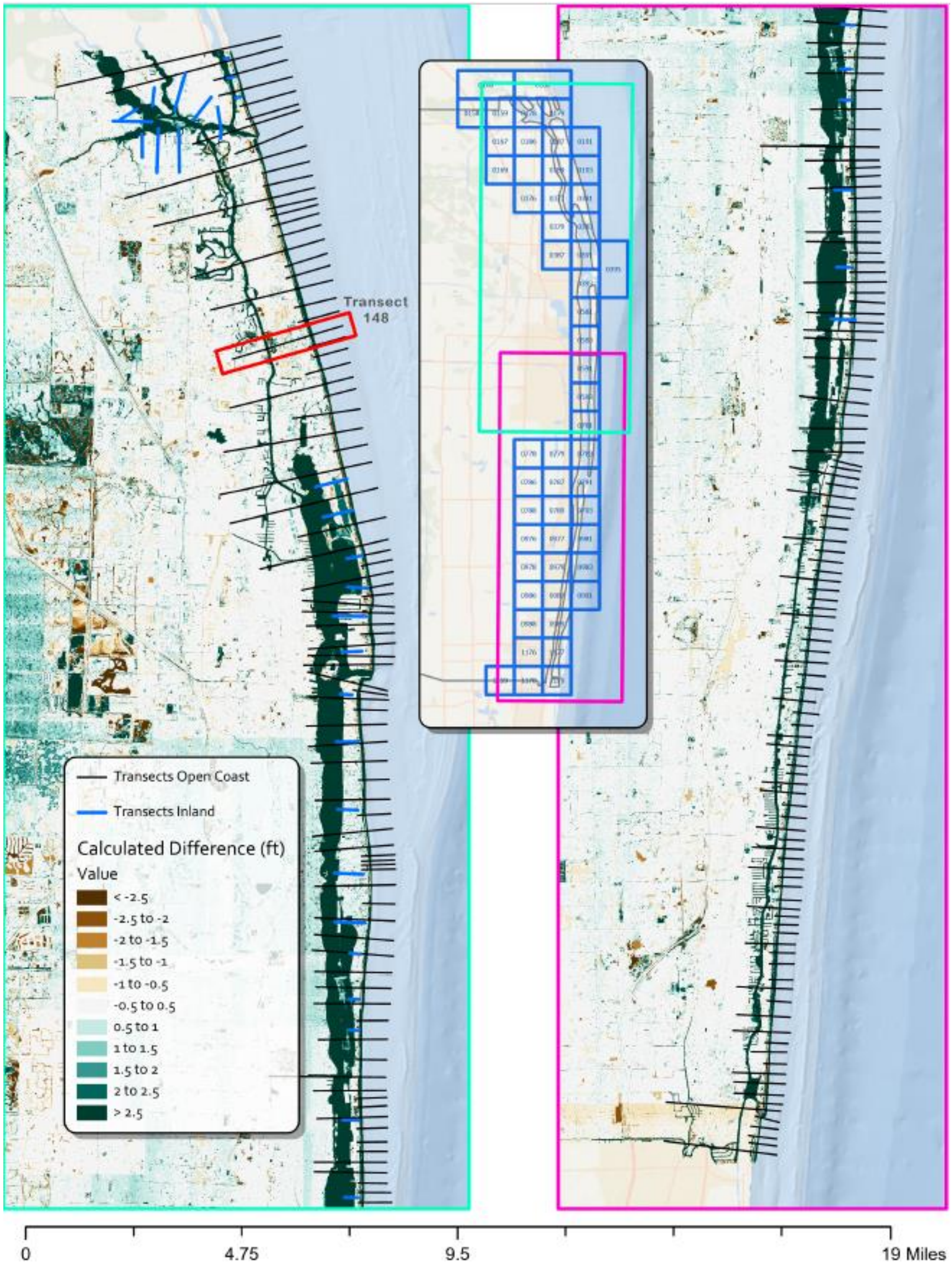


Figure 5.3: DEM Comparison with WHAFIS Transects: PBC DEM minus SWFLTB DEM

Figure 5.4: Area of Development along Transect 148: SWFLTB DEM (Left) vs. PBC DEM (Right)

Figure 5.5: Area of Development along Transect 148: 2005 Aerial (Left) vs. 2017 Aerial (Right)

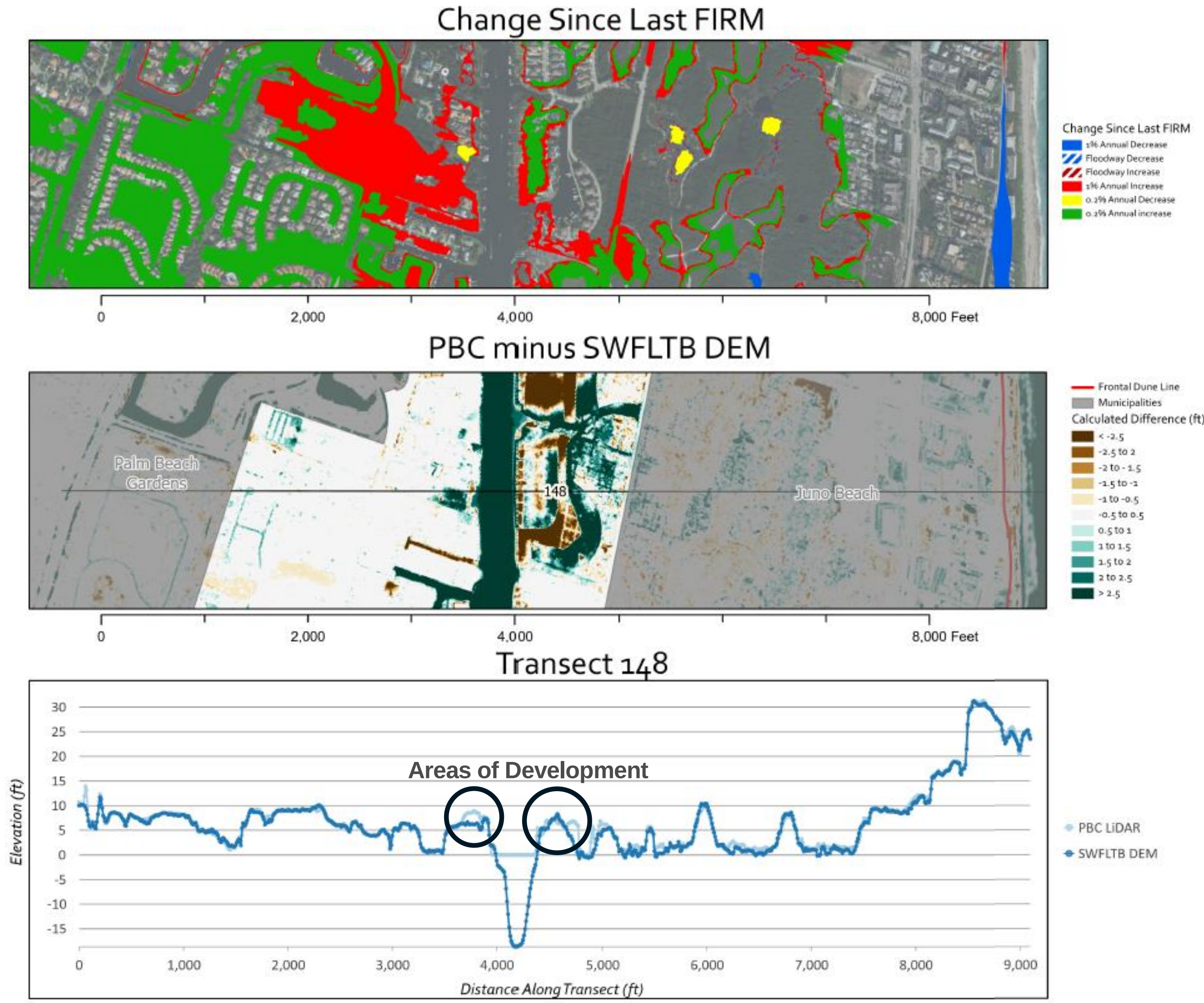


Figure 5.6: Comparison of Elevations and CSLF Map along WHAFIS Transect 148

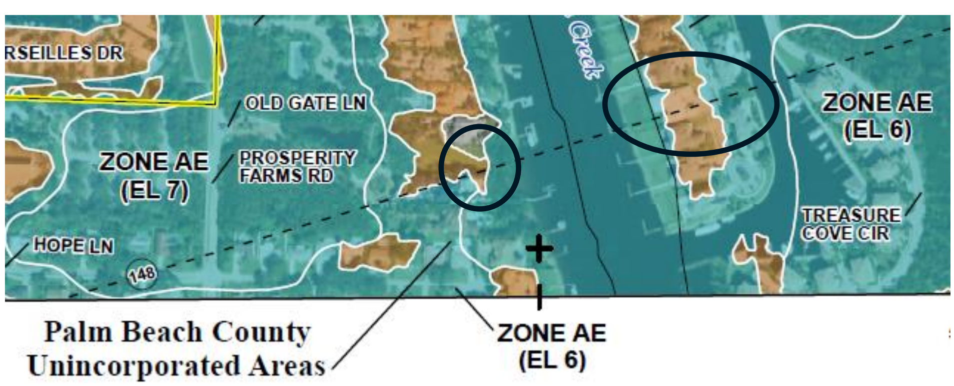


Figure 5.7: FEMA preliminary FIRM panel (0189)

5.2 Benchmarks

Since the analysis demonstrated localized areas of grade differences greater than the six-inch tolerance, the SWFLTB, USACE, and PBC DEMs were compared to the Palm Beach County Benchmark Data provided by the County on February 29, 2020, within the FIRM boundaries. It was found the PBC DEM deviates less from the provided benchmarks than the SWFLTB DEM or USACE DEM.

- PBC DEM – Benchmark average difference: 0.84 ft; Standard deviation: 3.41ft
- USACE DEM – Benchmark average difference: 1.26 ft; Standard deviation: 4.31 ft
- SWFLTB DEM – Benchmark average difference: 1.24 ft; Standard deviation: 4.32 ft

These are all large deviations, but it indicates the PBC DEM is slightly more accurate that the SWFLTB DEM or USACE DEM. Benchmark data points were originally provided with the 2016/2017 Palm Beach County LiDAR that are in much closer agreement with the PBC DEM. The standard deviation from these benchmarks was 0.13 ft. Elevations within the PBC DEM at the locations of the benchmarks were associated with the elevation of the 10-foot grids, not a single point, thus contributing to this deviation.

6. Conclusion

Multiple datasets were used to create the DEMs utilized by the Coastal Study and for the development of the updated preliminary FIRMs. Outlined in this report are the input behind these datasets and how each was applied. The various DEMs used were as follows:

- Coastal Study – SWFLTB DEM
- Updated FIRMs – USACE DEM
- 2016/2017 Palm Beach County LiDAR for comparison – PBC DEM.

No gaps between datasets were found within the area being assessed in this task within the SWFLTB DEM compiled by BakerAECOM. Based on our analysis of the information contained within the BakerAECOM Report *Technical Approach,* no obvious errors were found in the horizontal reprojections/transformations or vertical transformations. The methods used by BakerAECOM to stitch together various datasets in the creation of the SWFLTB DEM for use in the Coastal Study appear to be acceptable.

Within the coastal FIRM panels, areas were examined for elevation differences of 0.5 feet or greater and 1 foot or greater between the PBC DEM and SWFLTB DEM and between the PBC DEM and USACE DEM. Based on the accuracy of FEMA FIRMs and survey tolerances of the data used in this analysis, a deviation of 0.5 feet or greater was deemed to be large enough to possibly affect mappings of flood zone of the updated FIRMs. Of the 92,934 acres contained with the coastal FIRM panels,

- Incorporated boundaries represented 78.5% (72,918 acres) of the area included in the coastal FIRM panel area; unincorporated boundaries represented 21.5% (20,016 acres) of the area.
- Differences of less than +/-0.5 feet between the DEM's were documented for 73.6% of the coastal FIRM panel area when comparing the PBC DEM to the SWFLTB DEM; 59.0% within incorporated boundaries and 14.6% within unincorporated boundaries. Similar trends were identified when comparing the PBC DEM to the USACE DEM.
- As discussed in Section 3.2, the USACE DEM was updated with USACE data collected in 2016. The updated USACE data was roughly used to represent the barrier islands east of state road A1A, while the data to the west was consistent with the data used to generate the SWFLTB DEM. The barrier islands are mostly contained by incorporated boundaries. Accordingly, differences of less than +/-0.5 feet between the DEM's increased to 59.5% within incorporated boundaries for the USACE DEM from 59.0% for the SWFLTB DEM. The USACE DEM, which incorporated more recent data, exhibited better agreement with PBC DEM.

Elevation differences outside of FEMA's special flood hazard areas (SFHA) have limited, if any, influence on the updated FIRM Maps. As an additional method of comparison, elevation differences between the PBC DEM and the SWFLTB DEM as well as the PBC DEM and the USACE DEM were compared within the footprints of the FEMA's mapped Changes Since Last FIRM (CSLF). The footprints of the CSLF were estimated at 11,509 acres as compared to 92,934 acres within the coastal FIRM panels. Within the CSLF footprints (Table 6.1),

- Incorporated boundaries represented 83.9% (9,659 acres) of the area included in the CSLF footprints; unincorporated boundaries represented 16.1% (1,850 acres) of the area.
- Differences of less than +/-0.5 feet between the DEM's were documented for 78% of the CSLF footprints when comparing the PBC DEM to the SWFLTB DEM; 65.0% within incorporated boundaries and 12.9% within unincorporated boundaries. Similar trends but with increased agreement for differences less than +/-0.5 feet (as noted above) were identified when comparing the PBC DEM to the USACE DEM.
- Differences of greater than 0.5 feet between DEM's were documented for 22.0% of the CSLF footprints when comparing the PBC DEM to the SWFLTB DEM; with the PBC DEM being above the SWFLTB DEM for 15.0% (1,732 acres) of the area and below for 7.0% (804 acres) of the area.

Table 6.1: PBC DEM minus SWFLTB DEM within CSLF Footprints

PBC DEM minus SWFLTB DEM	Incorporated (acre)	Unicorporated (acre)	Total (acre)	Incorporated (%)	Unincorporated (%)	Total (%)
PBC ≥ 1.0 foot above	509	112	621	4.4%	1.0%	5.4%
PBC 0.5 to 1.0 feet above	964	147	1,111	8.4%	1.3%	9.7%
PBC < 0.5 feet above/below	7,486	1,487	8,973	65.0%	12.9%	78.0%
PBC 0.5 to 1.0 feet below	473	66	539	4.1%	0.6%	4.7%
PBC ≥ 1.0 feet below	227	38	265	2.0%	0.3%	2.3%
Total	9,659	1,850	11,509	83.9%	16.1%	100.0%
PBC above	1,473	259	1,732	12.8%	2.3%	15.0%
PBC below	700	104	804	6.1%	0.9%	7.0%

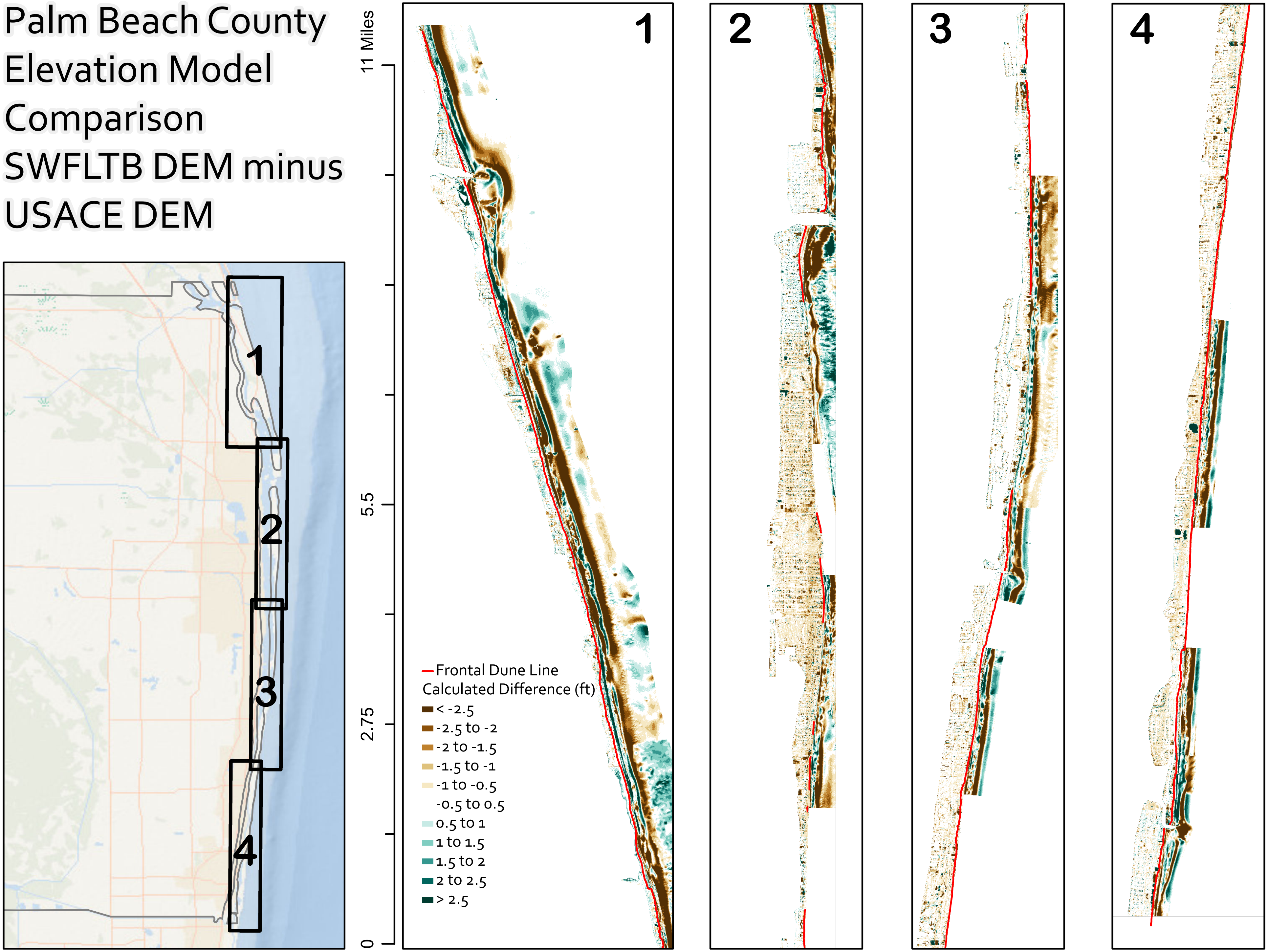
Based on the DEM comparisons, inclusion of the PBC DEM in FEMA's coastal study would help address the following.

- Differences may have expanded (overestimated) the inland extents of the SFHA mapped by FEMA in the central portion of the County. The DEM comparisons indicated that the PBC DEM was approximately 0.5 to 1.0 feet above the SWFLTB DEM west of the Lake Worth Lagoon. The differences (FIRM panels 0393, 0581, 05983, 0591, 0593, 0781, 0783, 0791, and 0793) extended approximately 15.5 miles between 45th Street, West Palm Beach and East Ocean Avenue, Boynton Beach. The differences appear to be inherent to the 2007 Florida Department of Emergency Management LiDAR data used by FEMA to generate the DEM in this area and therefore may be attributed to data collection techniques (e.g. flight lines, airframes, sensors, equipment).
- Differences may have limited (reduced) the inland extents of the SFHA mapped by FEMA in the southern portion of the County. The data used by FEMA in the creation of the SWFLTB DEM changed from the 2007 Florida Department of Emergency Management to the 2001 Palm Beach County LiDAR and resulted in an apparent vertical offset. The differences (FIRM panels 1159, 1178, and 1179) indicated that the PBC DEM was approximately 0.5 to 1 foot below the SWFLTB DEM.
- Larger differences (e.g. greater than 1 foot) appear to be due in part to the occurrence of construction and development during the time between the capture of the SWFLTB DEM in 2007 and the PBC DEM in 2016/17. Differences identified by the DEM comparisons may also be attributed in part to post-processing of the survey data and gridding methods. LiDAR survey data is processed to eliminate buildings, trees, and other obstructions to represent "bare earth" (i.e. ground elevations). Post-processing techniques, gridding methods, and technological advances in data collection since 2007 may account for some of the differences identified herein. A location-by-location analysis (which was beyond the scope of work) is necessary to evaluate whether these differences with respect to updated BFE would affect/alter the mapping of flood zones shown in FEMA's preliminary FIRM panels.

Appendix A

SWFLTB DEM minus USACE DEM

Palm Beach County Elevation Model Comparison SWFLTB DEM minus USACE DEM

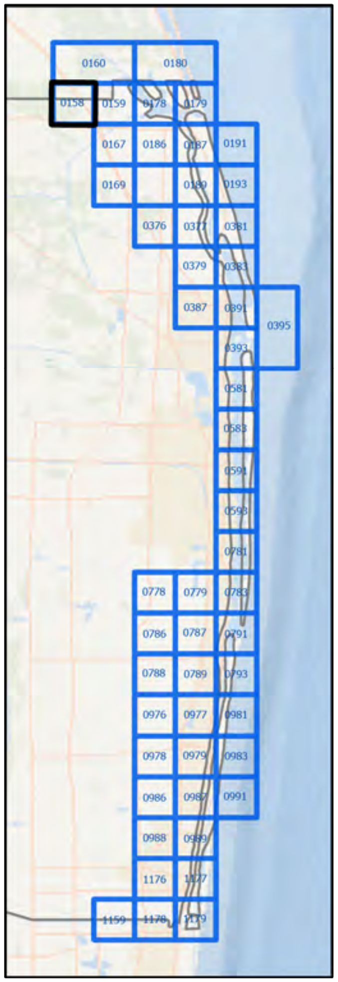


Appendix B

PBC DEM minus SWFLTB DEM by FIRM Panel

Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

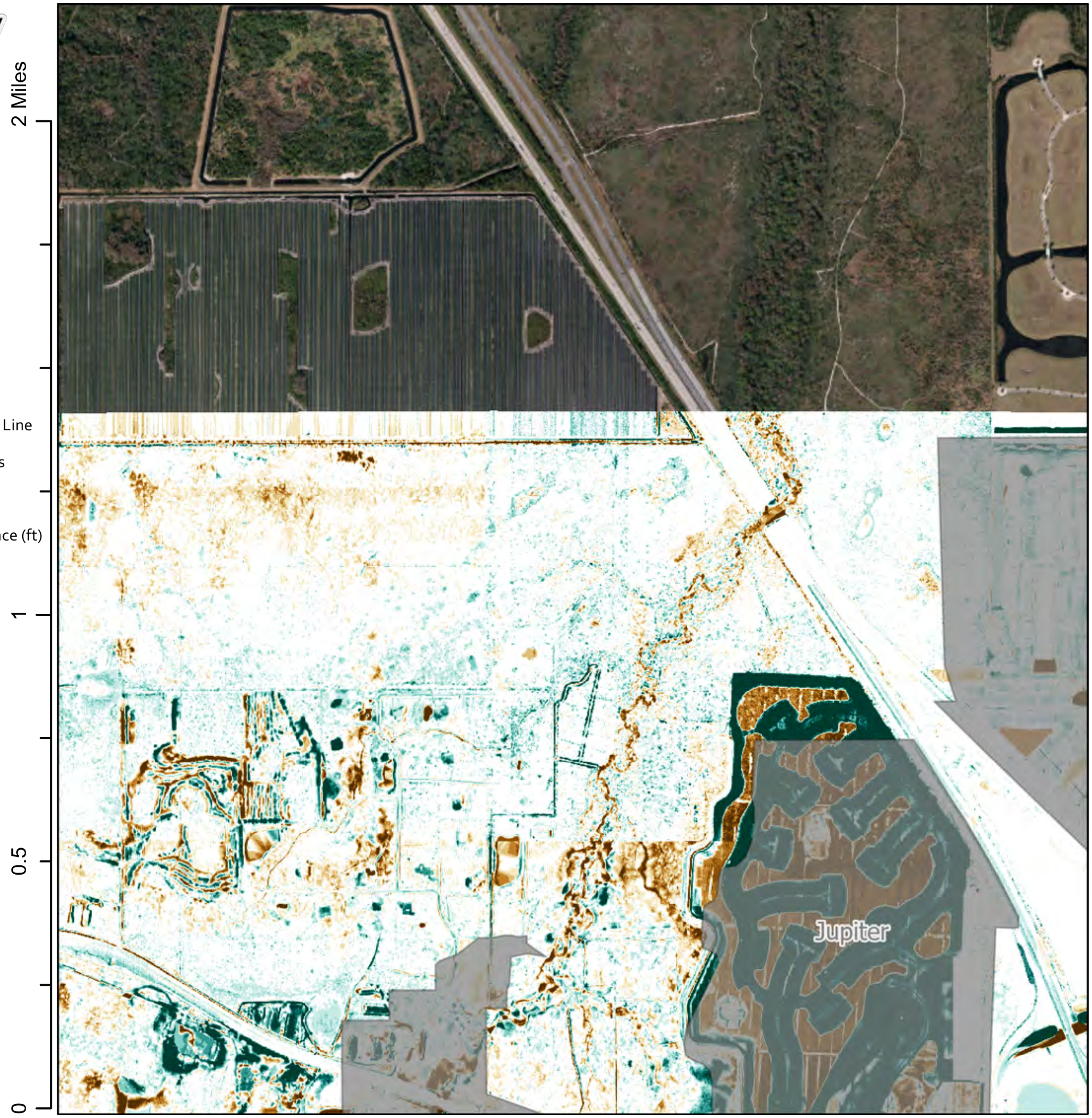
FIRM Panel: 0158



- Frontal Dune Line
- Municipalities
- FIRM Panels

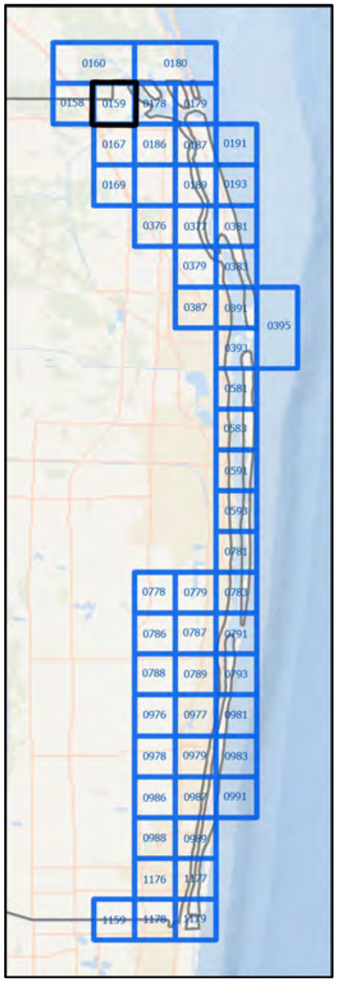
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

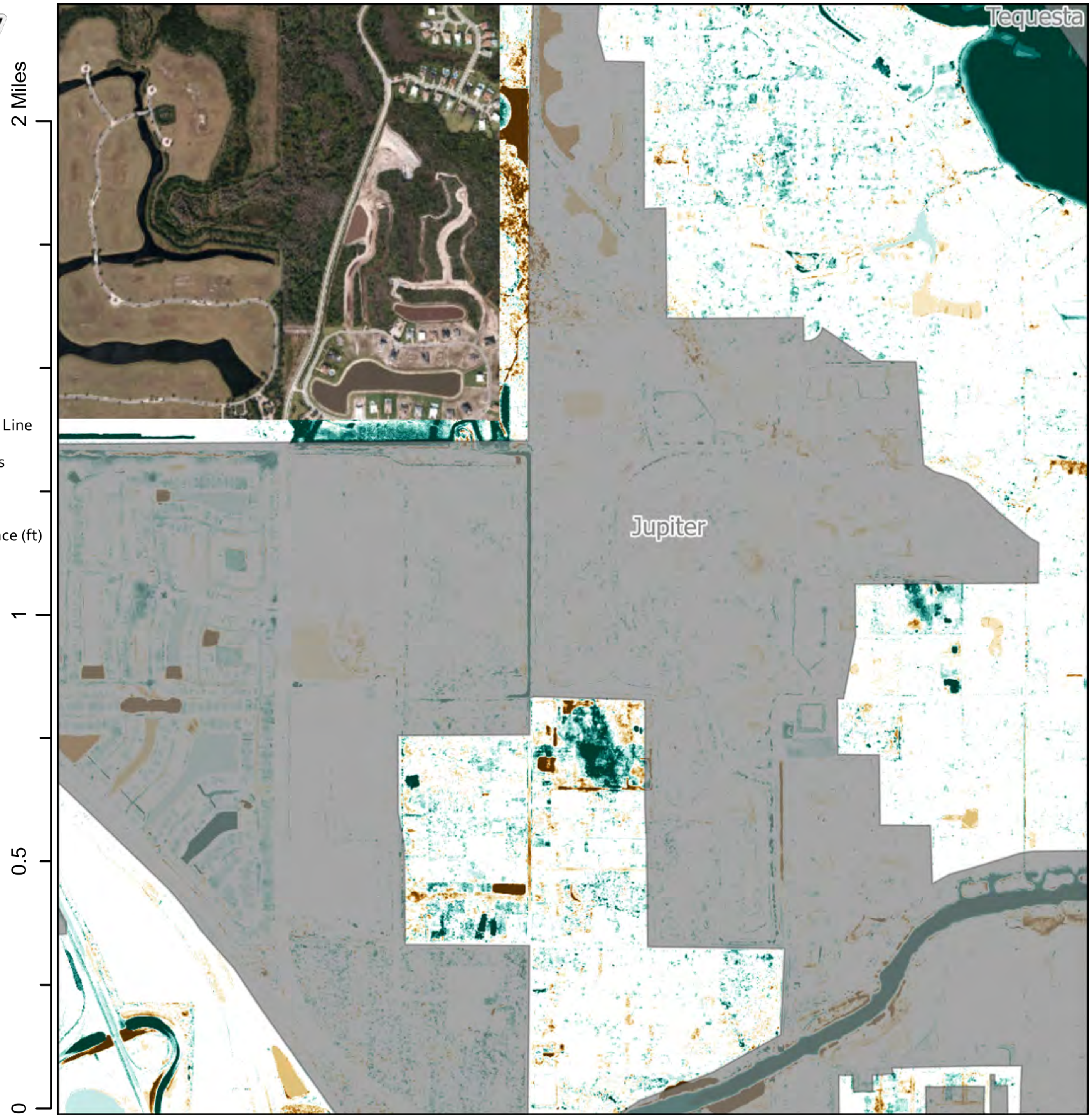
FIRM Panel: 0159



Frontal Dune Line
Municipalities
FIRM Panels

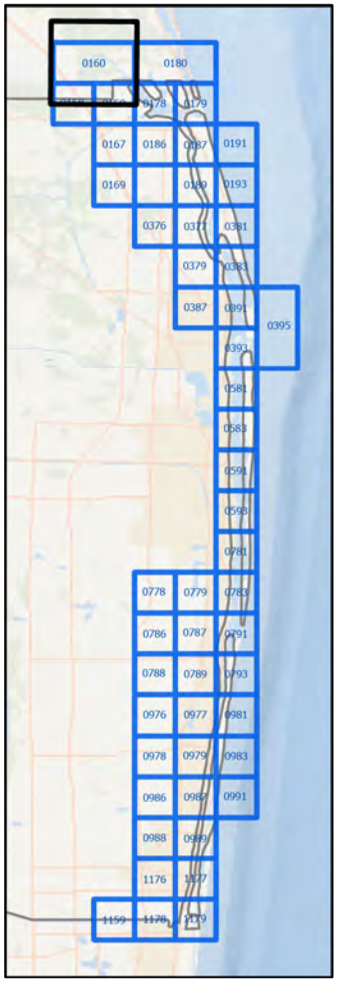
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

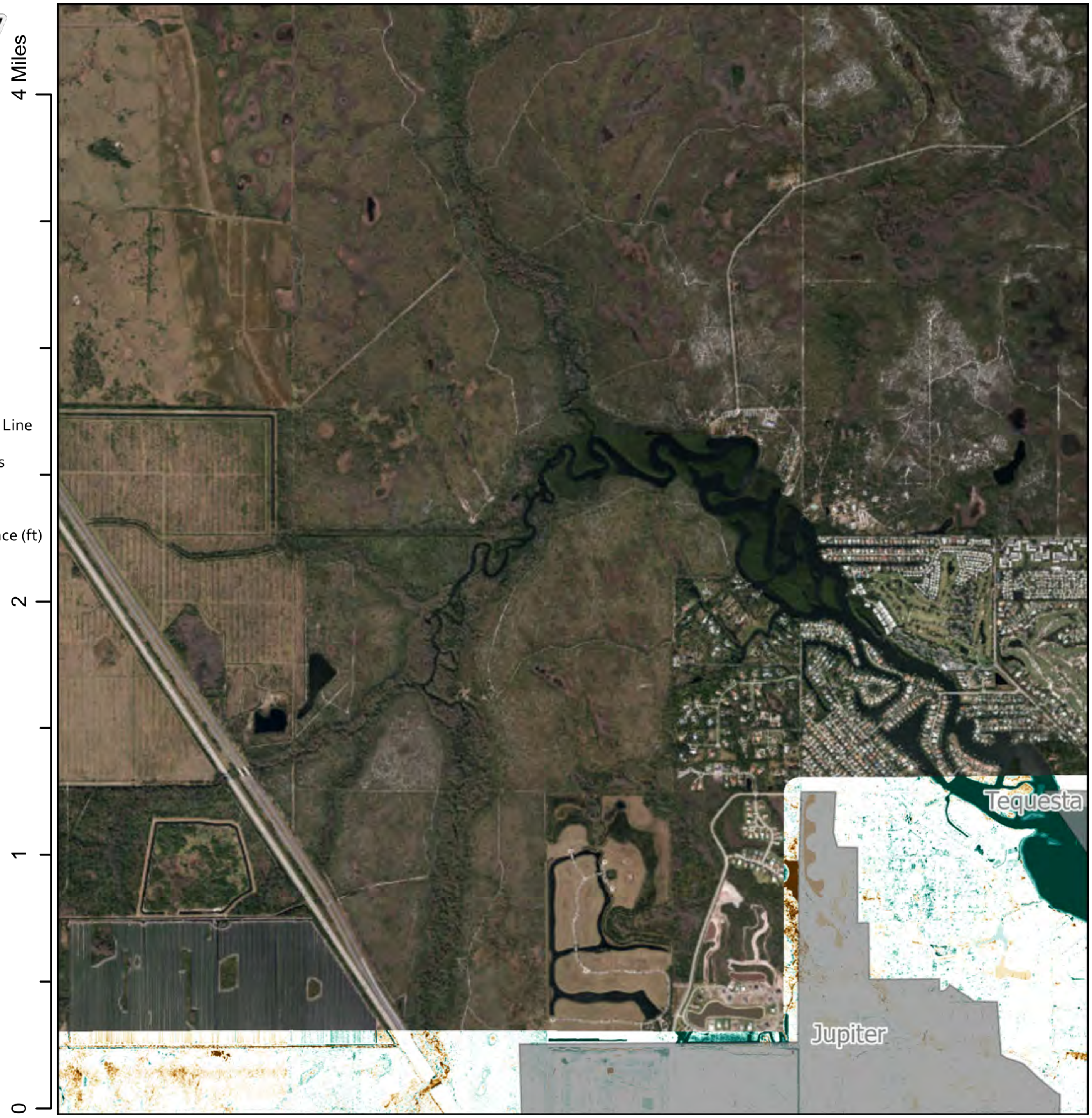
FIRM Panel: 0160



- Frontal Dune Line
- Municipalities
- FIRM Panels

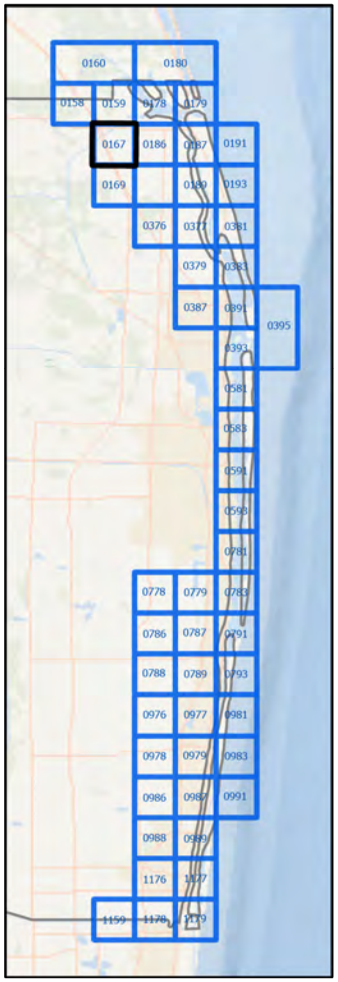
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

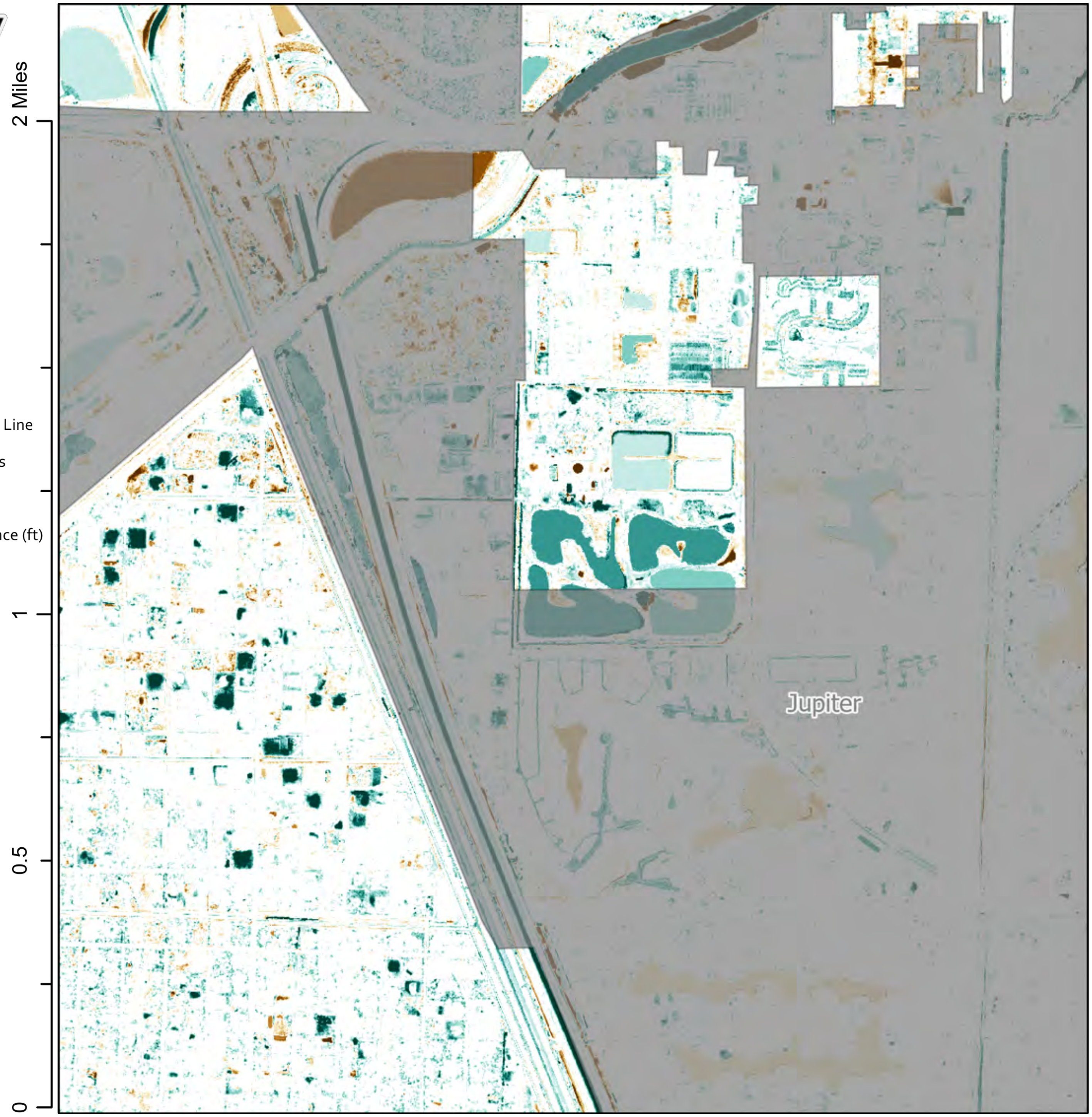
FIRM Panel: 0167



- Frontal Dune Line
- Municipalities
- FIRM Panels

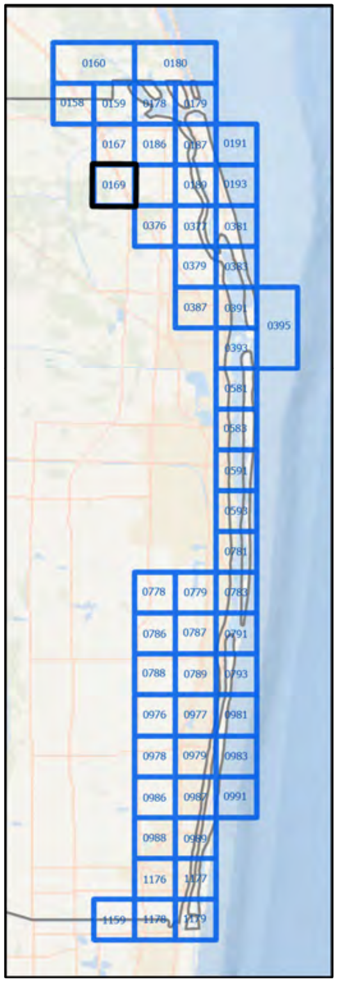
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0169



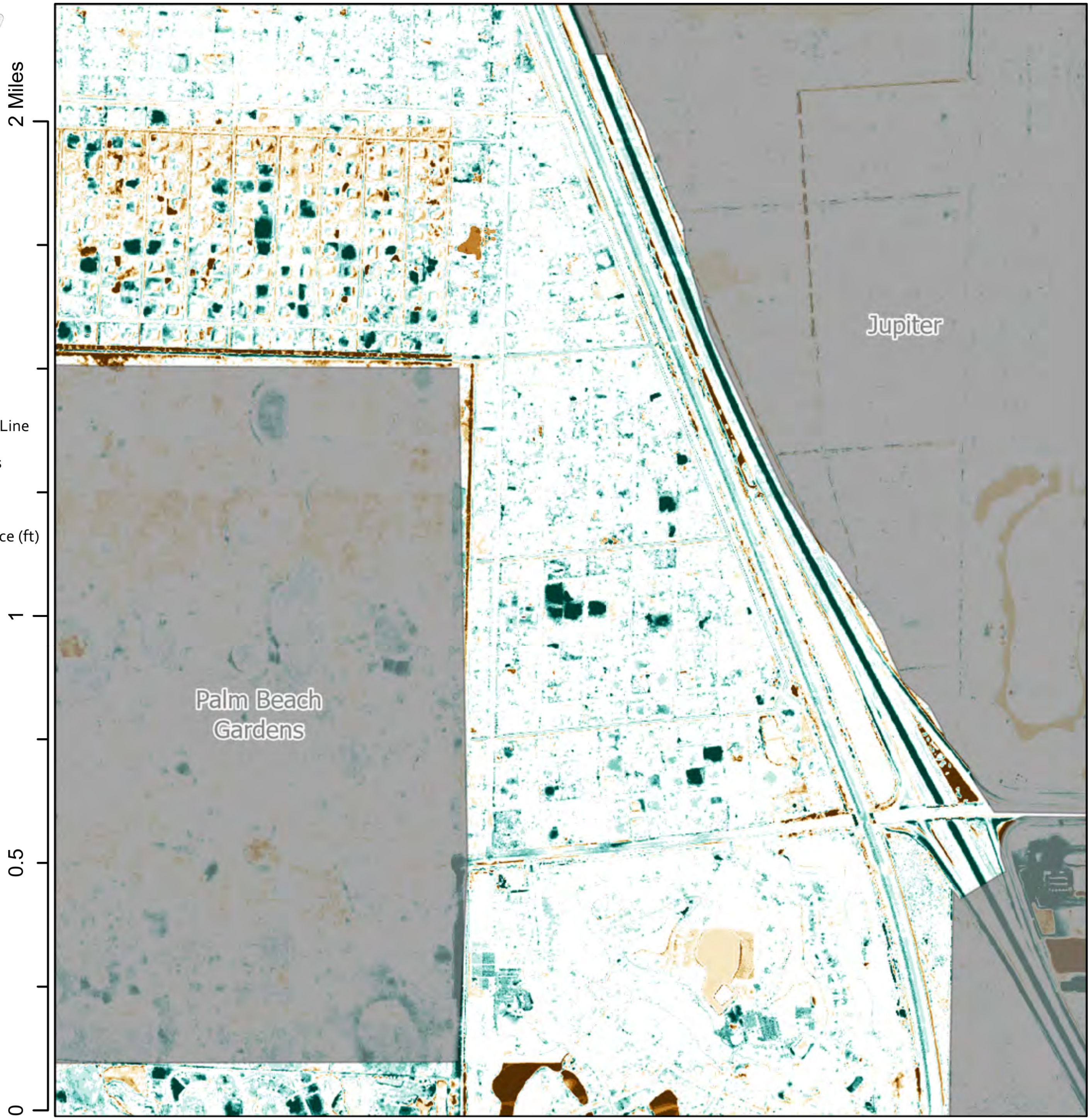
Frontal Dune Line

Municipalities

FIRM Panels

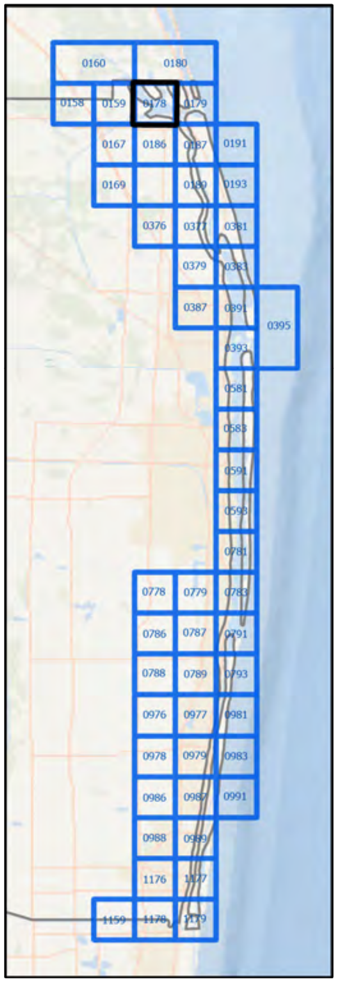
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0178



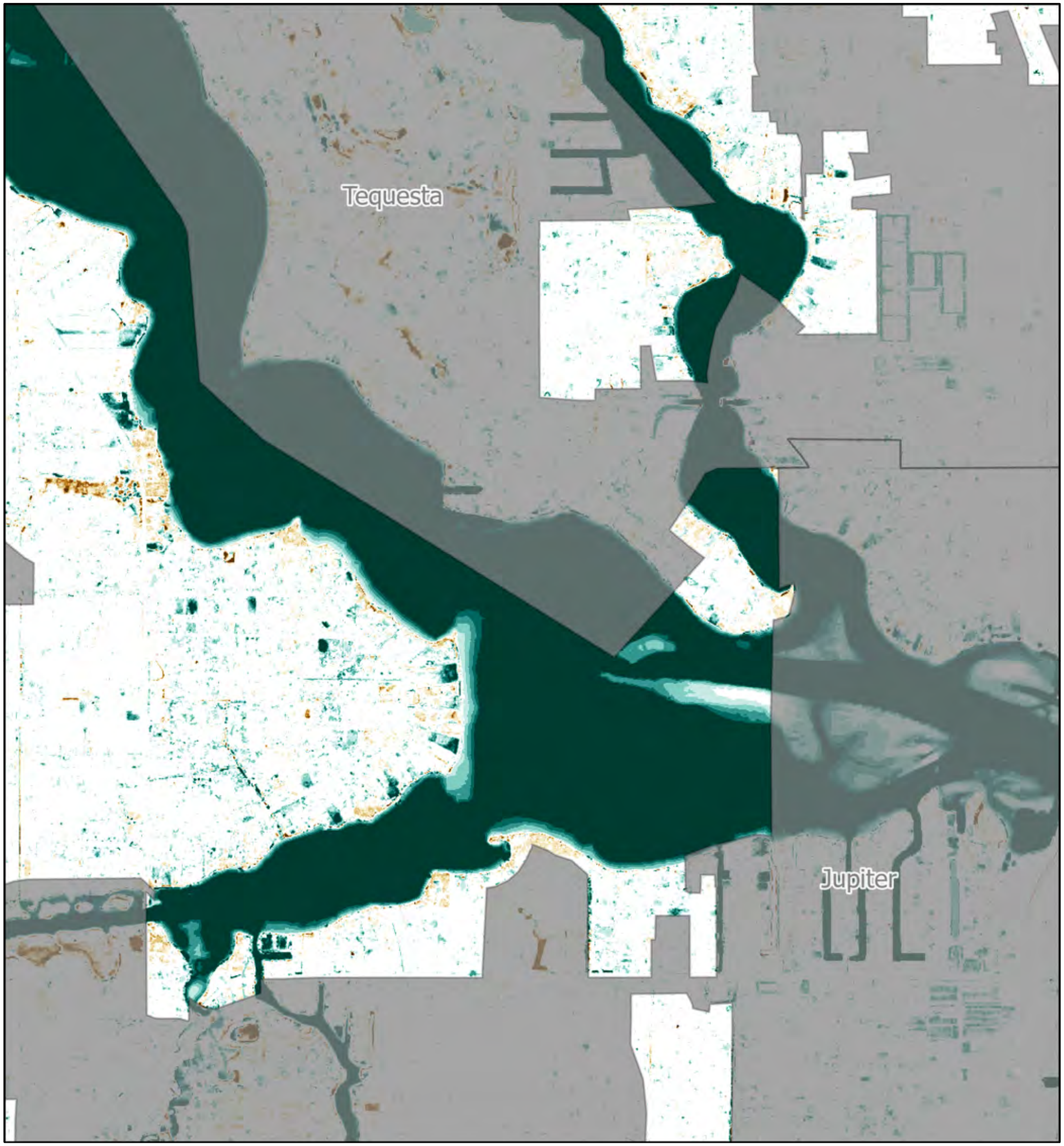
Frontal Dune Line

Municipalities

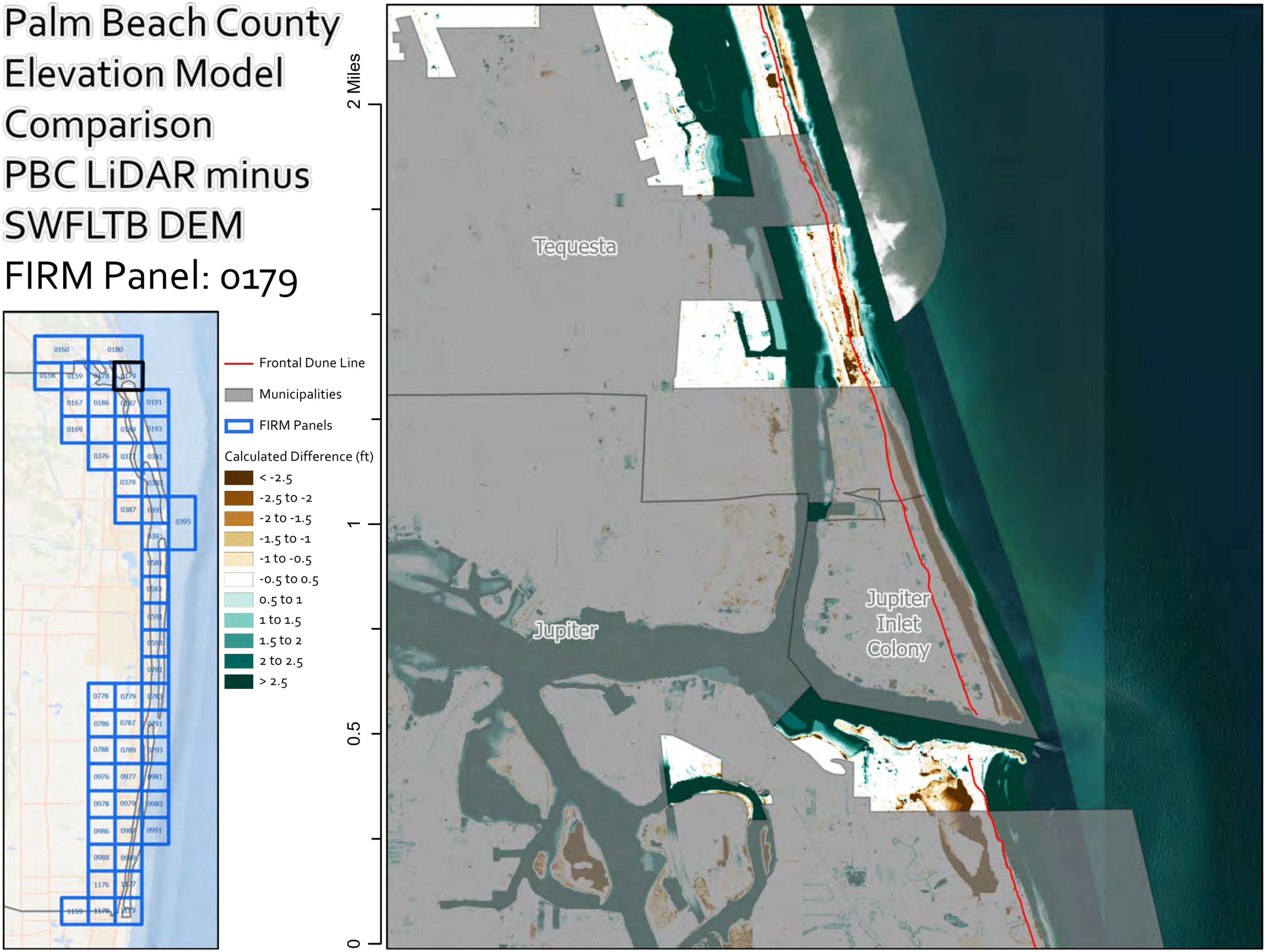
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

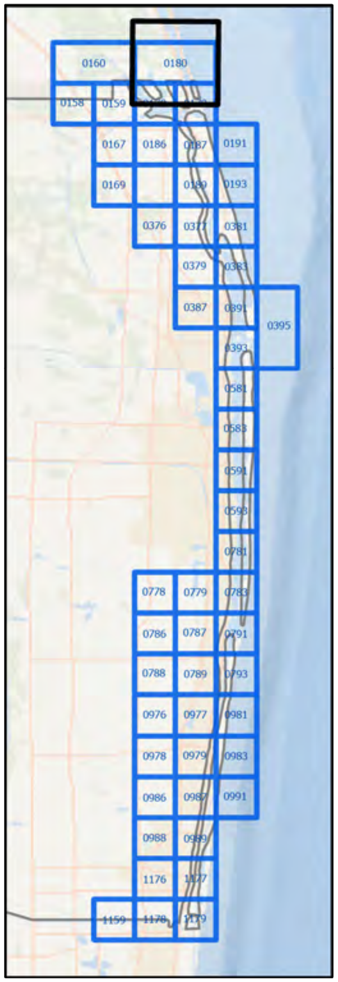


Palm Beach County Elevation Model Comparison
PBC LiDAR minus SWFLTB DEM
FIRM Panel: 0179



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

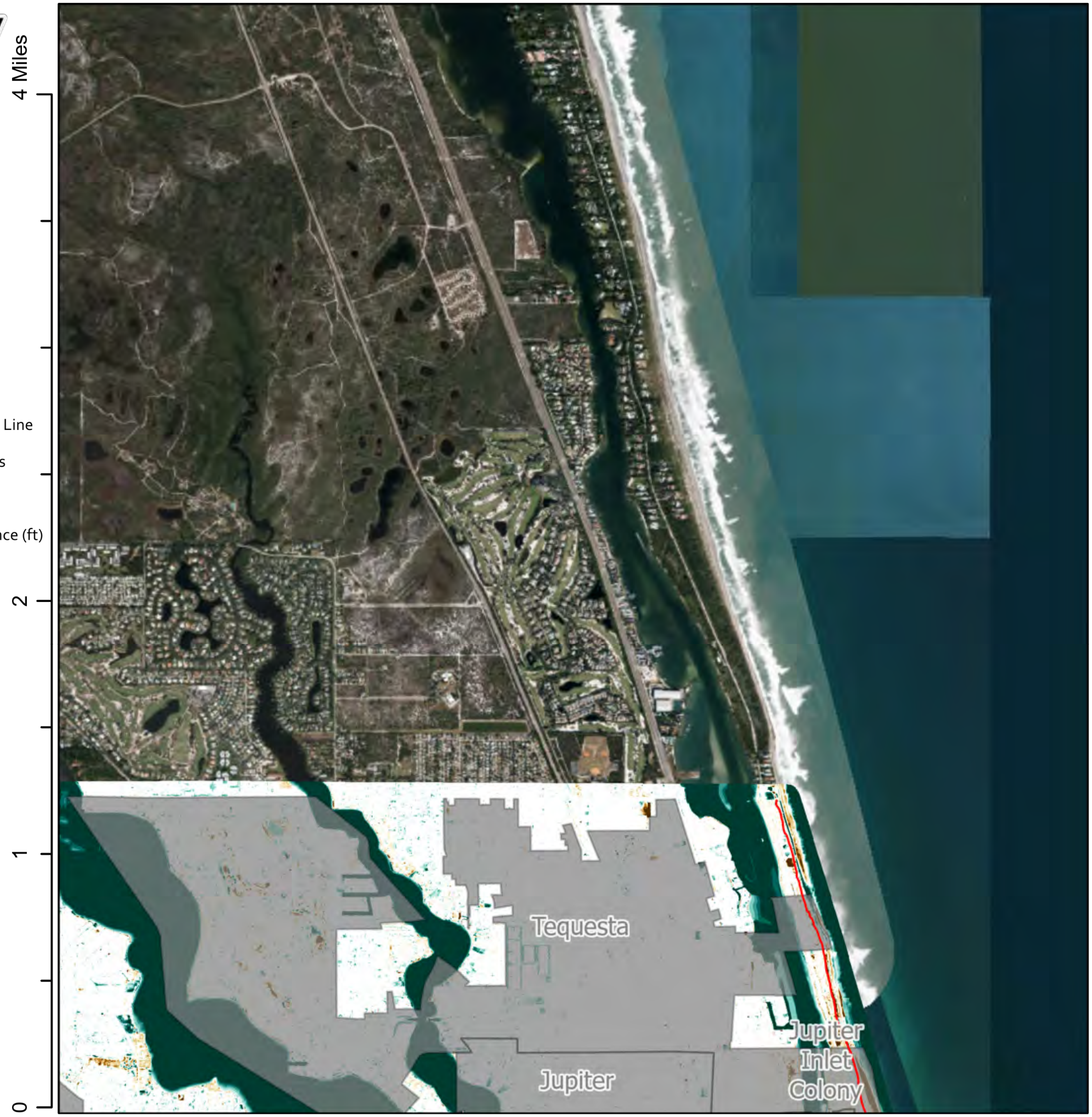
FIRM Panel: 0180



- Frontal Dune Line
- Municipalities
- FIRM Panels

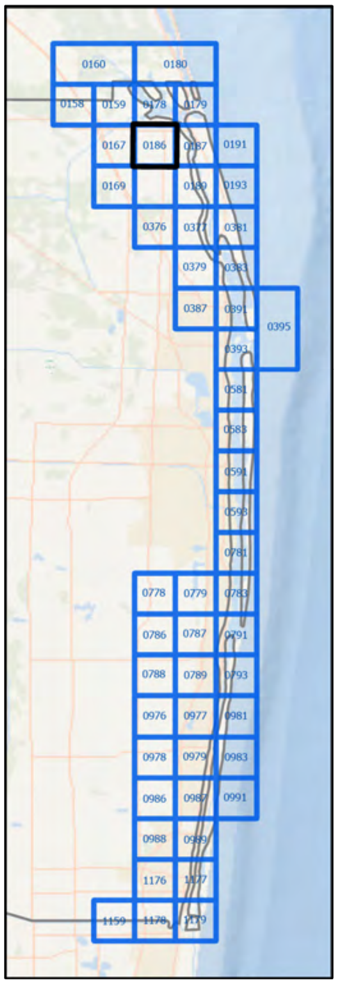
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0186



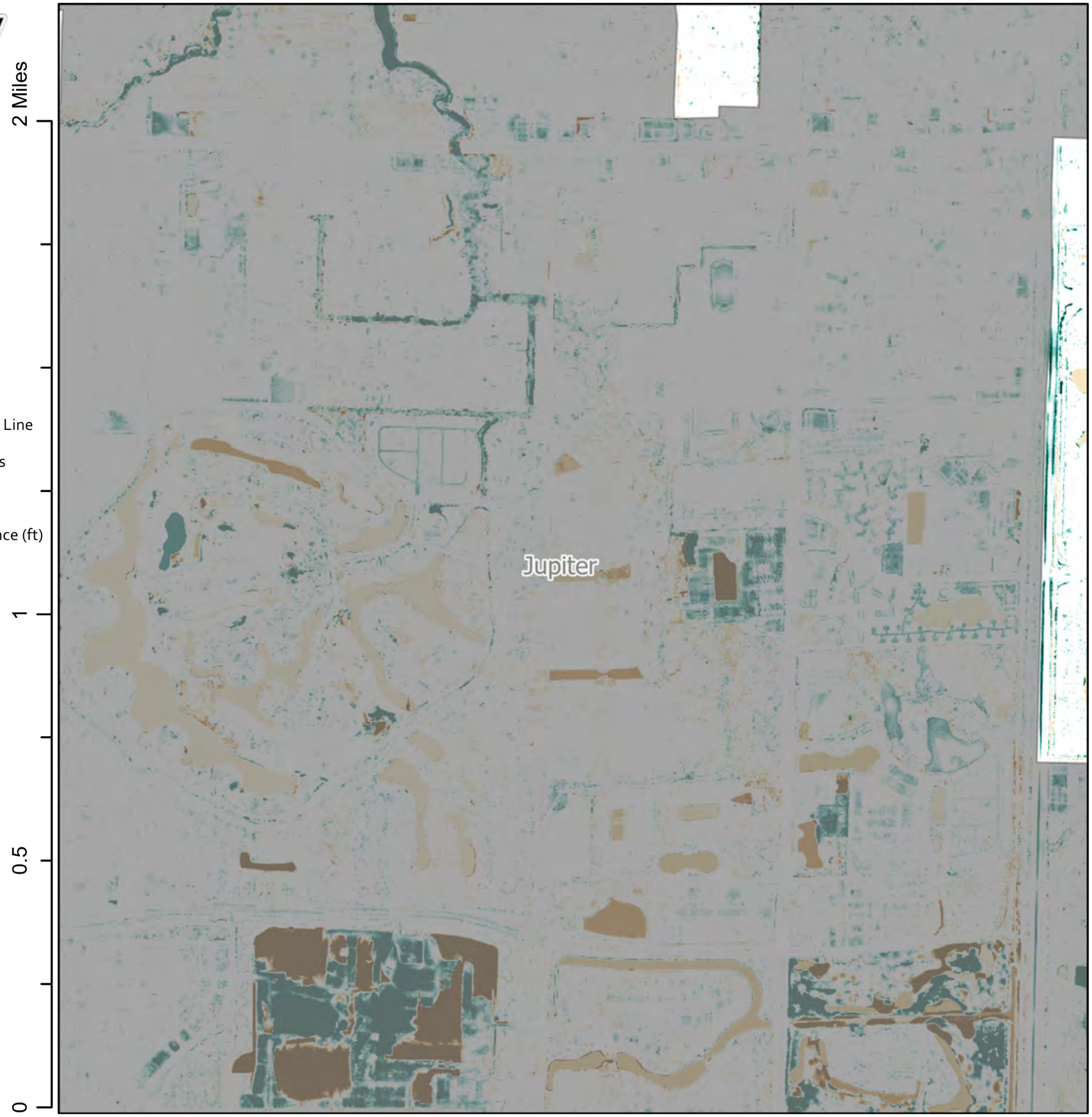
Frontal Dune Line

Municipalities

FIRM Panels

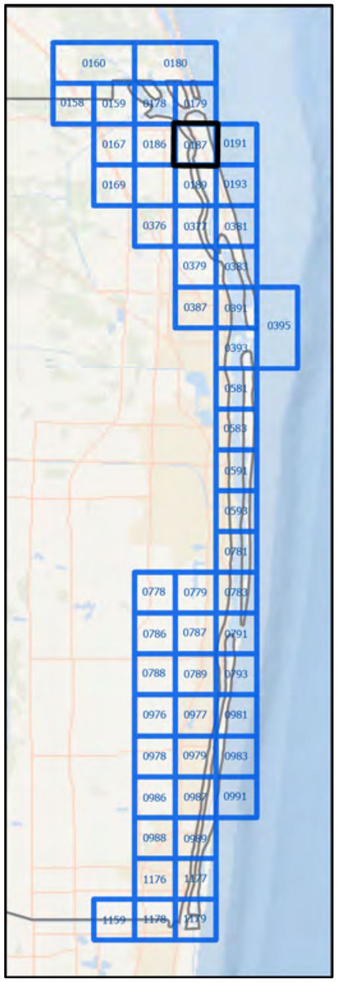
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0187



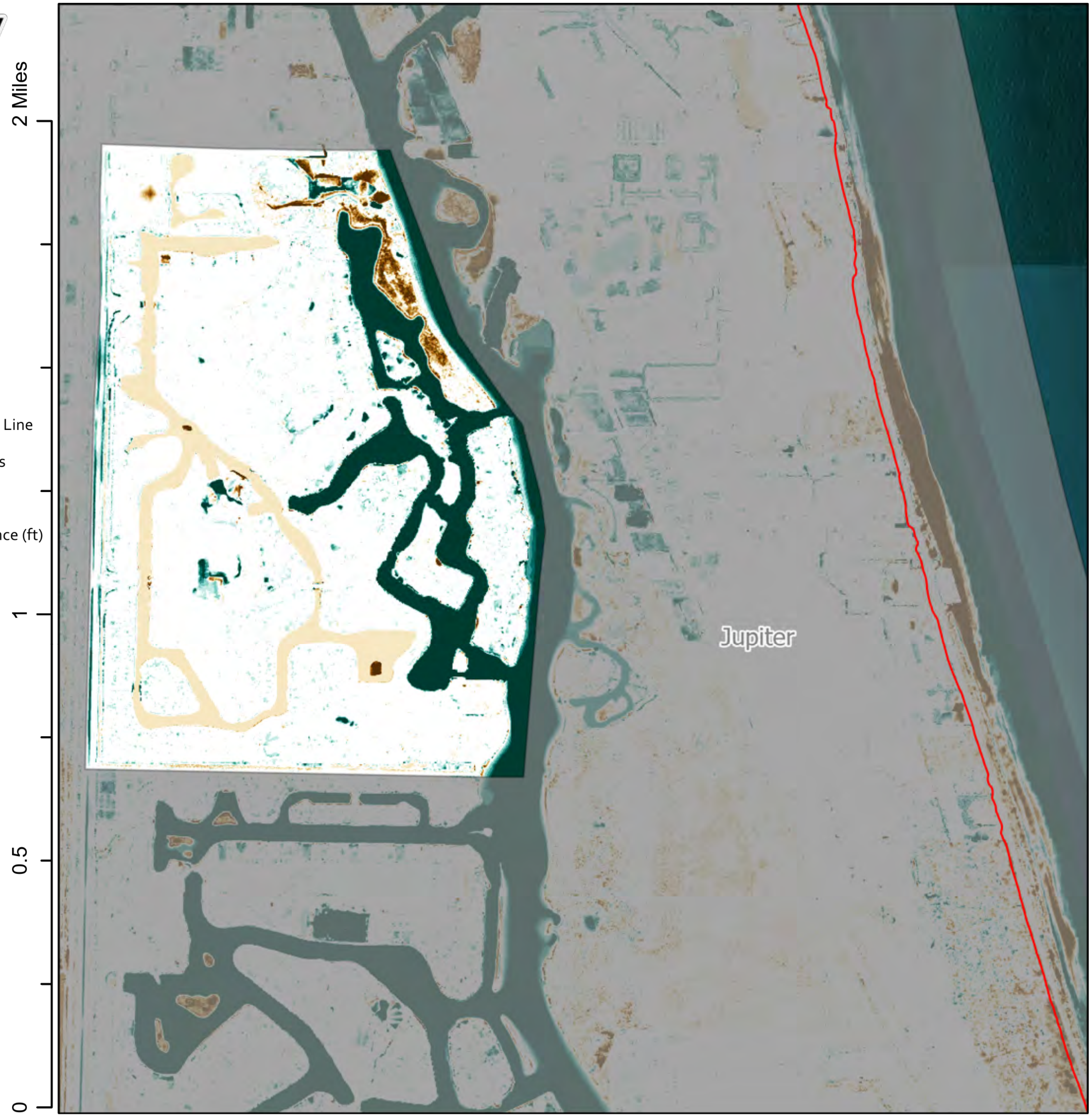
Frontal Dune Line

Municipalities

FIRM Panels

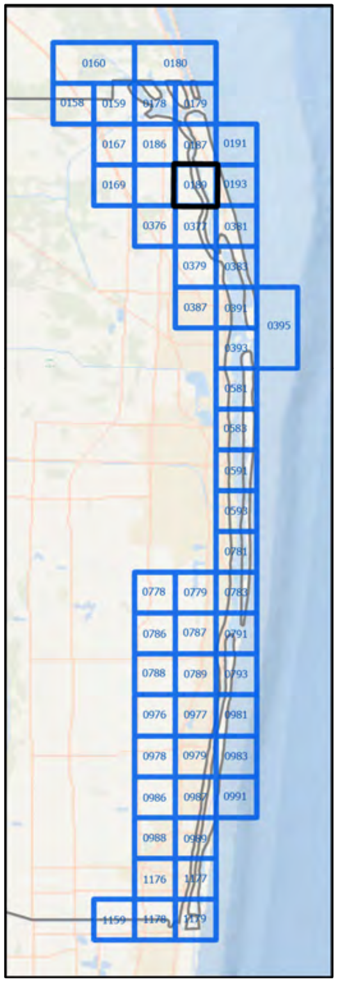
Calculated Difference (ft)

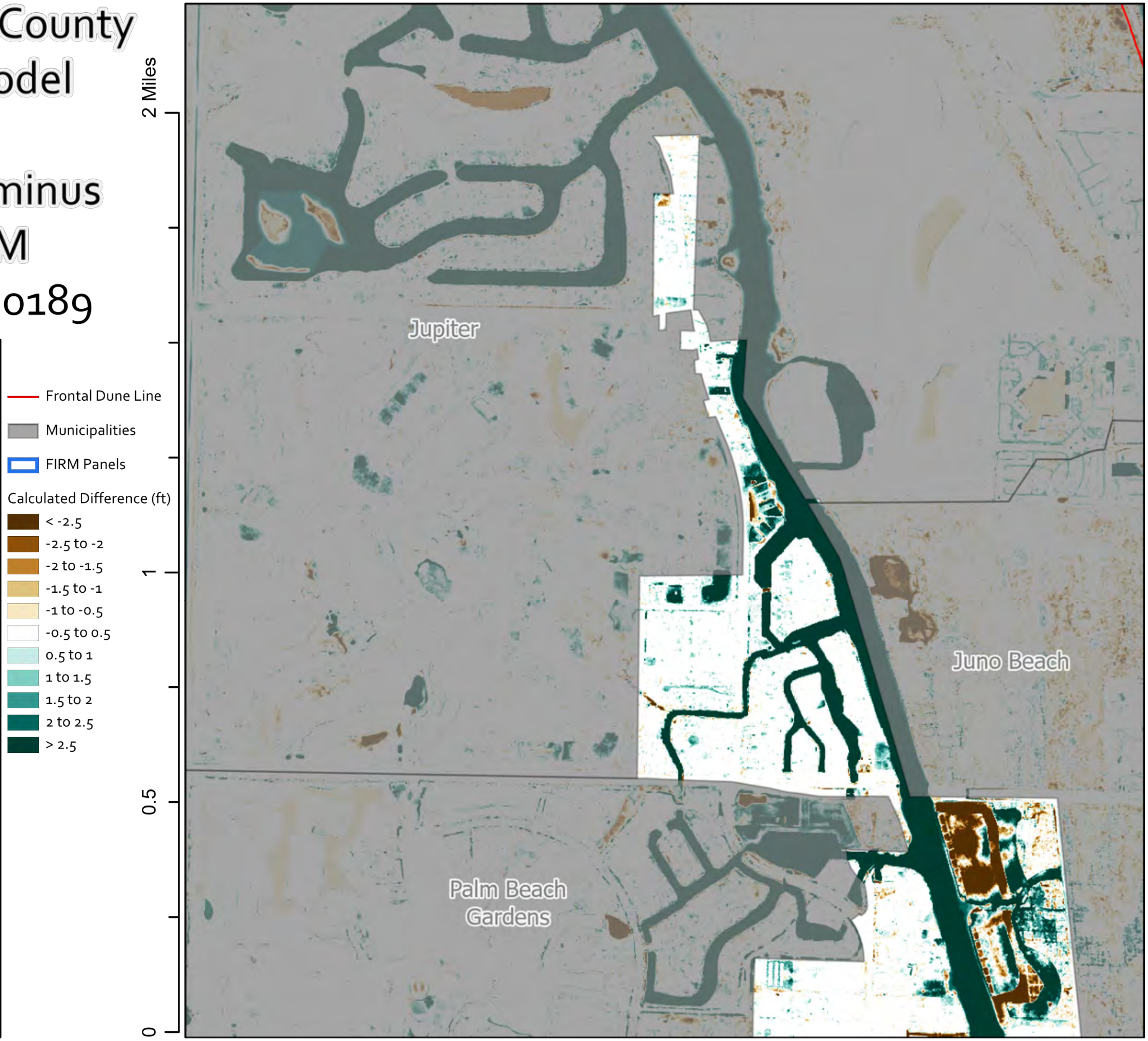
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

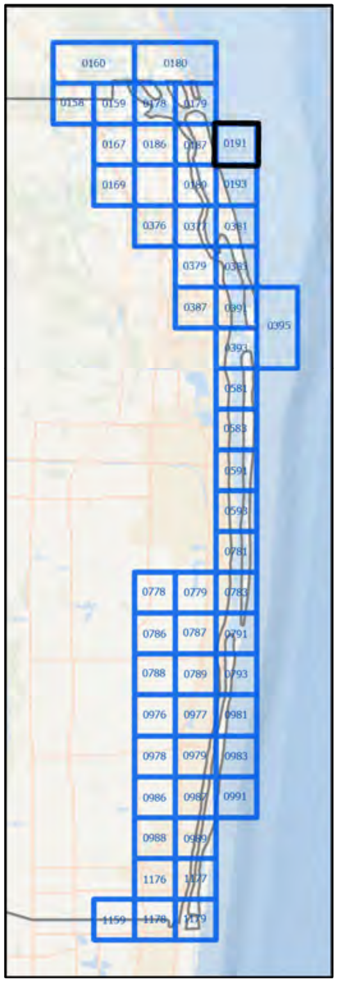
FIRM Panel: 0189





Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

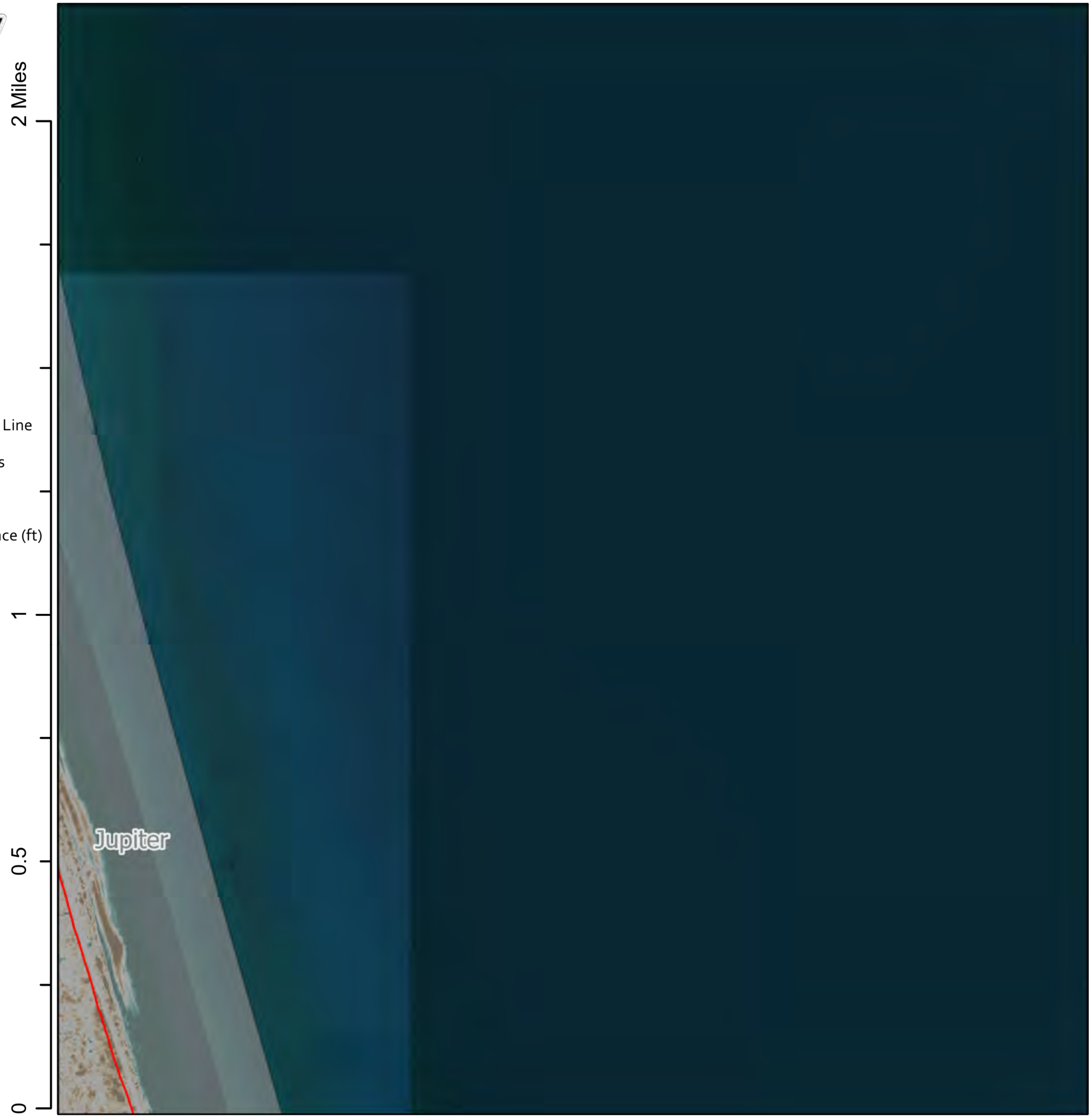
FIRM Panel: 0191



- Frontal Dune Line
- Municipalities
- FIRM Panels

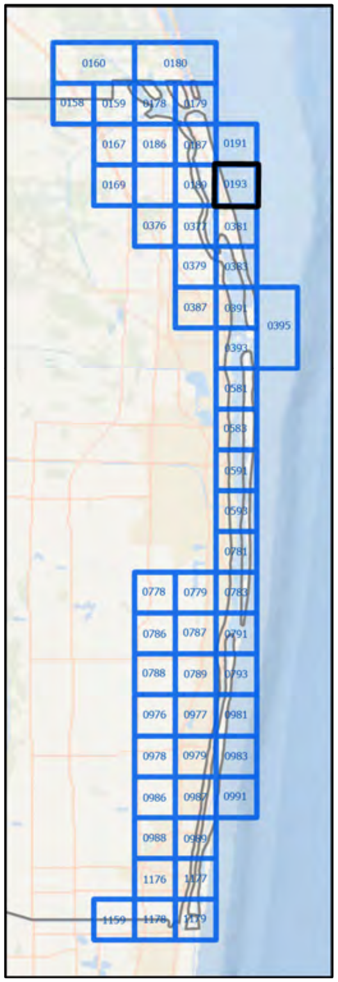
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

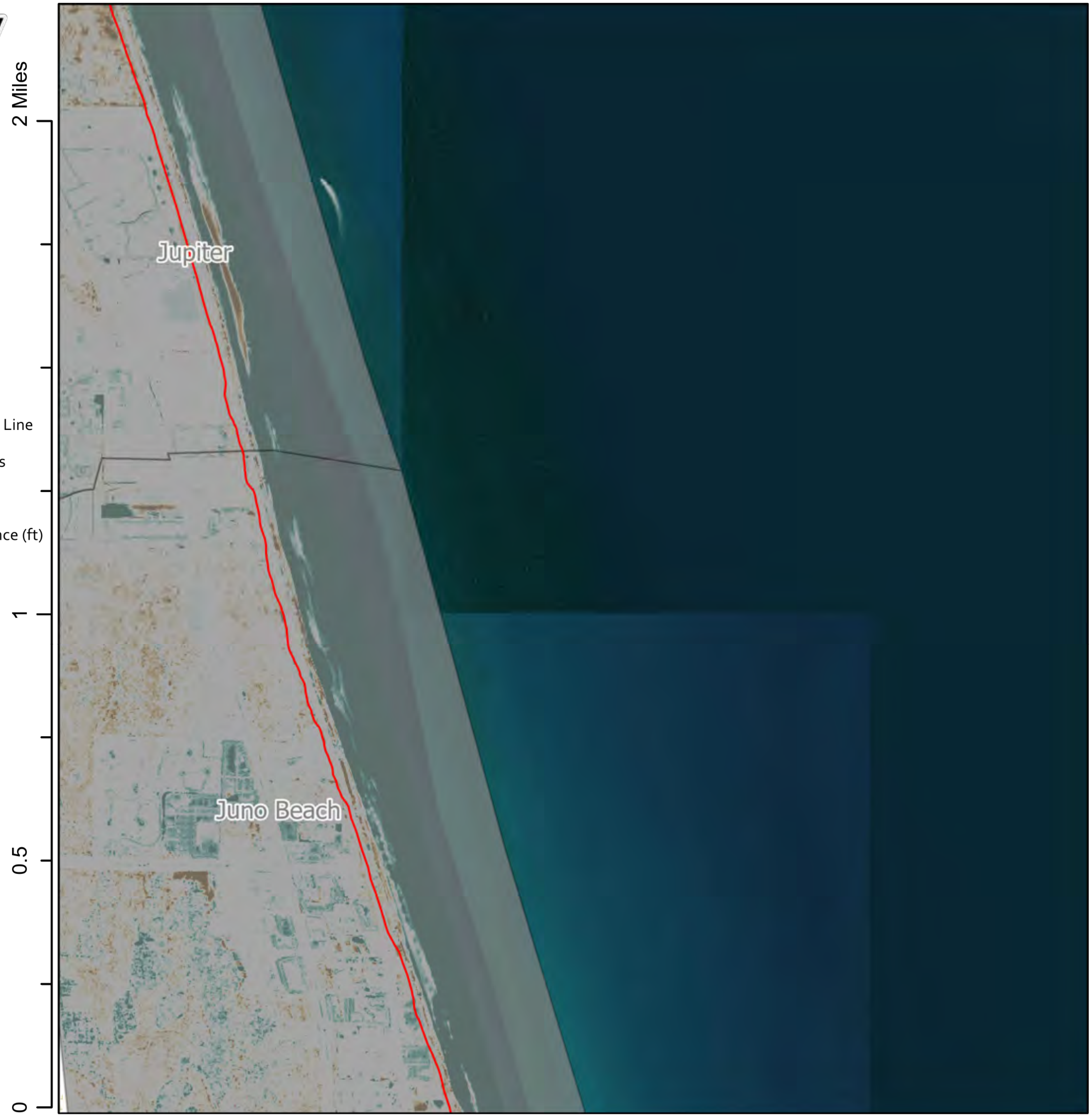
FIRM Panel: 0193



- Frontal Dune Line
- Municipalities
- FIRM Panels

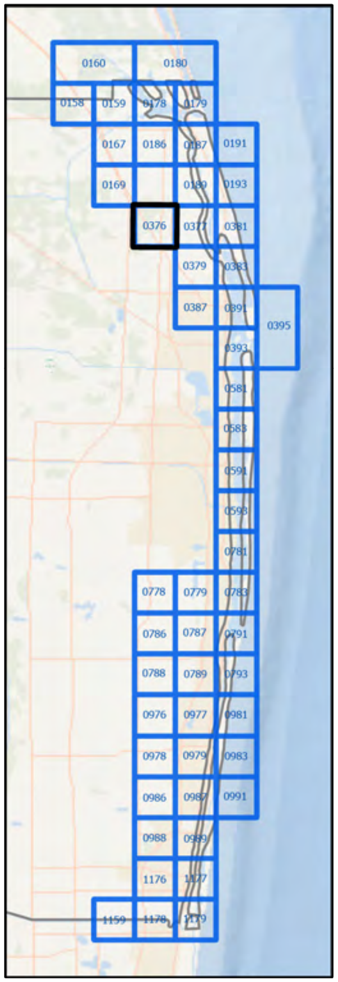
Calculated Difference (ft)

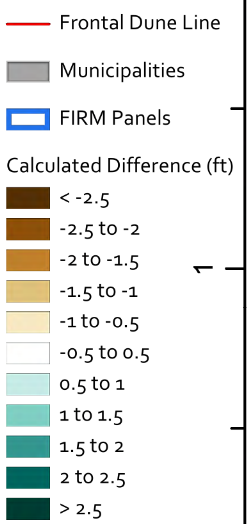
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

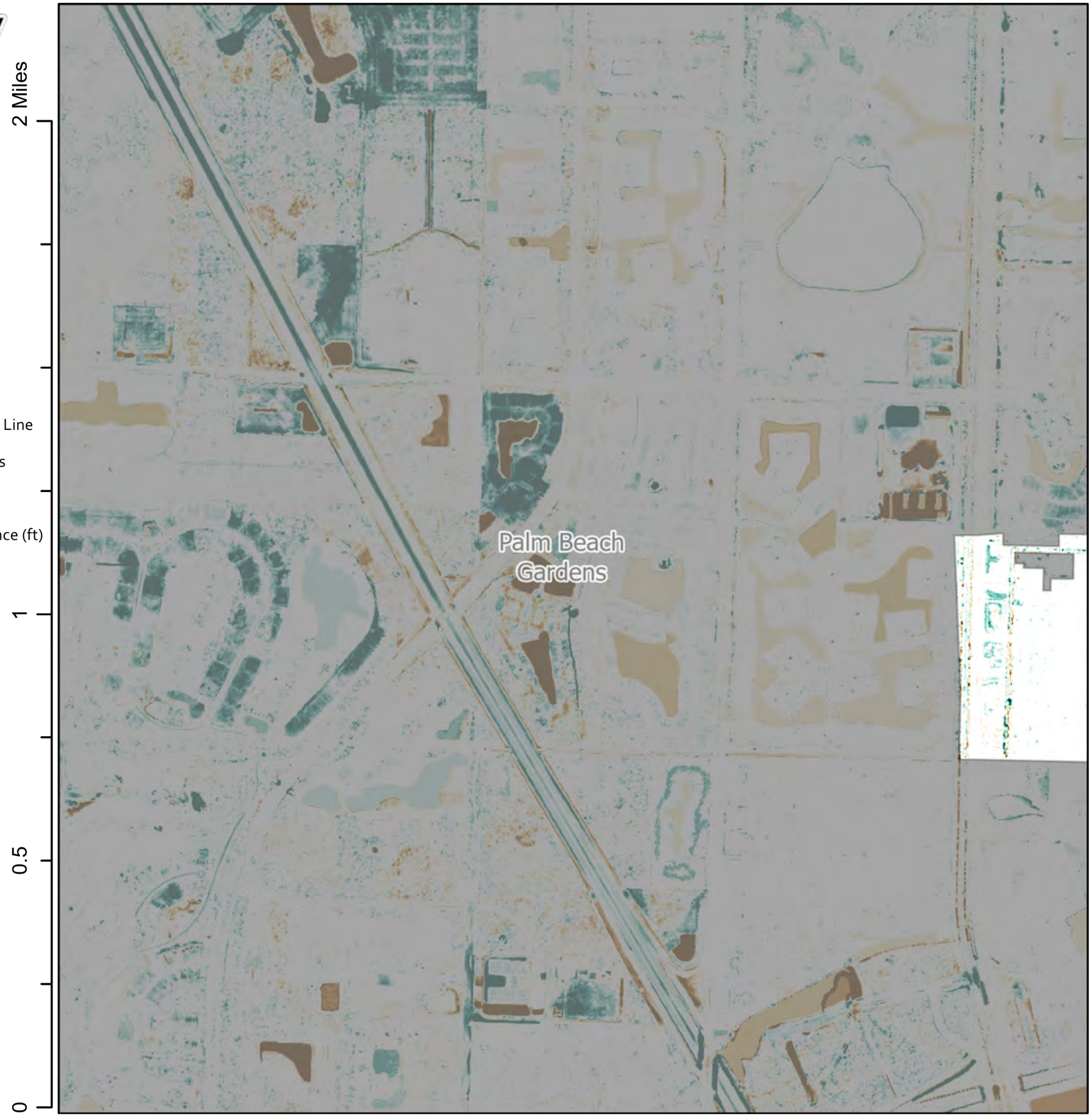


Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0376

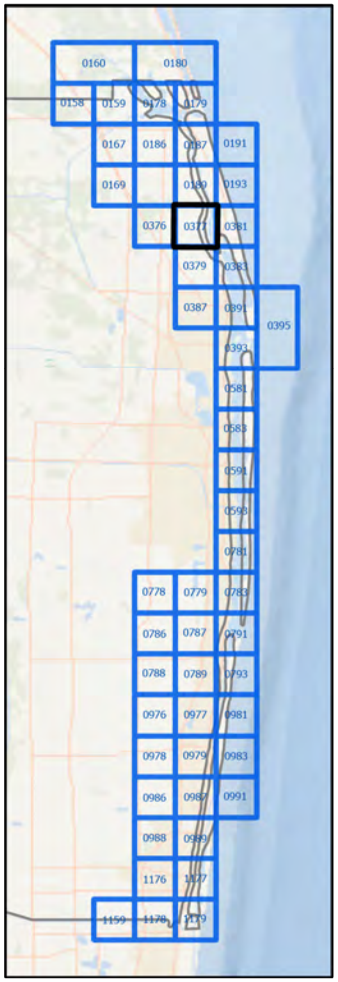






Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0377



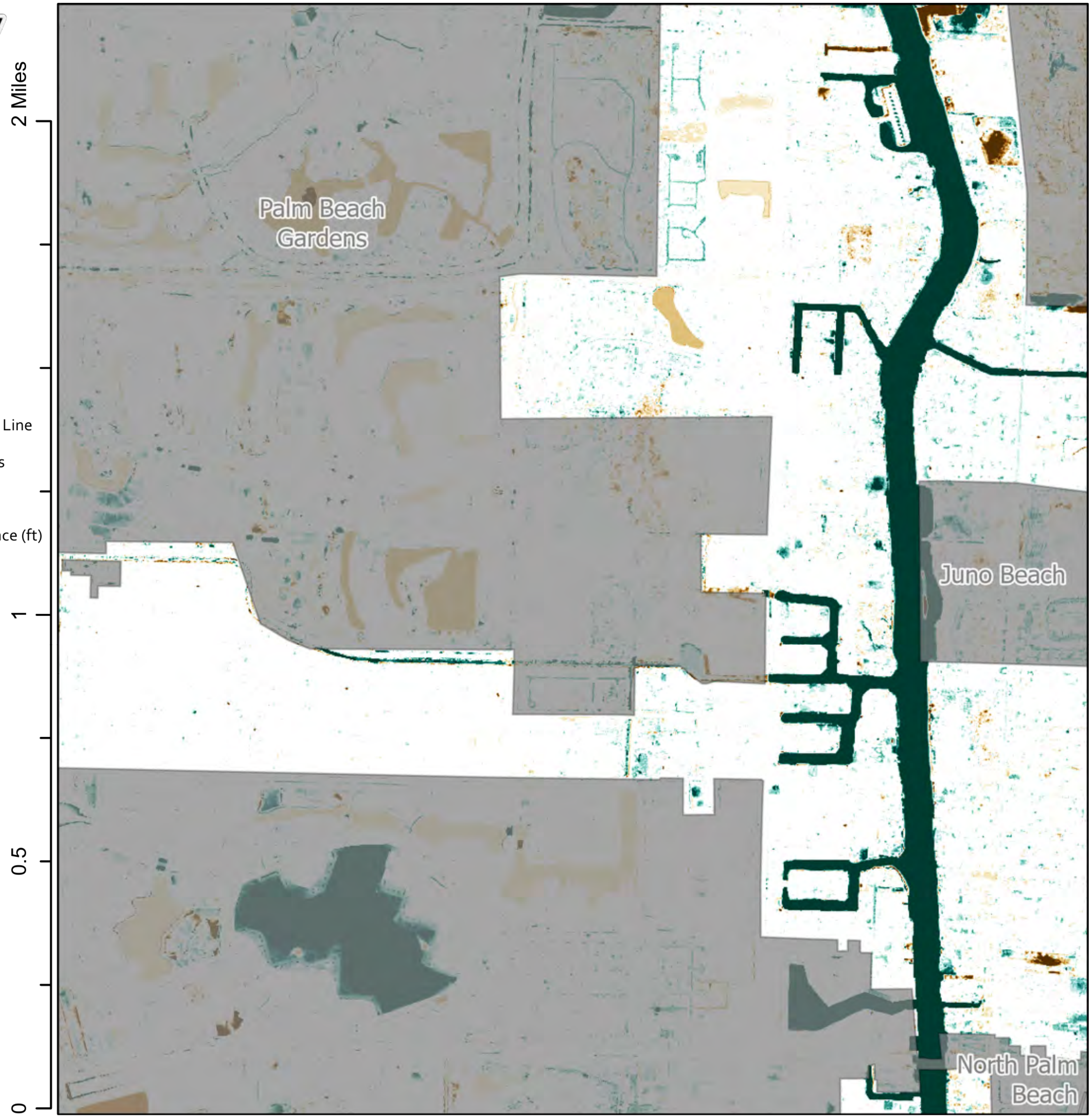
Frontal Dune Line

Municipalities

FIRM Panels

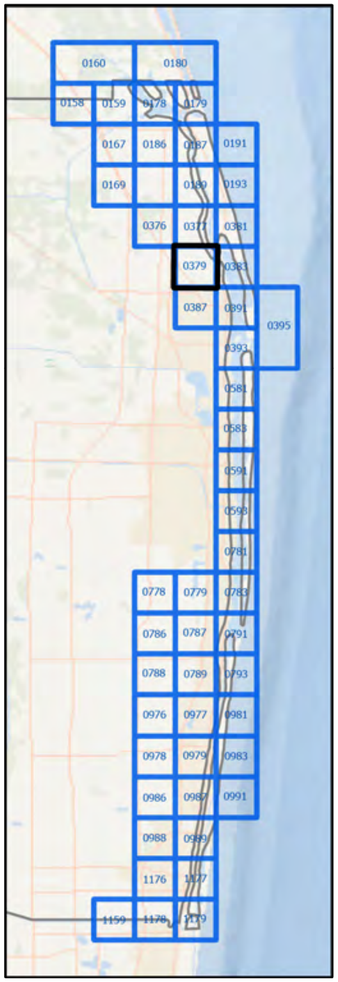
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0379



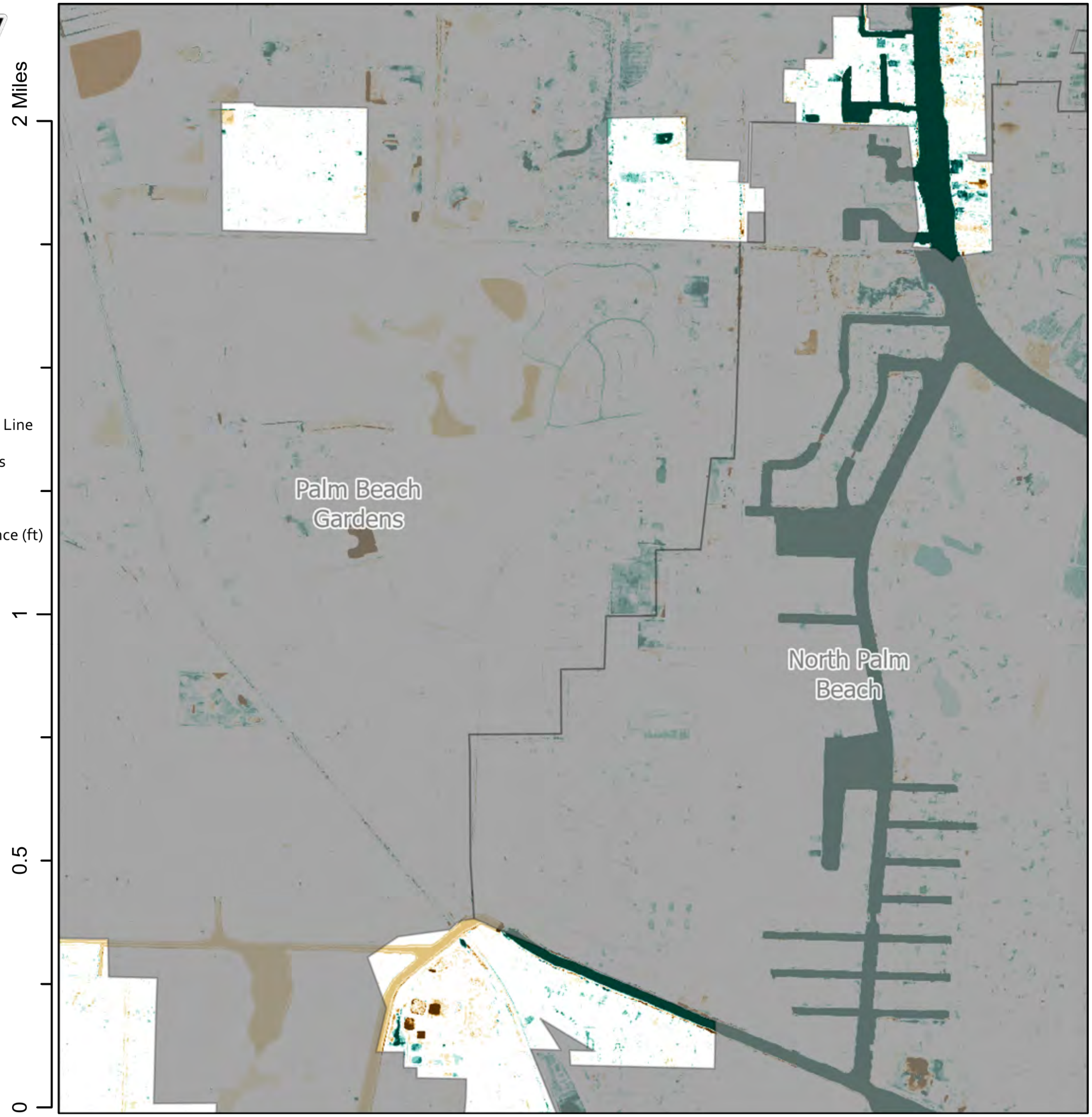
Frontal Dune Line

Municipalities

FIRM Panels

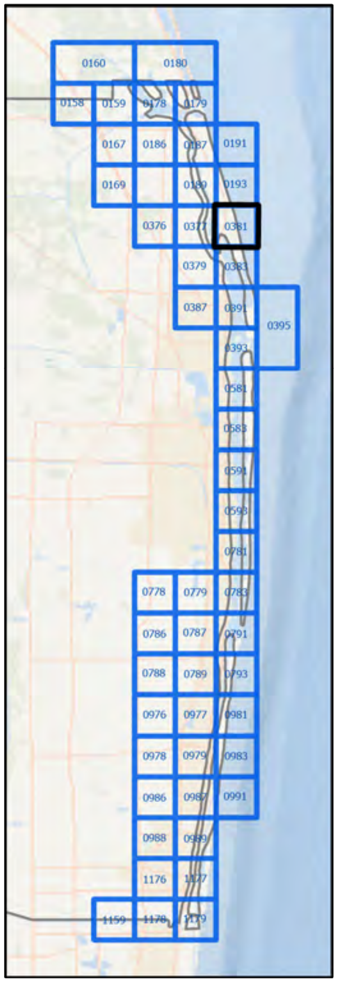
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



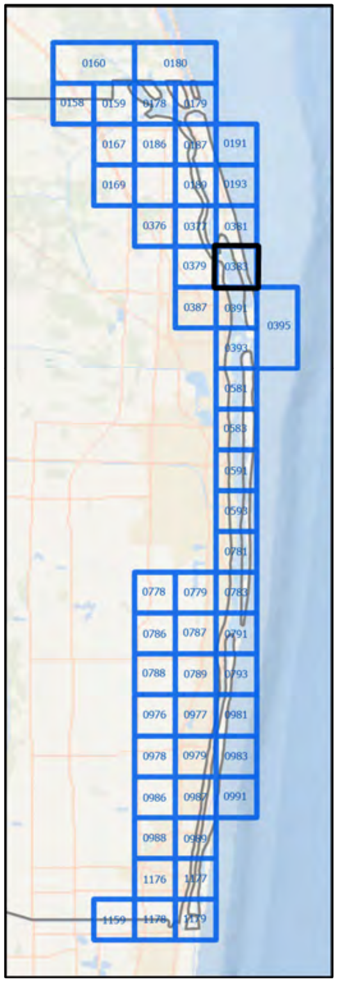
Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0381



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0383



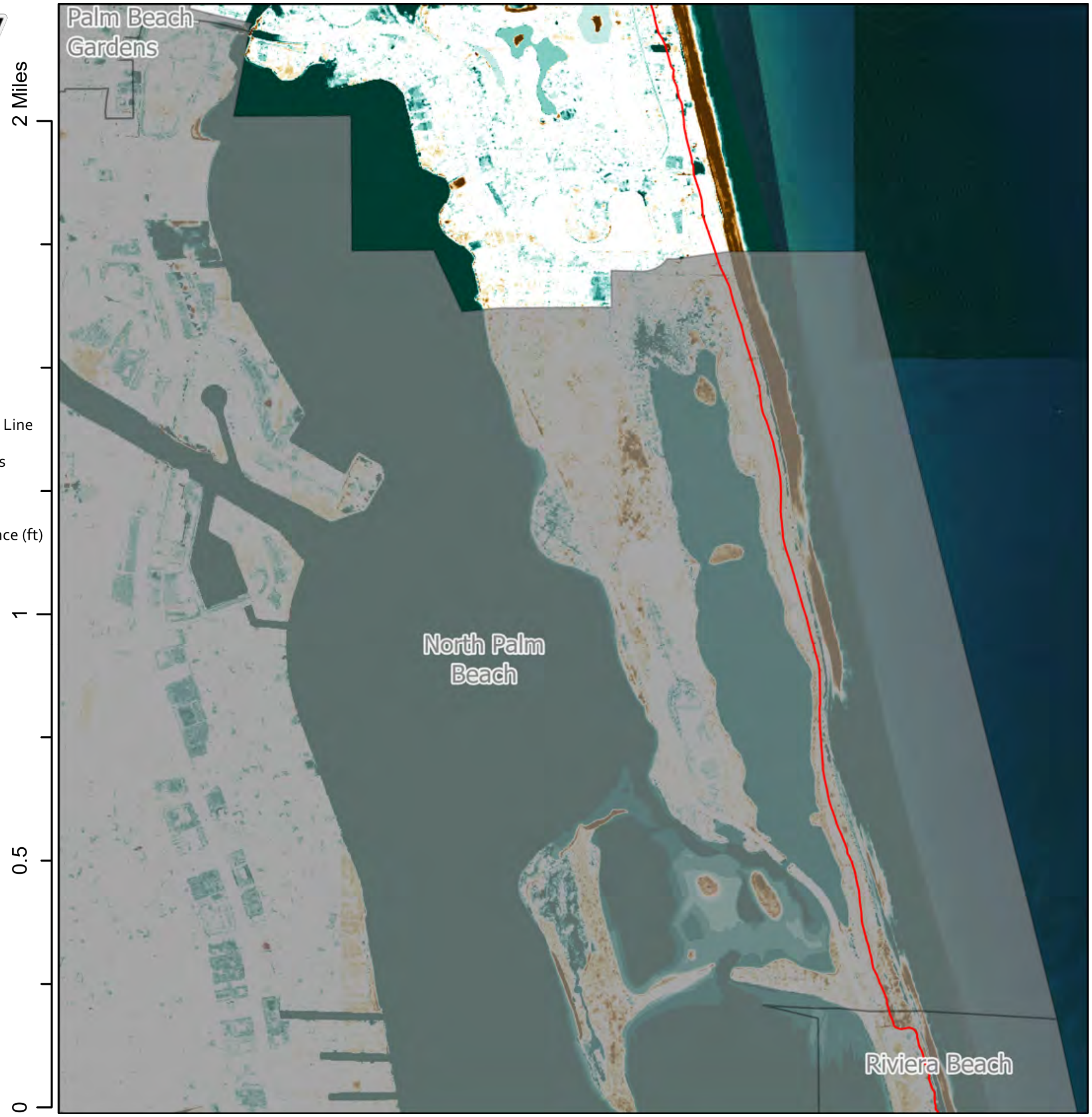
Frontal Dune Line

Municipalities

FIRM Panels

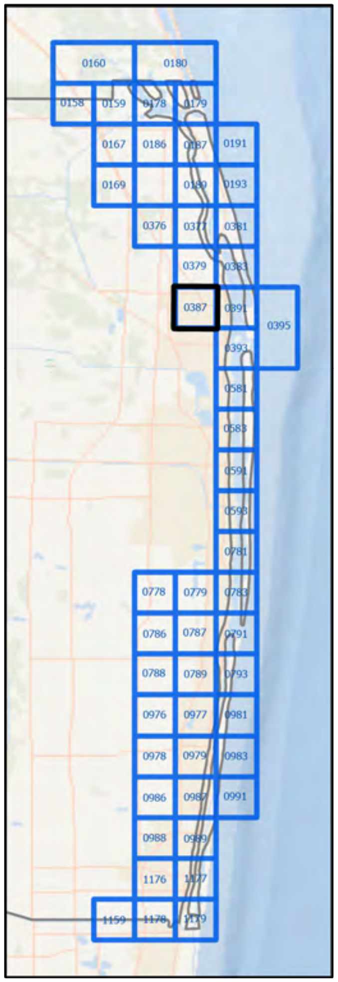
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0387



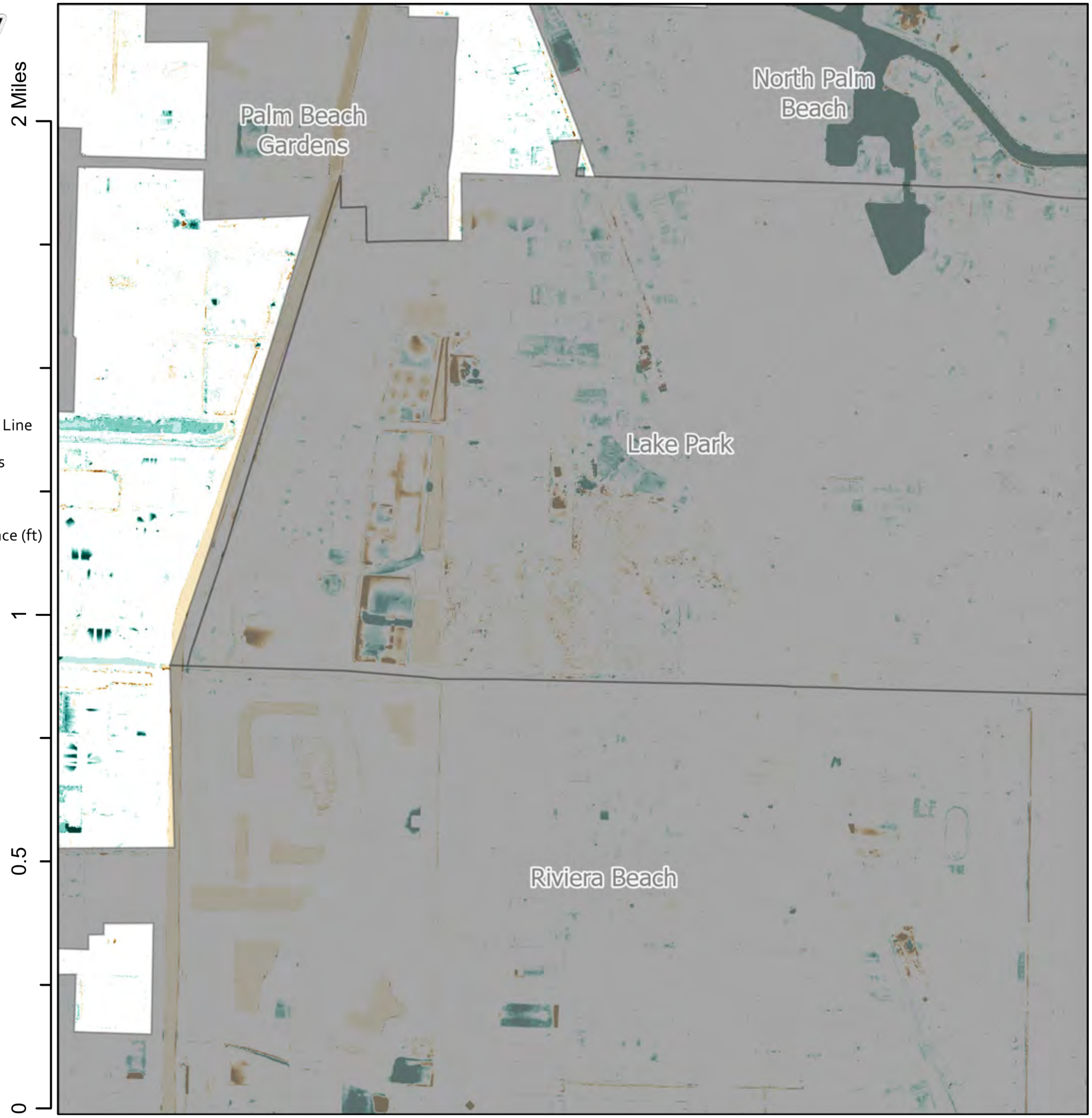
— Frontal Dune Line

Municipalities

FIRM Panels

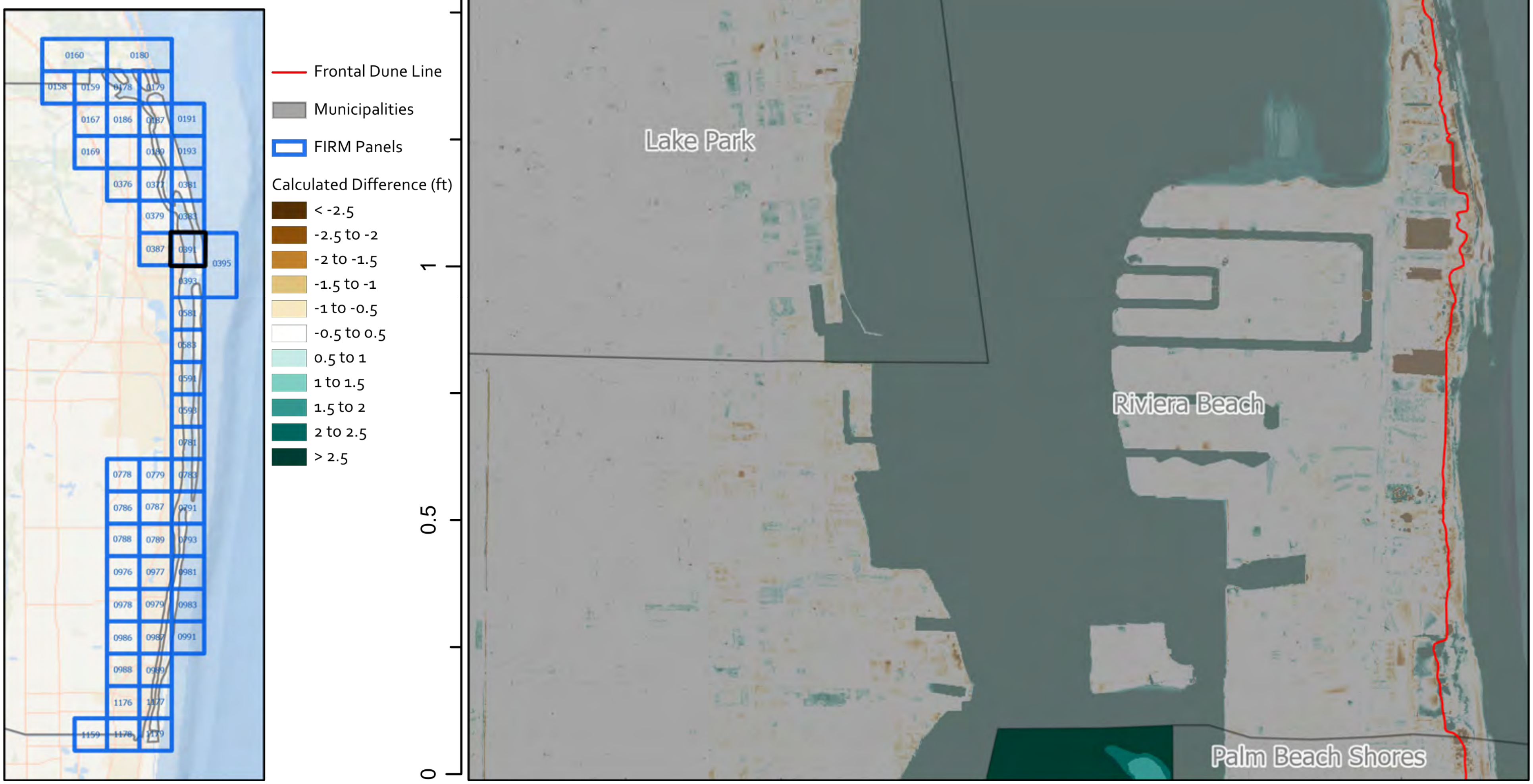
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



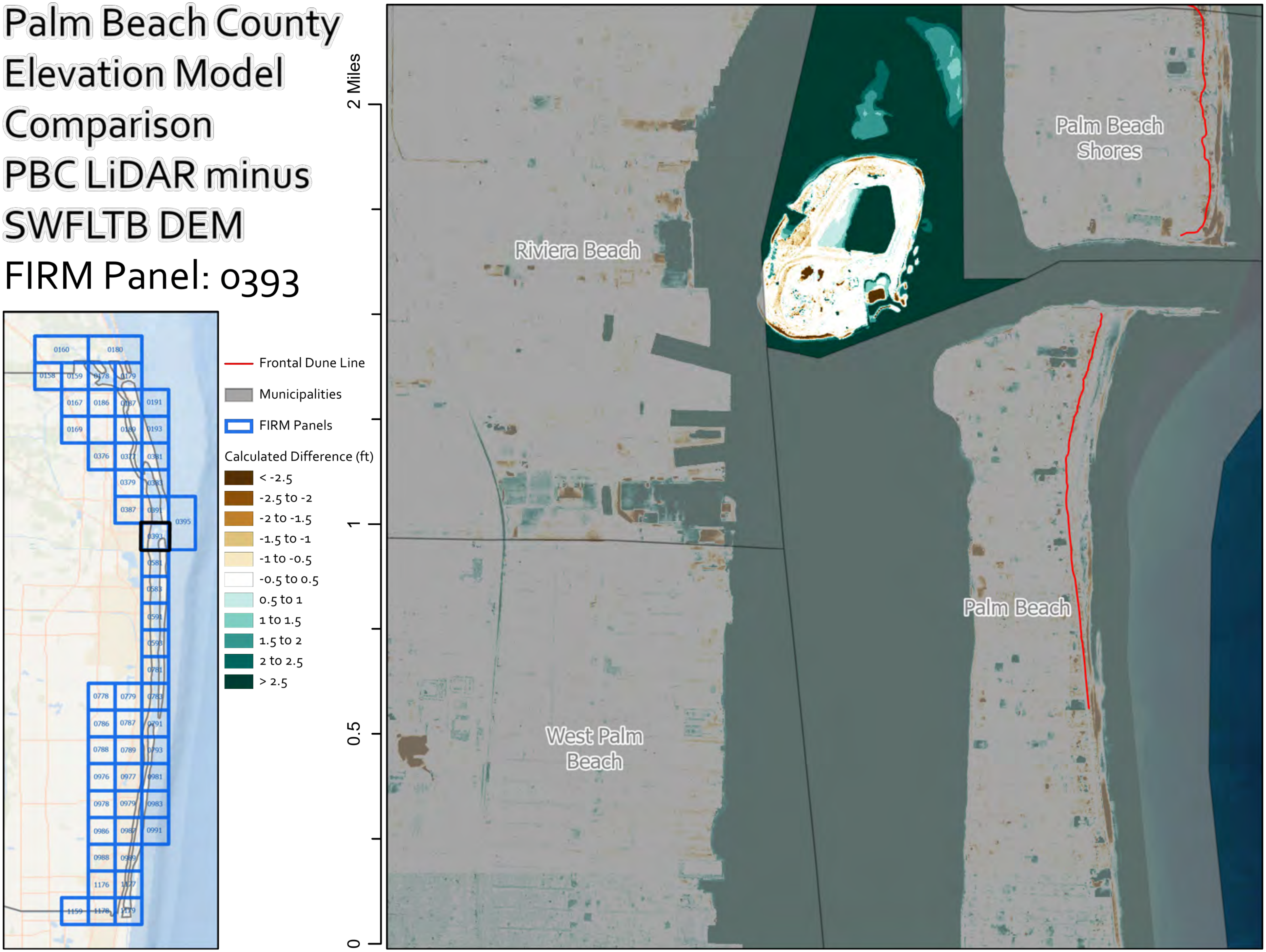
Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0391



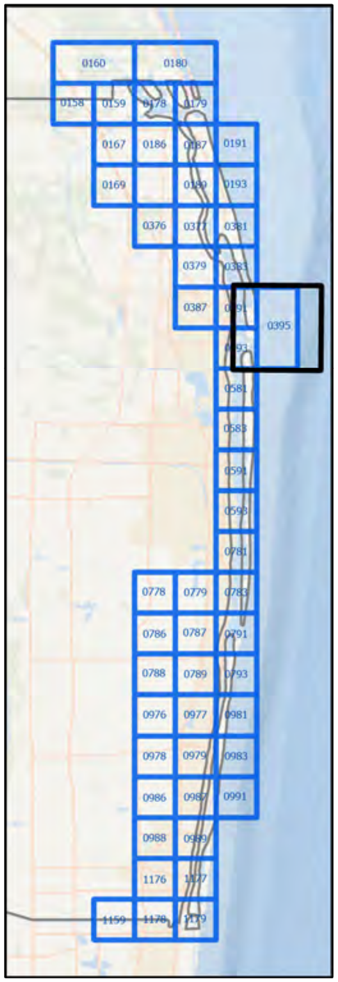
Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0393



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

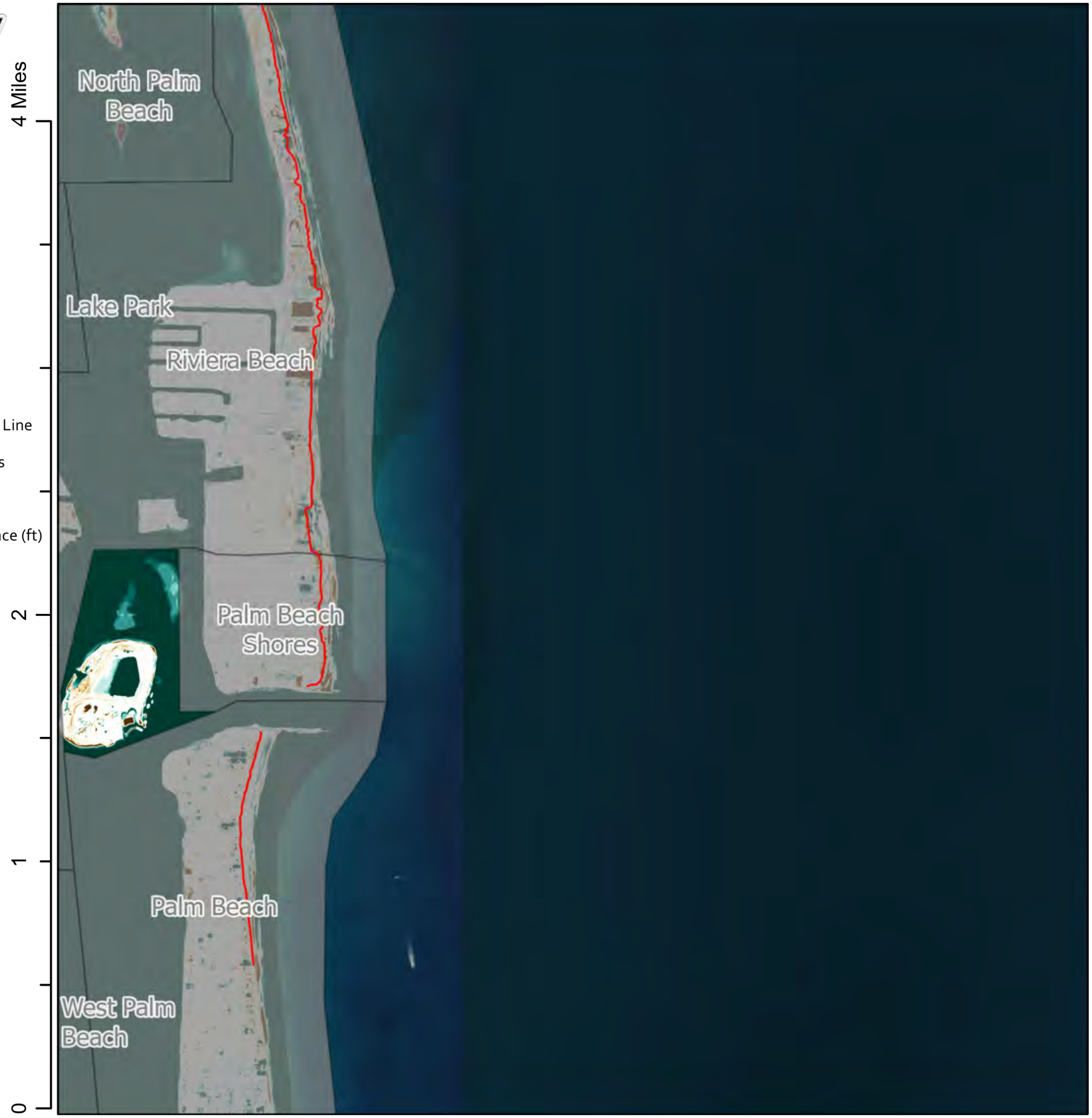
FIRM Panel: 0395



- Frontal Dune Line
- Municipalities
- FIRM Panels

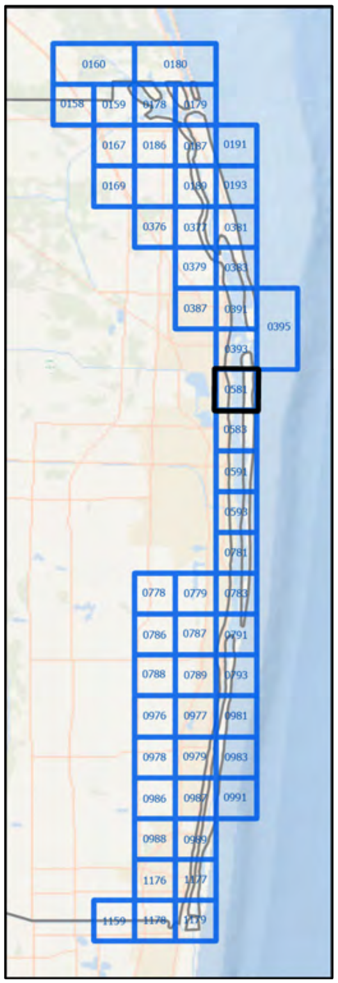
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

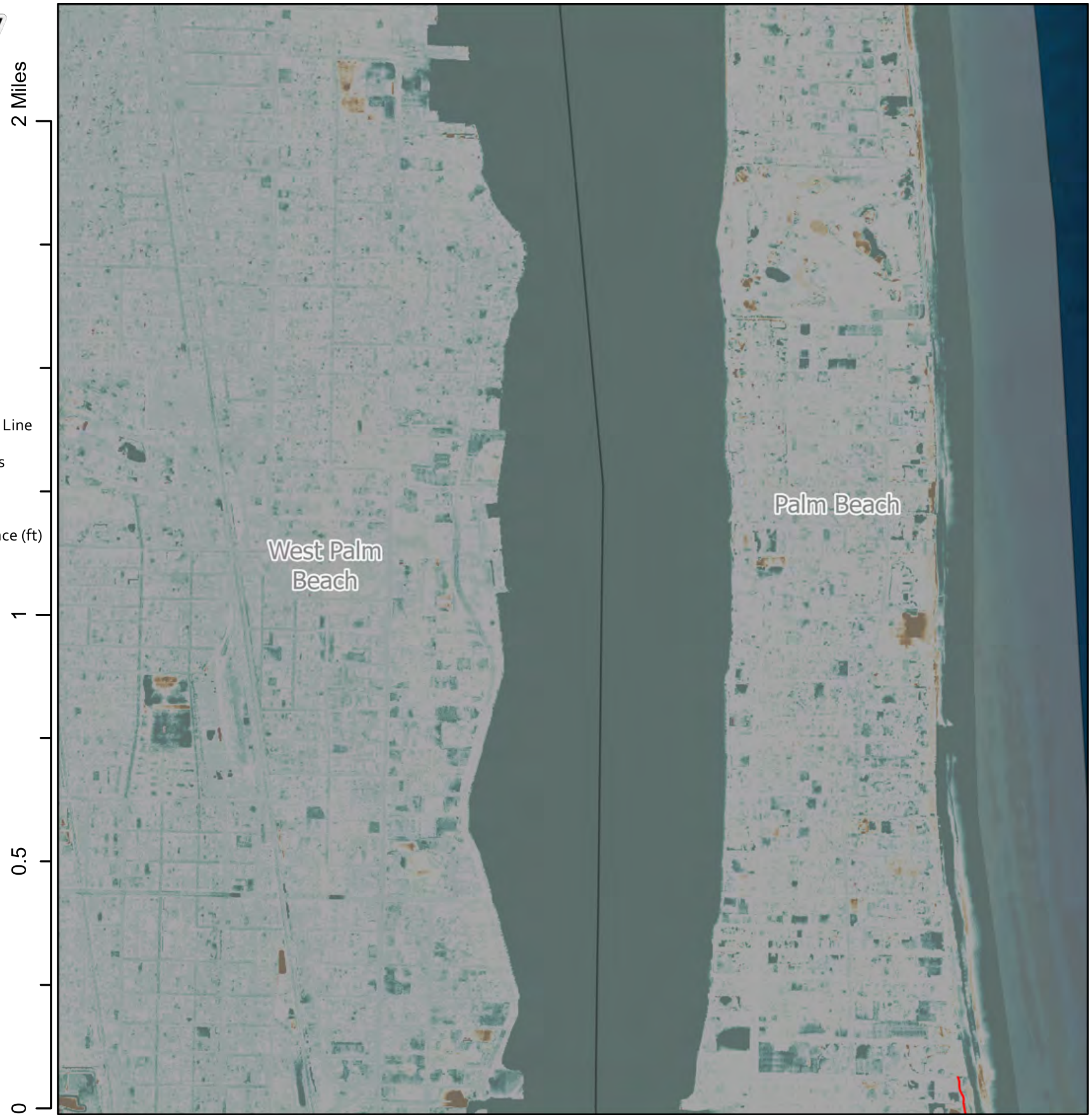
FIRM Panel: 0581



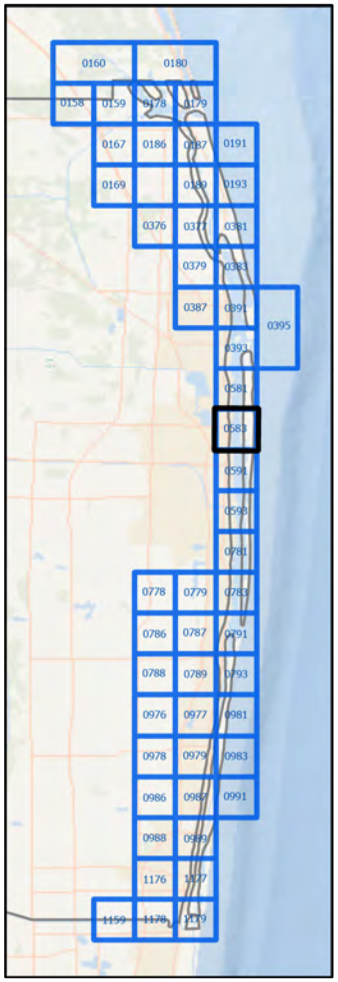
- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



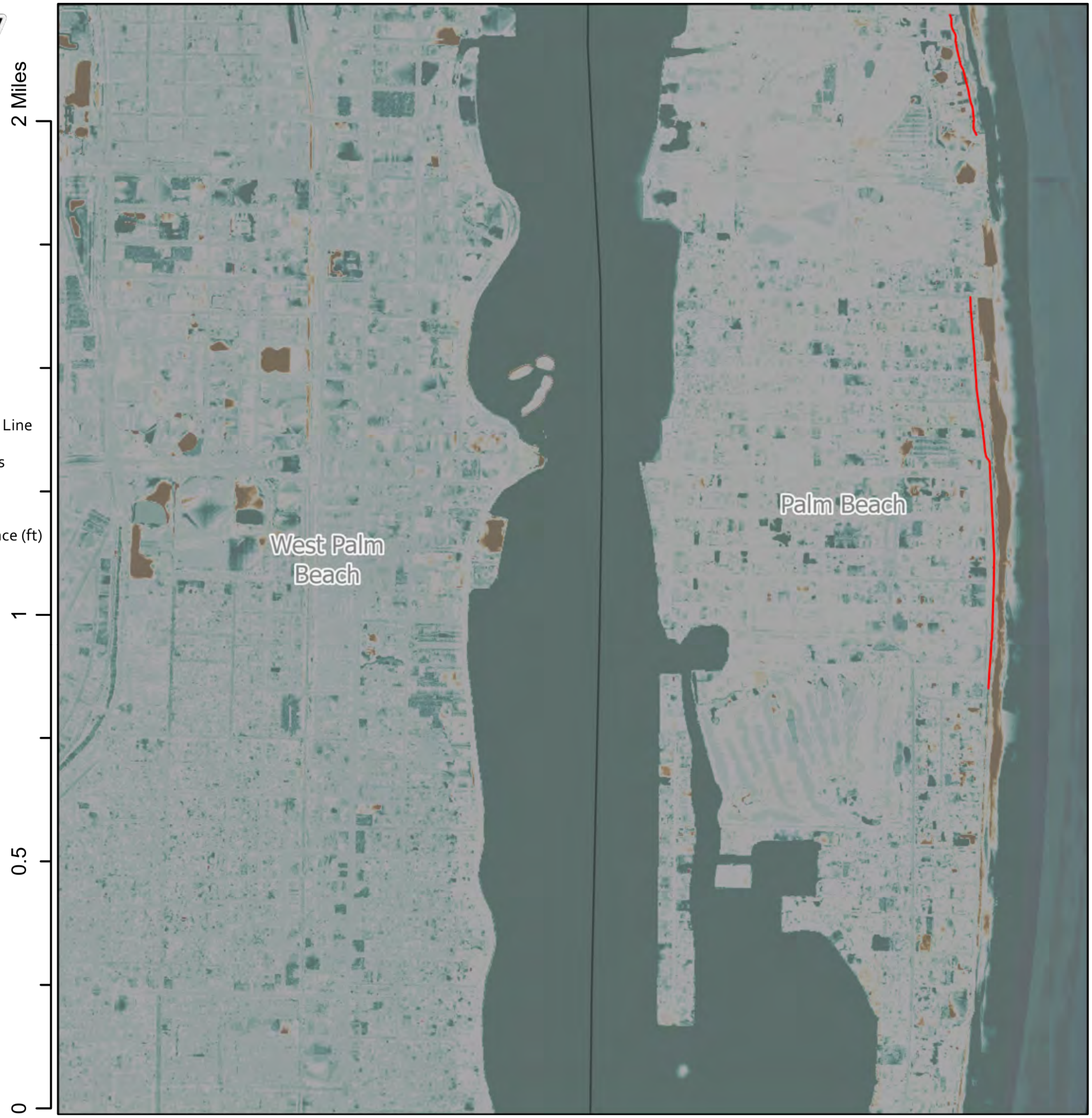
Palm Beach County Elevation Model Comparison
PBC LiDAR minus SWFLTB DEM
FIRM Panel: 0583



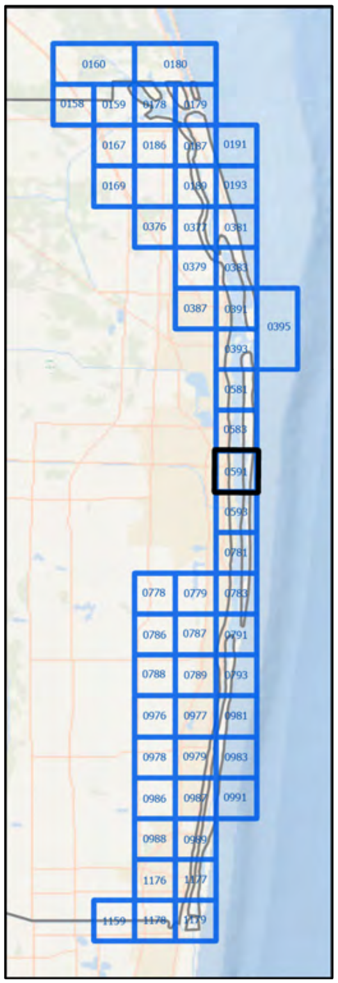
Frontal Dune Line
Municipalities
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



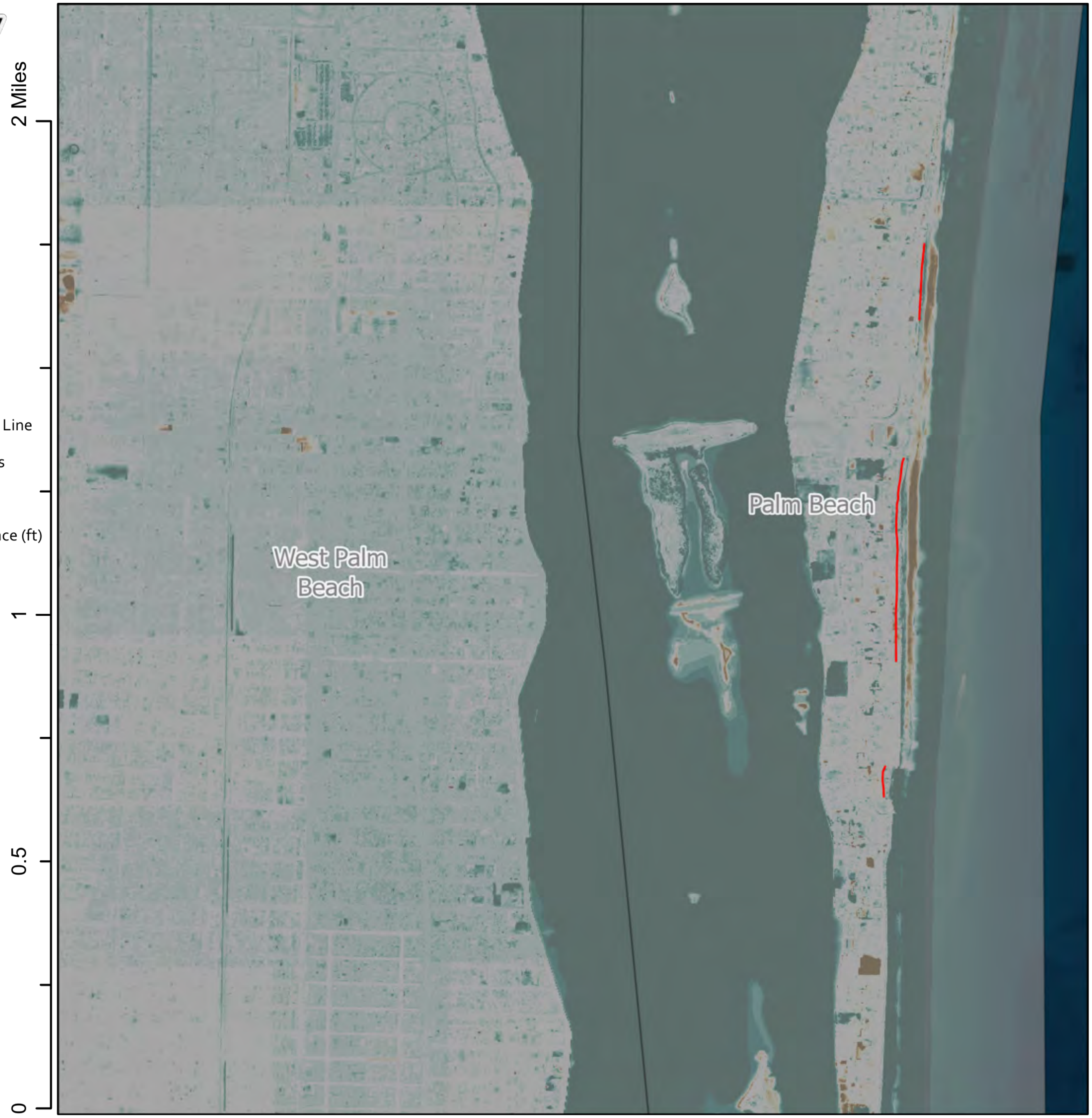
Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM FIRM Panel: 0591



- Frontal Dune Line
- Municipalities
- FIRM Panels

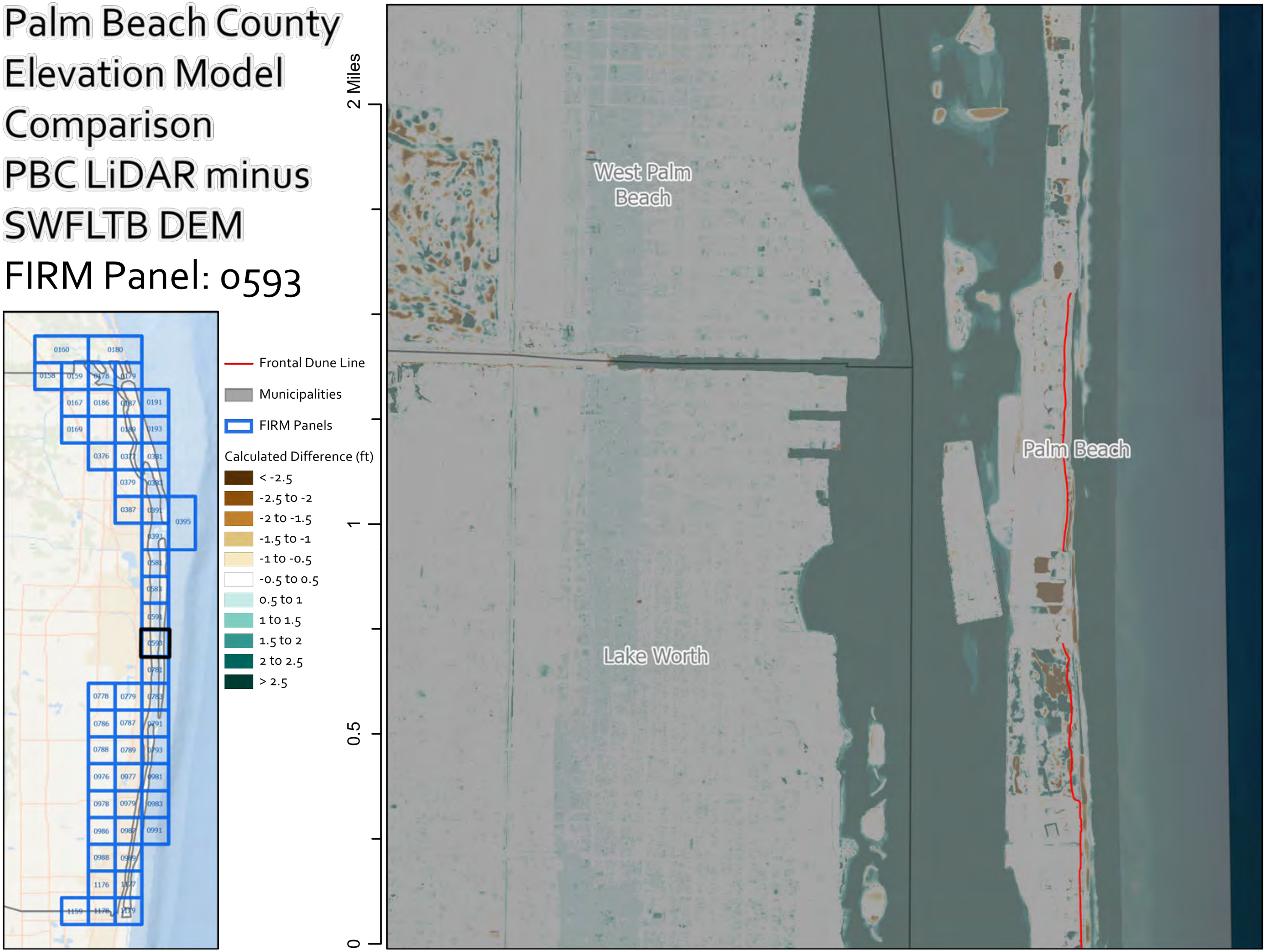
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



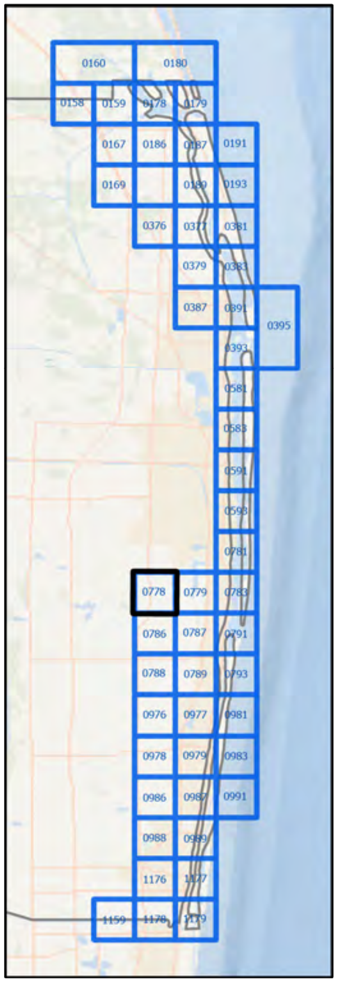
Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0593



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0778



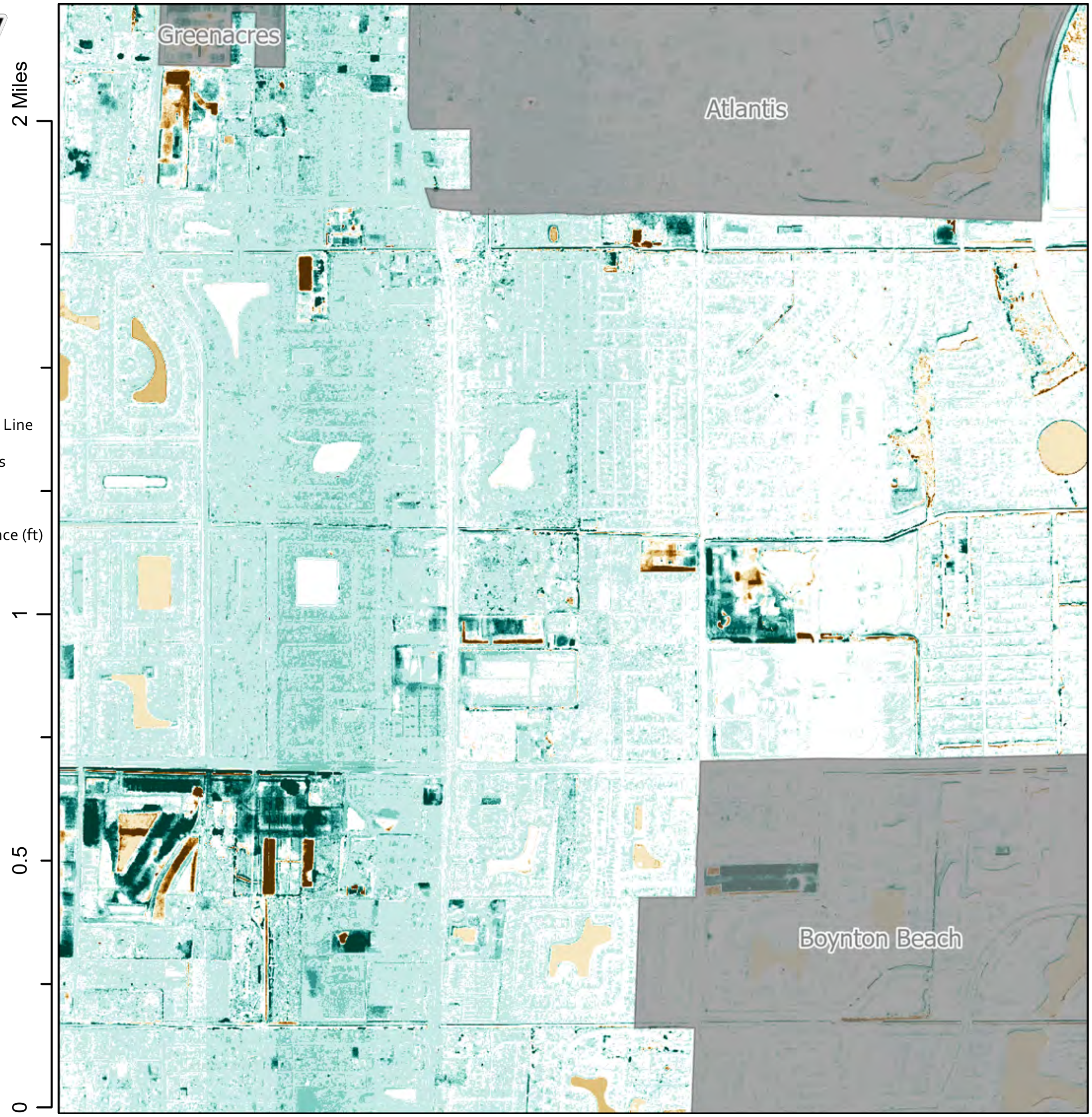
Frontal Dune Line

Municipalities

FIRM Panels

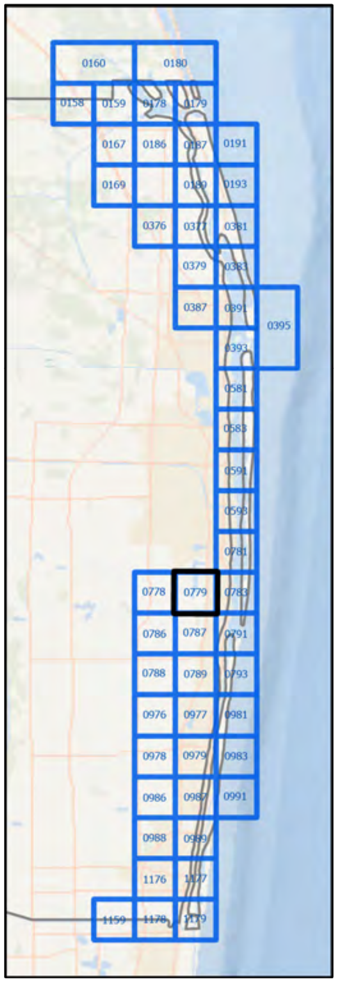
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0779



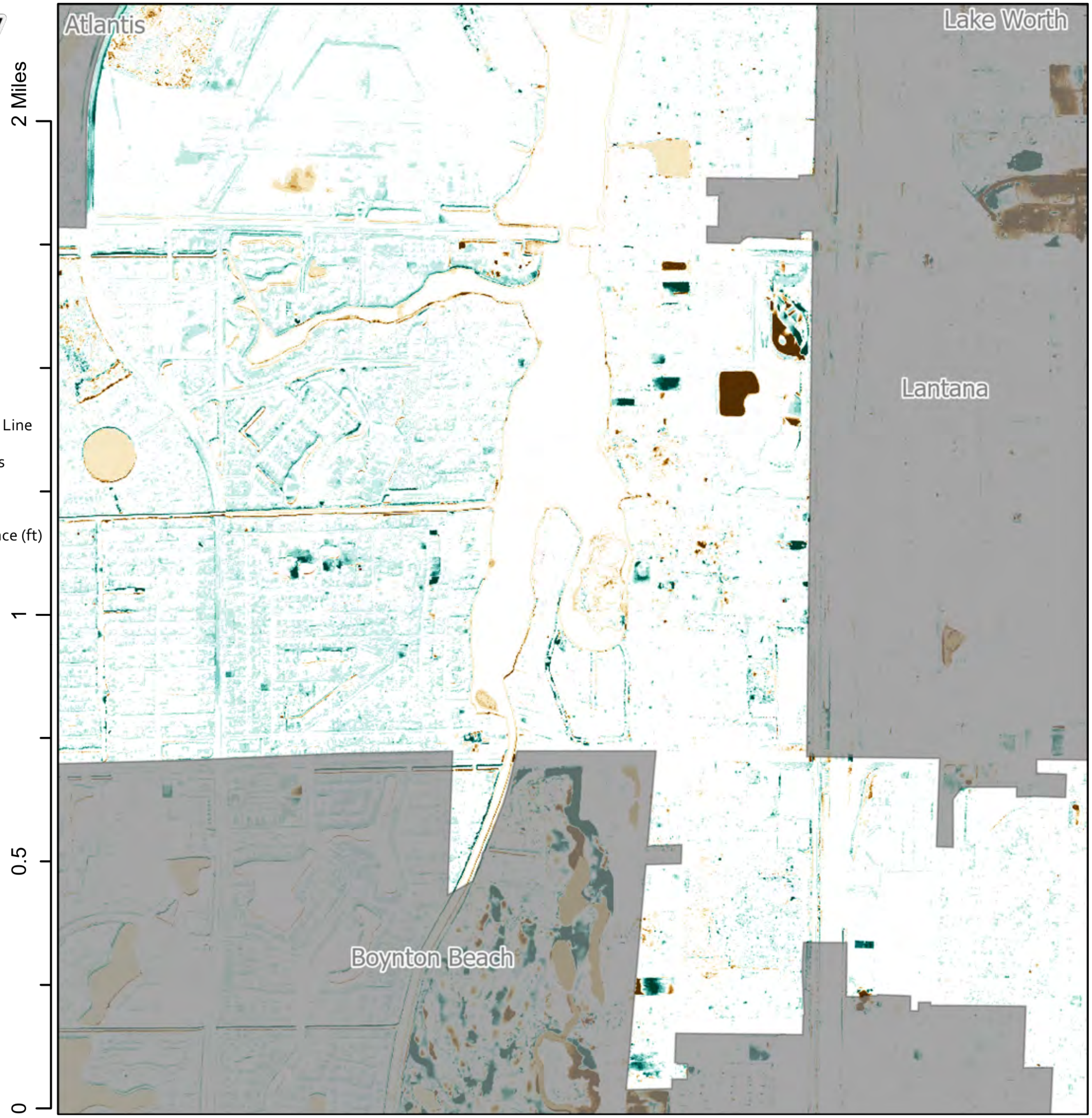
Frontal Dune Line

Municipalities

FIRM Panels

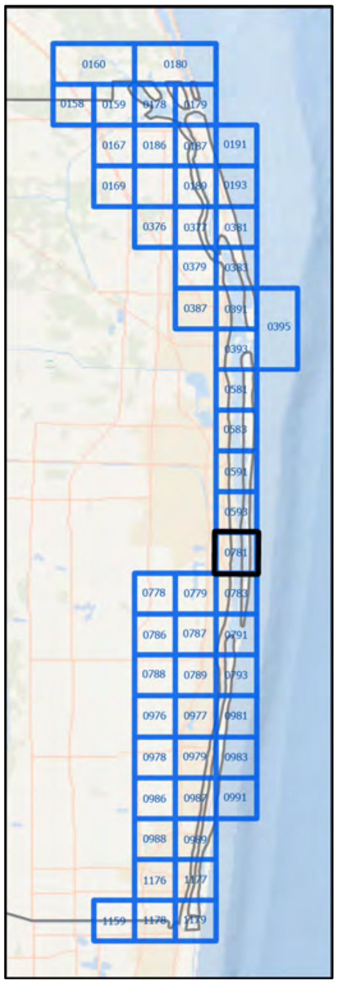
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0781



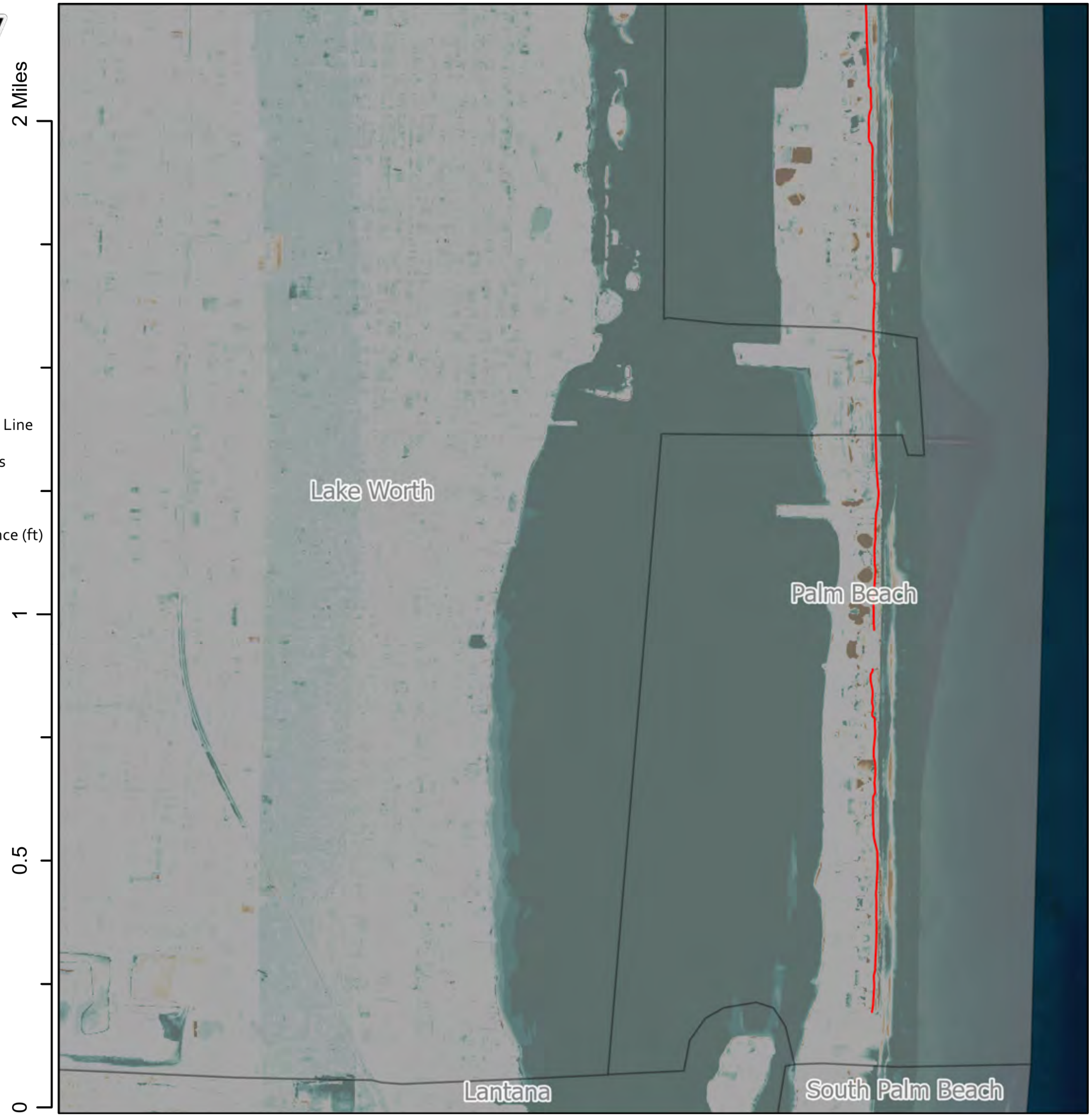
Frontal Dune Line

Municipalities

FIRM Panels

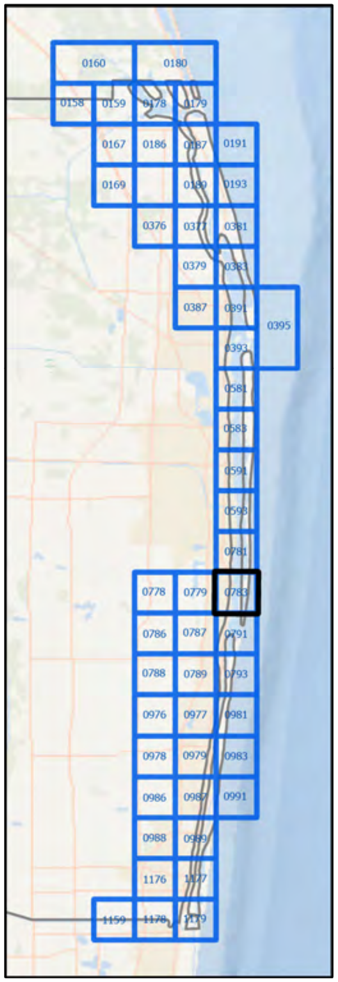
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

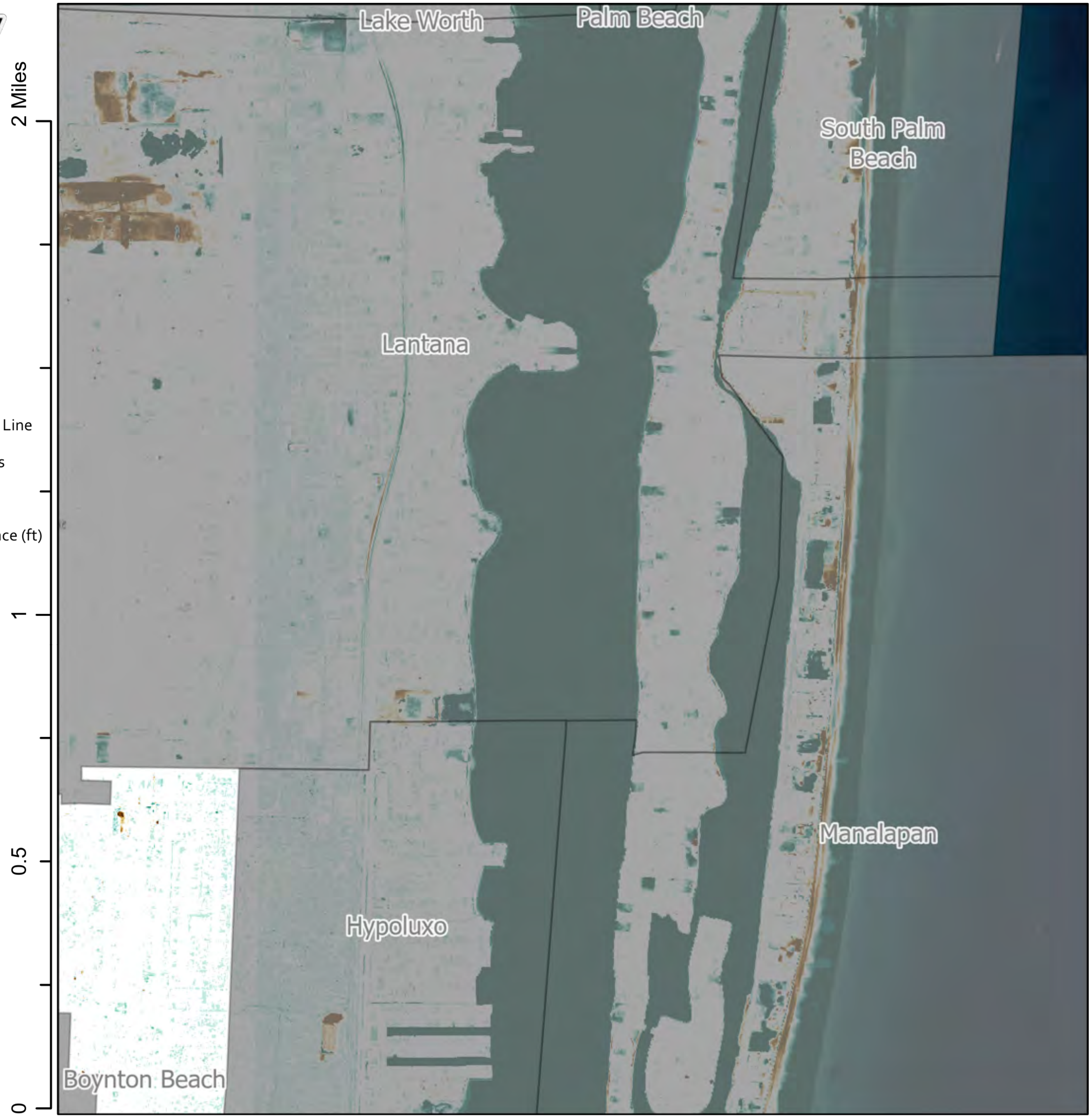
FIRM Panel: 0783



- Frontal Dune Line
- Municipalities
- FIRM Panels

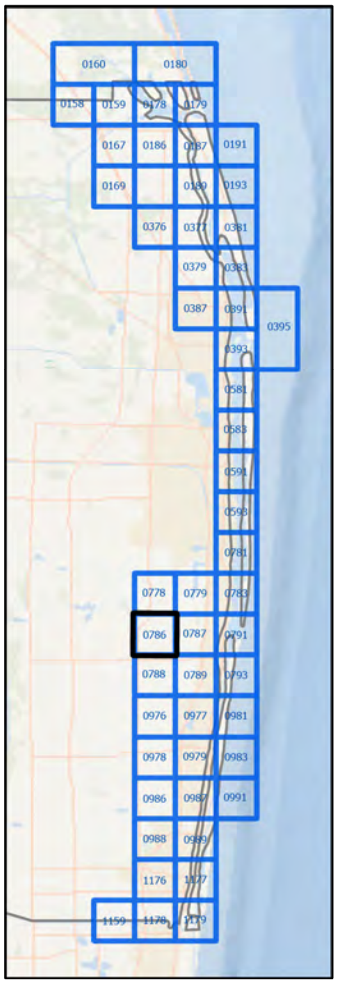
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0786



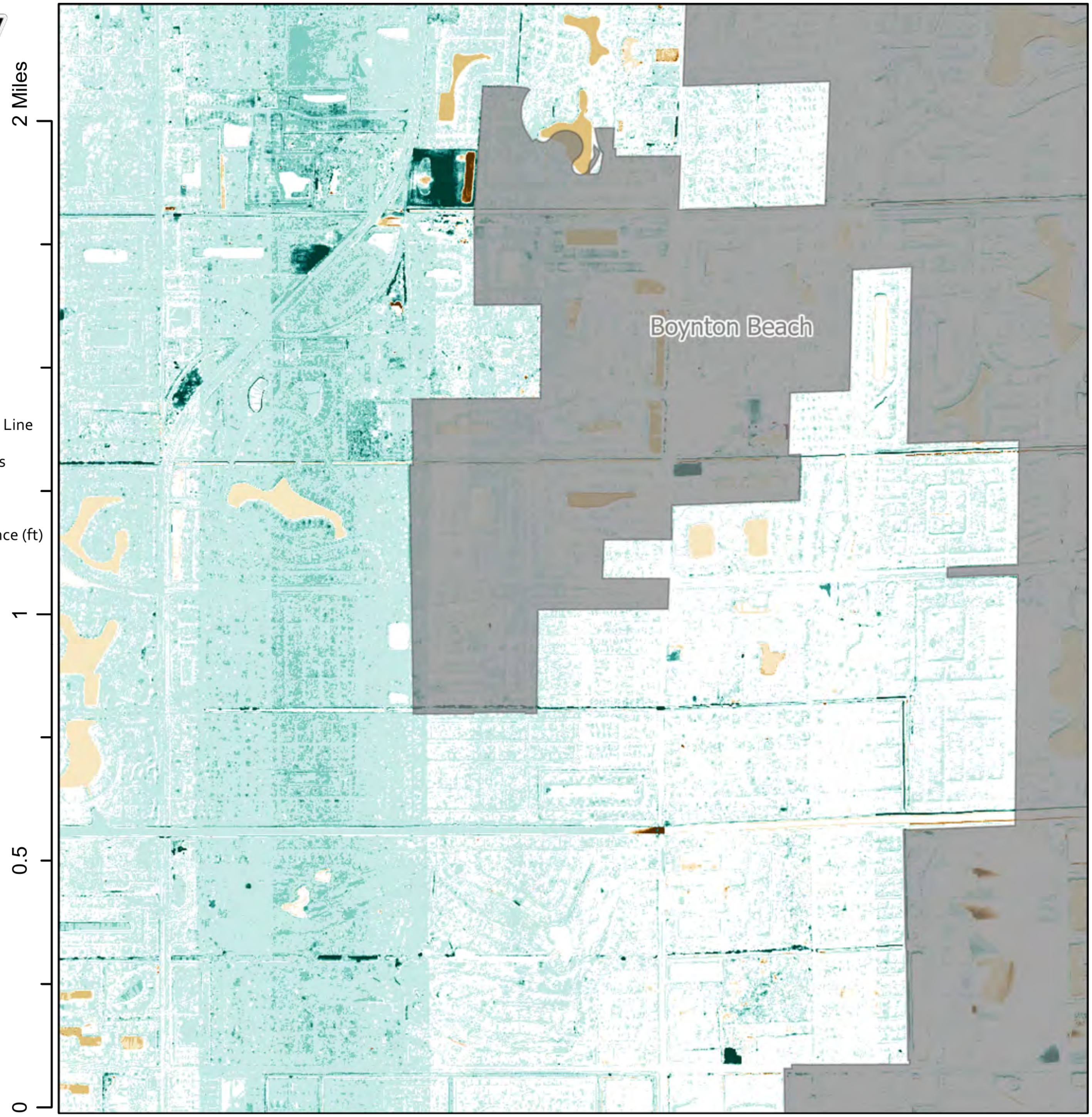
Frontal Dune Line

Municipalities

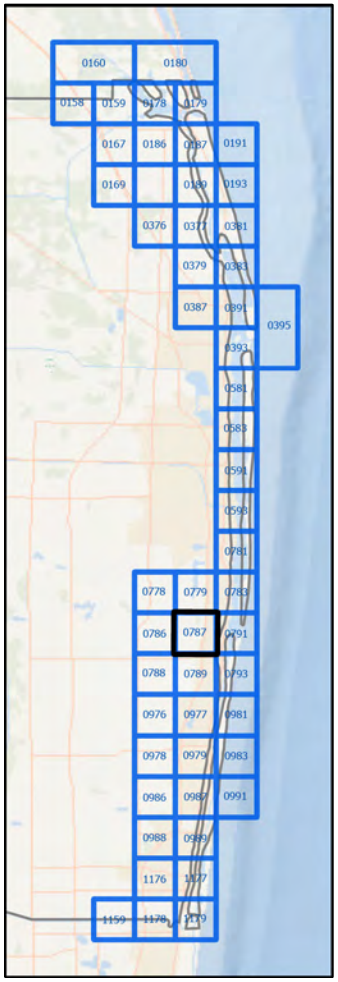
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison
PBC LiDAR minus SWFLTB DEM
FIRM Panel: 0787



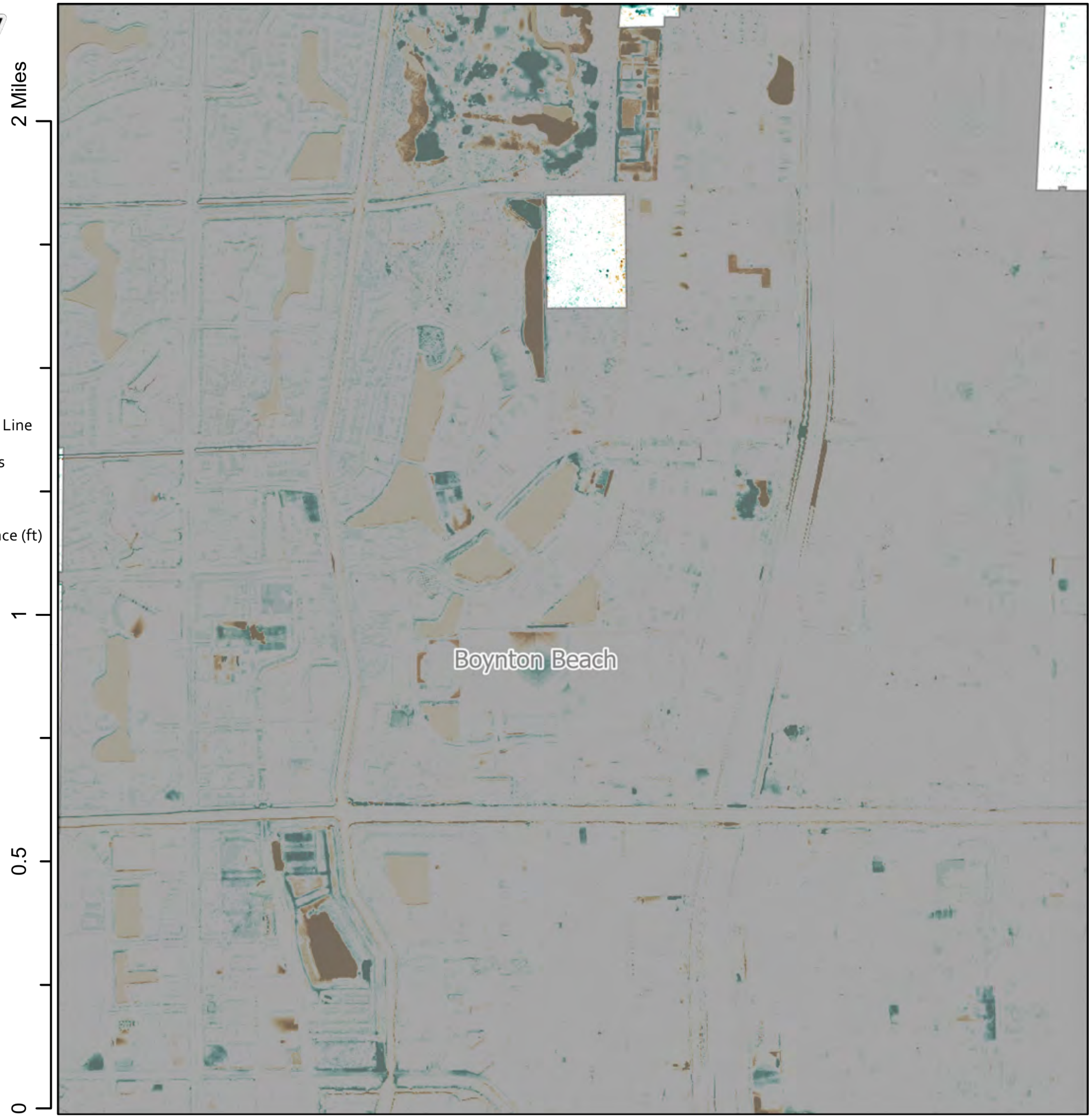
Frontal Dune Line

Municipalities

FIRM Panels

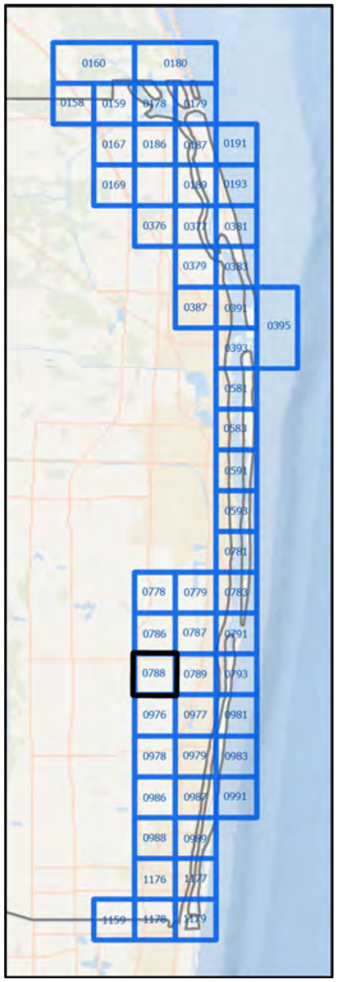
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0788



Frontal Dune Line

Municipalities

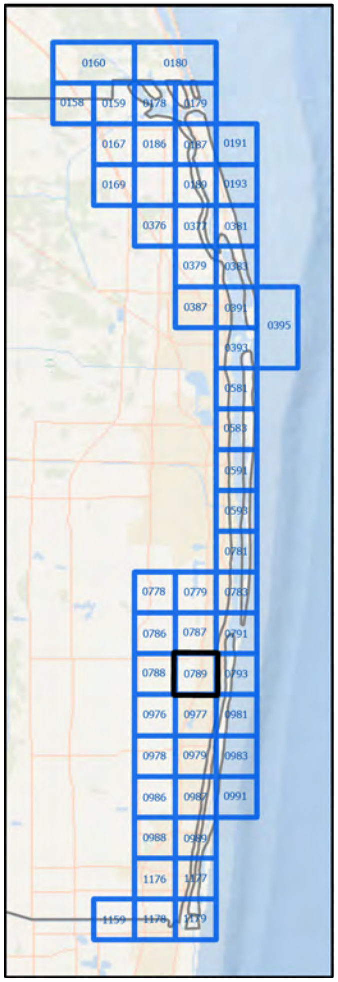
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0789



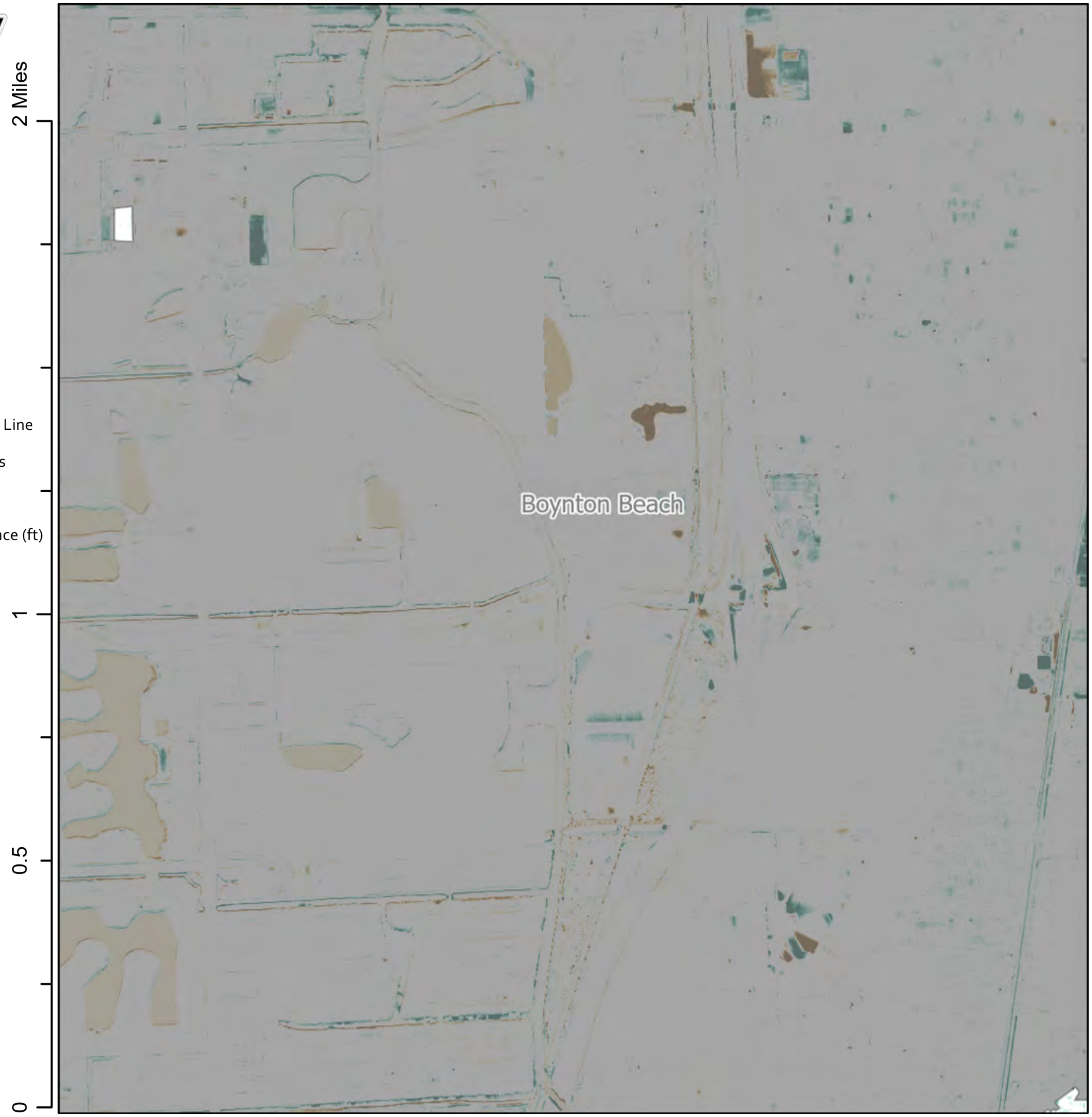
Frontal Dune Line

Municipalities

FIRM Panels

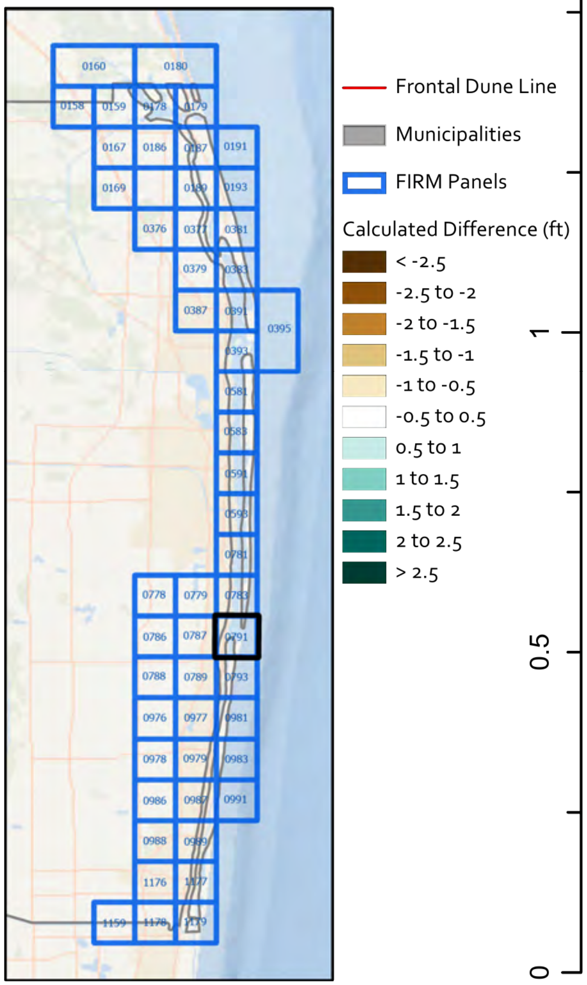
Calculated Difference (ft)

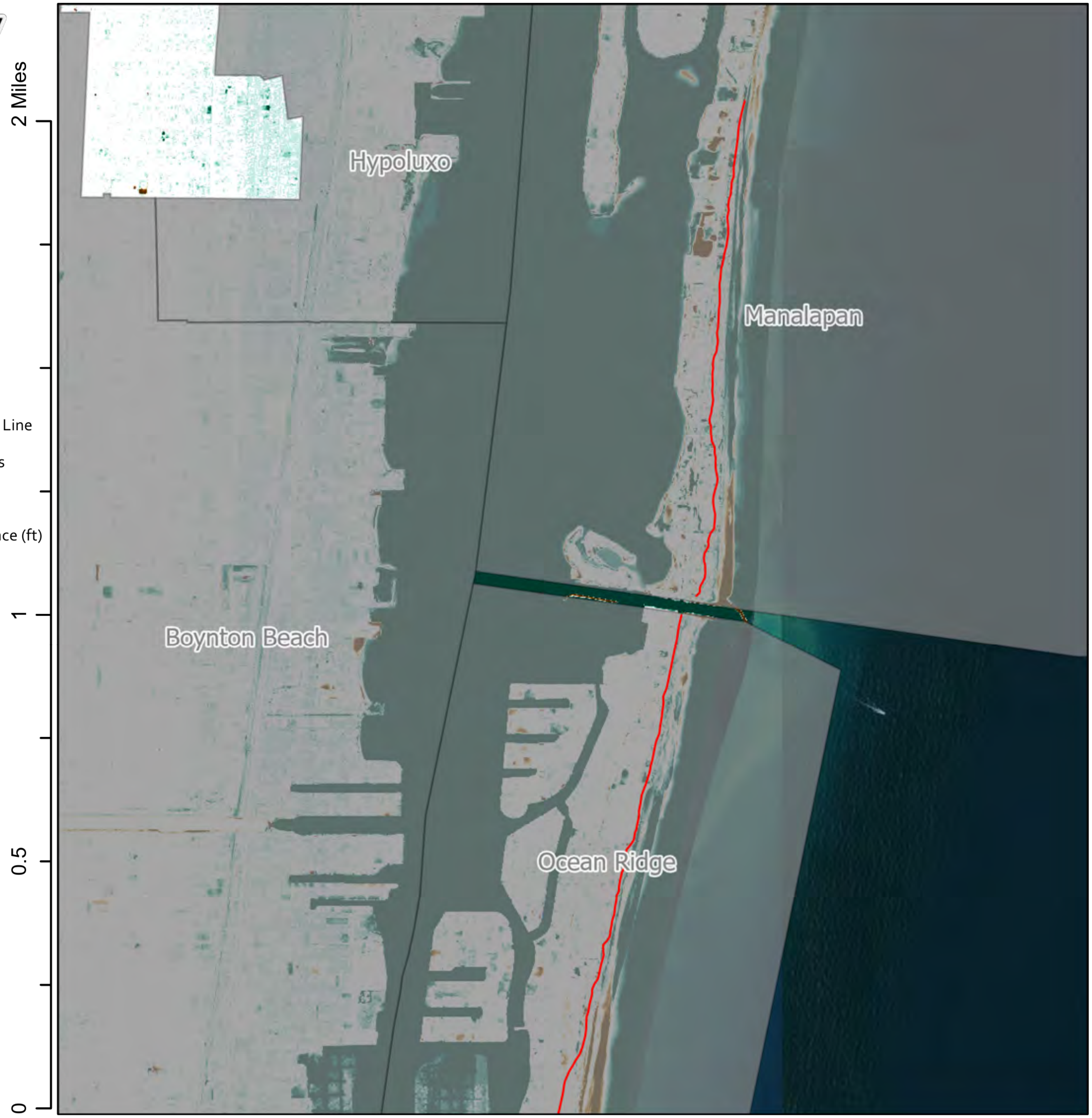
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

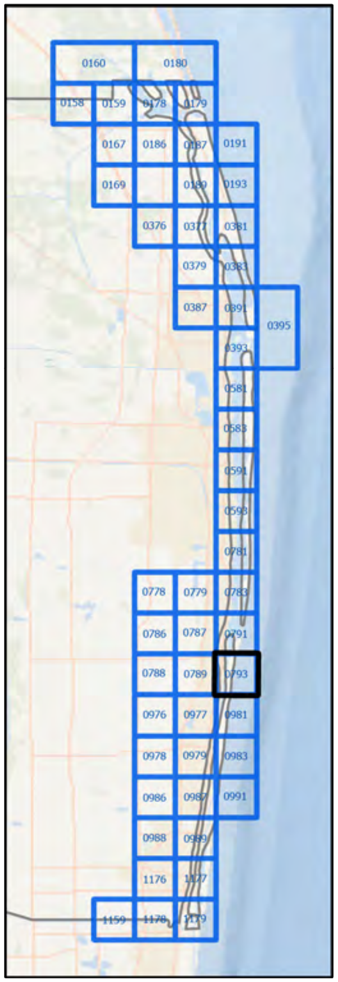
FIRM Panel: 0791





Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

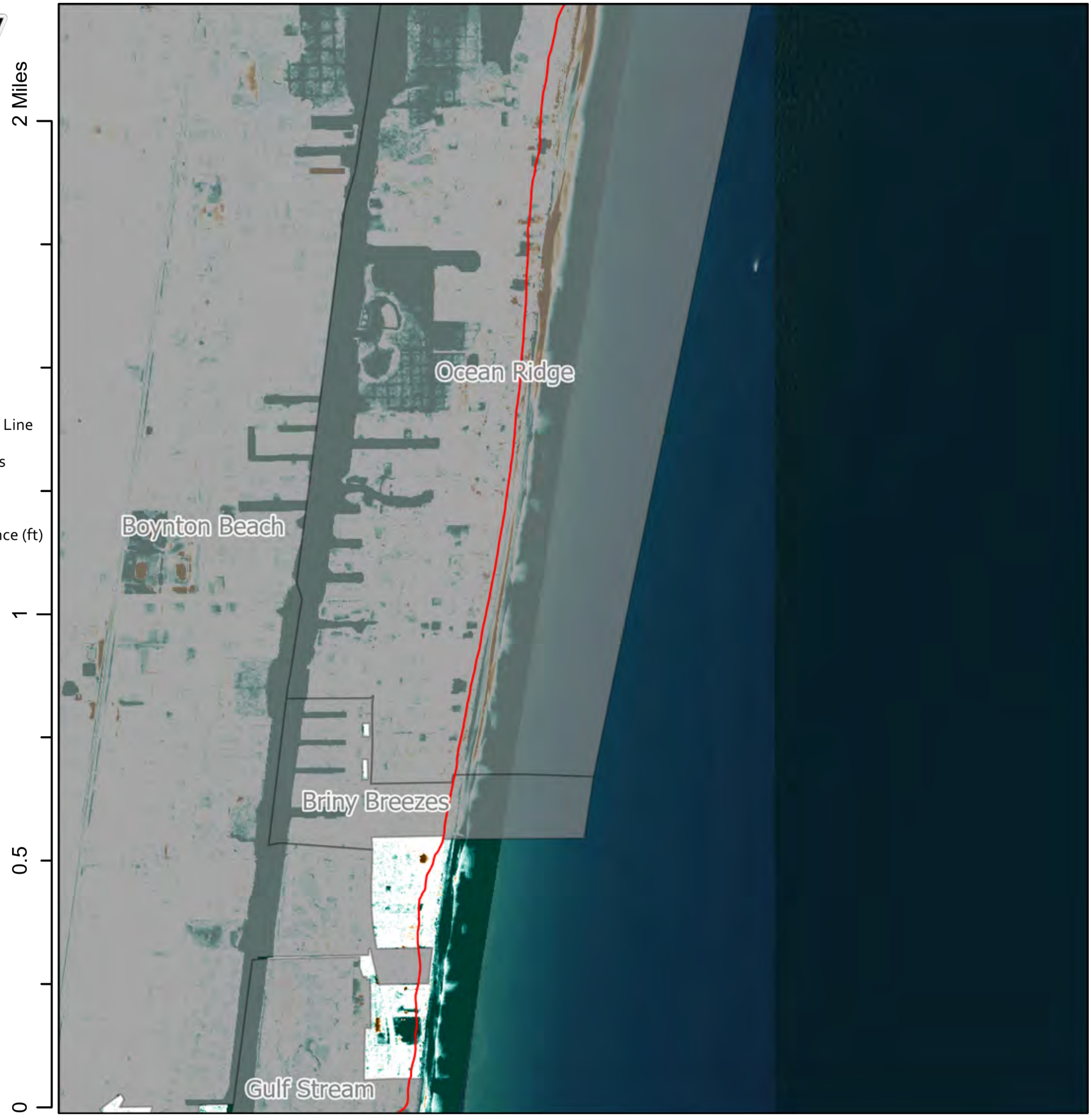
FIRM Panel: 0793



- Frontal Dune Line
- Municipalities
- FIRM Panels

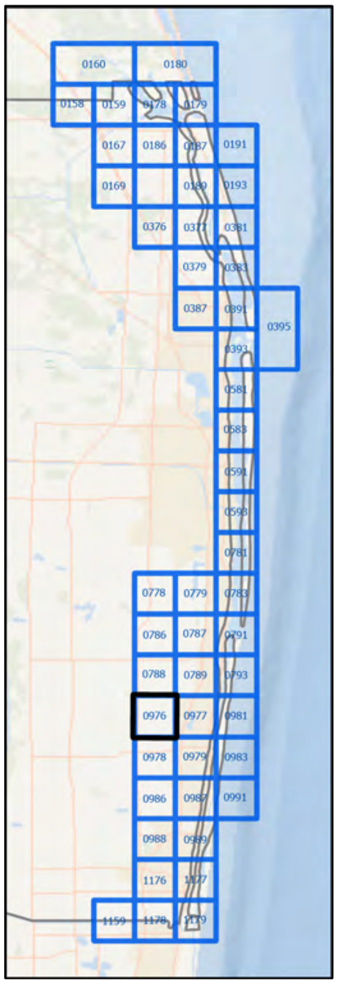
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

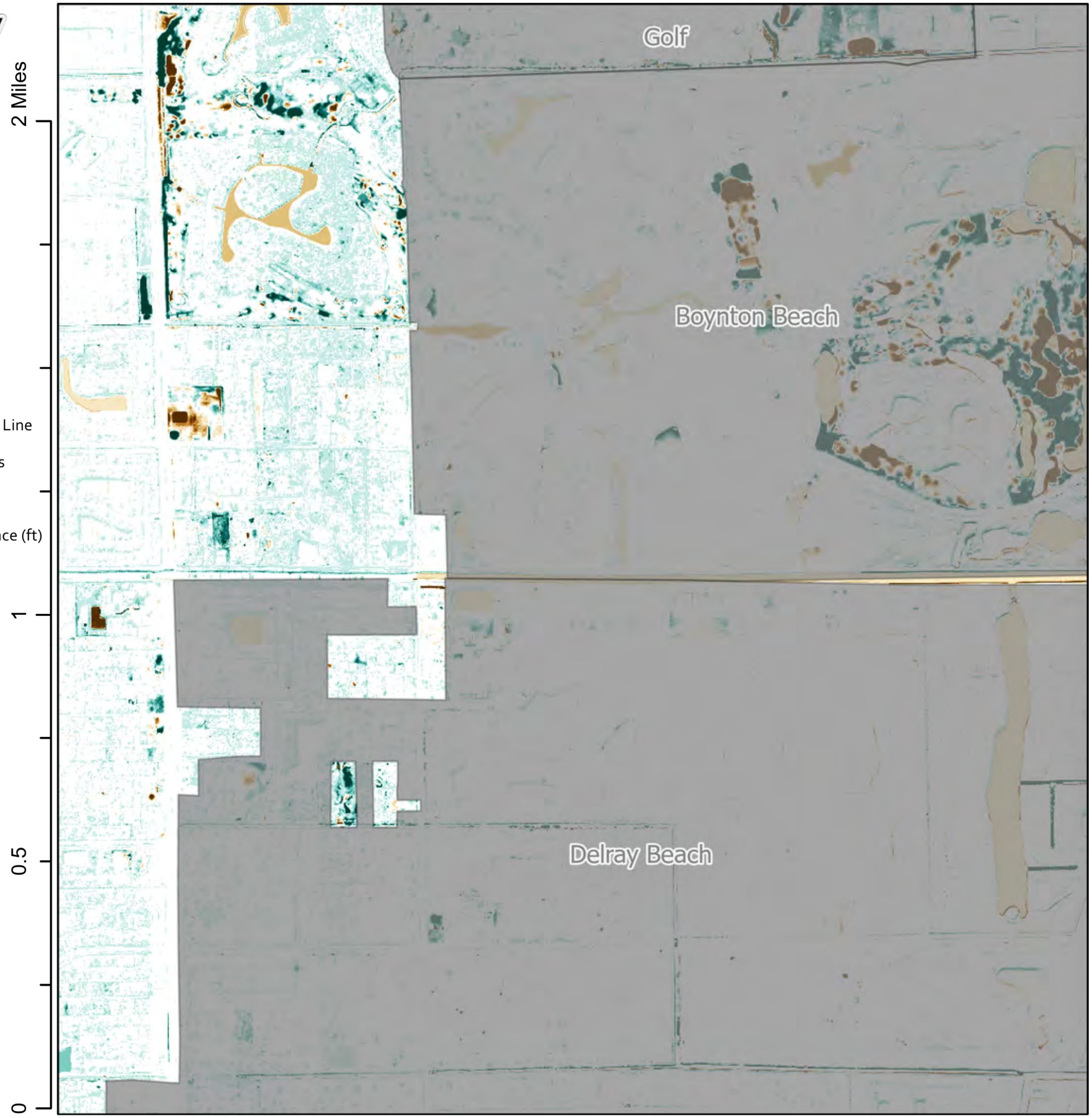
FIRM Panel: 0976



- Frontal Dune Line
- Municipalities
- FIRM Panels

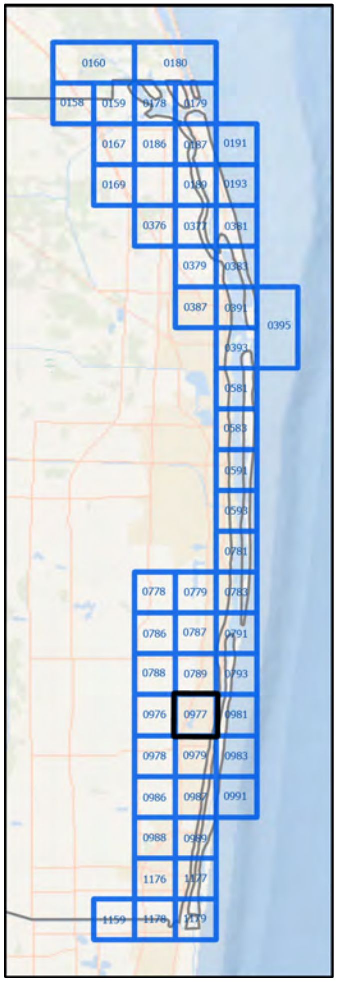
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

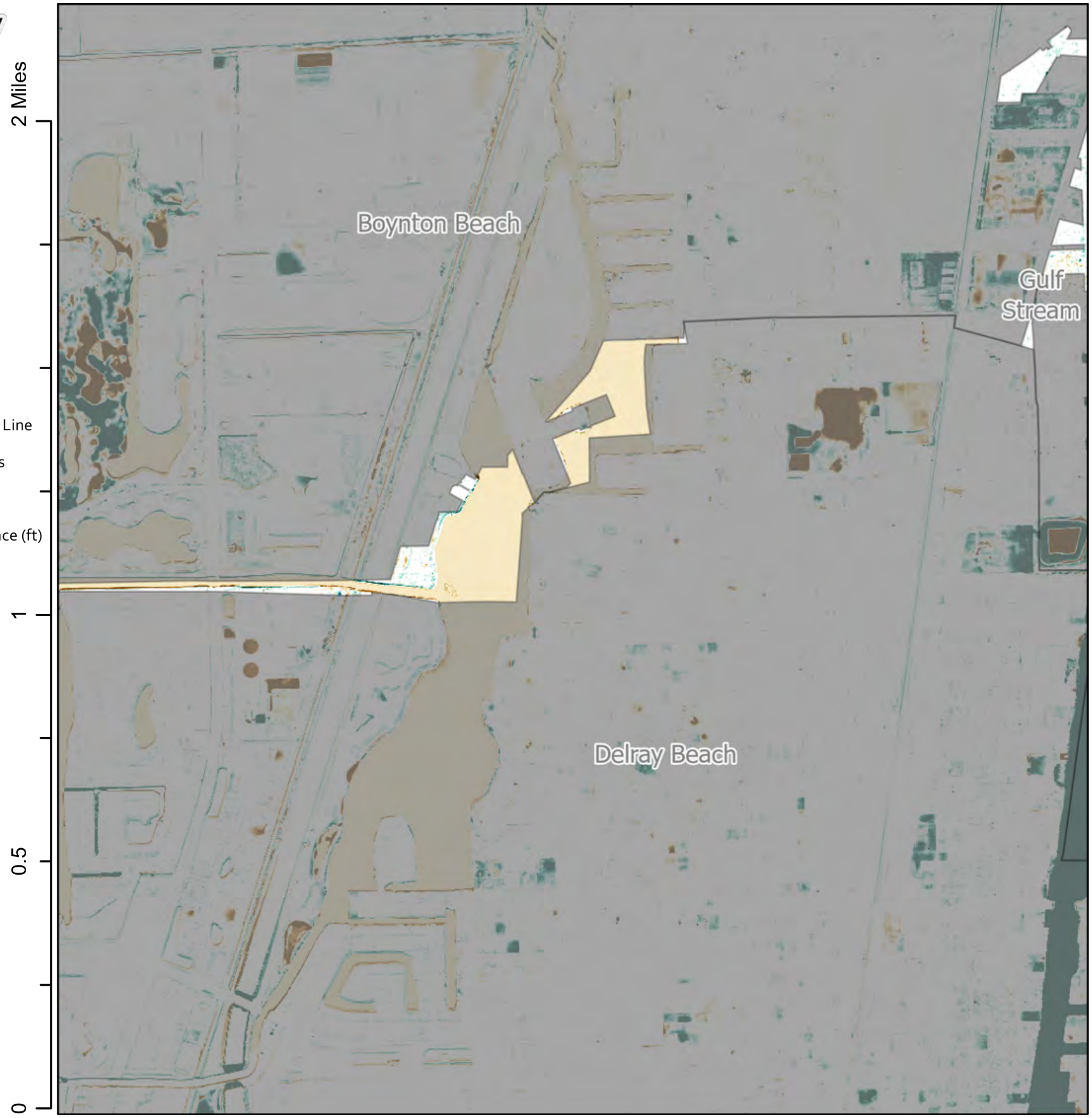
FIRM Panel: 0977



- Frontal Dune Line
- Municipalities
- FIRM Panels

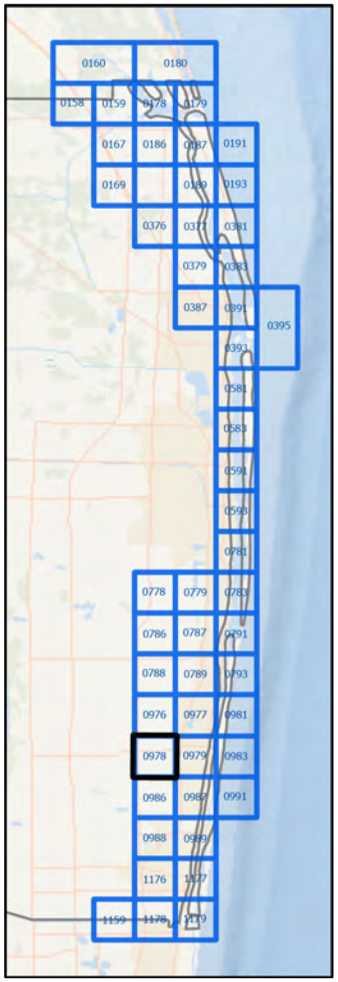
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0978



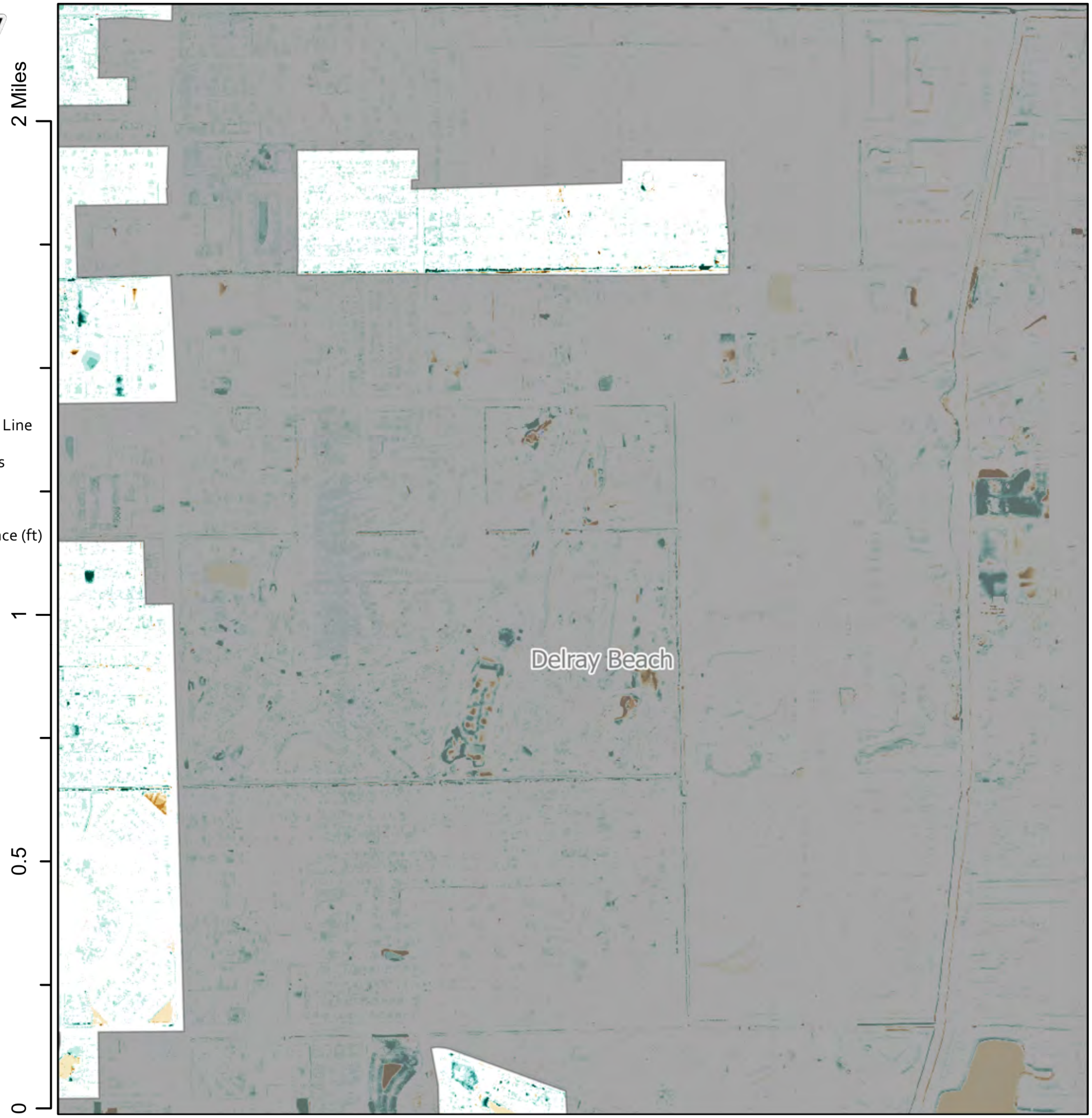
Frontal Dune Line

Municipalities

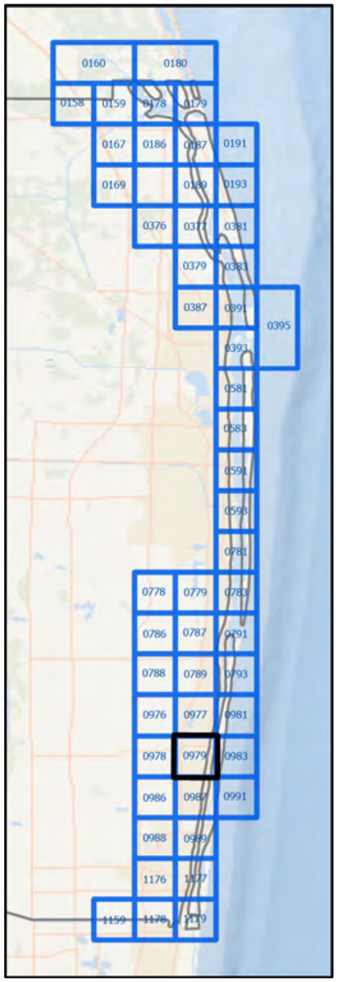
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison
PBC LiDAR minus SWFLTB DEM
FIRM Panel: 0979



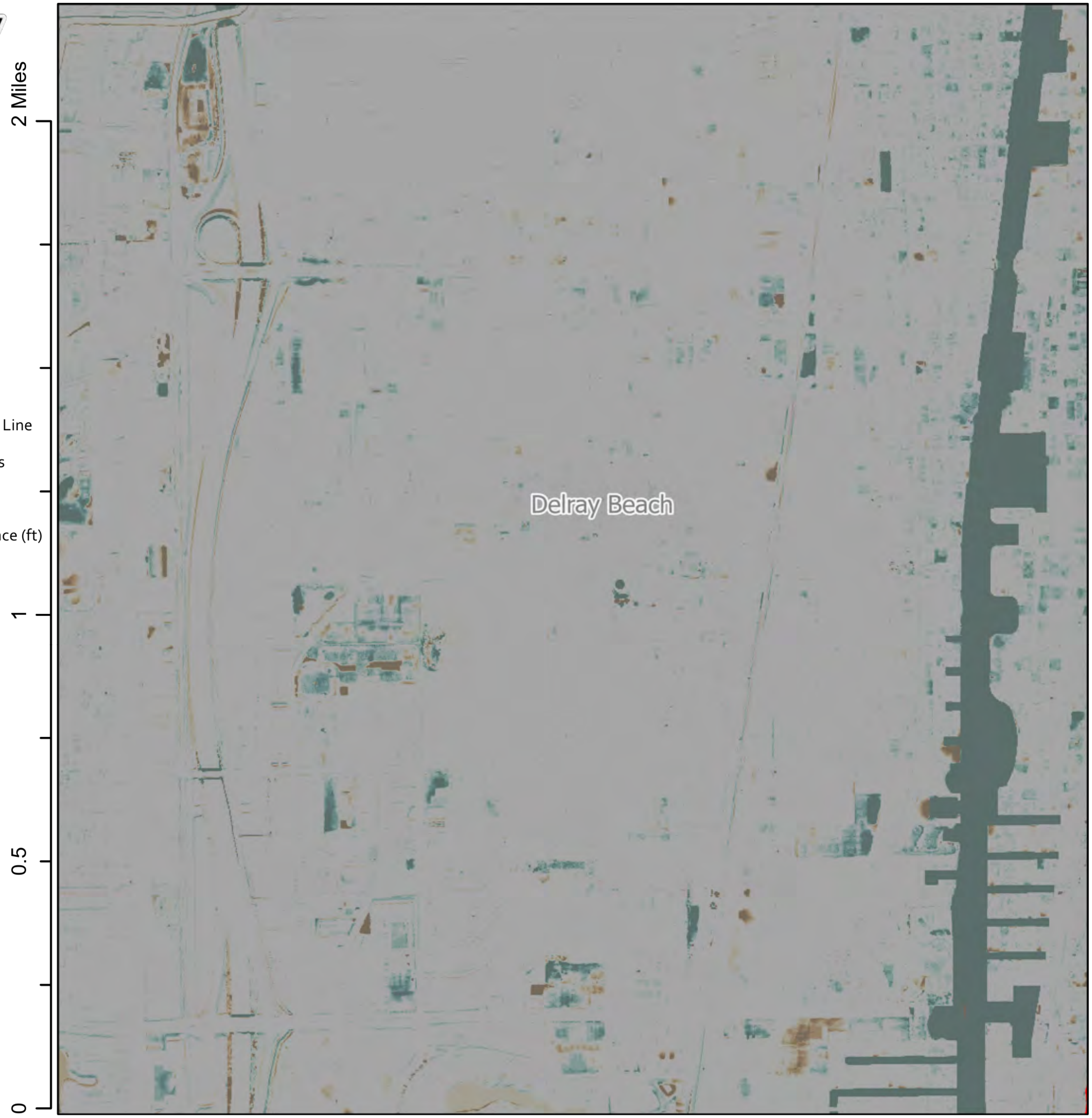
Frontal Dune Line

Municipalities

FIRM Panels

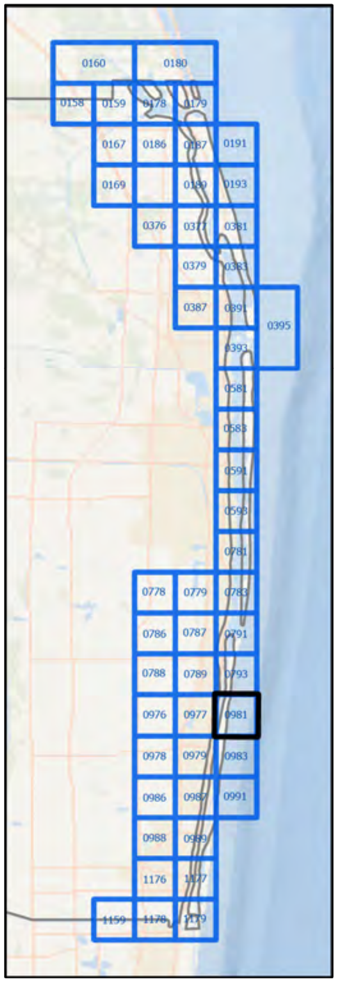
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0981



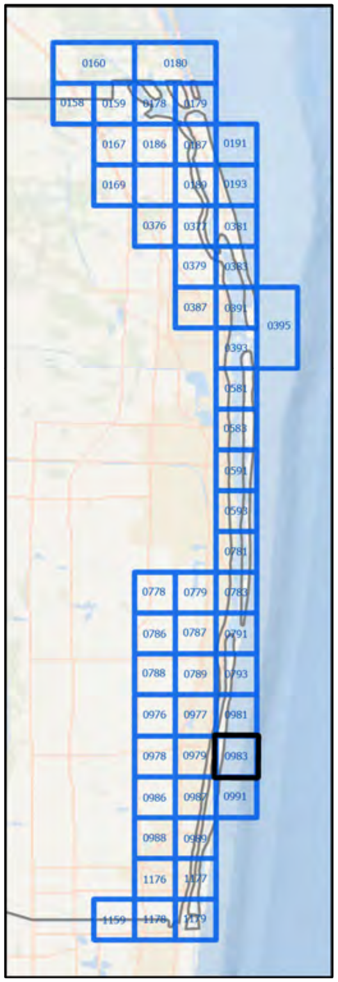
- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0983



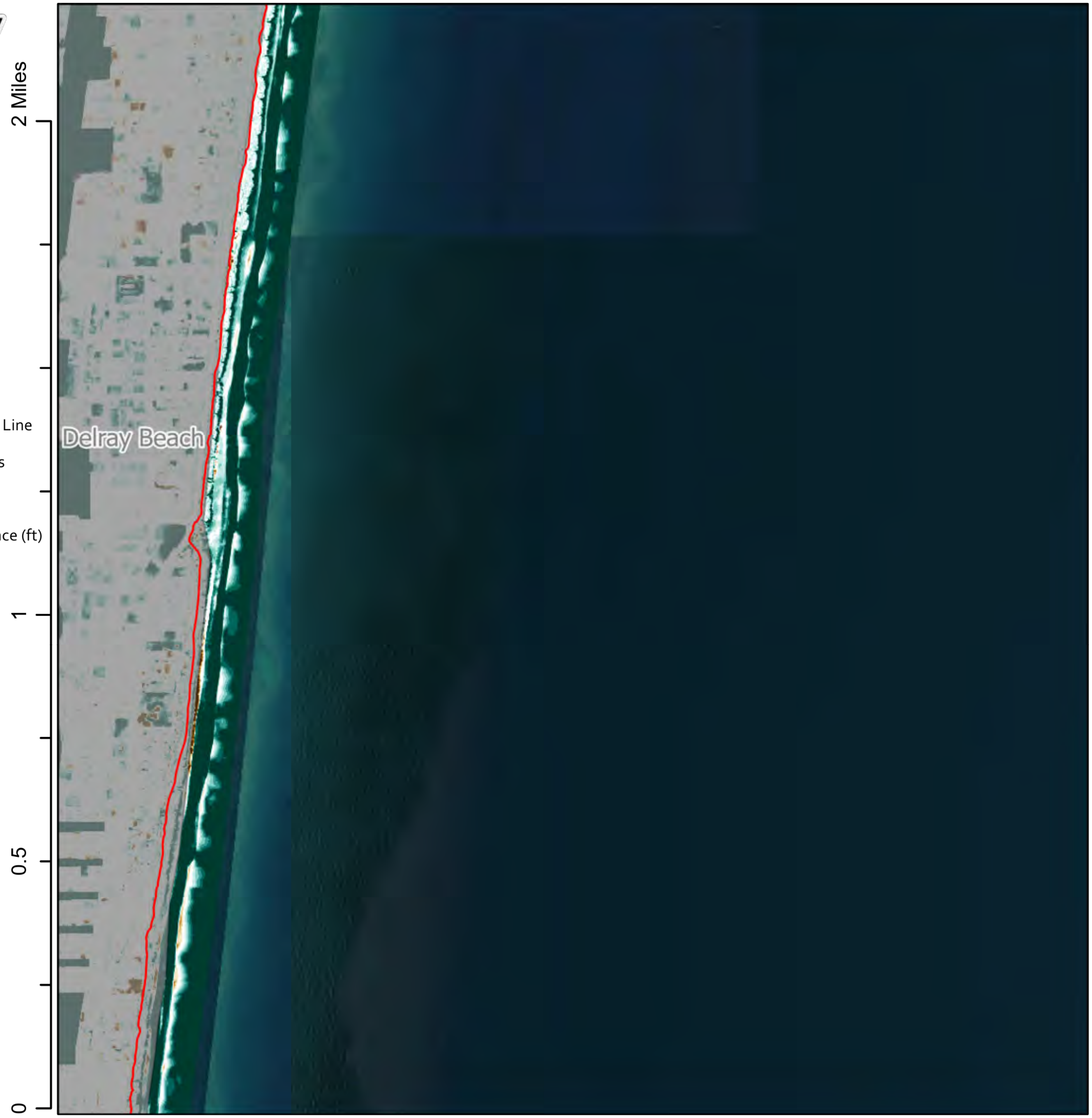
Frontal Dune Line

Municipalities

FIRM Panels

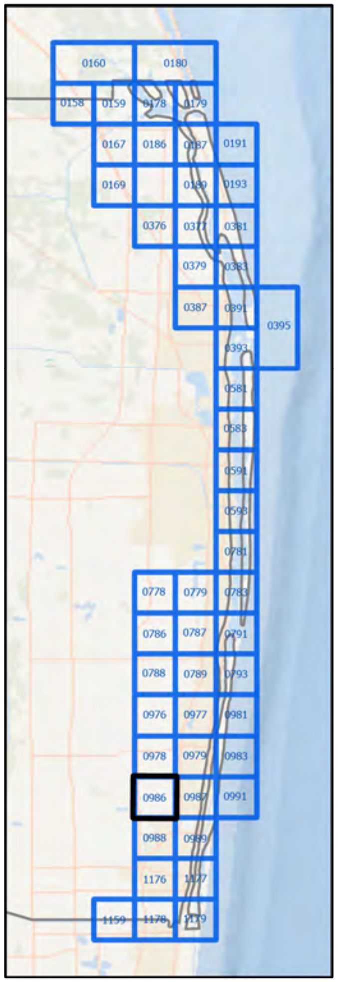
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0986



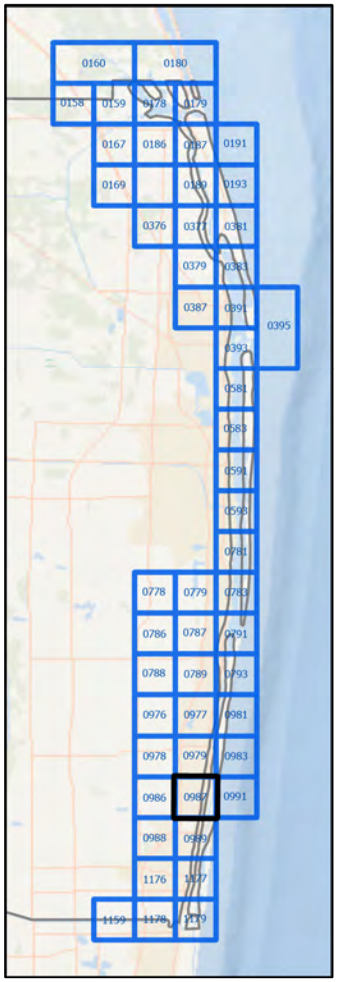
- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0987



Frontal Dune Line

Municipalities

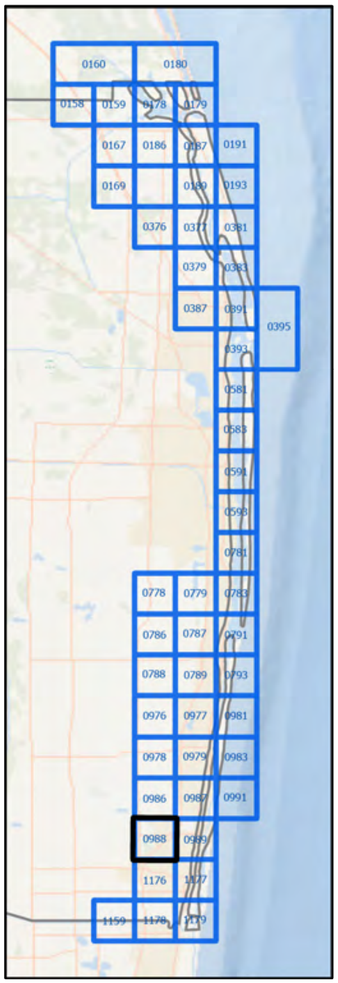
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0988



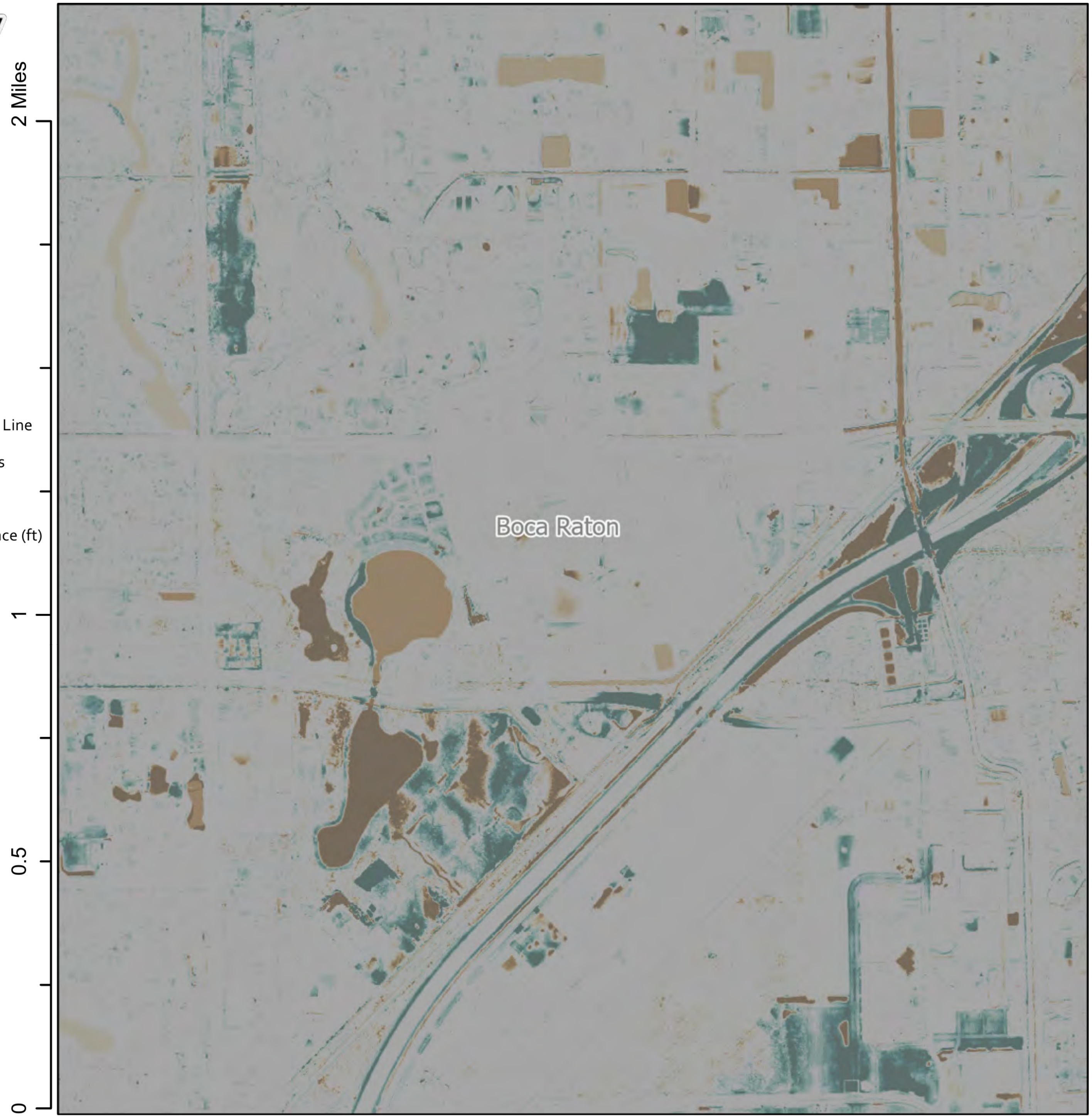
Frontal Dune Line

Municipalities

FIRM Panels

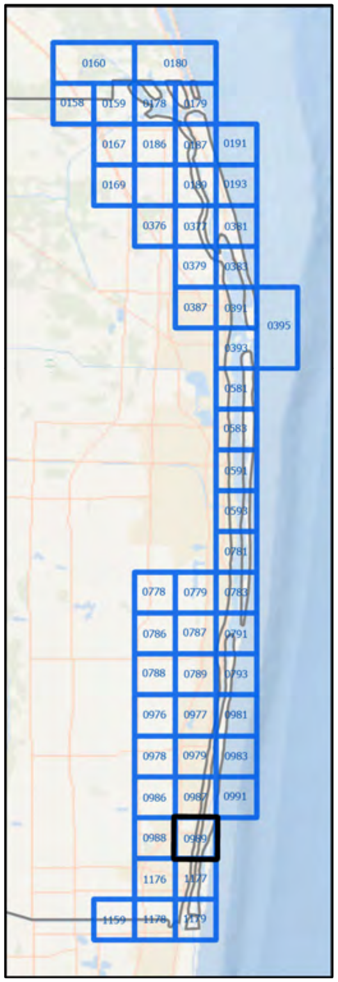
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0989



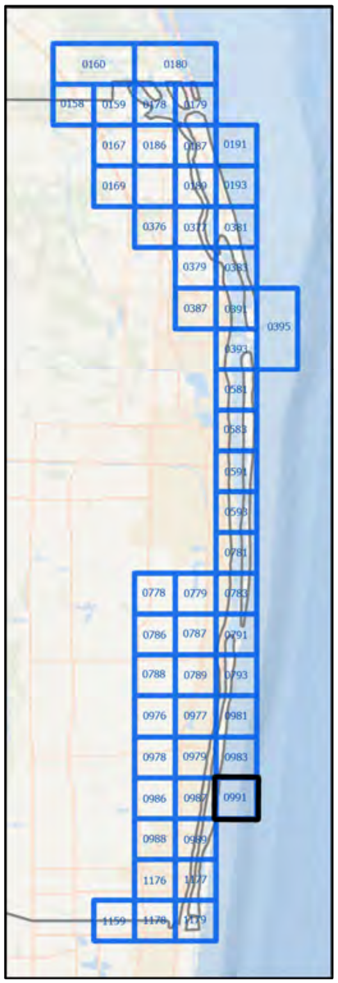
- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 0991



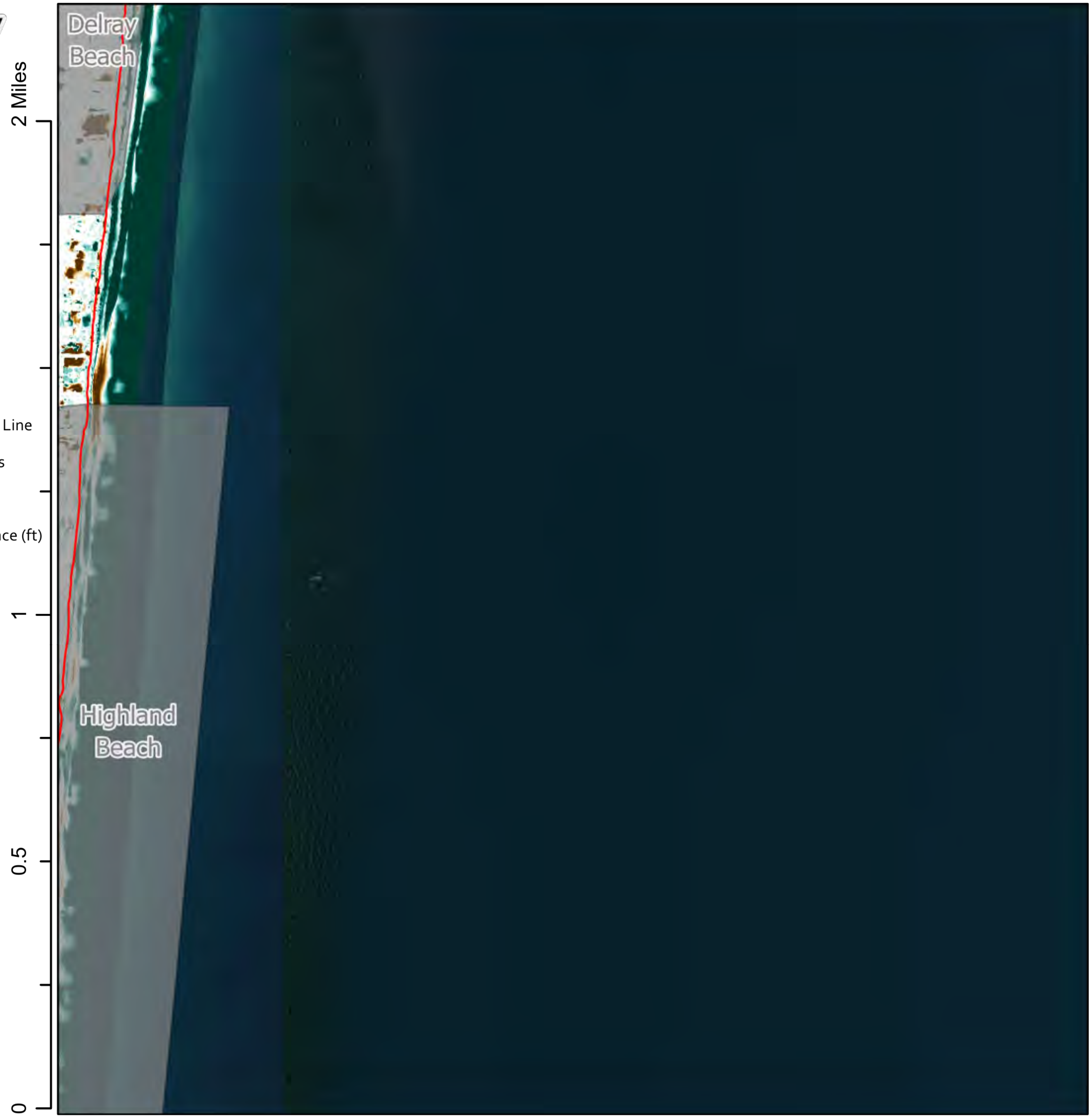
Frontal Dune Line

Municipalities

FIRM Panels

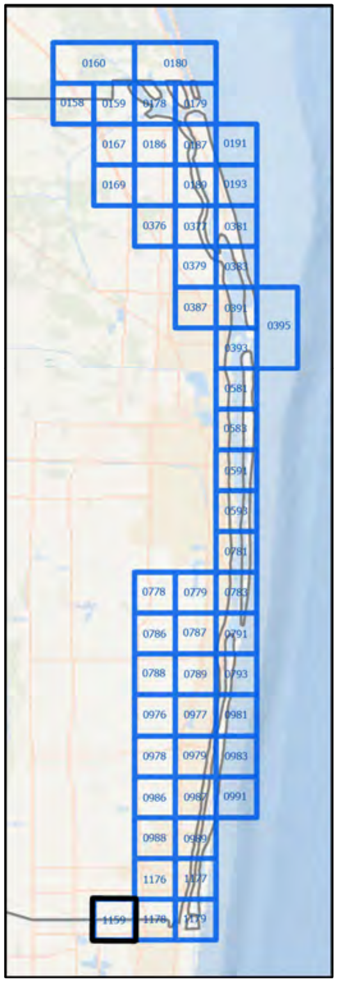
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 1159



Frontal Dune Line

Municipalities

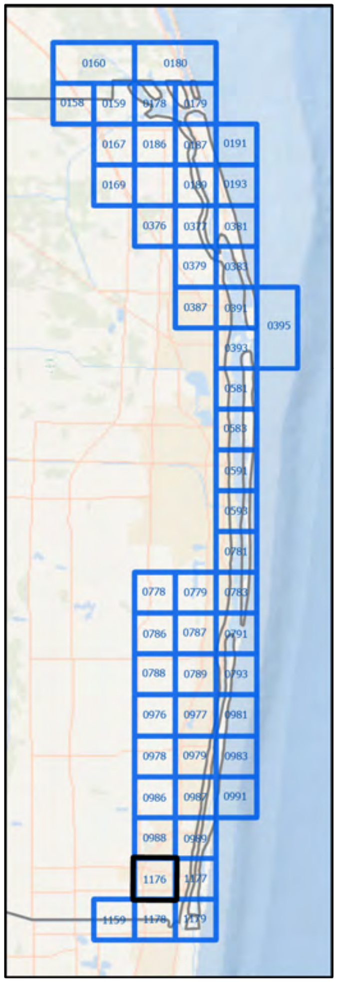
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

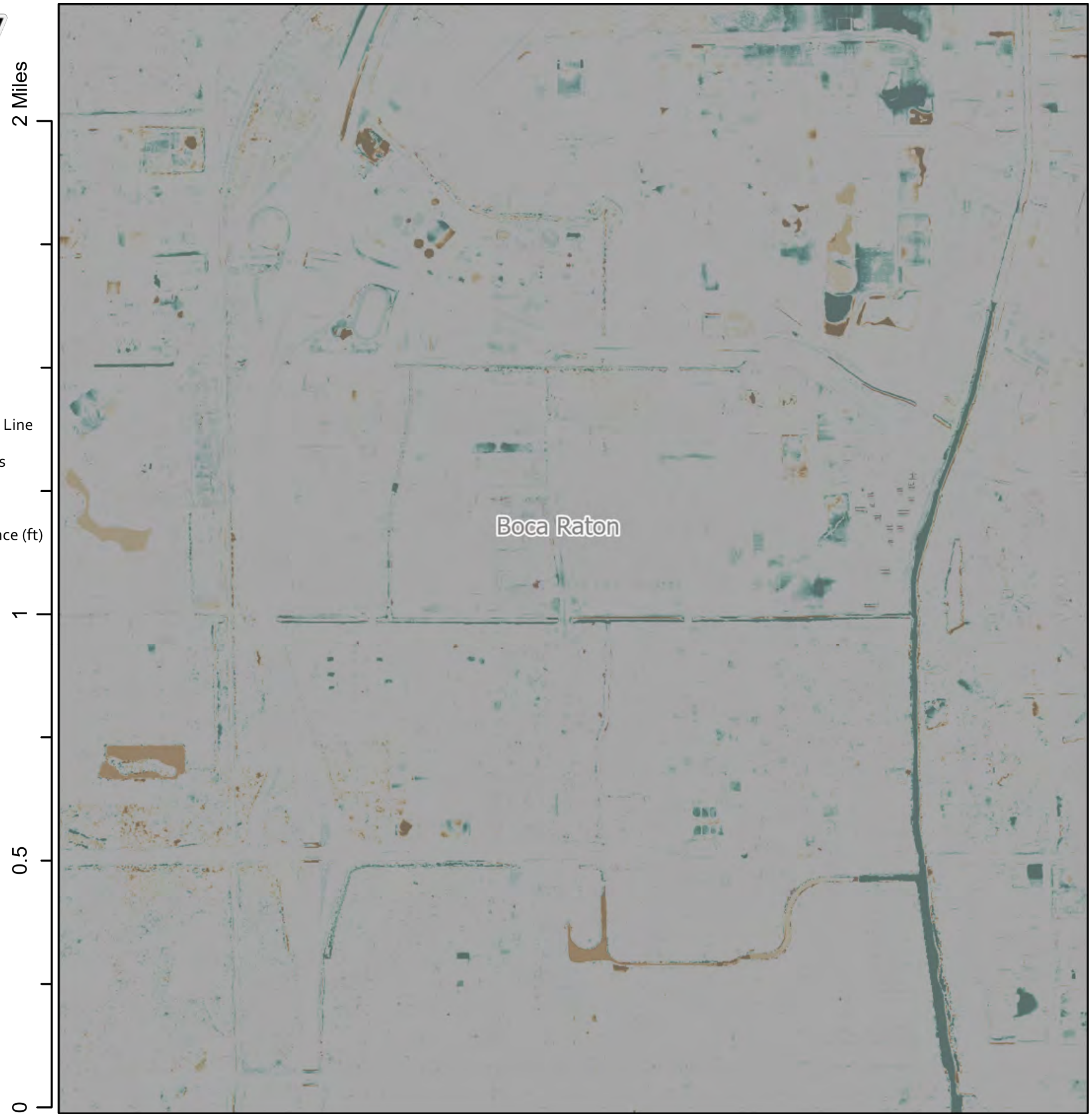
FIRM Panel: 1176



- Frontal Dune Line
- Municipalities
- FIRM Panels

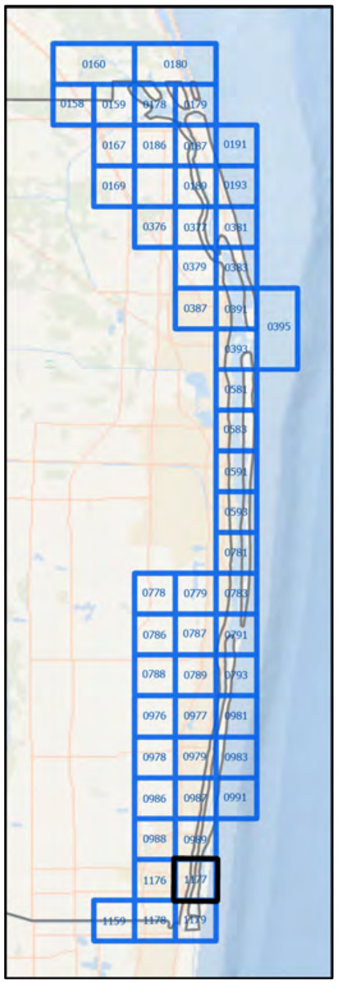
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

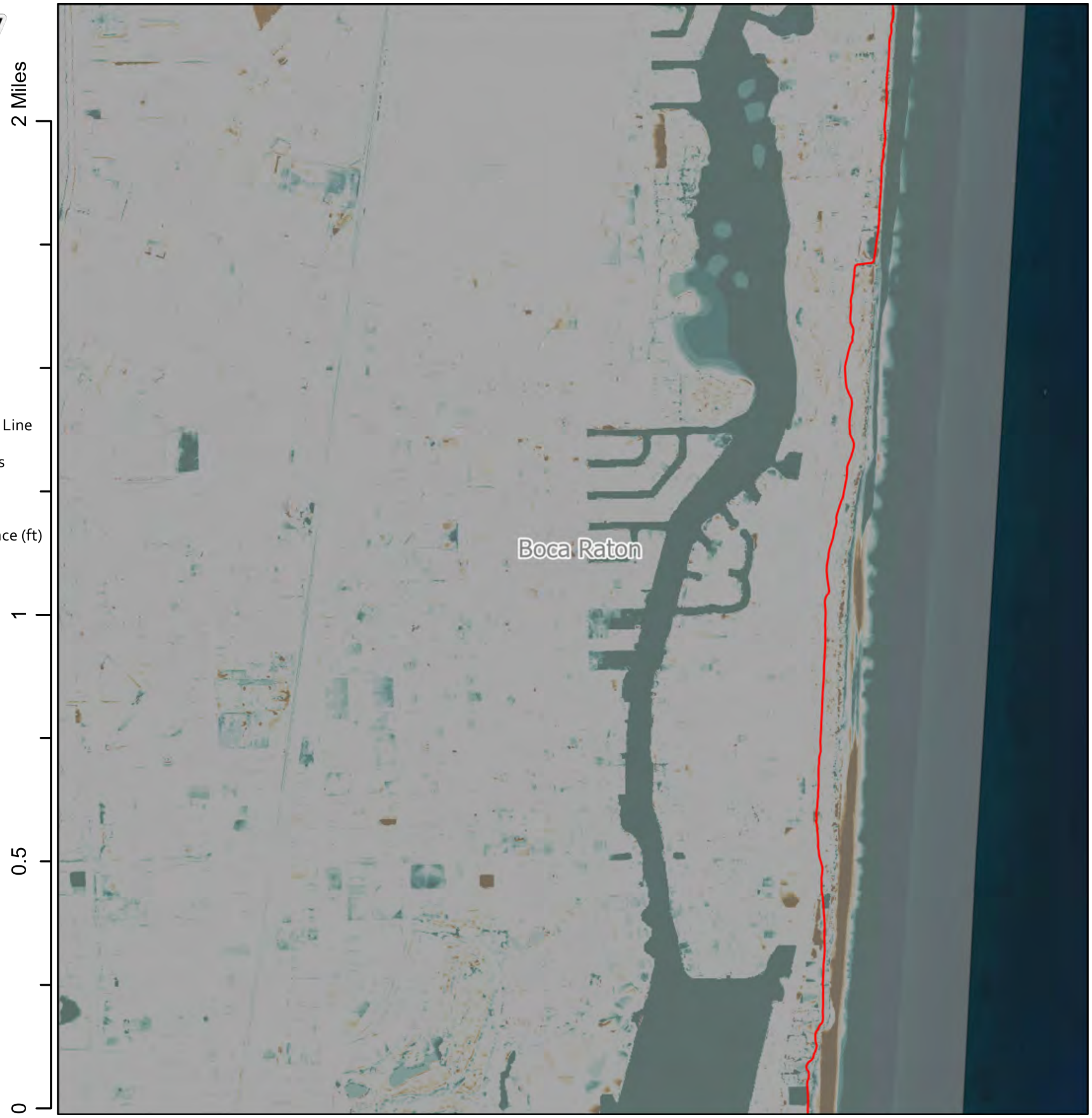
FIRM Panel: 1177



- Frontal Dune Line
- Municipalities
- FIRM Panels

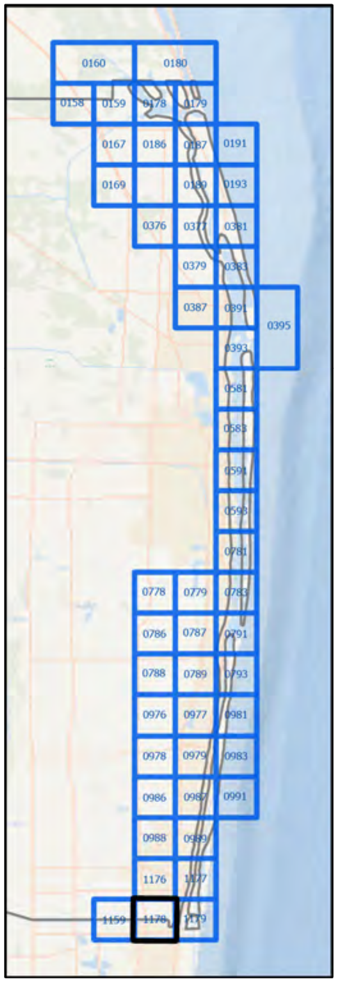
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

FIRM Panel: 1178



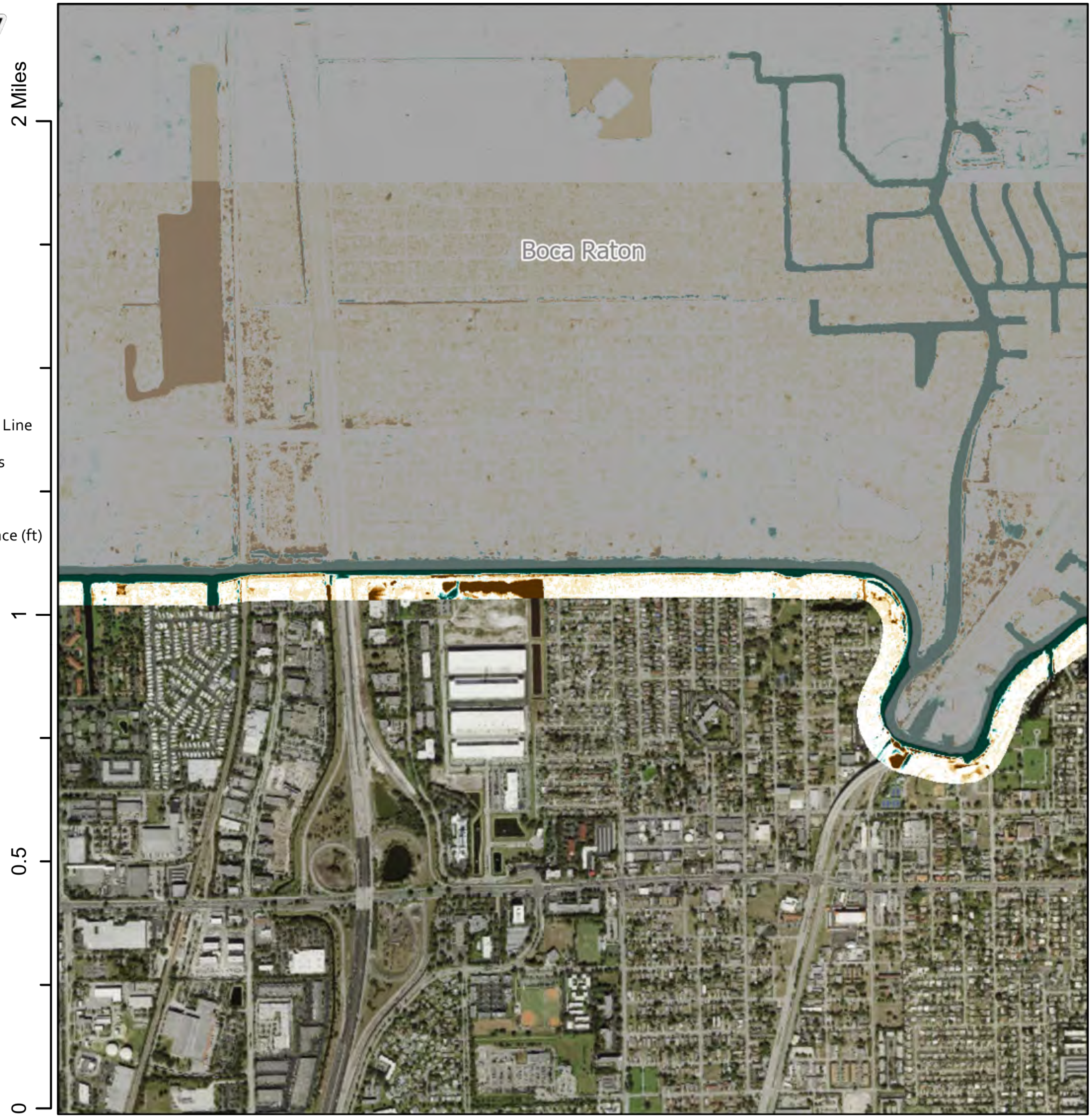
Frontal Dune Line

Municipalities

FIRM Panels

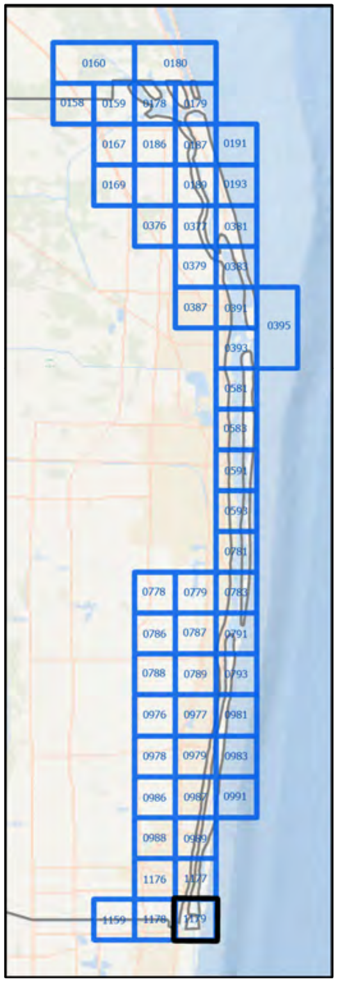
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus SWFLTB DEM

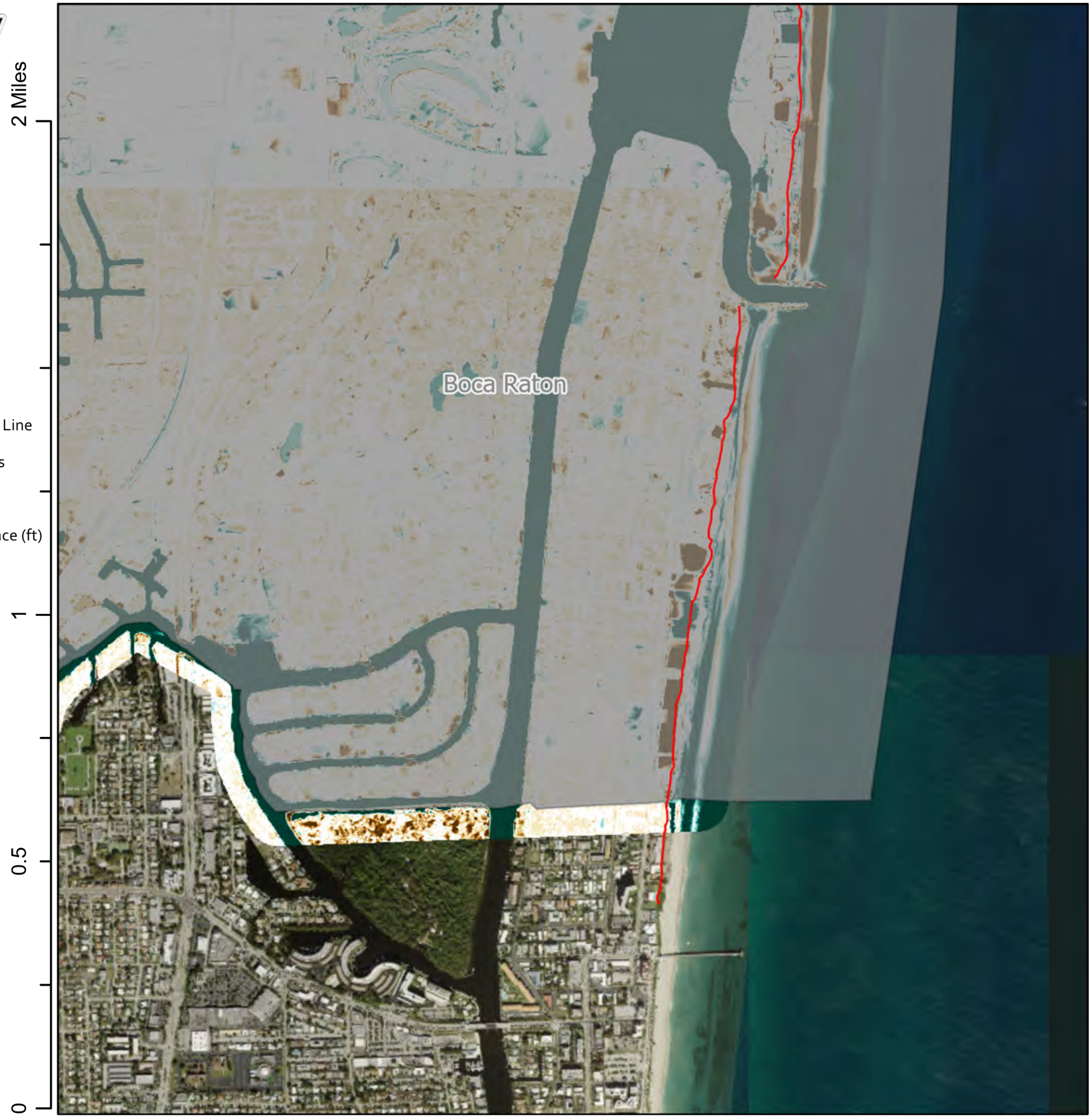
FIRM Panel: 1179



- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

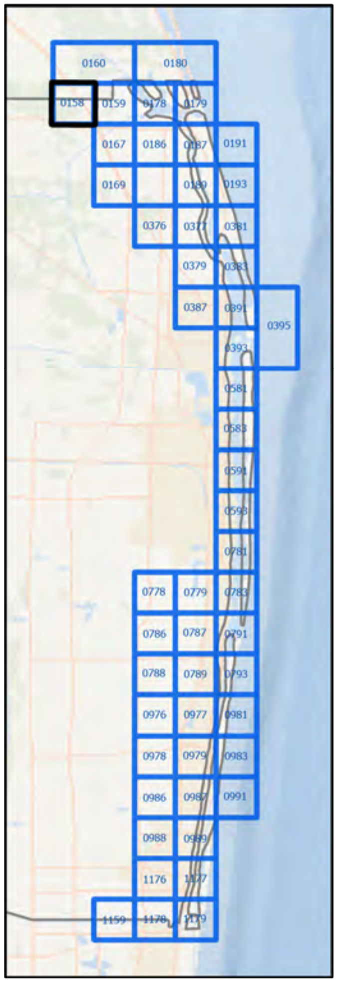


Appendix C

PBC DEM minus USACE DEM by FIRM Panel

Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0158



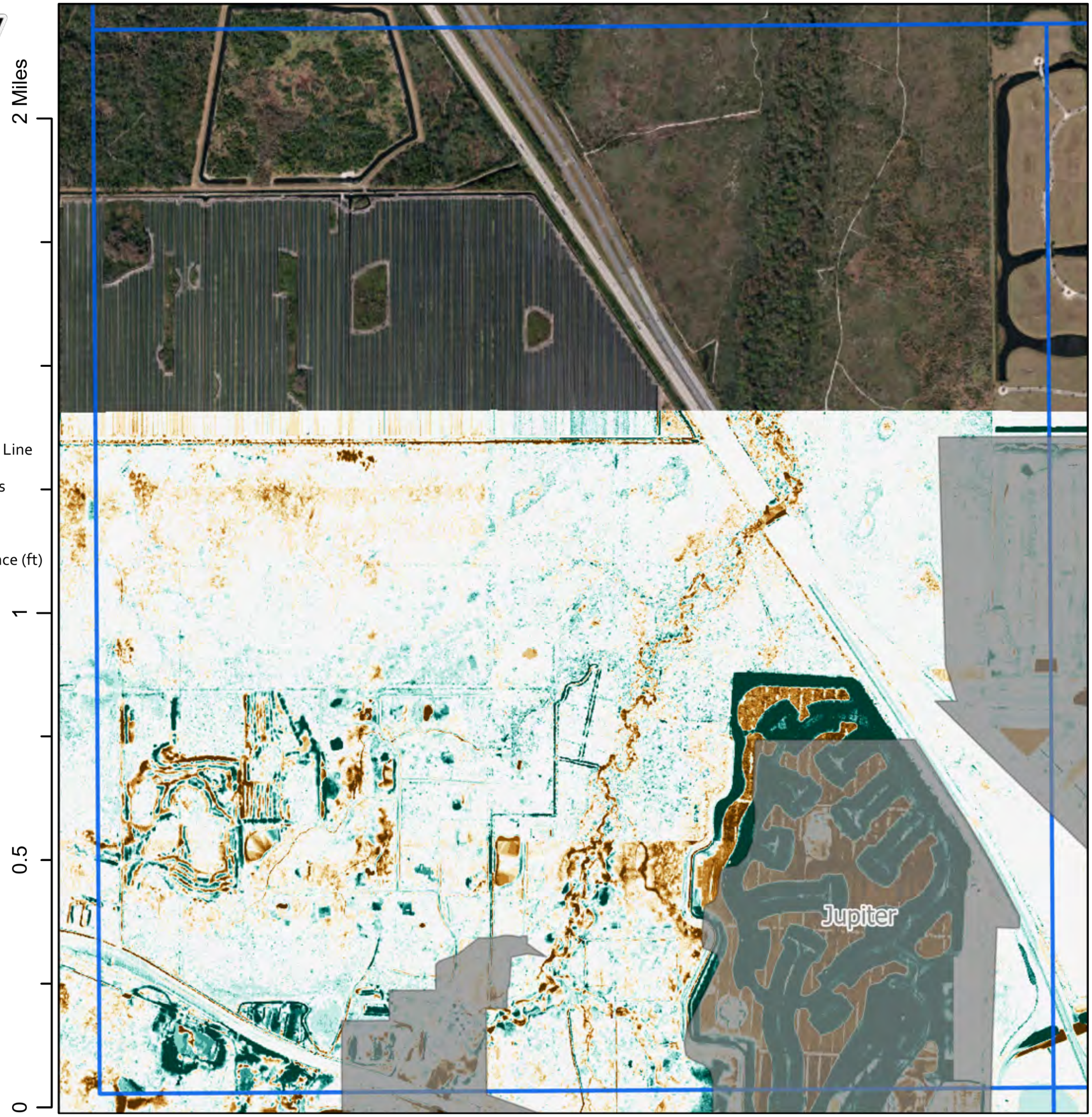
Frontal Dune Line

Municipalities

FIRM Panels

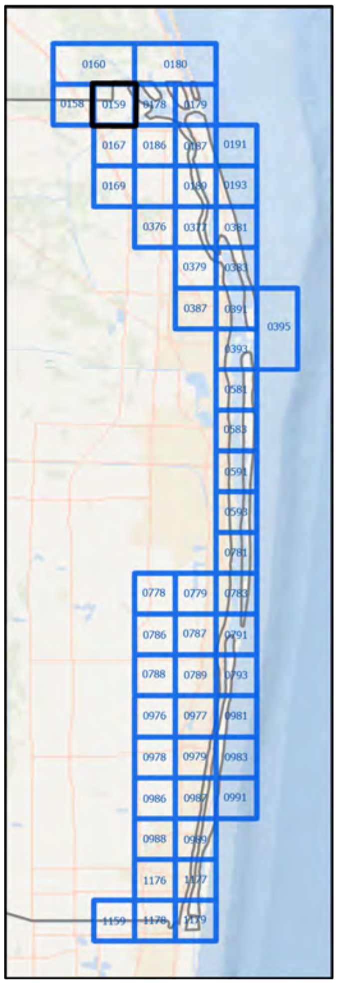
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0159



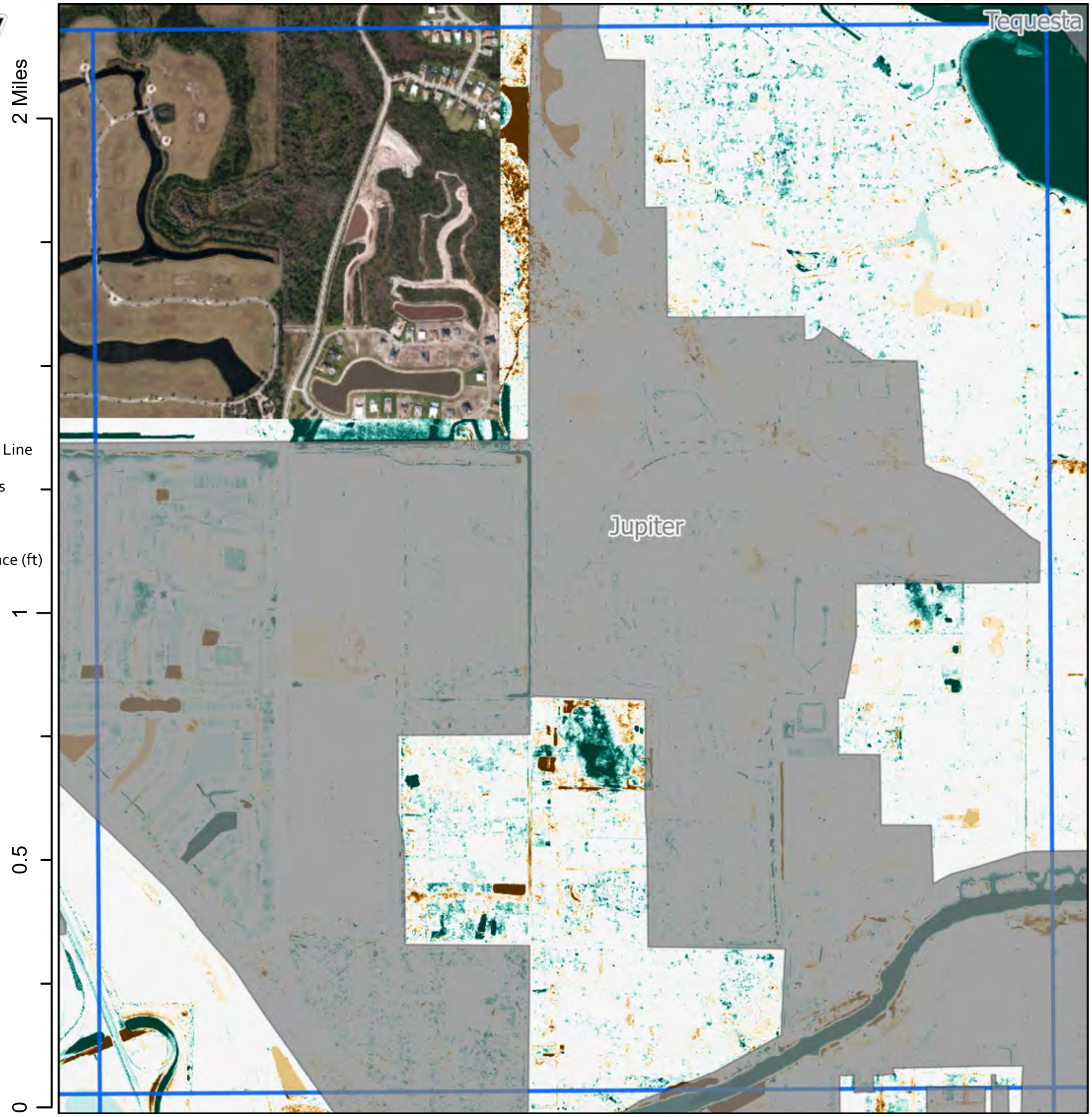
Frontal Dune Line

Municipalities

FIRM Panels

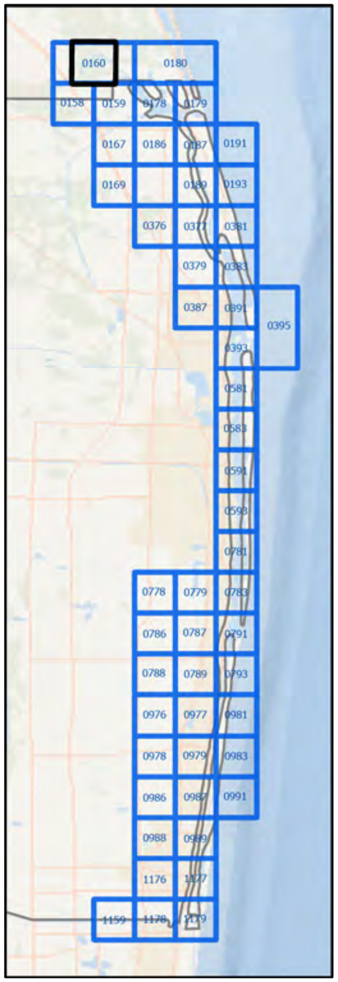
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0160



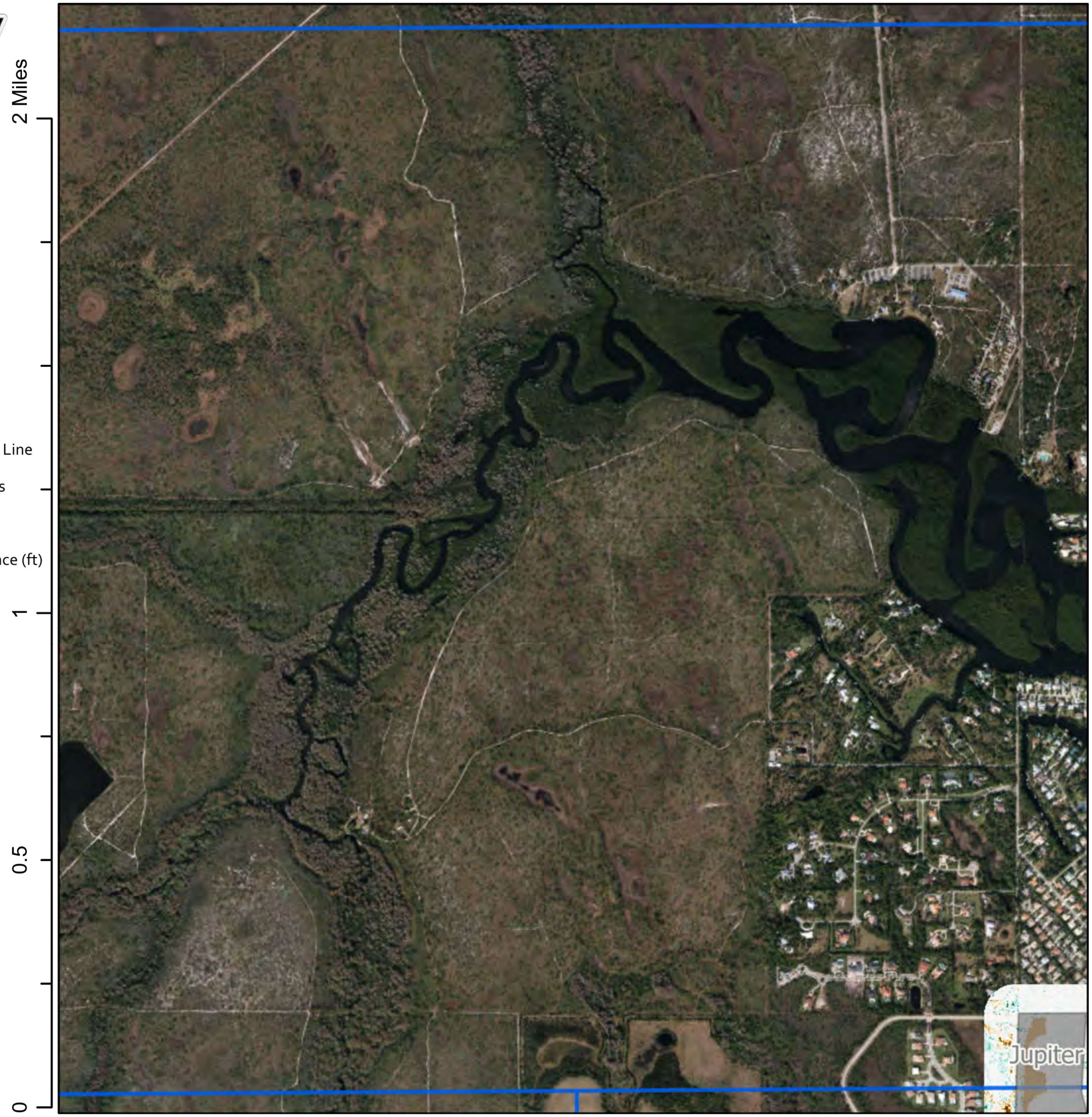
Frontal Dune Line

Municipalities

FIRM Panels

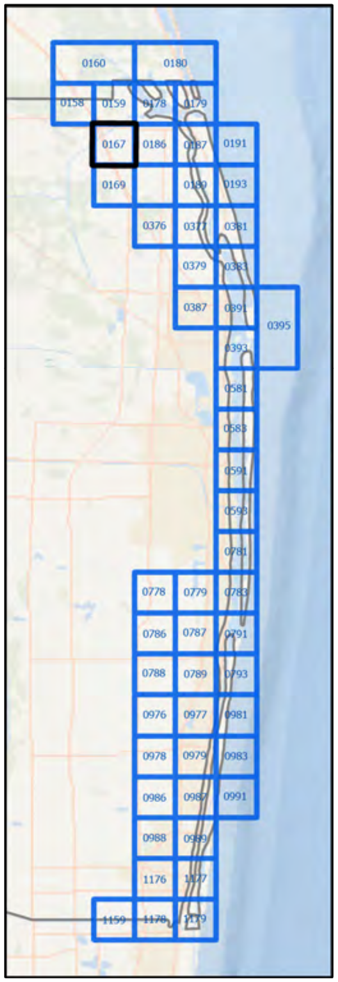
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0167



Frontal Dune Line

Municipalities

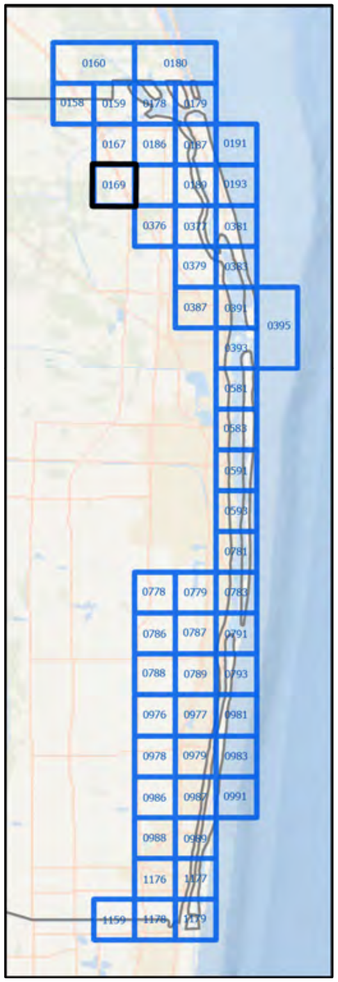
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0169



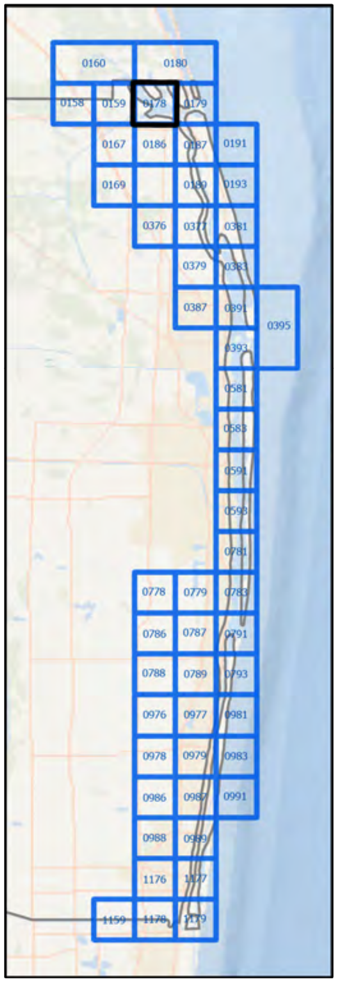
Frontal Dune Line
Municipalities
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0178



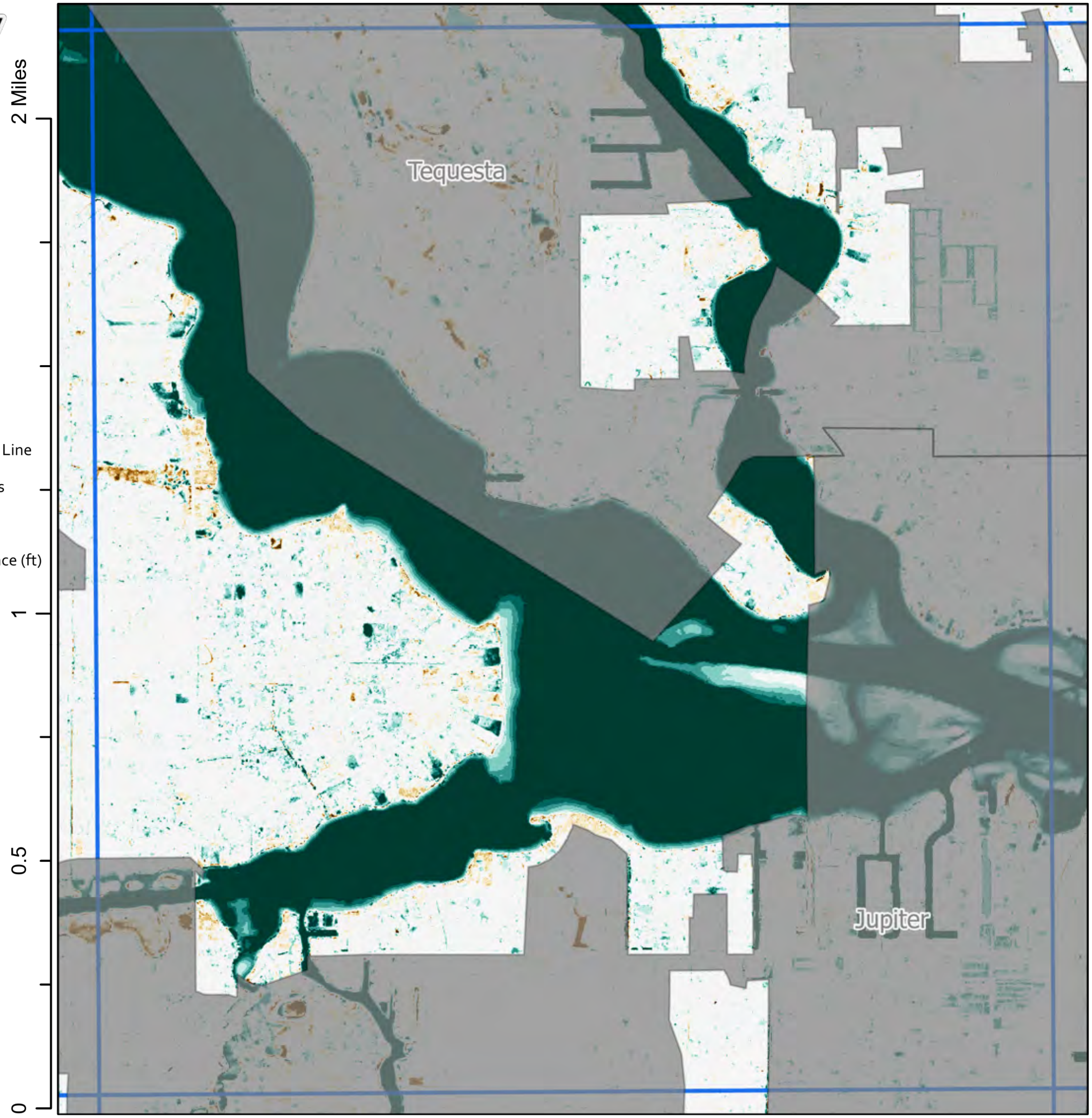
Frontal Dune Line

Municipalities

FIRM Panels

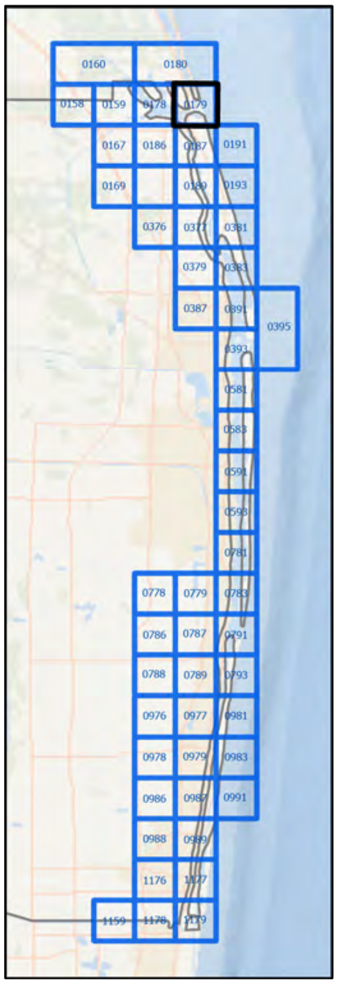
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0179



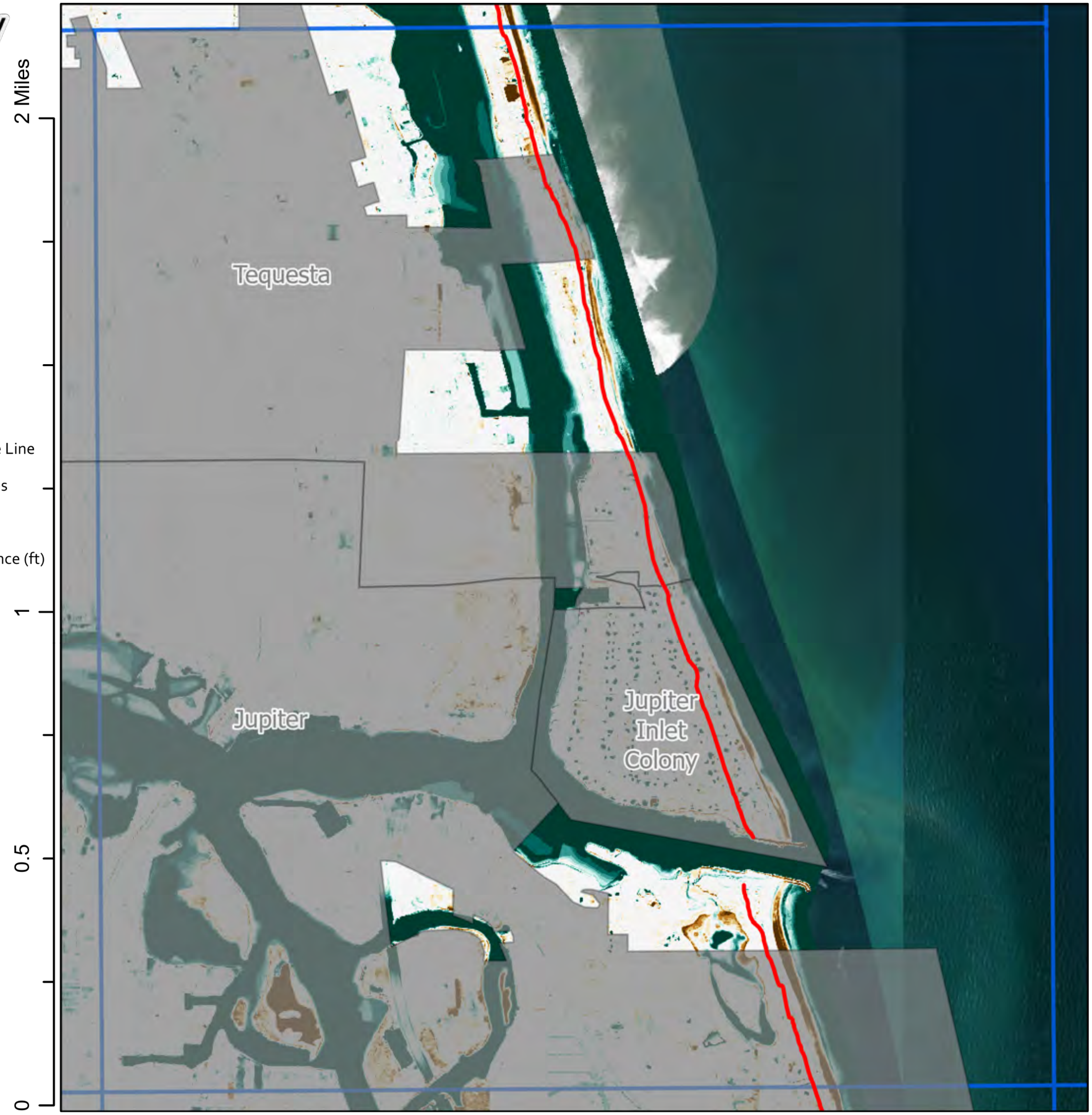
Frontal Dune Line

Municipalities

FIRM Panels

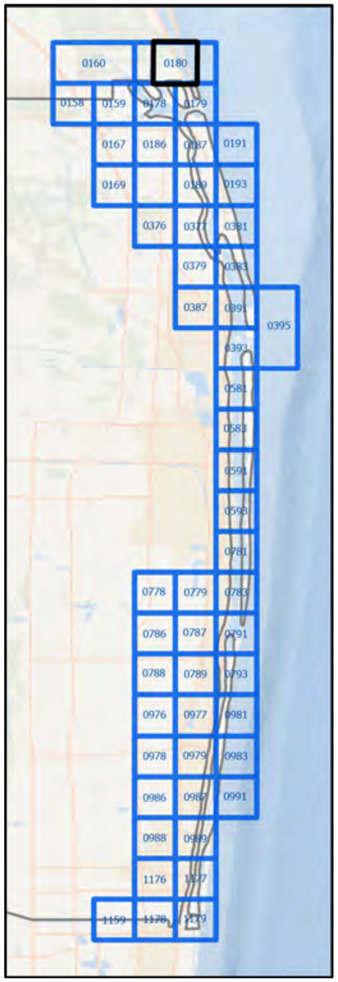
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0180



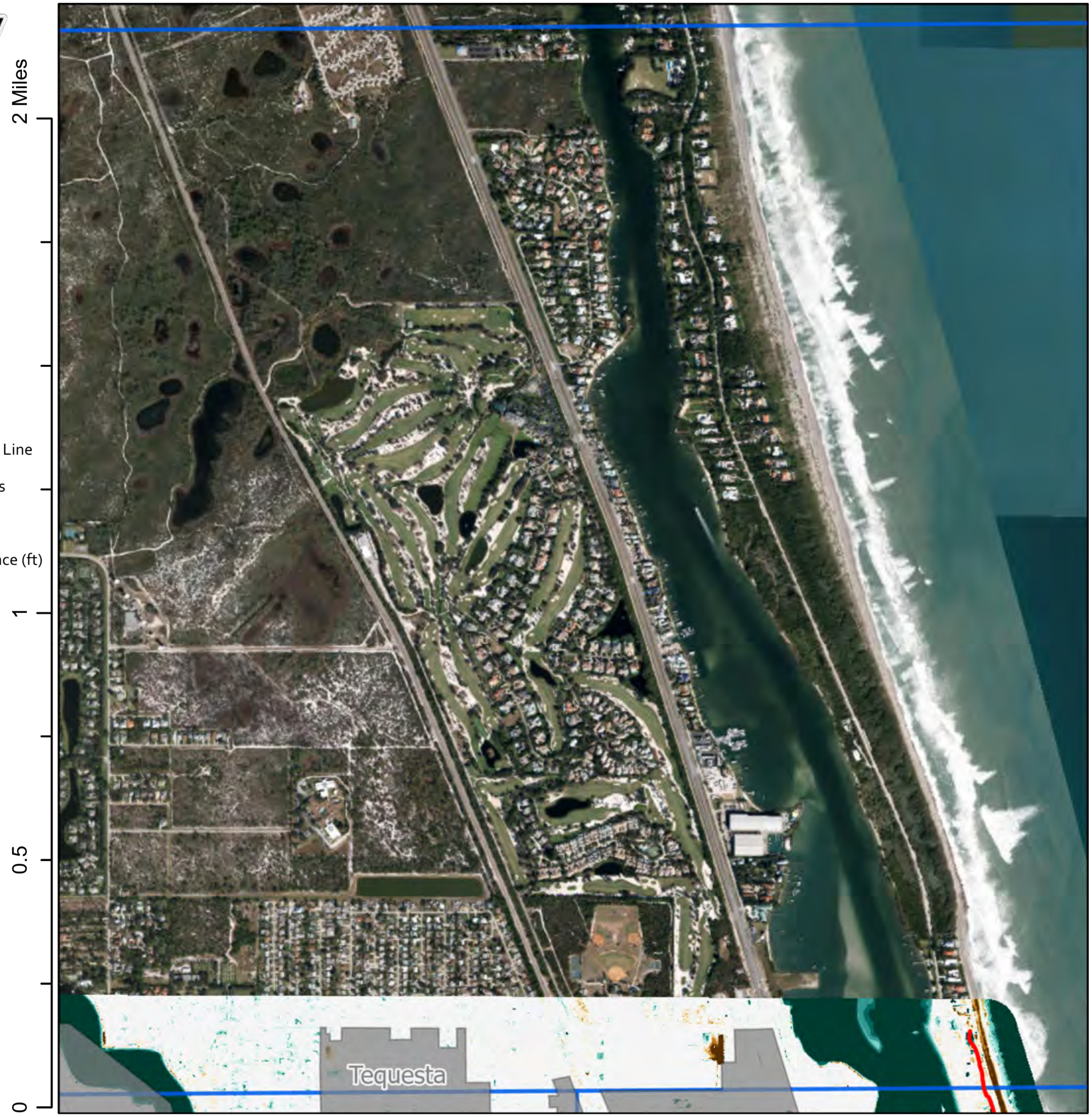
Frontal Dune Line

Municipalities

FIRM Panels

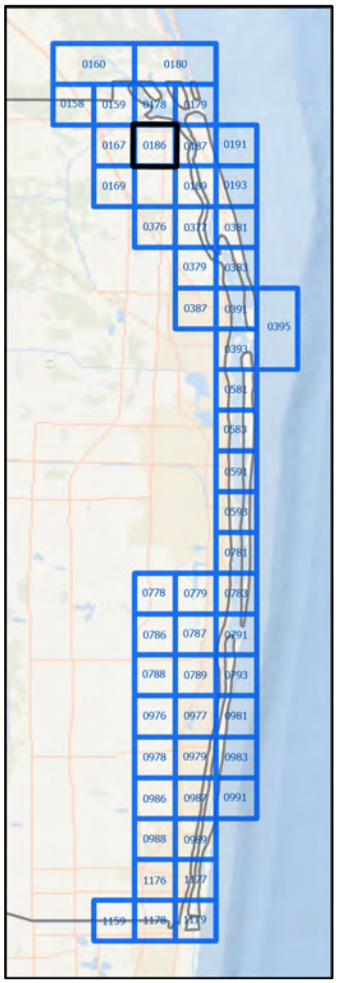
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0186



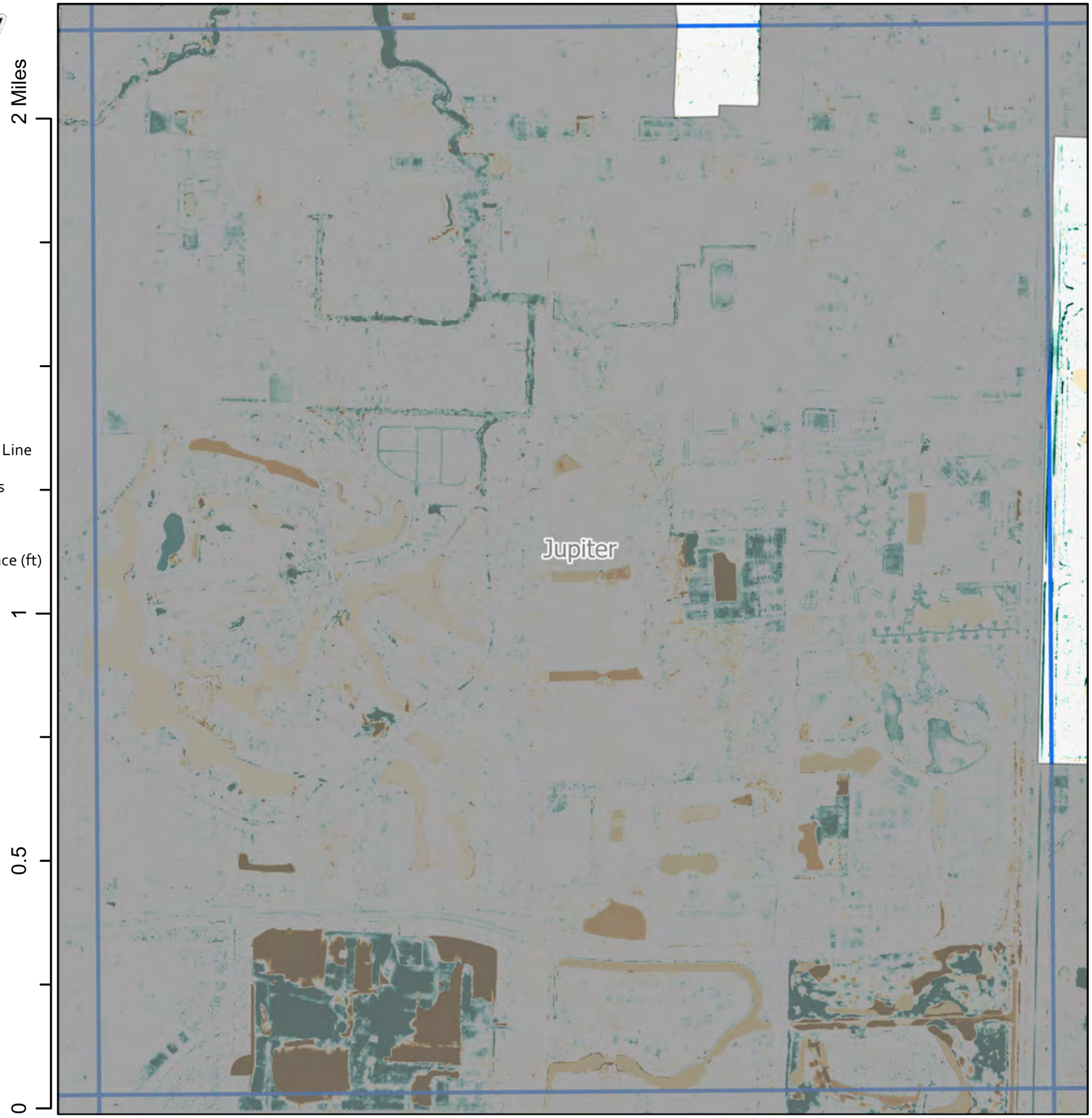
Frontal Dune Line

Municipalities

FIRM Panels

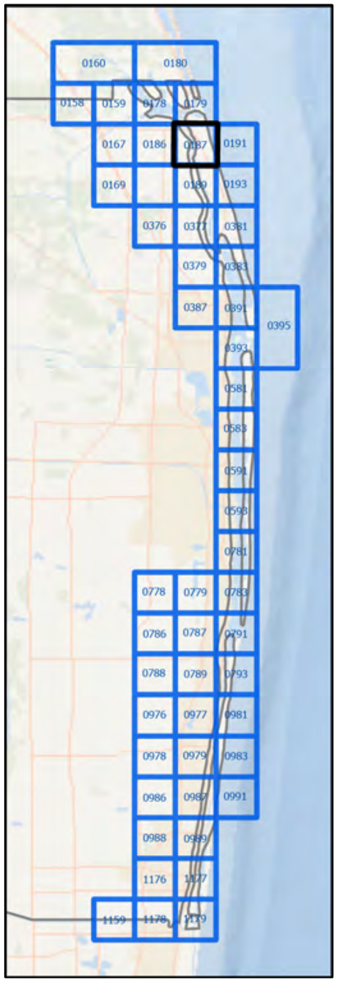
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0187



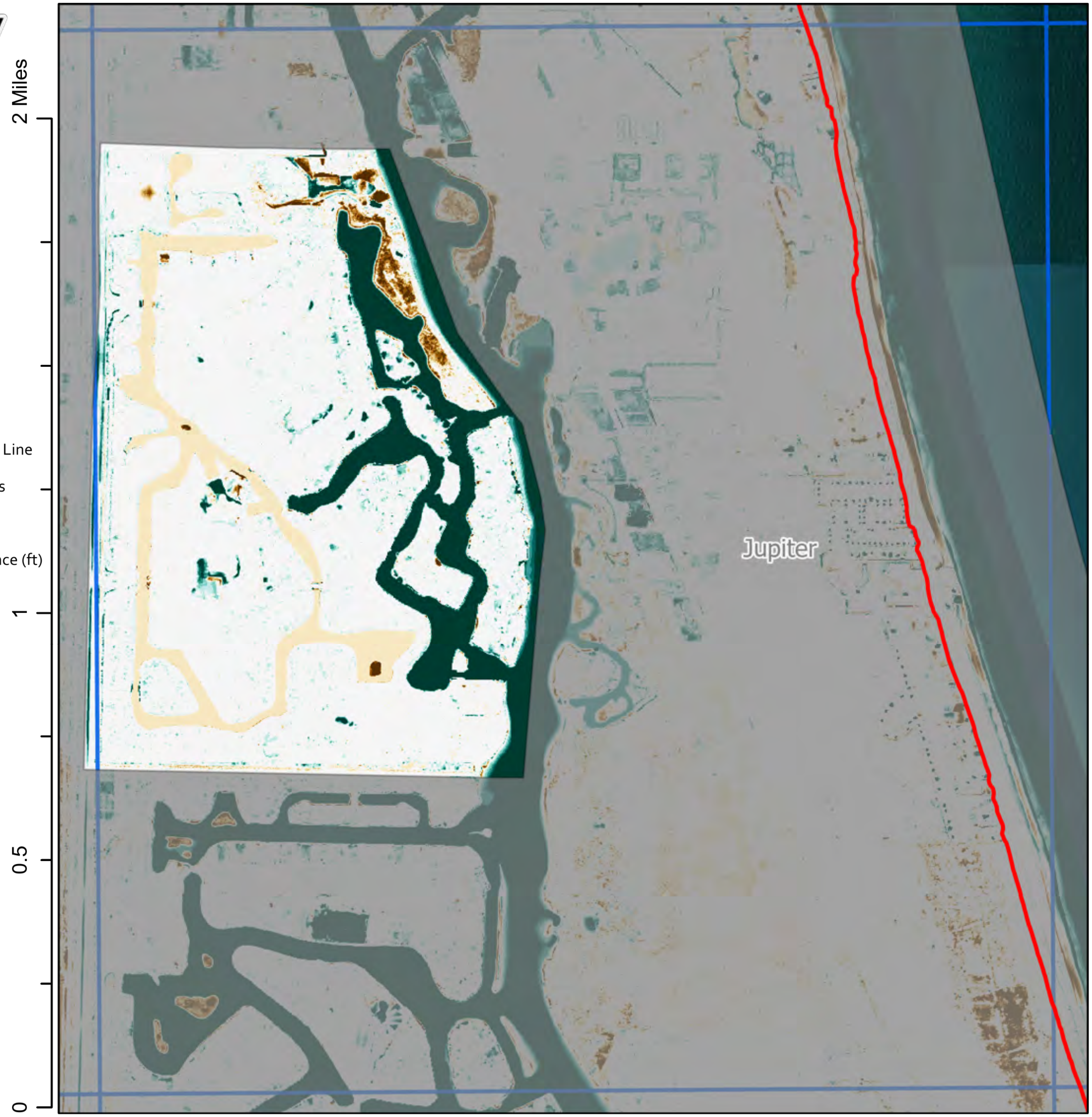
Frontal Dune Line

Municipalities

FIRM Panels

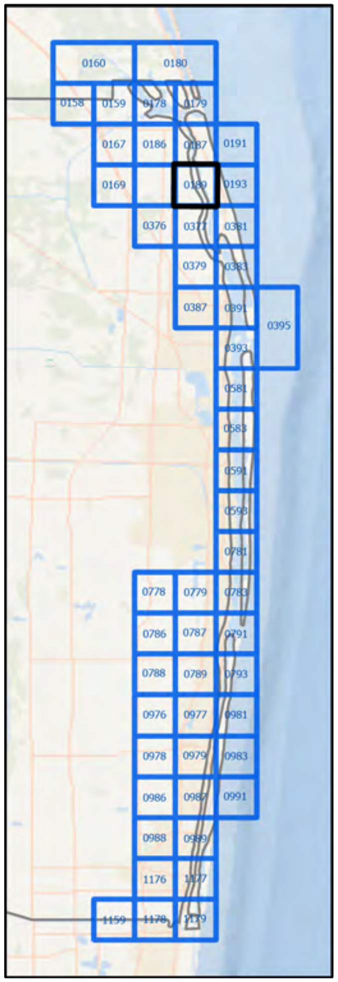
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0189



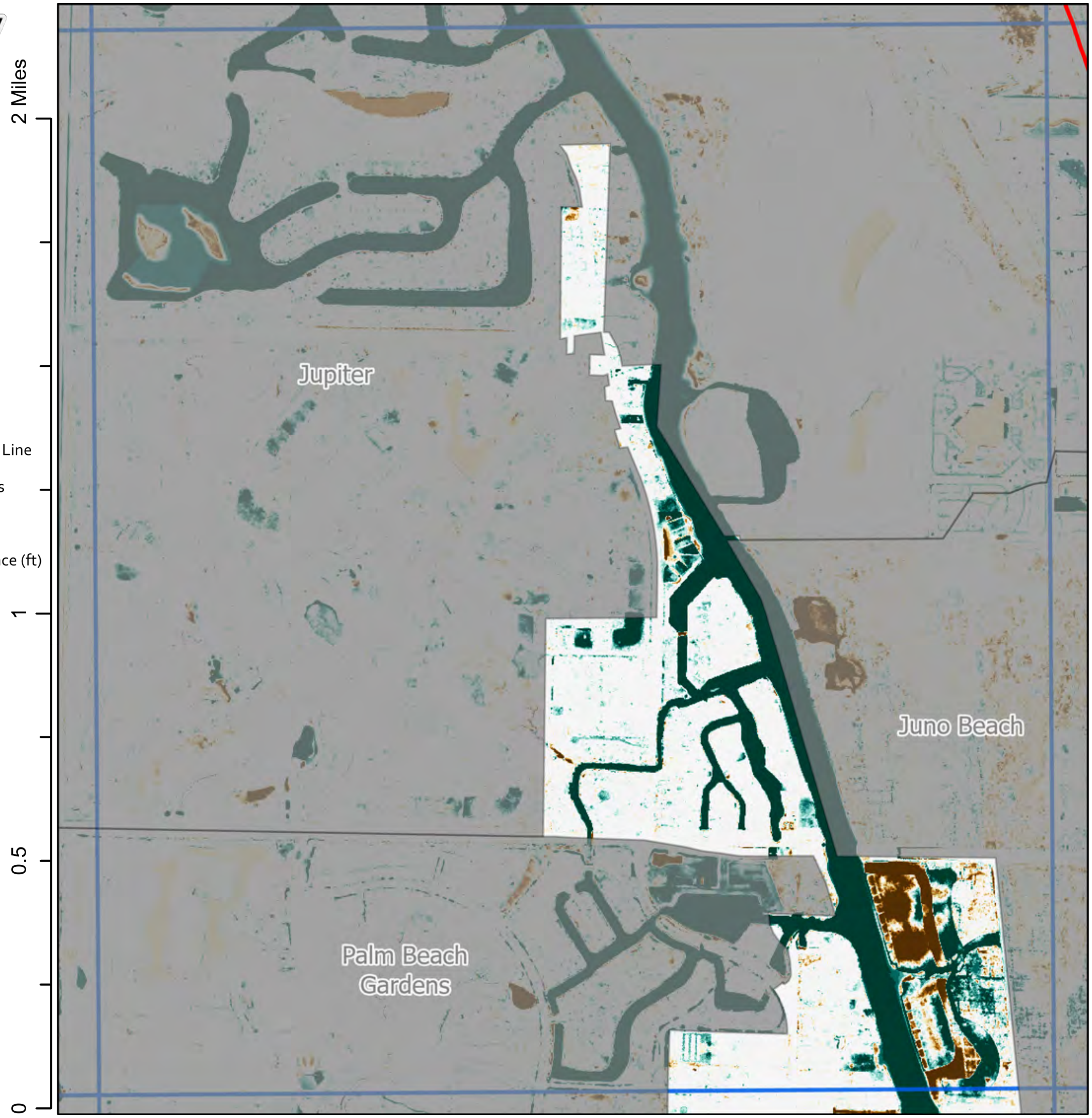
Frontal Dune Line

Municipalities

FIRM Panels

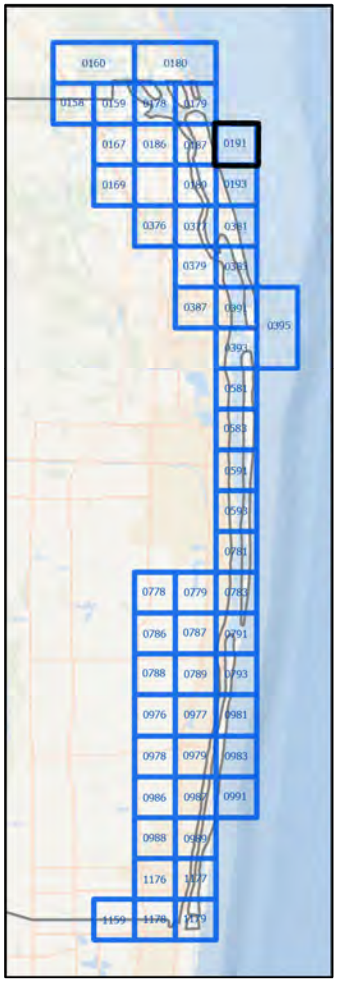
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0191



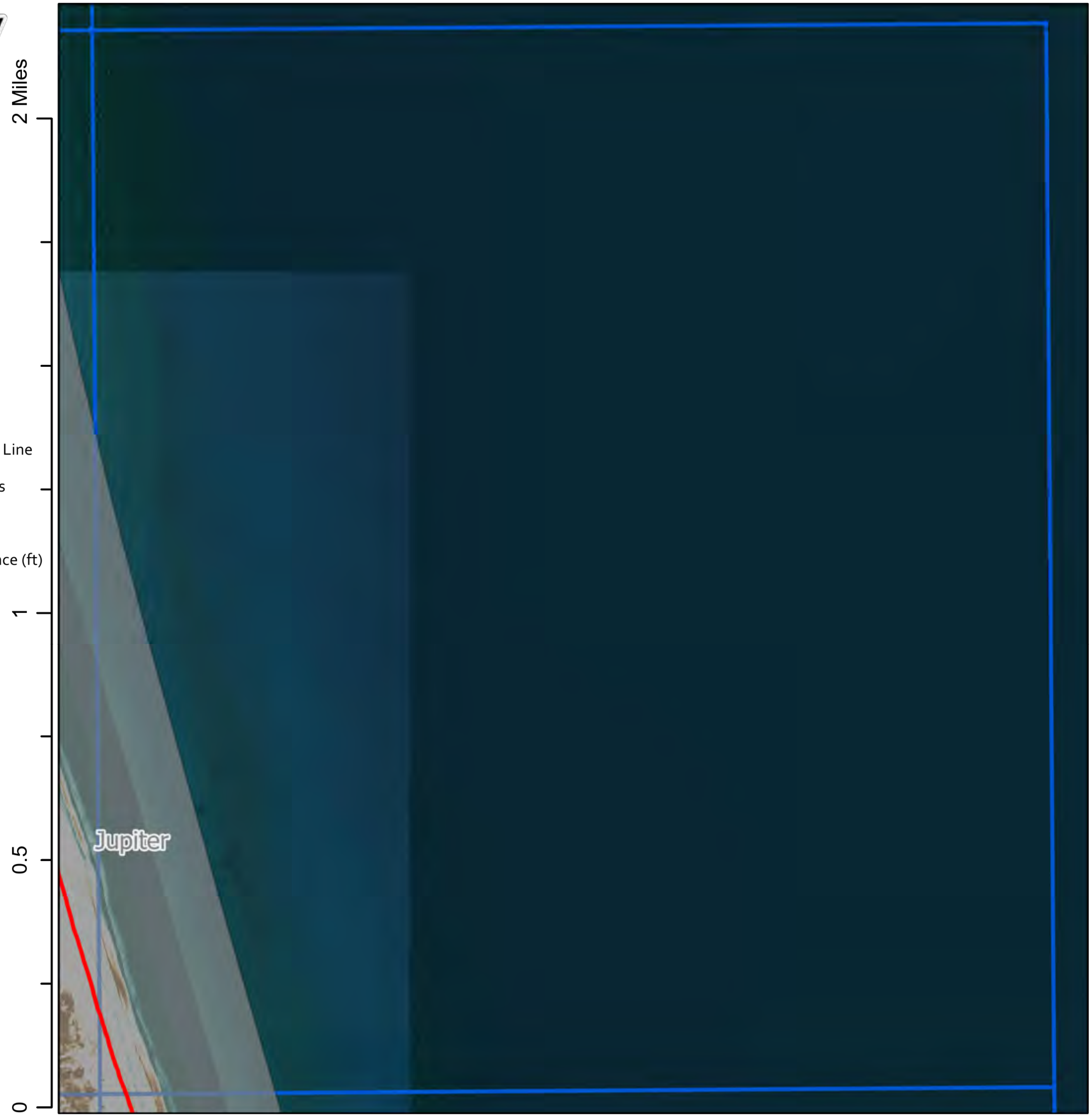
Frontal Dune Line

Municipalities

FIRM Panels

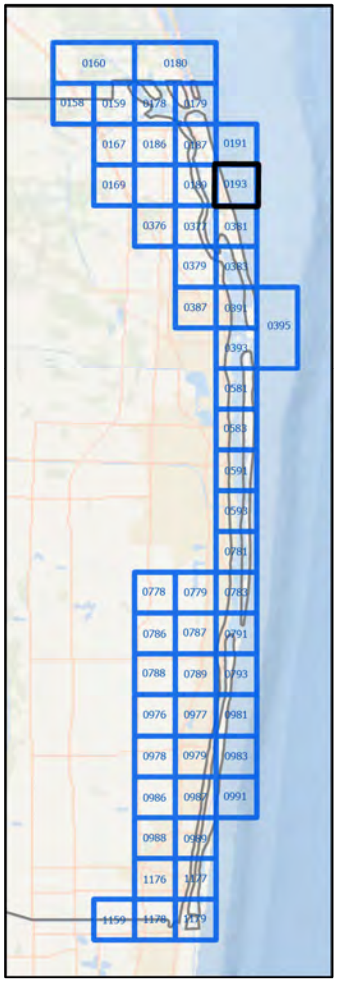
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0193



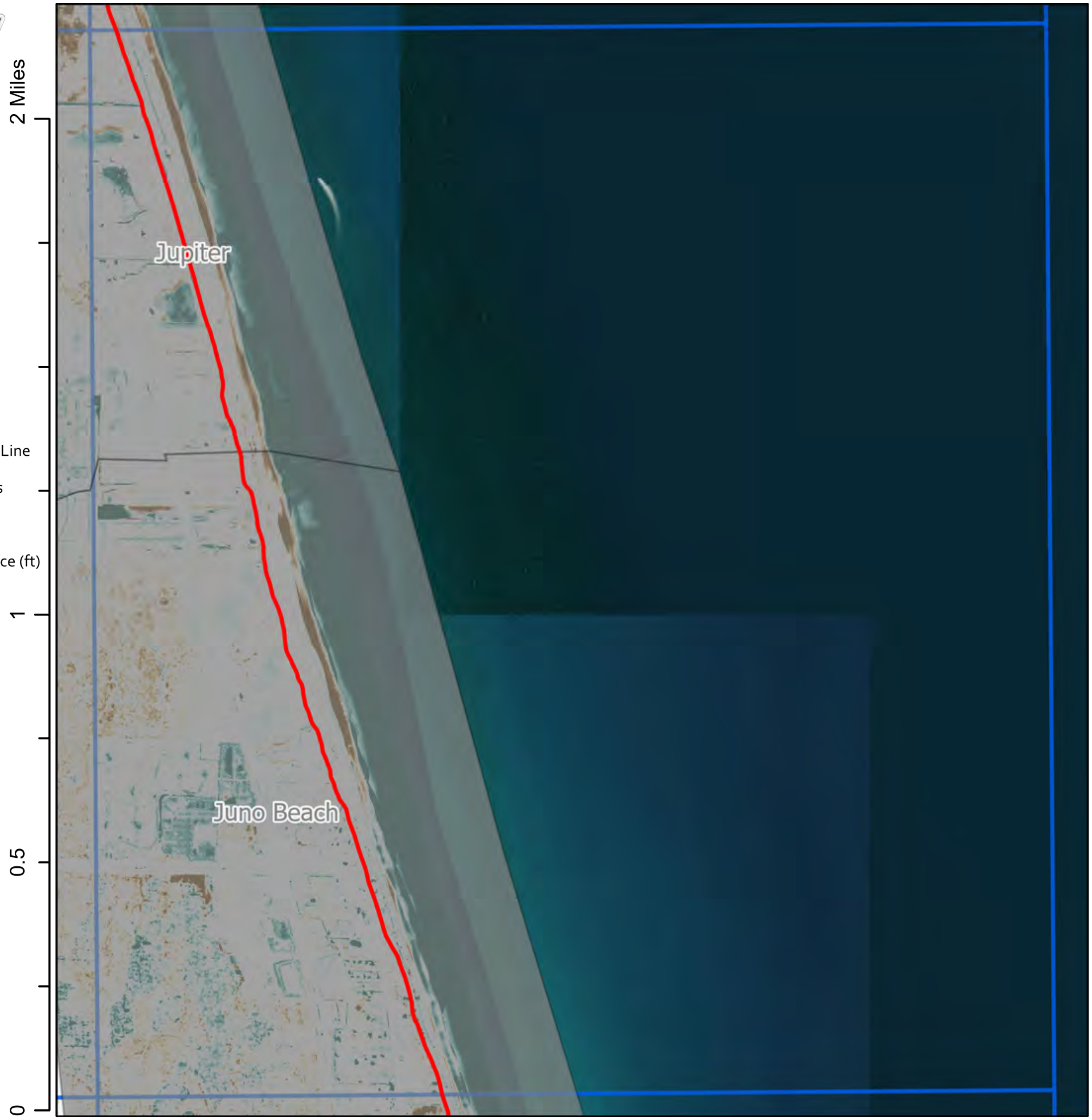
Frontal Dune Line

Municipalities

FIRM Panels

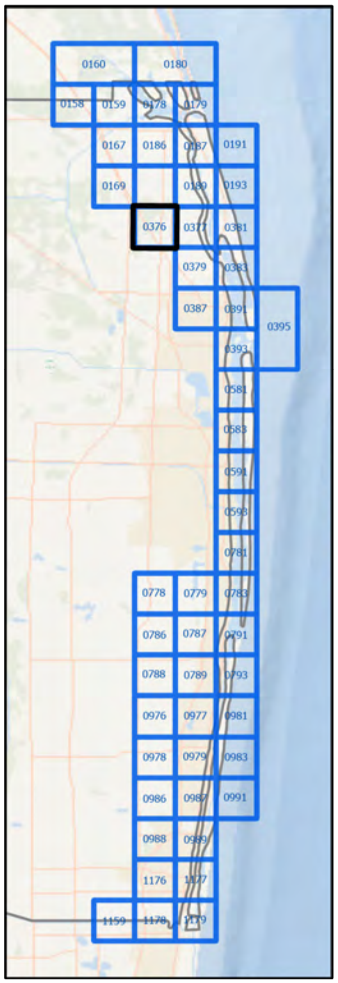
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

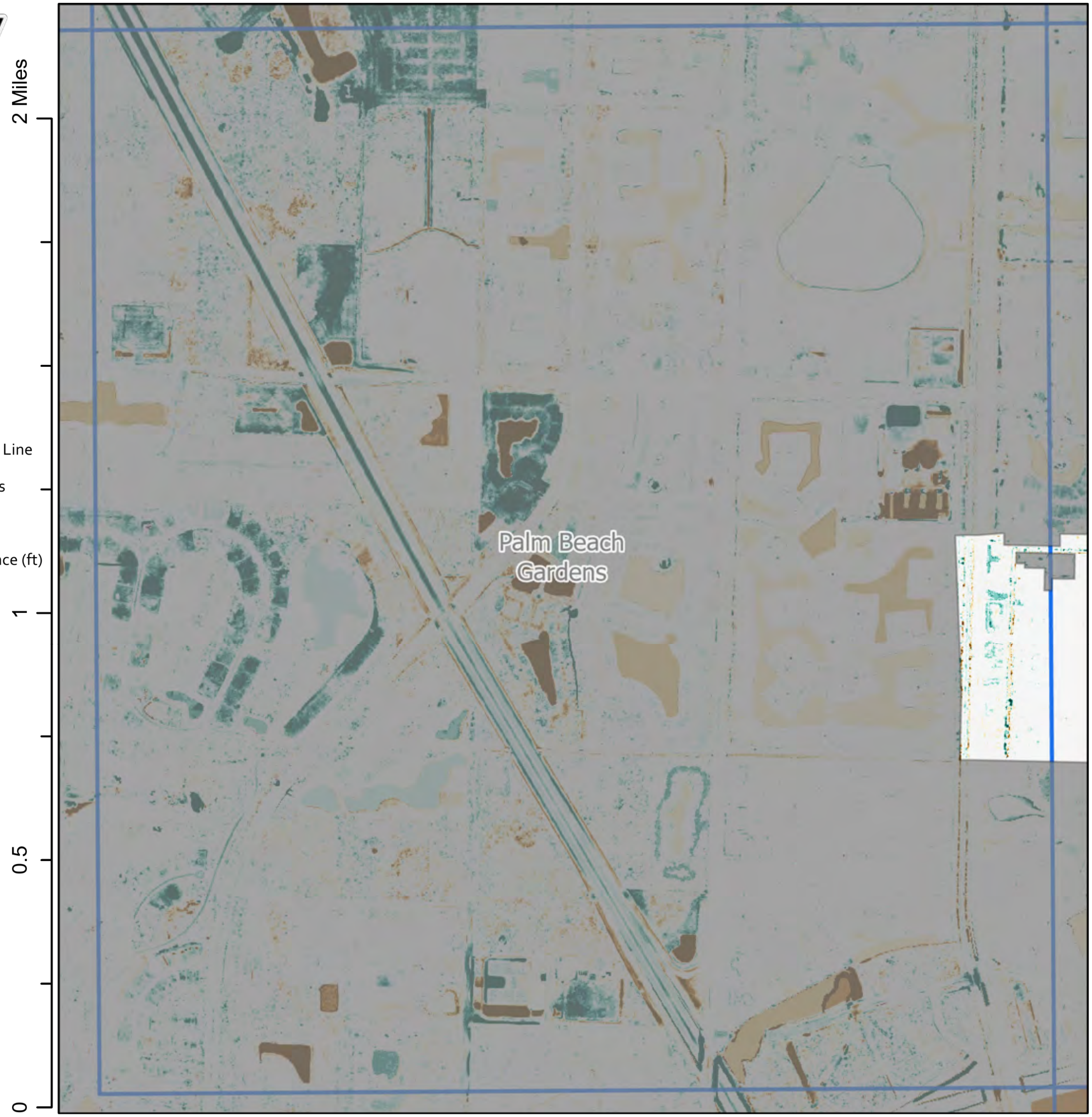
FIRM Panel: 0376



- Frontal Dune Line
- Municipalities
- FIRM Panels

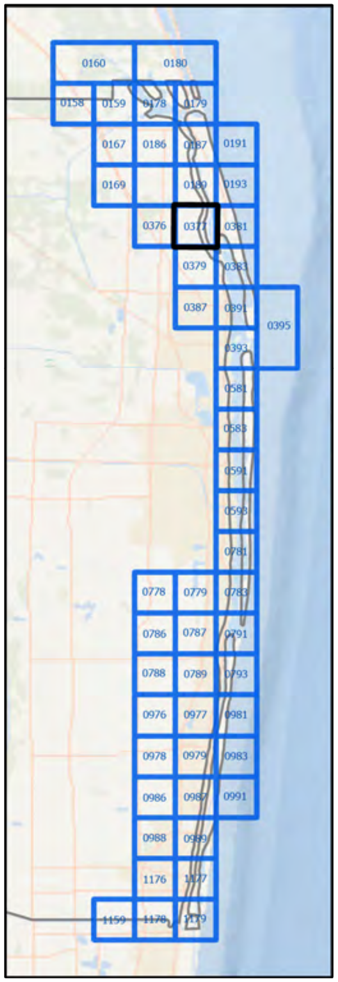
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



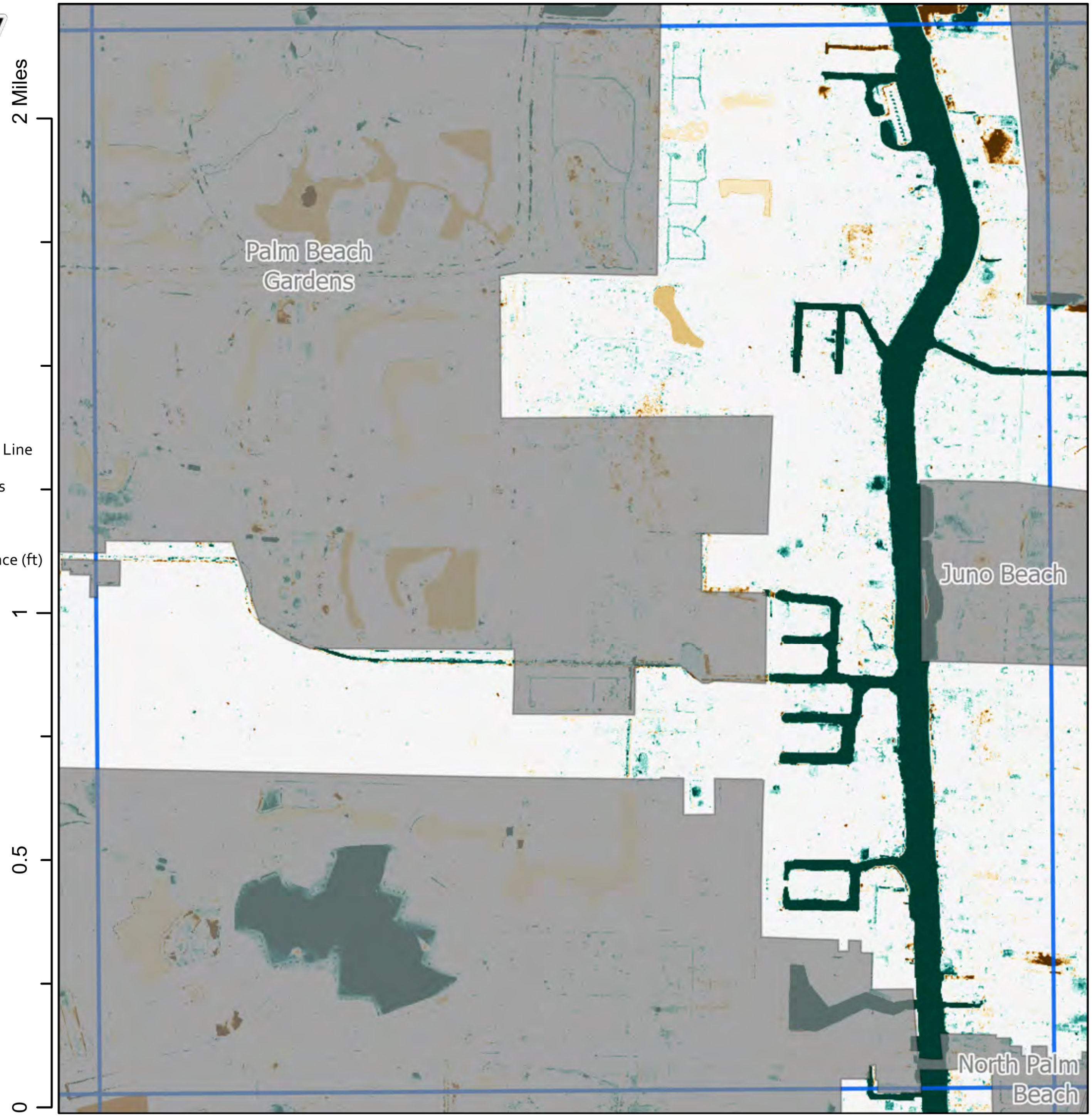
Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0377



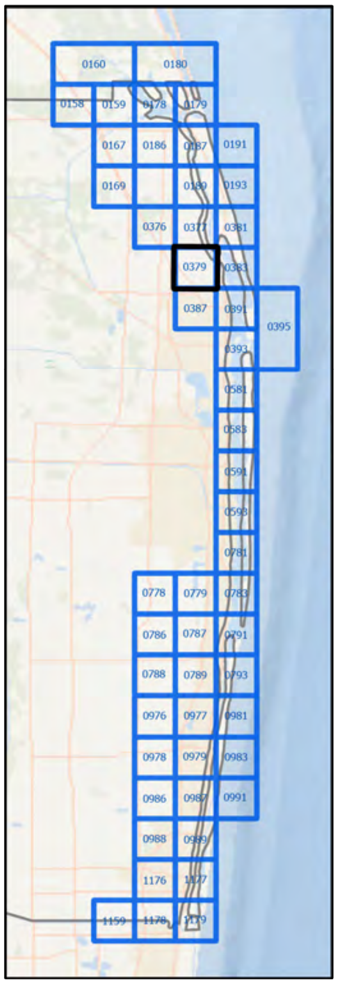
Frontal Dune Line
Municipalities
FIRM Panels

Calculated Difference (ft)
< -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
> 2.5

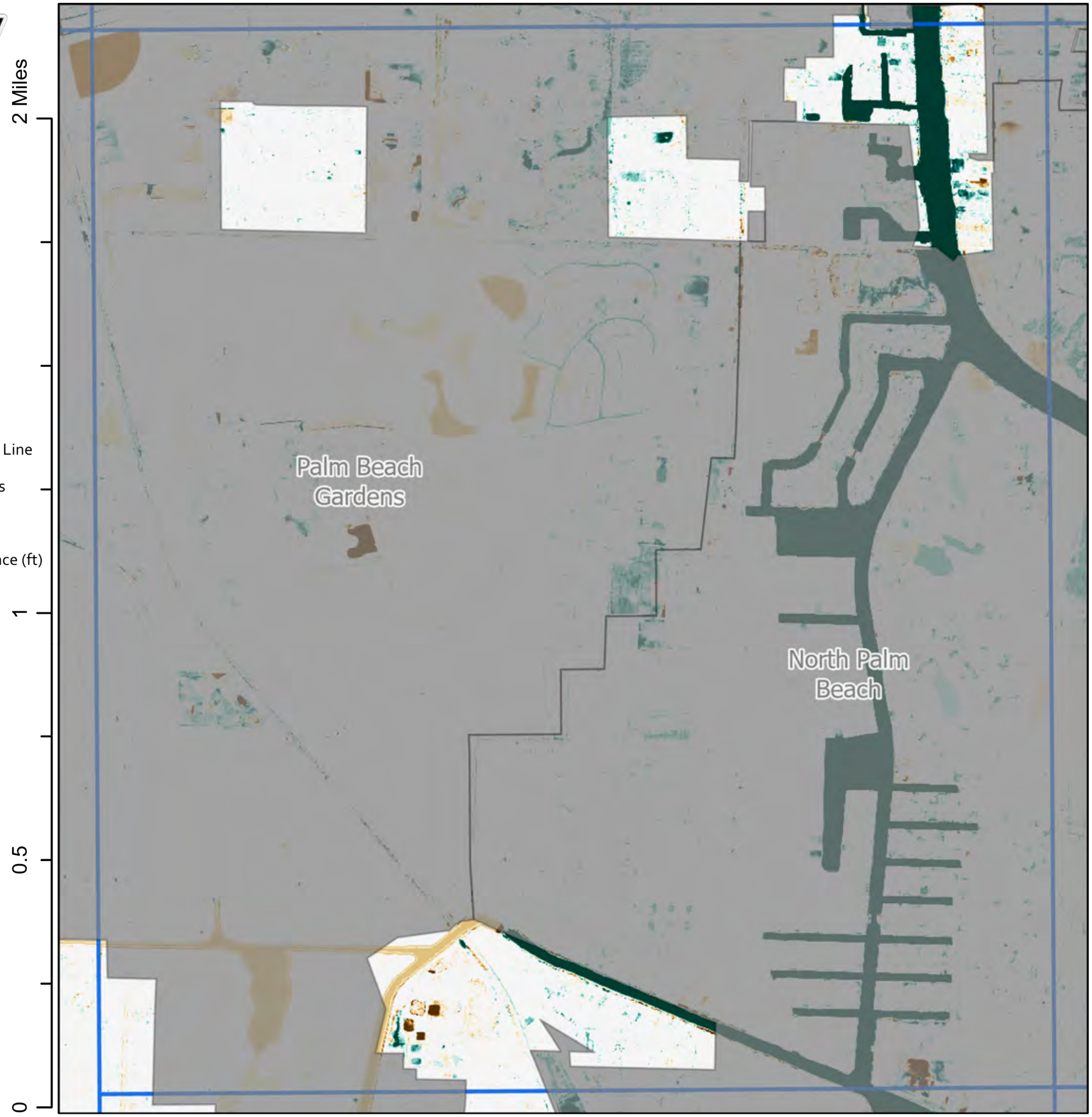


Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0379

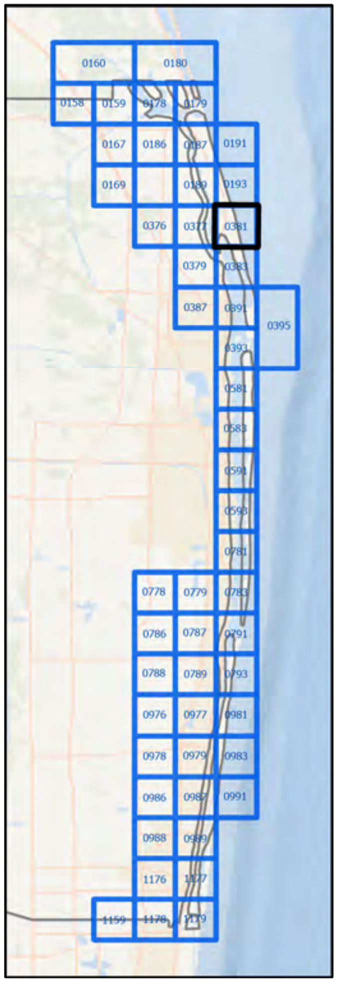


Frontal Dune Line
Municipalities
FIRM Panels
Calculated Difference (ft)
< -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
> 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0381



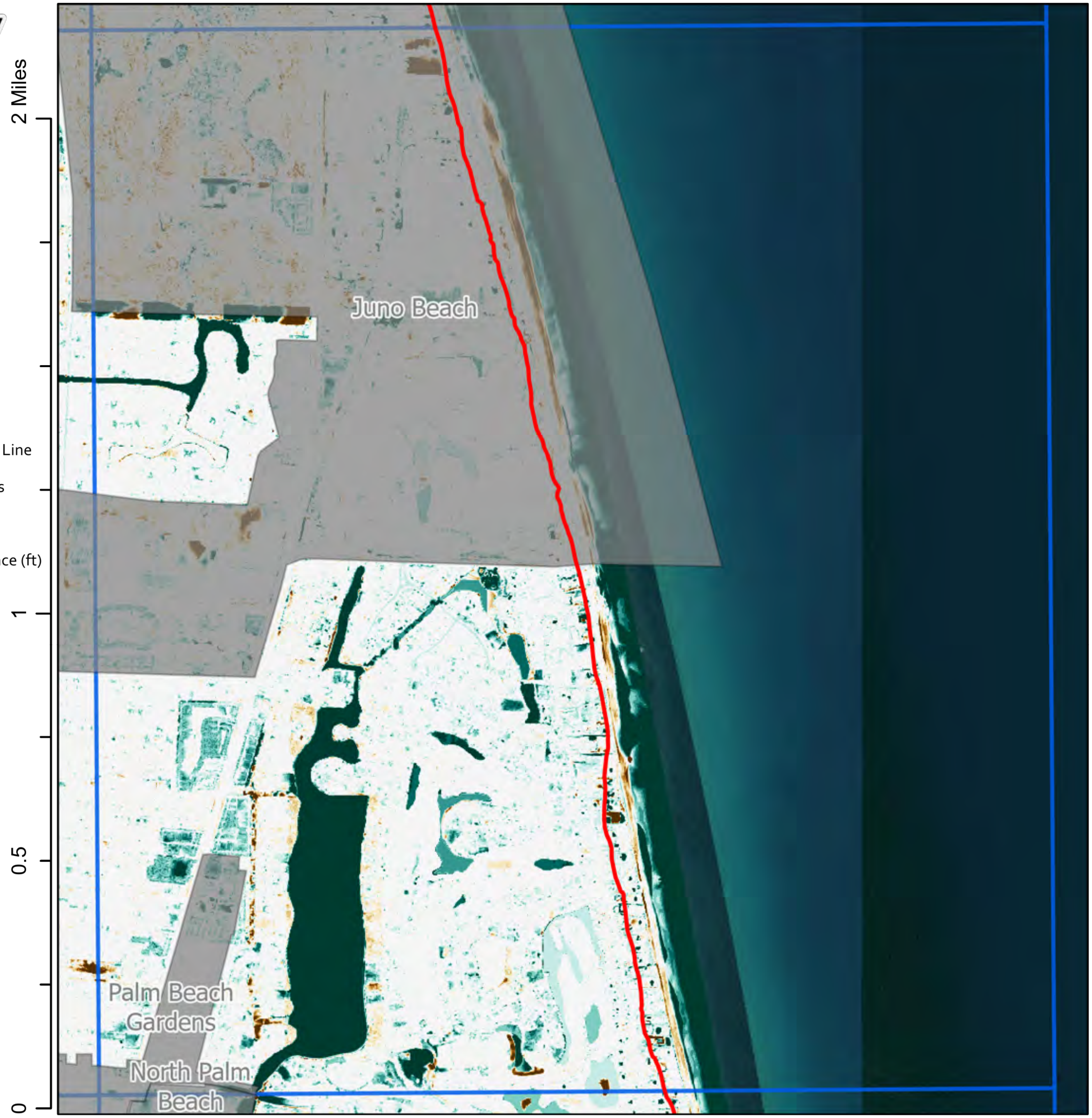
Frontal Dune Line

Municipalities

FIRM Panels

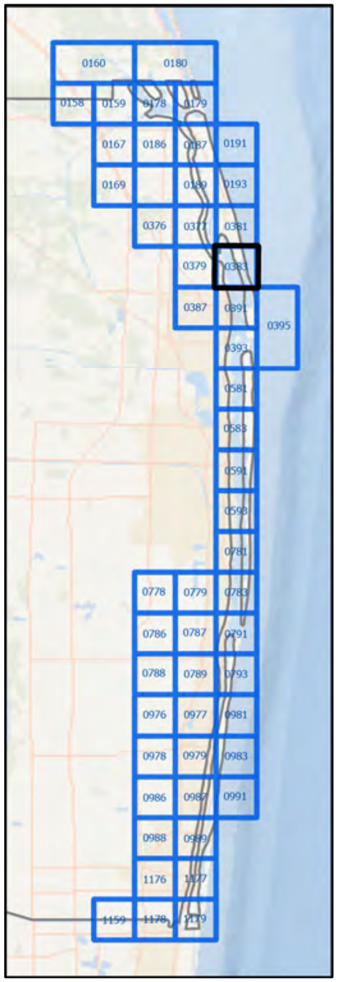
Calculated Difference (ft)

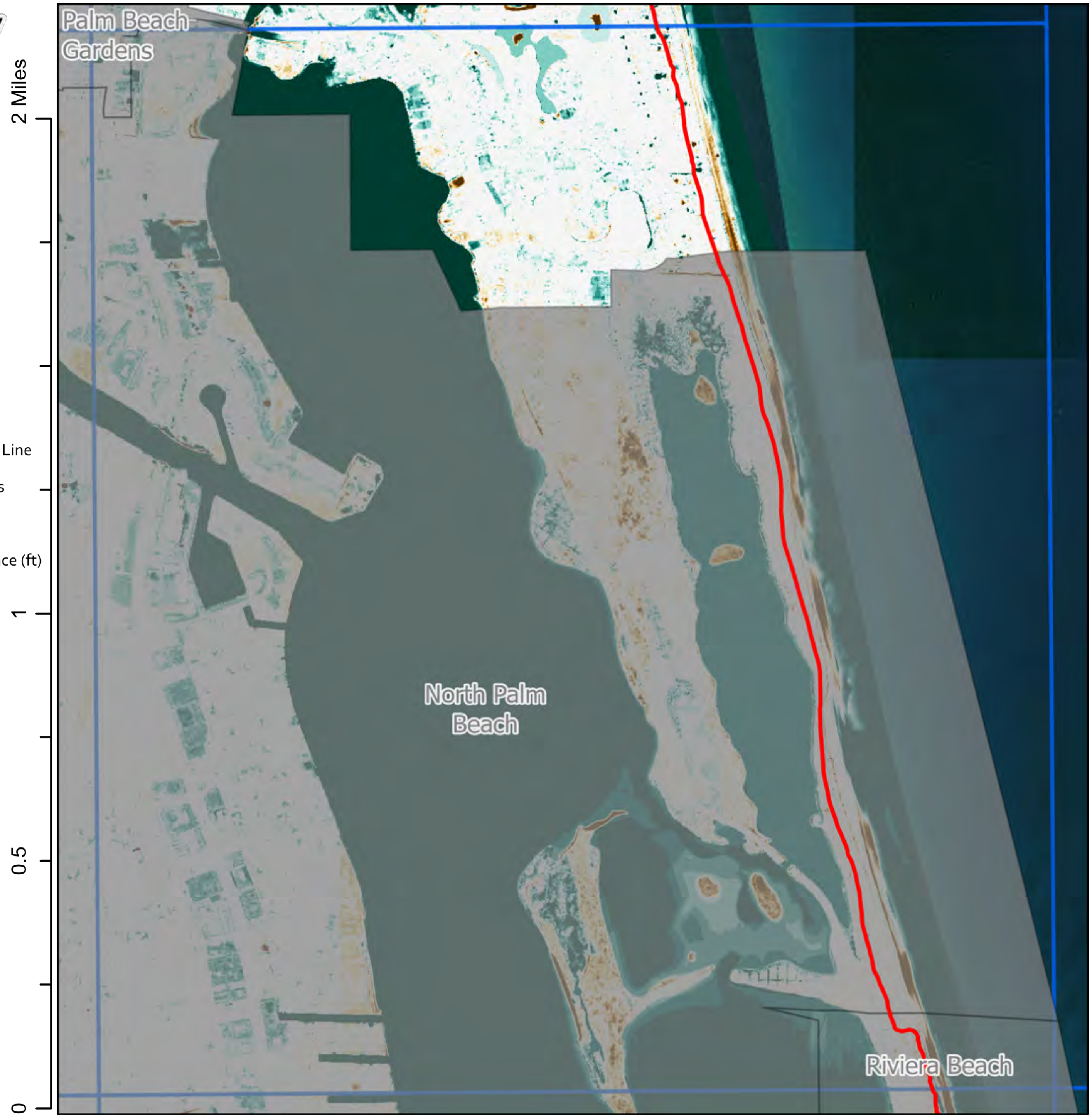
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

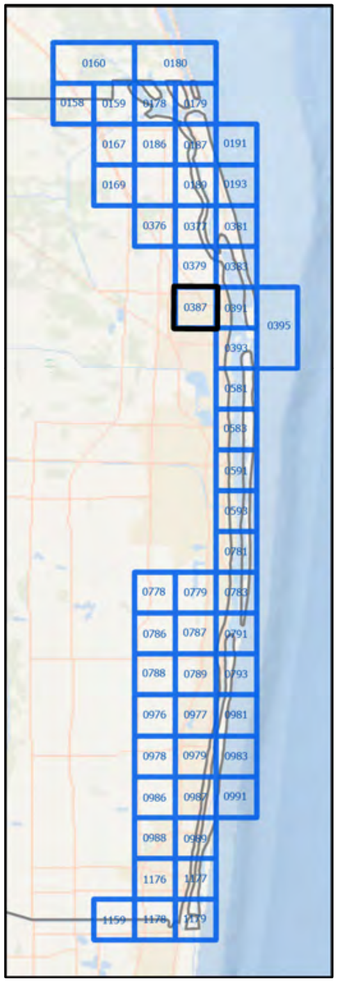
FIRM Panel: 0383





Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

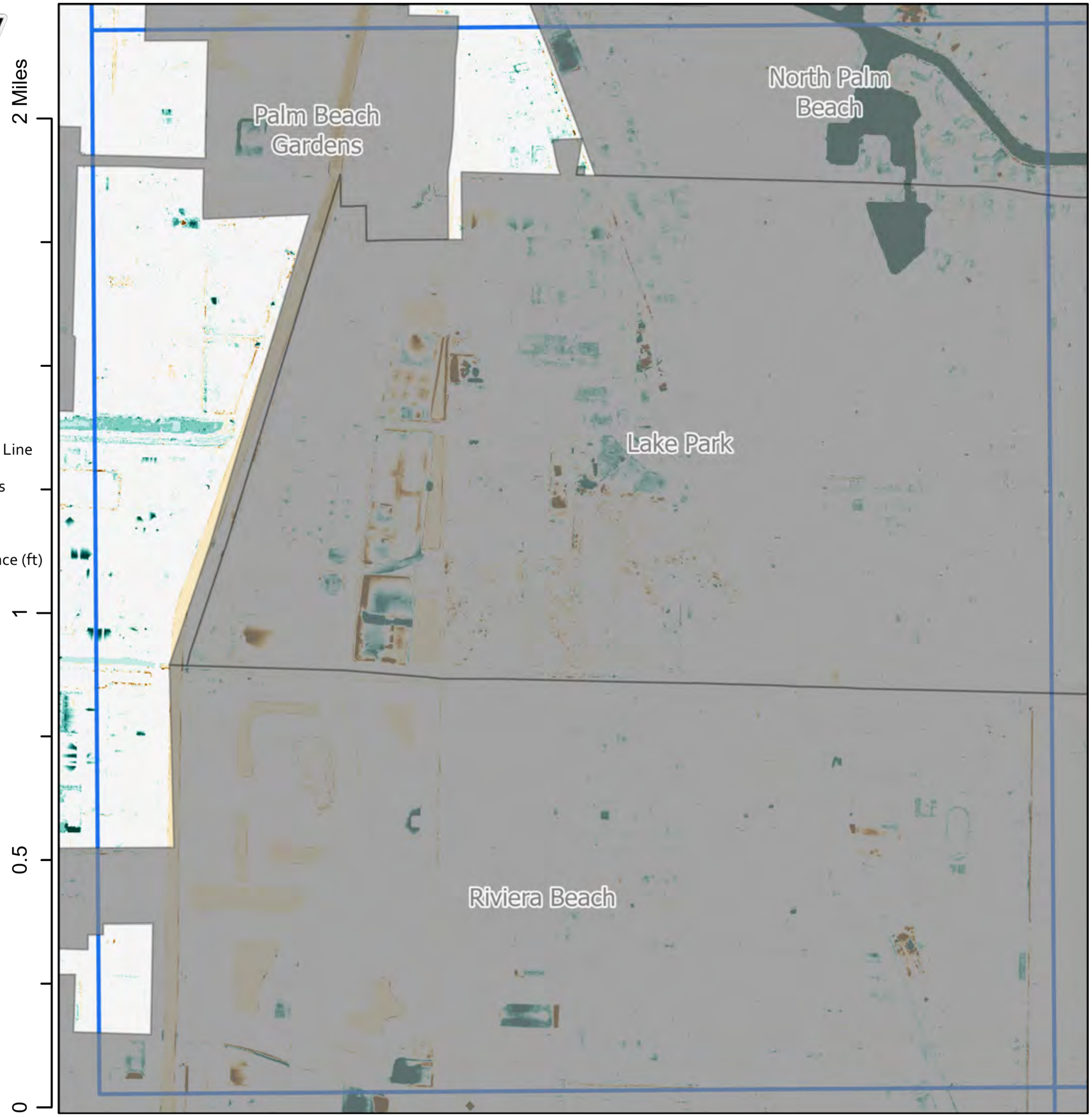
FIRM Panel: 0387



- Frontal Dune Line
- Municipalities
- FIRM Panels

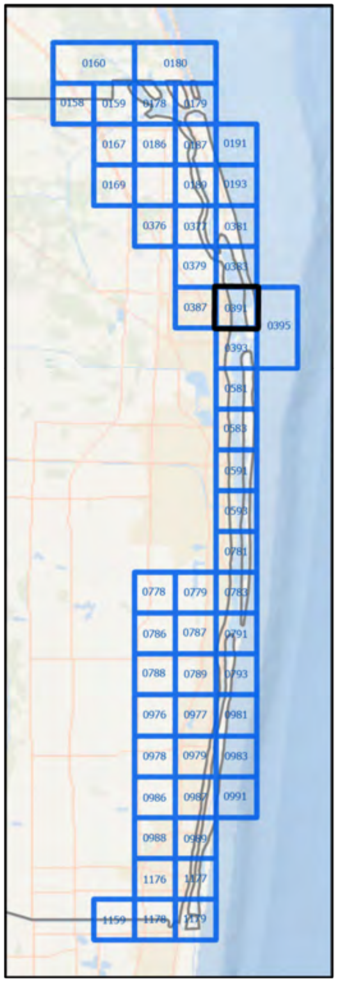
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0391



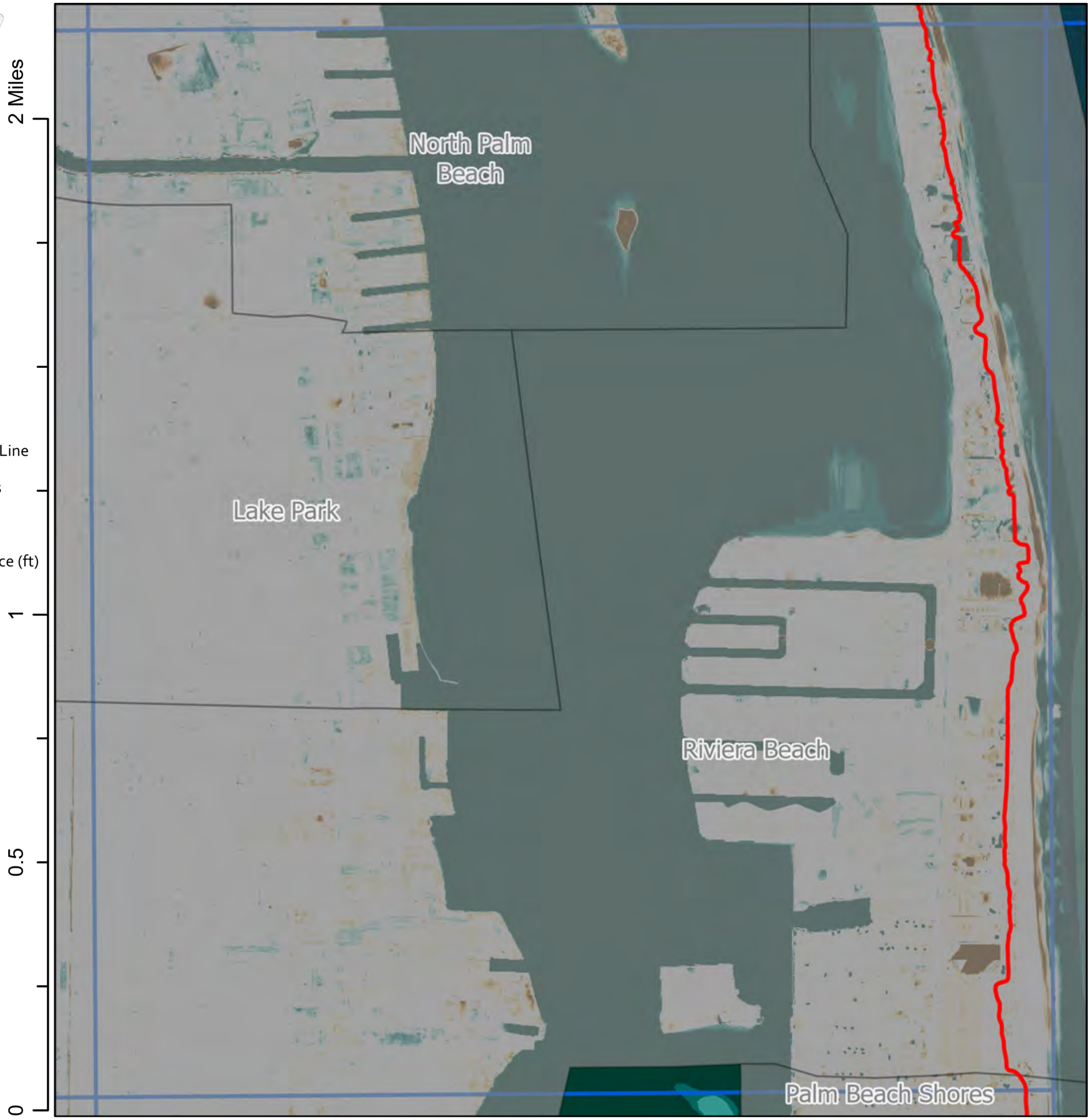
Frontal Dune Line

Municipalities

FIRM Panels

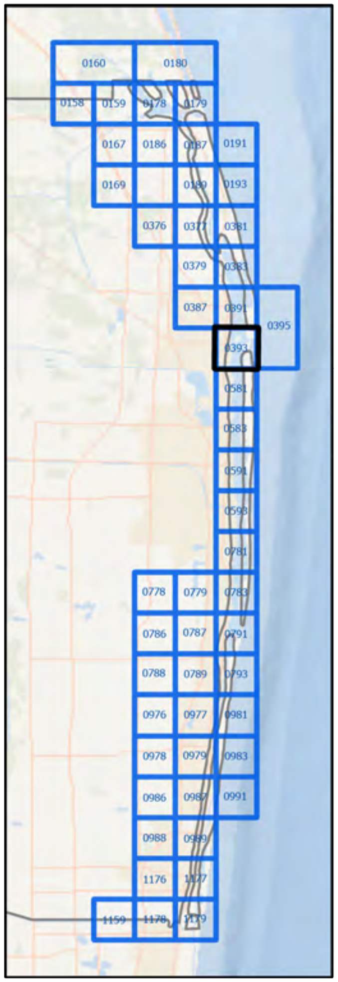
Calculated Difference (ft)

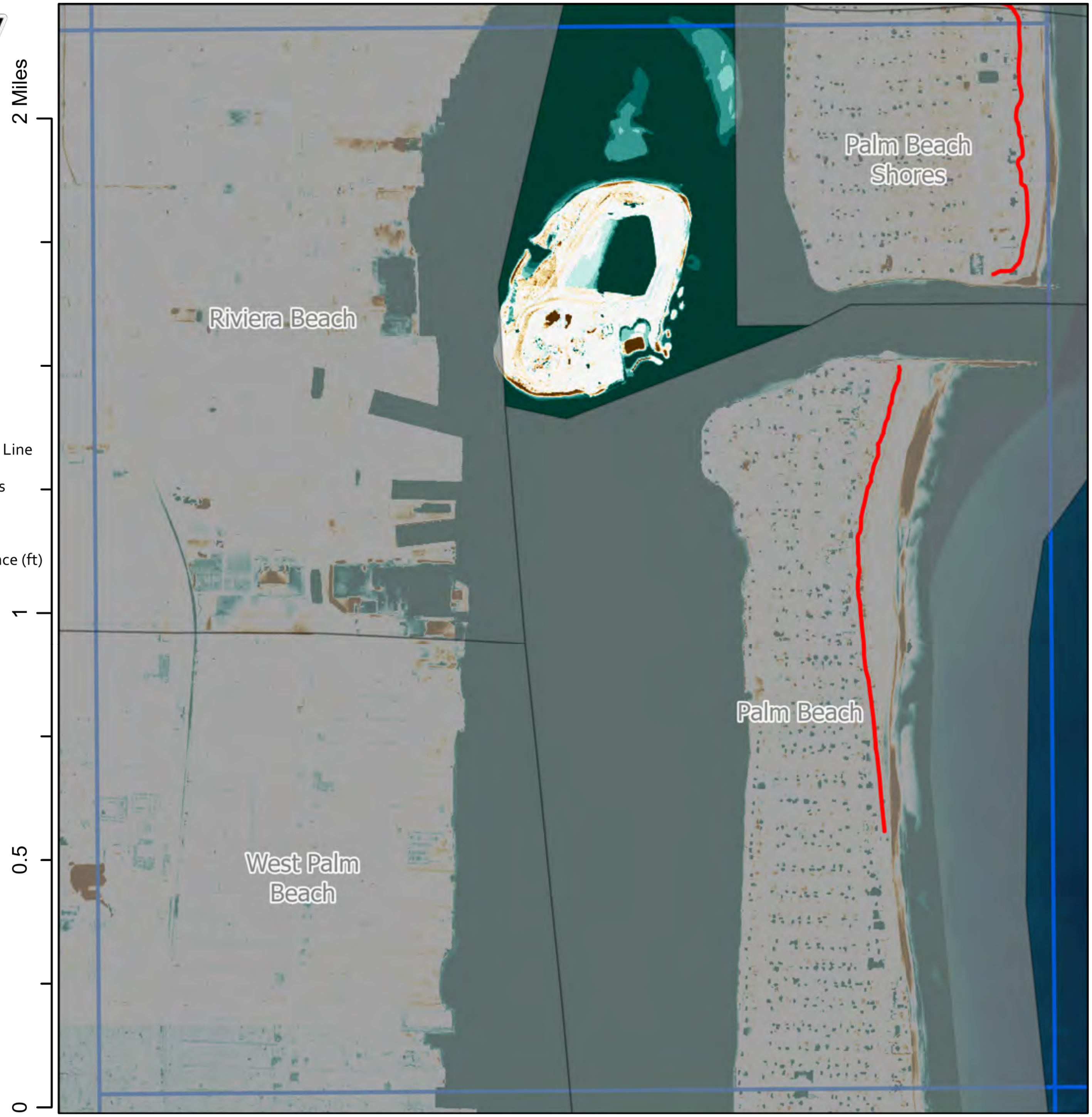
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0393





Frontal Dune Line

Municipalities

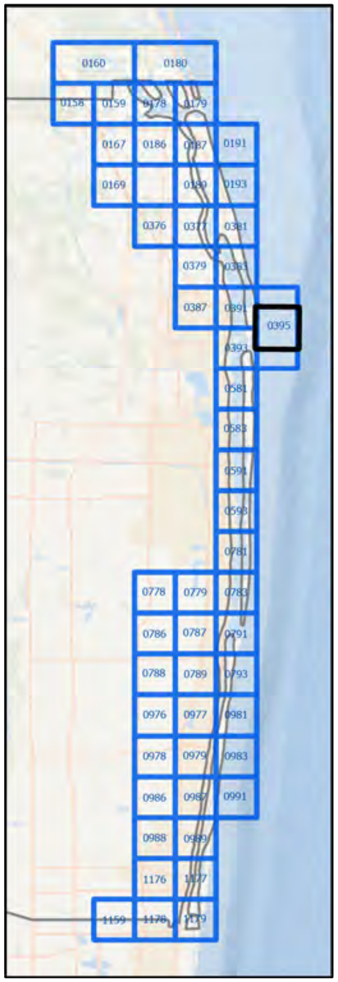
FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0395



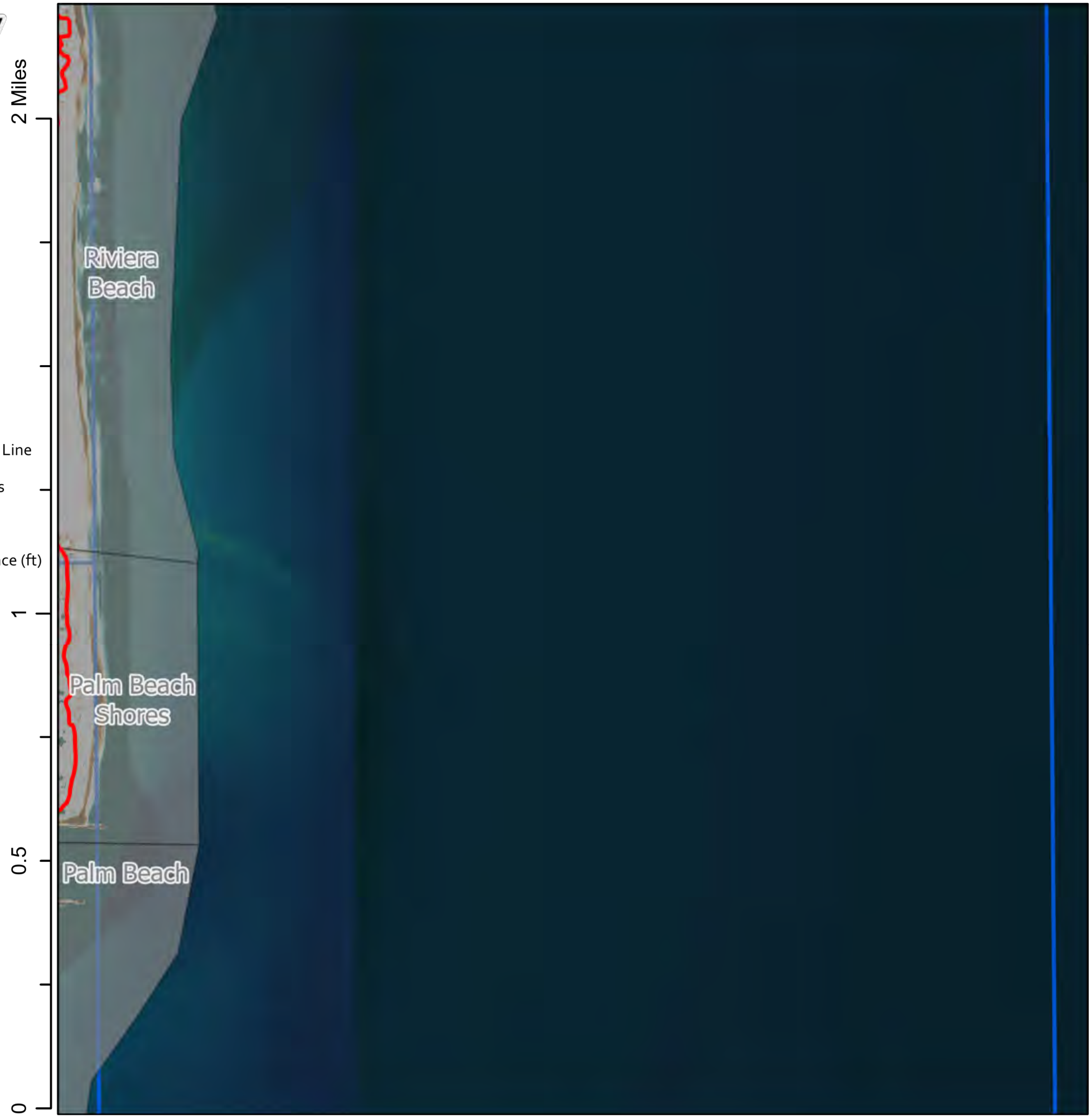
Frontal Dune Line

Municipalities

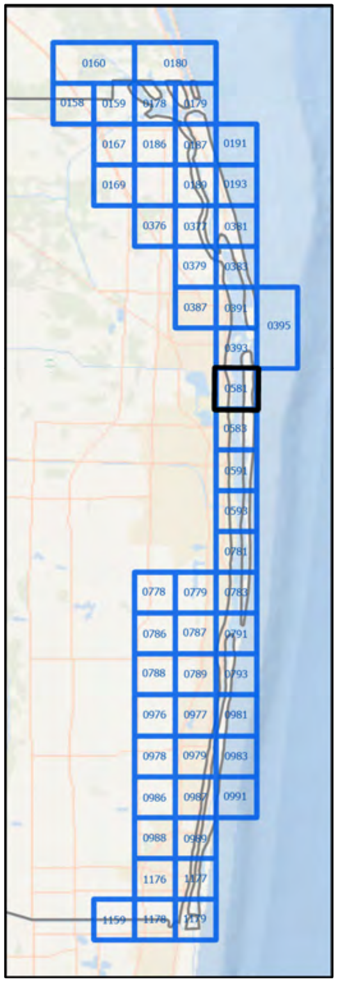
FIRM Panels

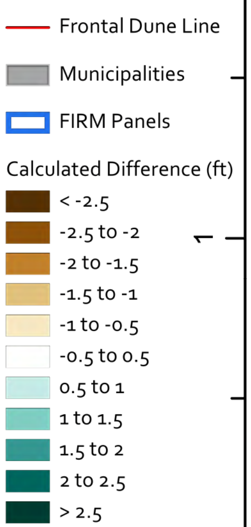
Calculated Difference (ft)

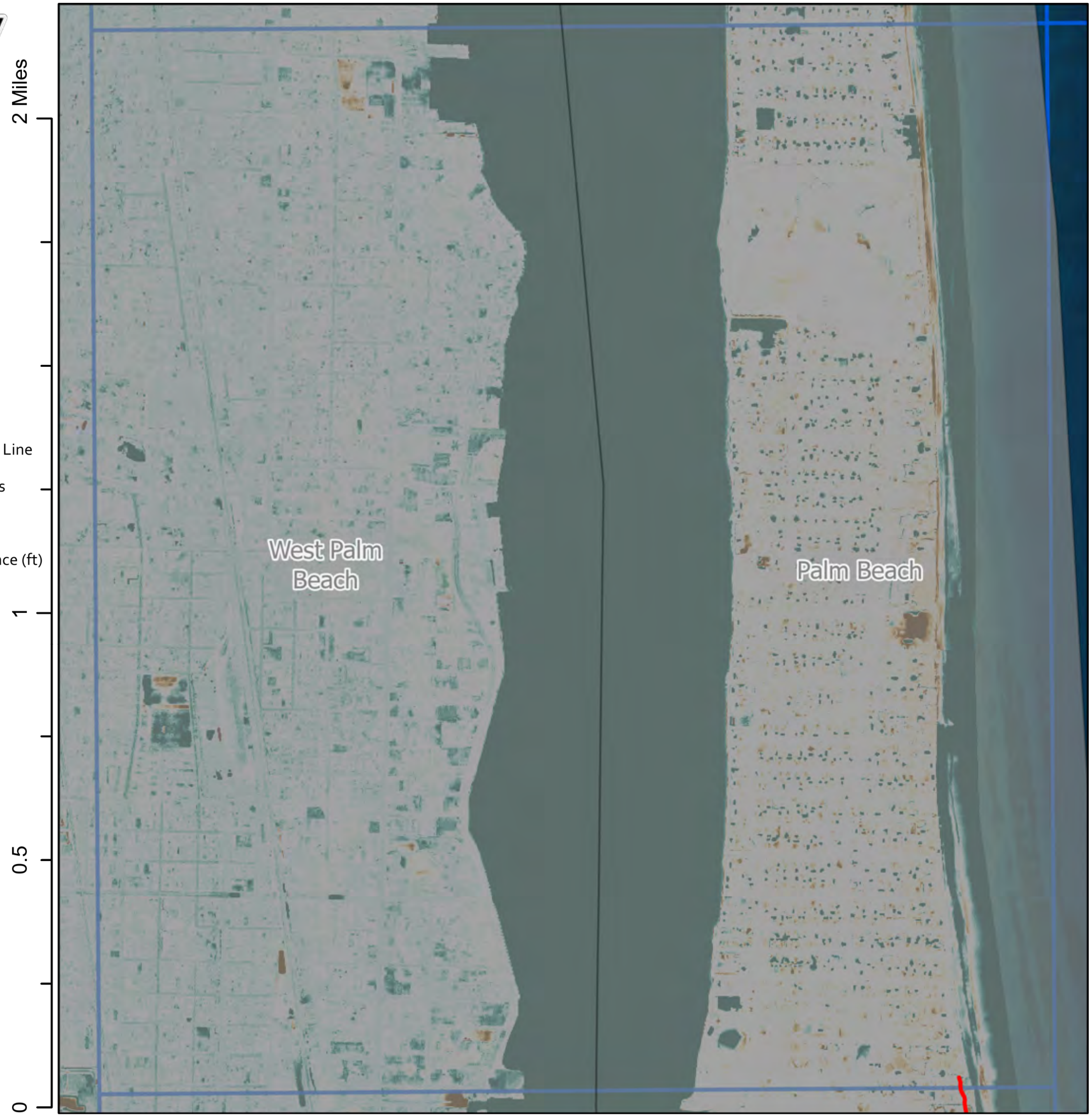
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM FIRM Panel: 0581

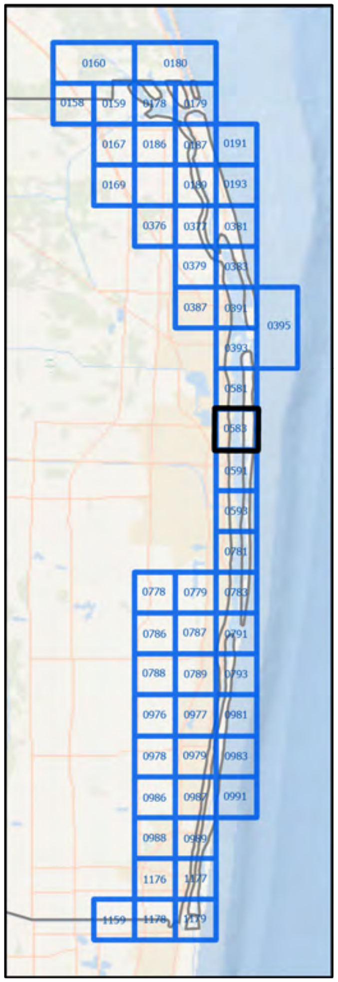


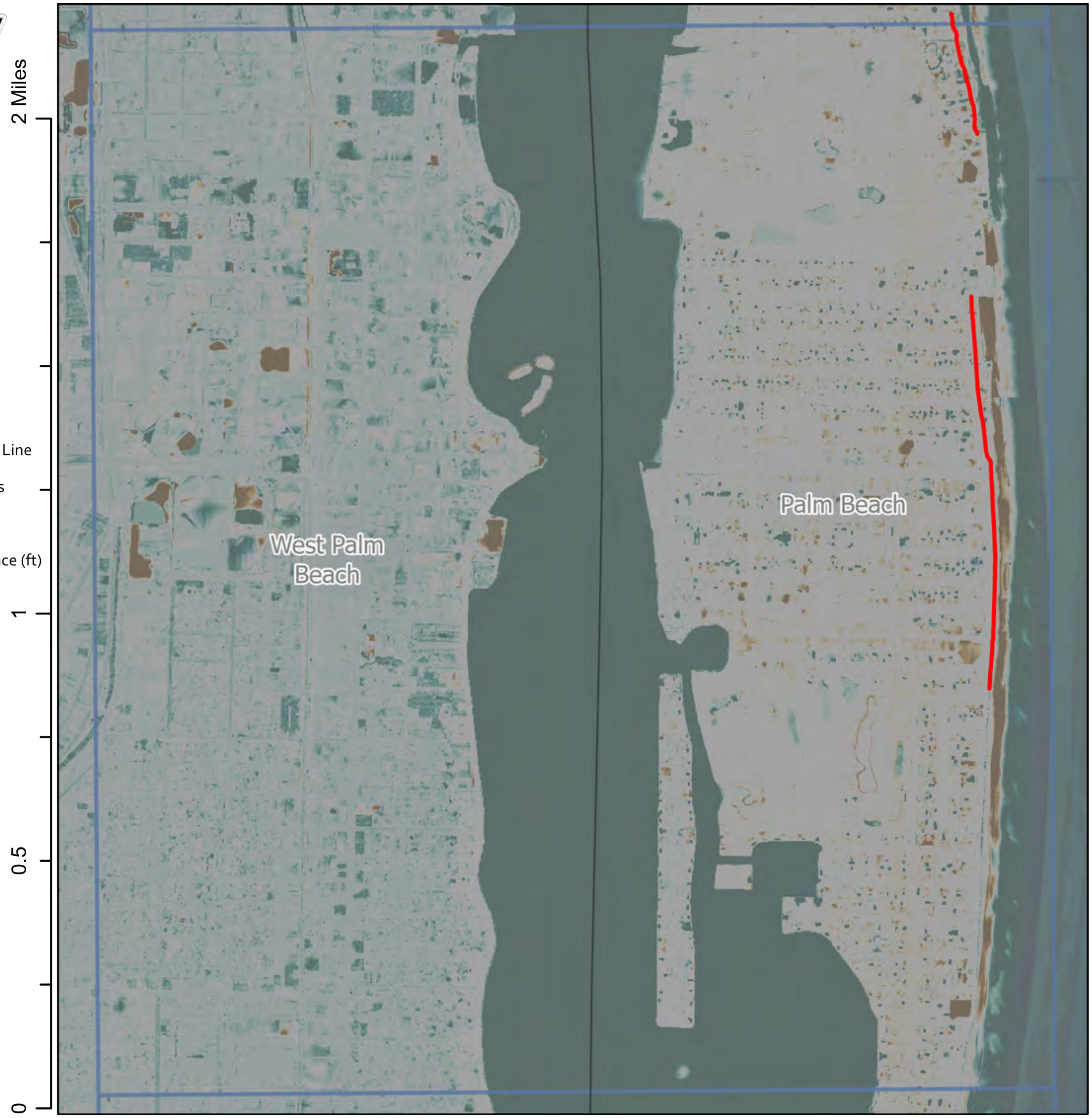




Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0583





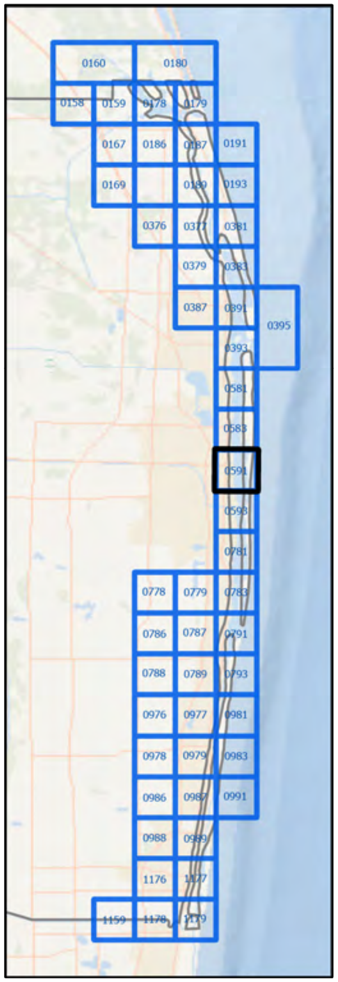
- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0591



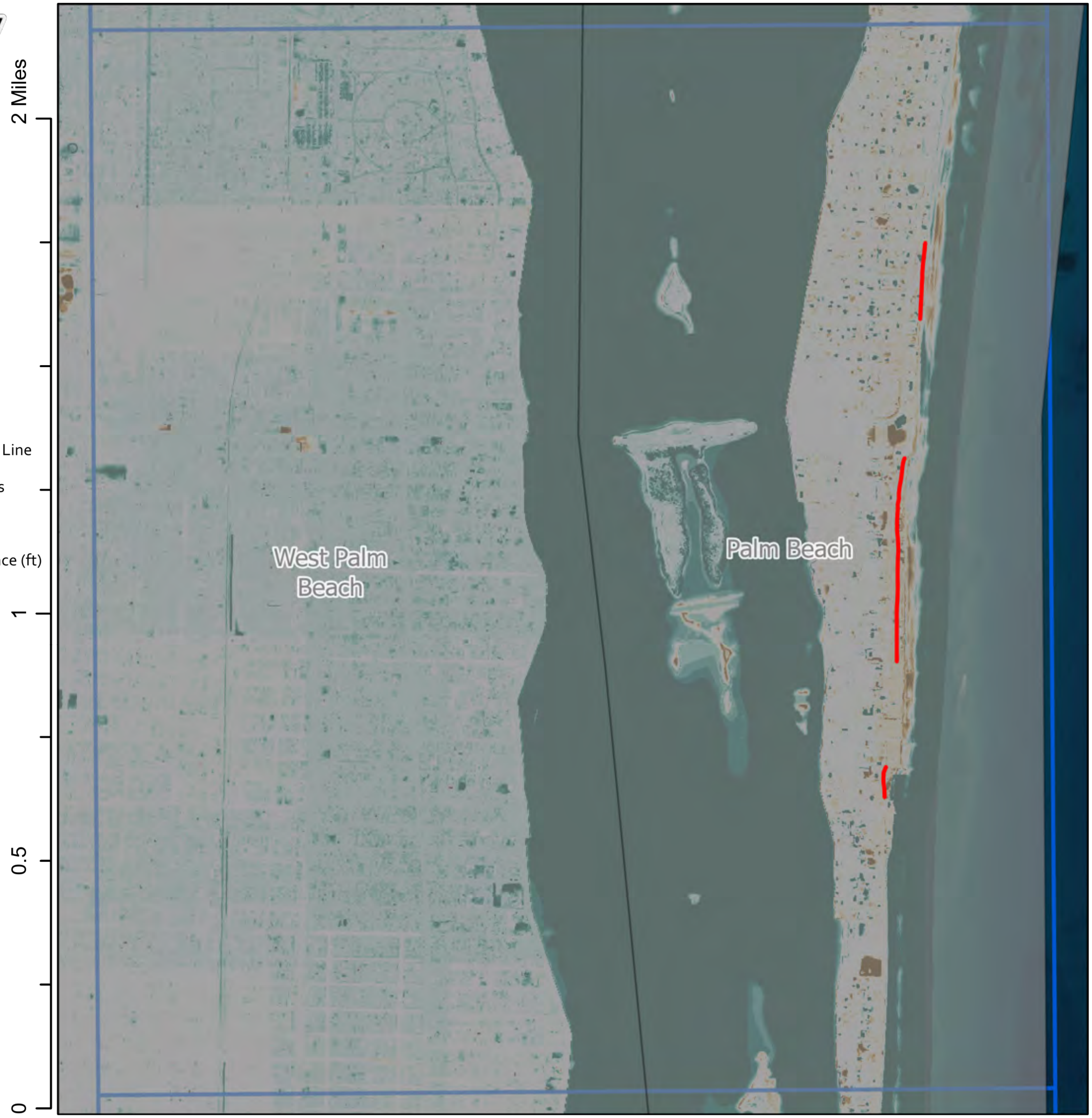
Frontal Dune Line

Municipalities

FIRM Panels

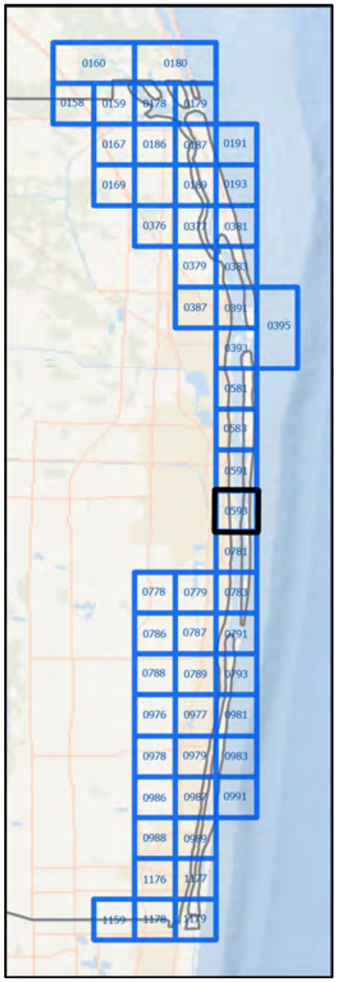
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0593



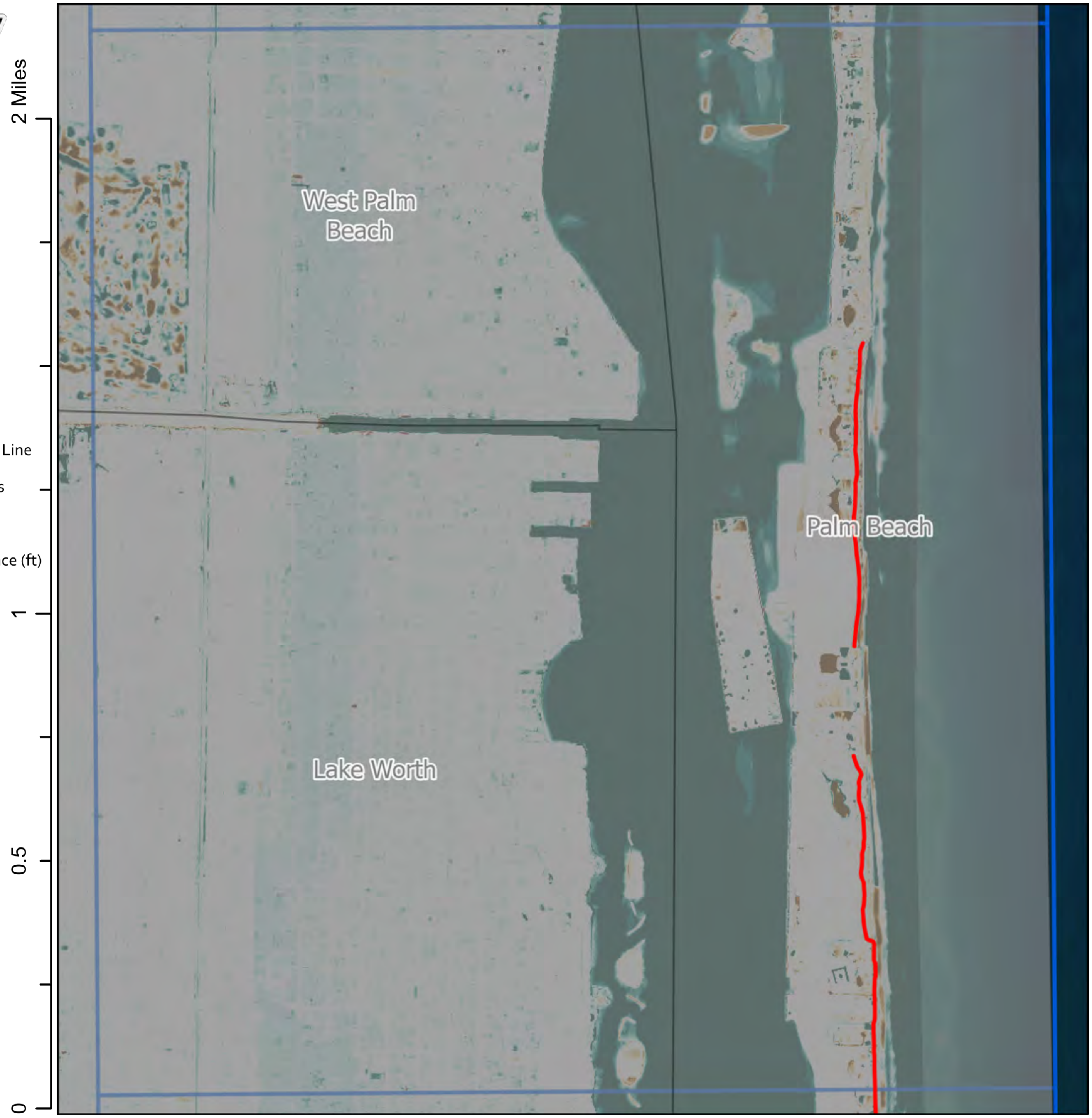
Frontal Dune Line

Municipalities

FIRM Panels

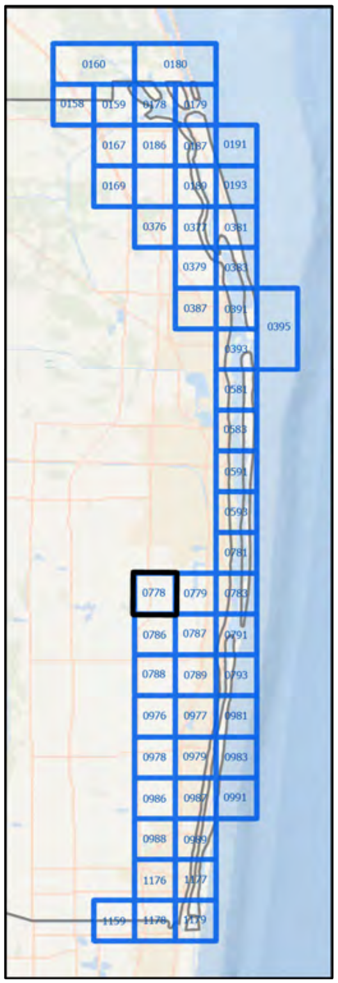
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

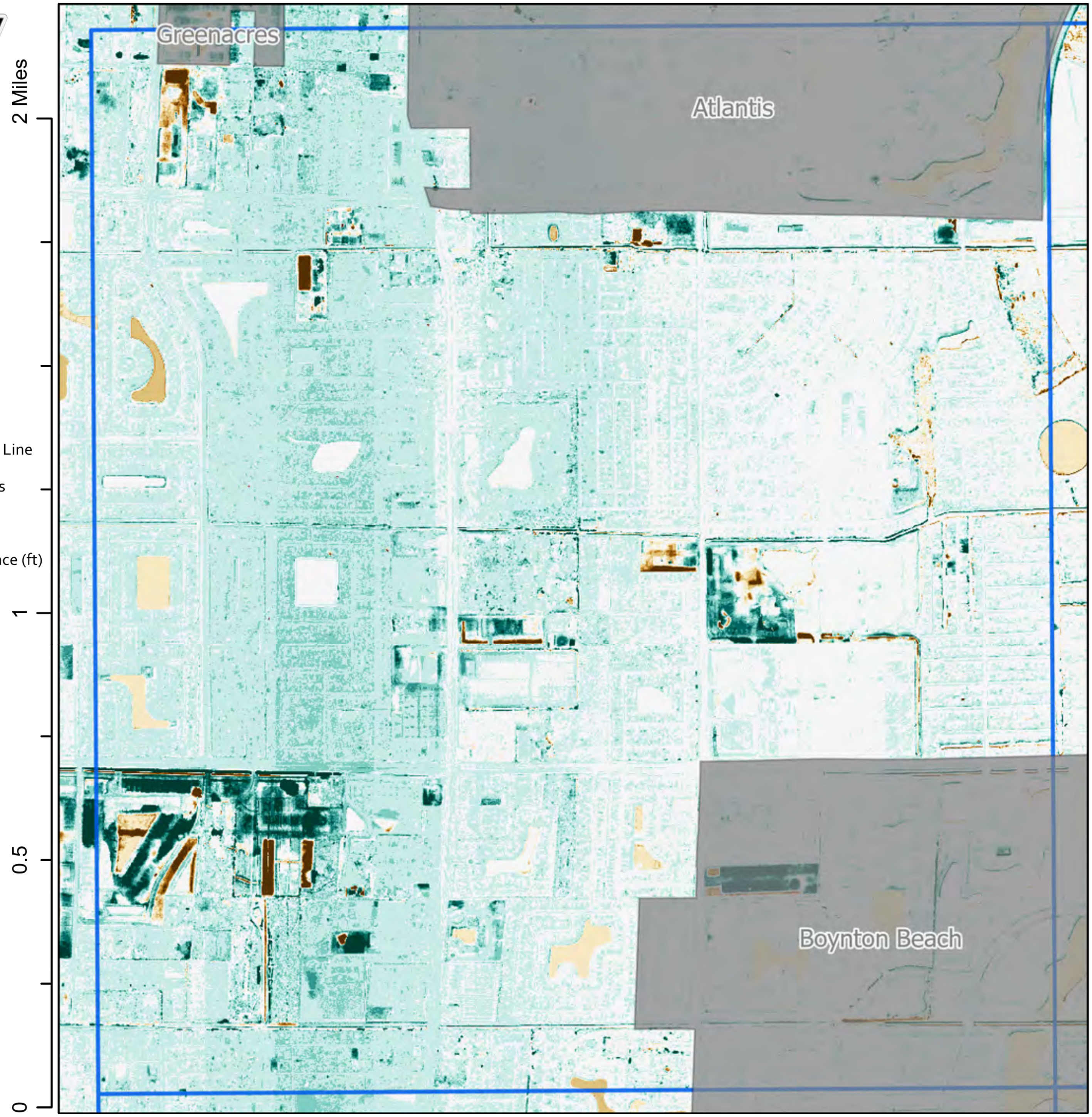
FIRM Panel: 0778



- Frontal Dune Line
- Municipalities
- FIRM Panels

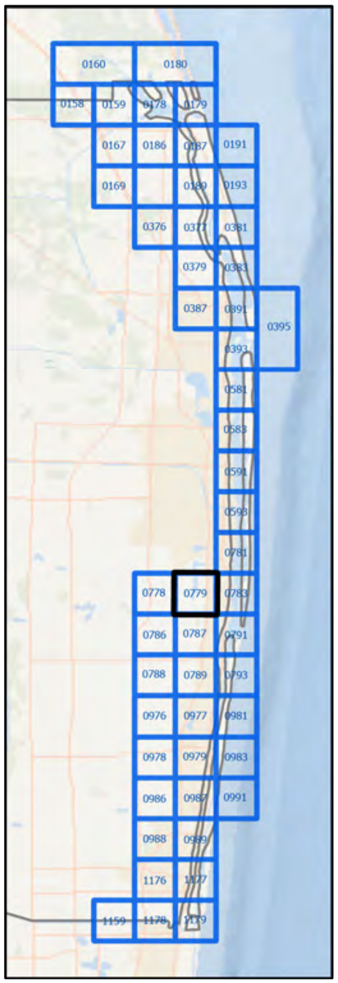
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0779

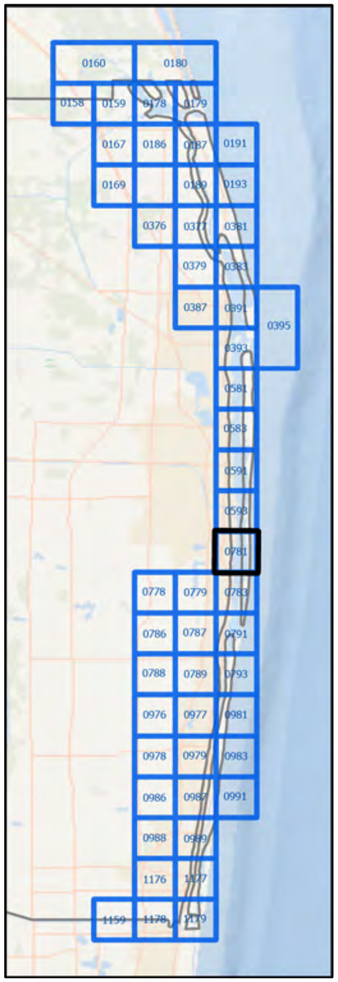


Frontal Dune Line
Municipalities
FIRM Panels

Calculated Difference (ft)
< -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
> 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

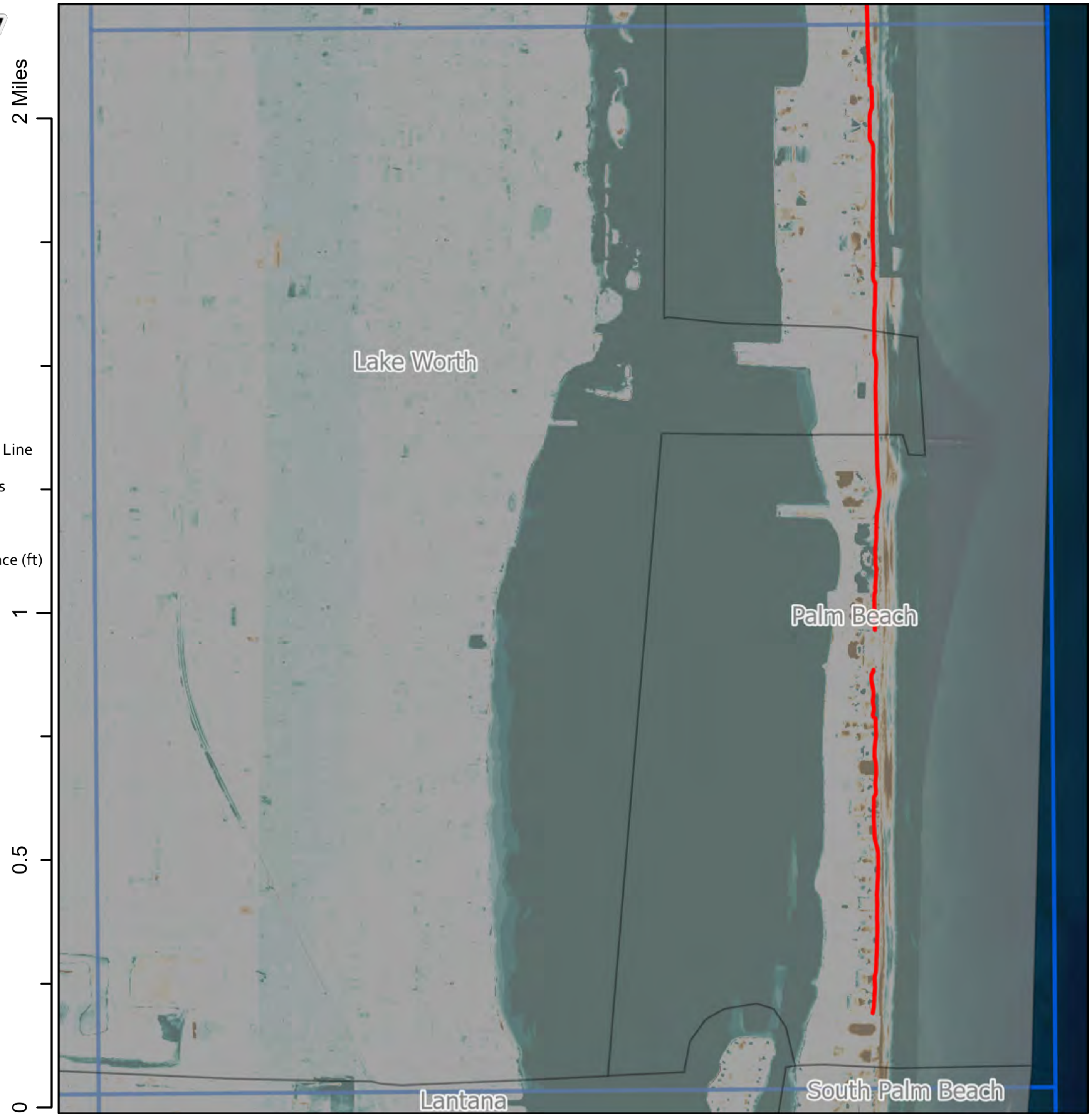
FIRM Panel: 0781



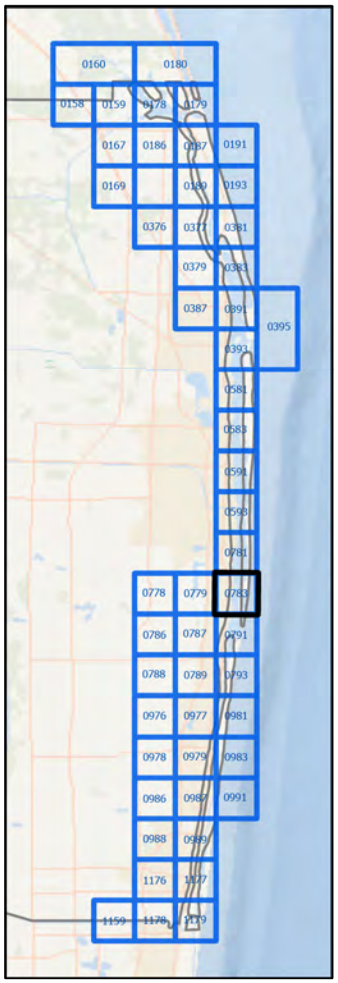
- Frontal Dune Line
- Municipalities
- FIRM Panels

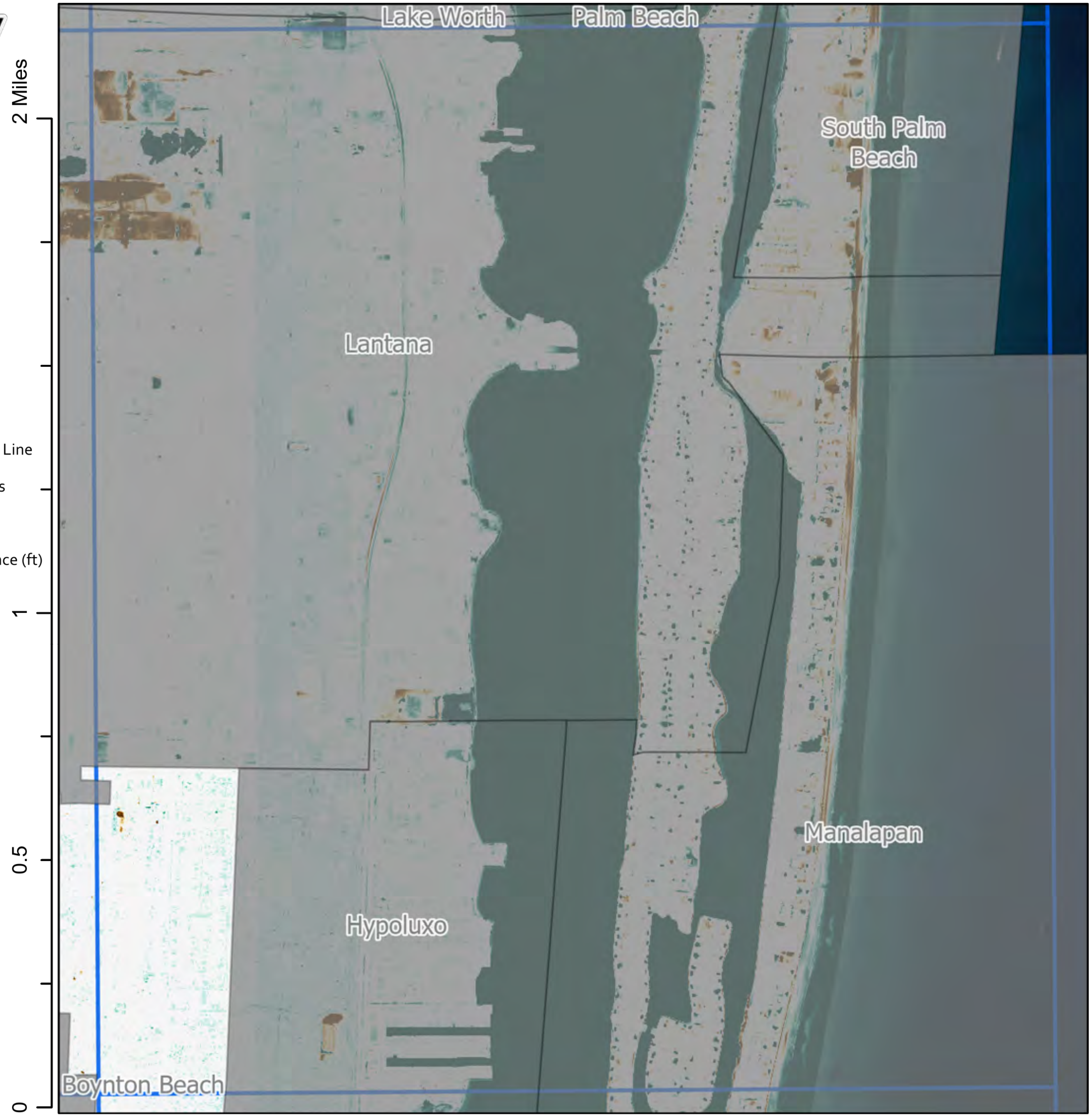
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM FIRM Panel: 0783



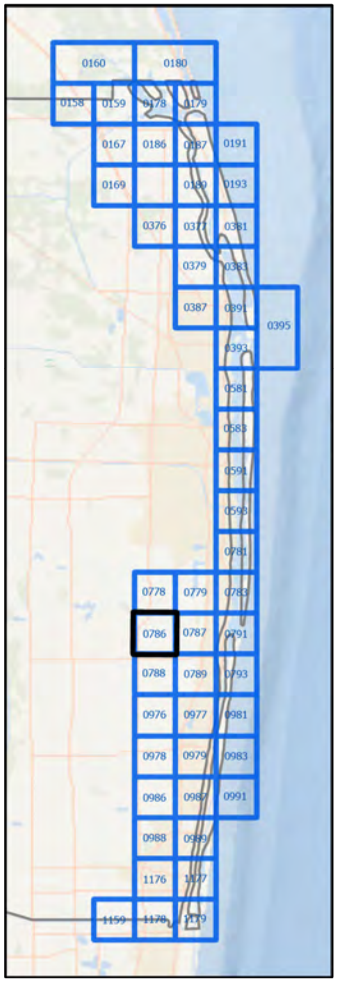


- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison
PBC LiDAR minus USACE DEM
FIRM Panel: 0786



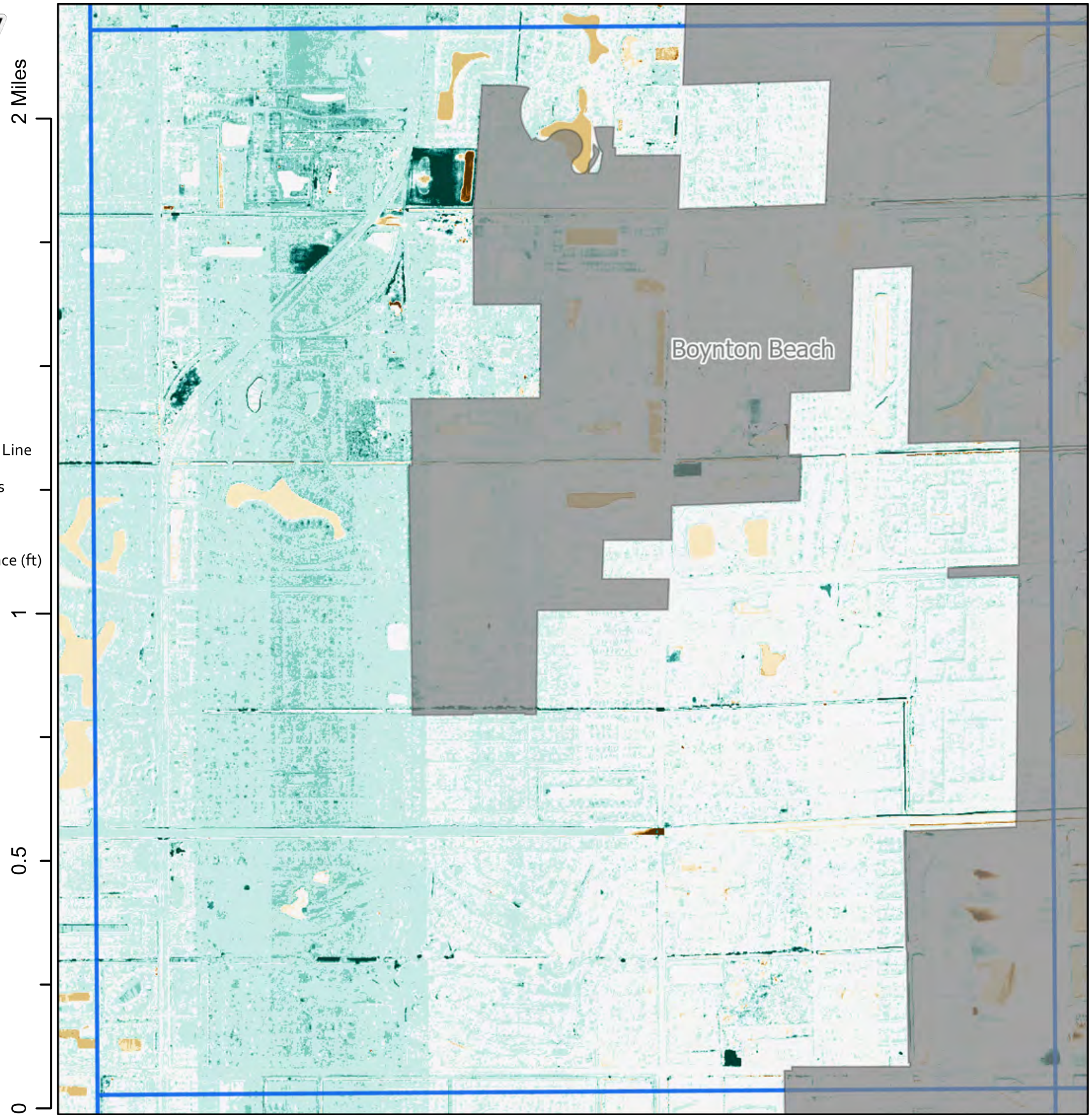
Frontal Dune Line

Municipalities

FIRM Panels

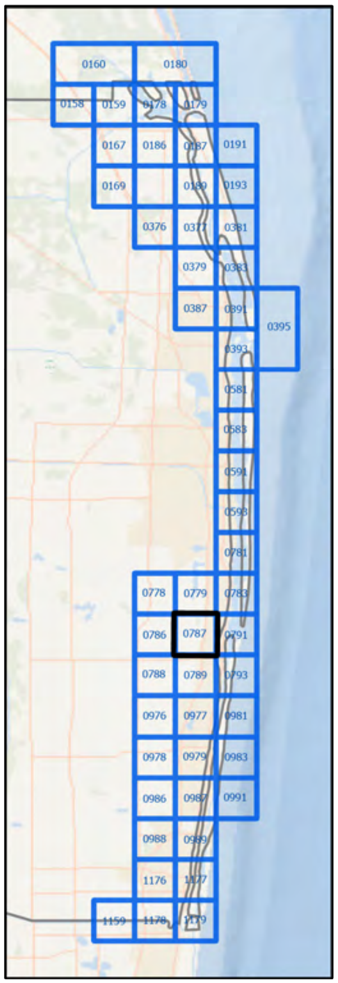
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0787



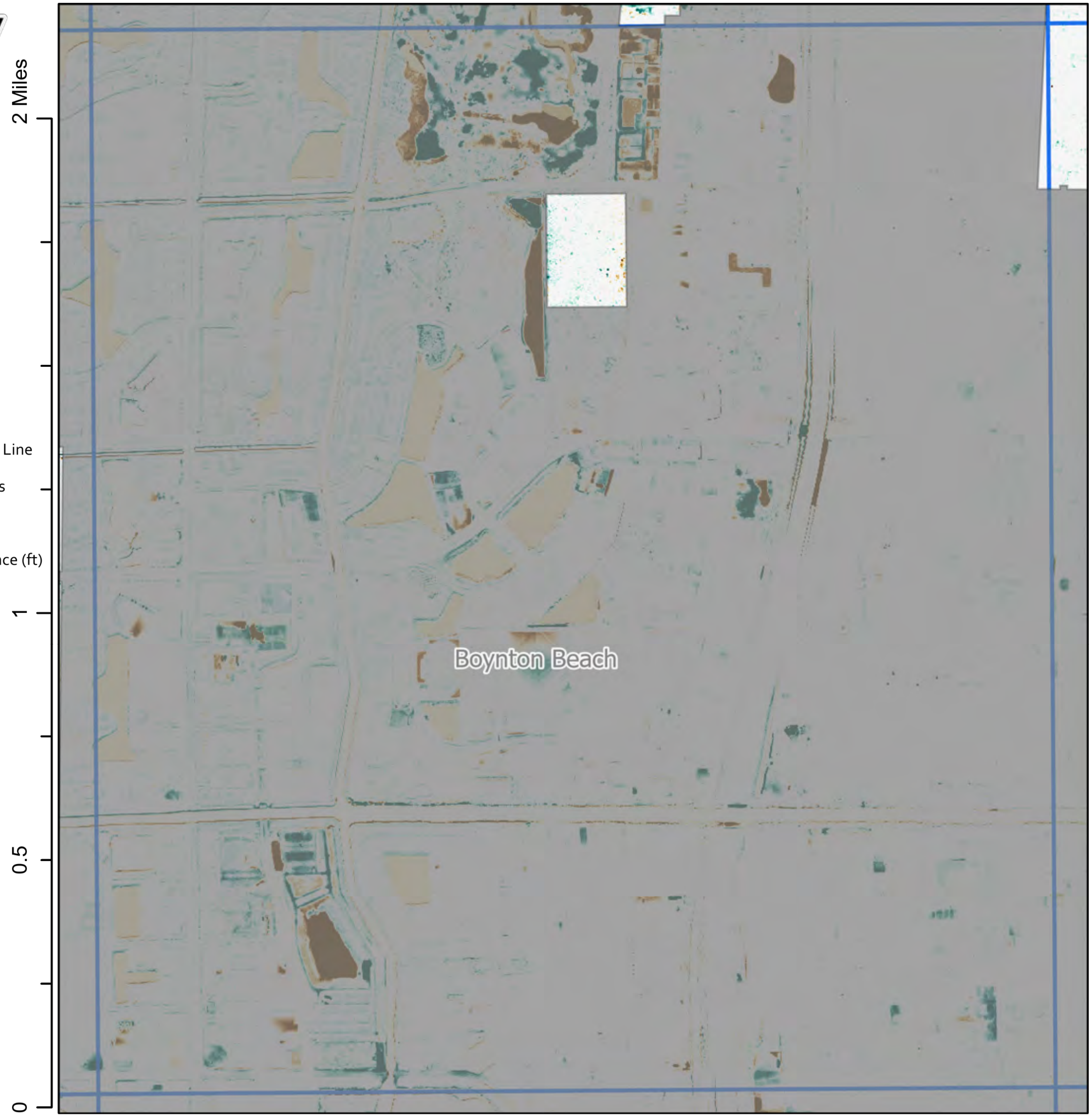
Frontal Dune Line

Municipalities

FIRM Panels

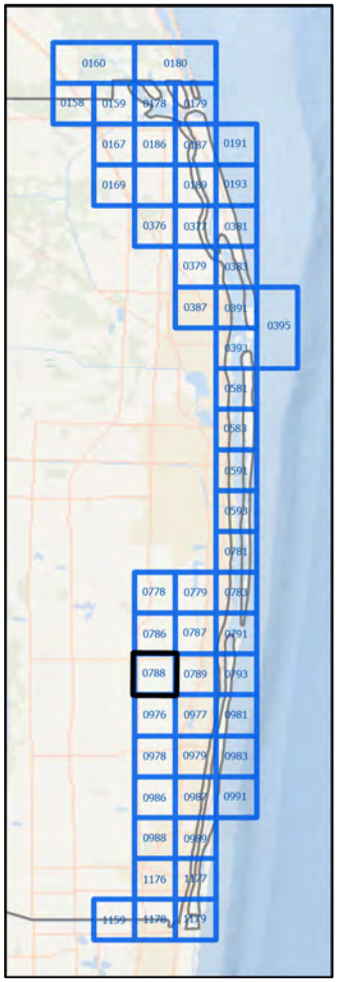
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

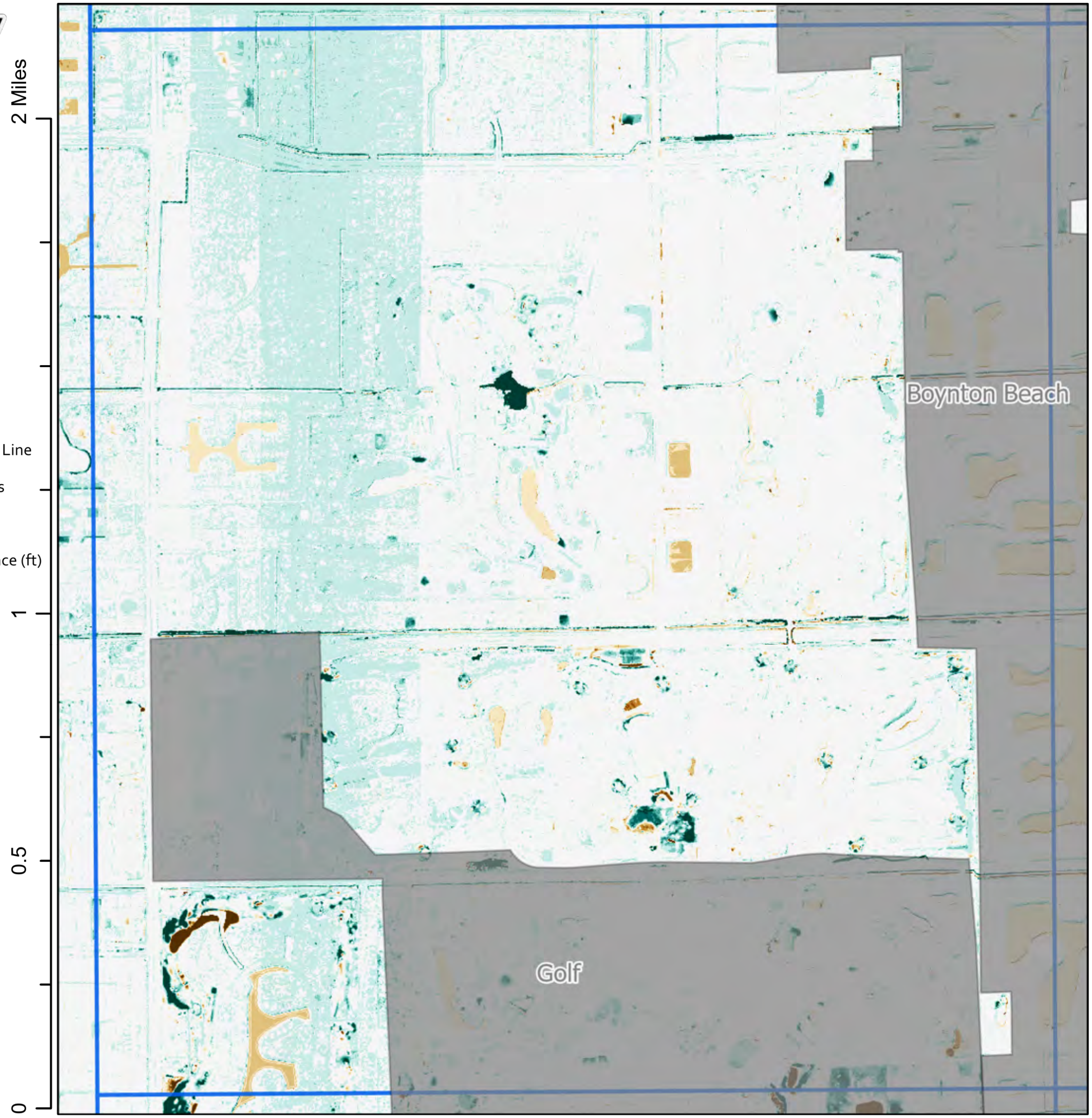
FIRM Panel: 0788



Frontal Dune Line
Municipalities
FIRM Panels

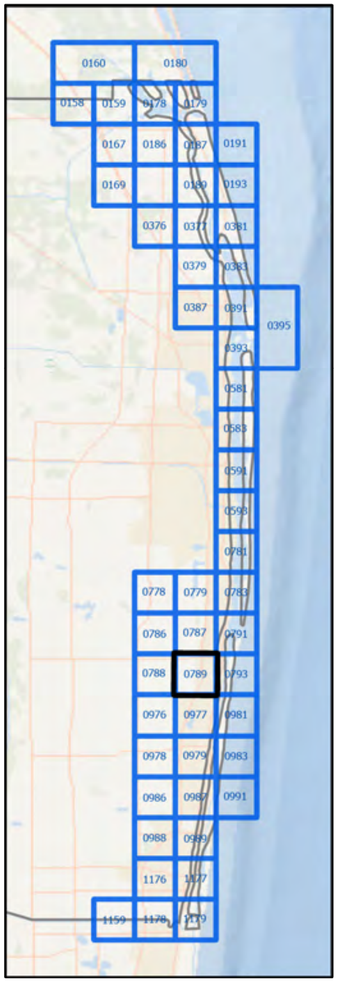
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0789



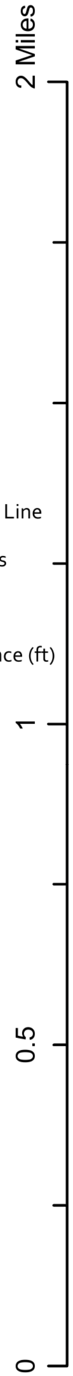
Frontal Dune Line

Municipalities

FIRM Panels

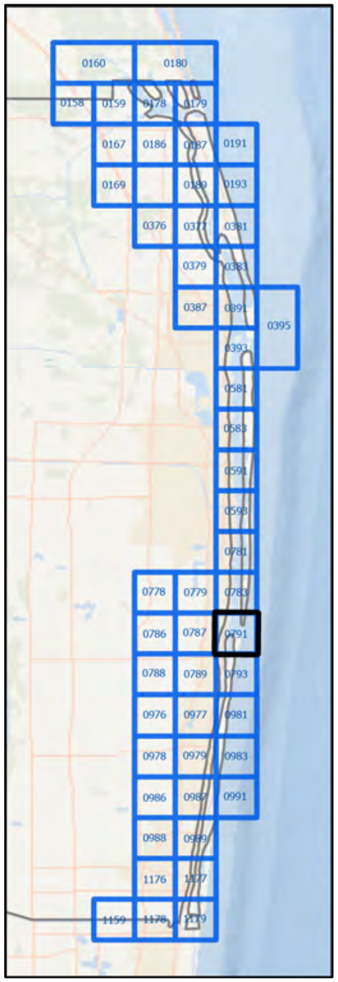
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0791



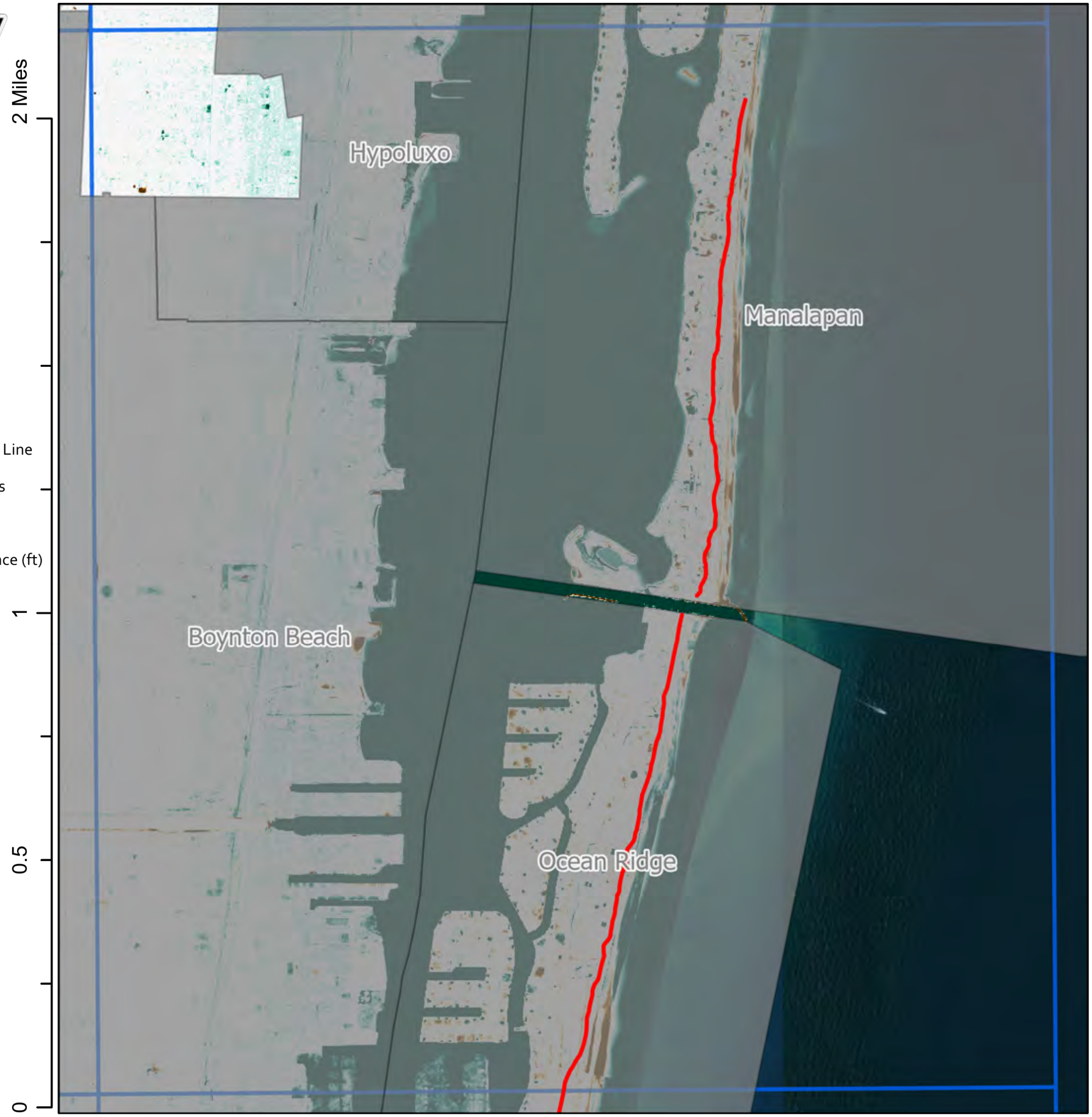
Frontal Dune Line

Municipalities

FIRM Panels

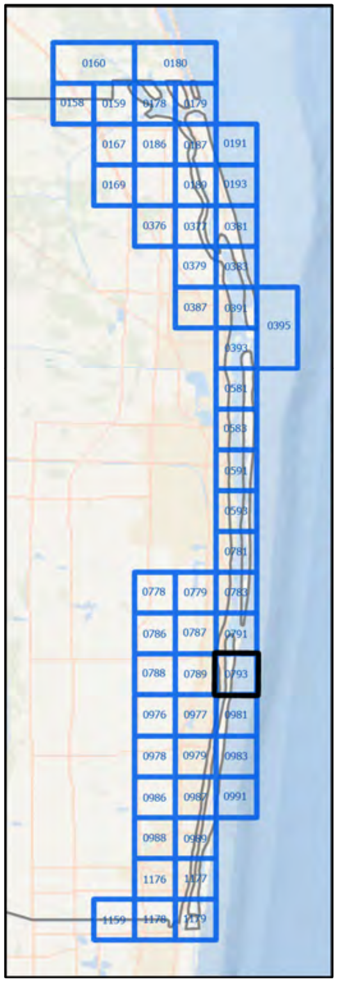
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0793



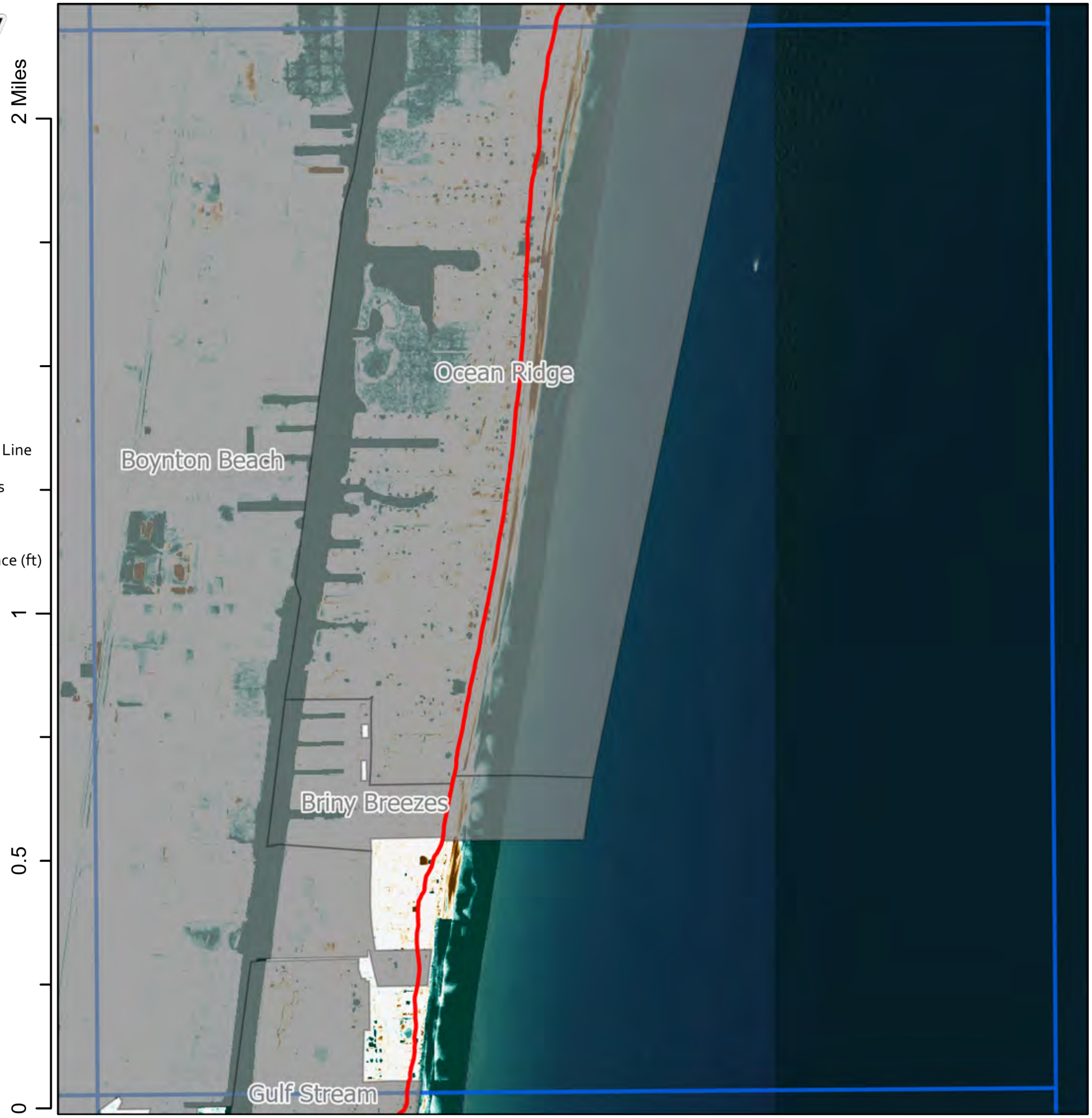
Frontal Dune Line

Municipalities

FIRM Panels

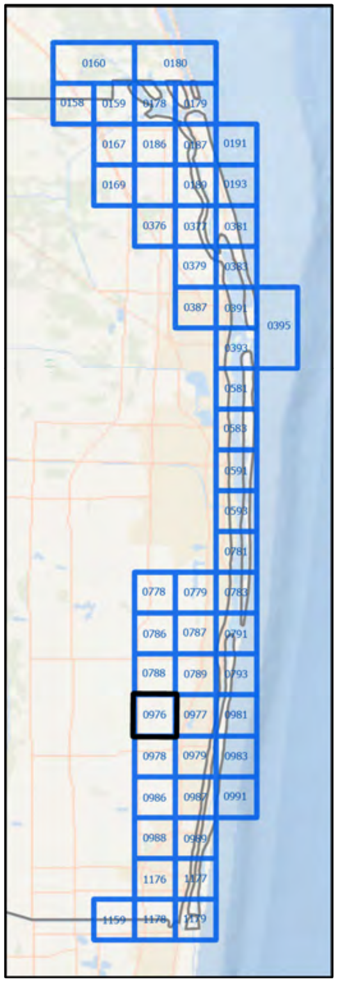
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

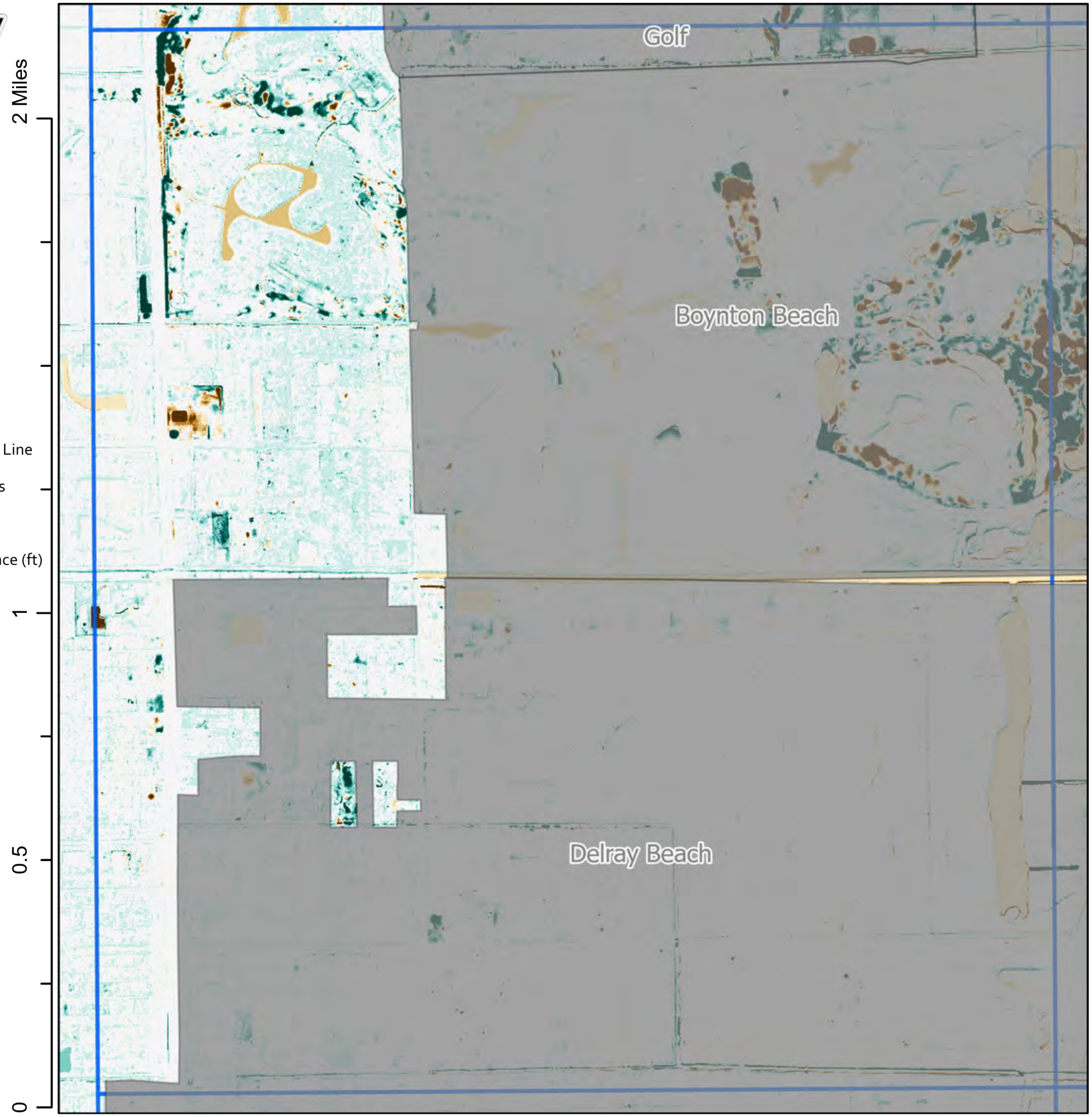
FIRM Panel: 0976



- Frontal Dune Line
- Municipalities
- FIRM Panels

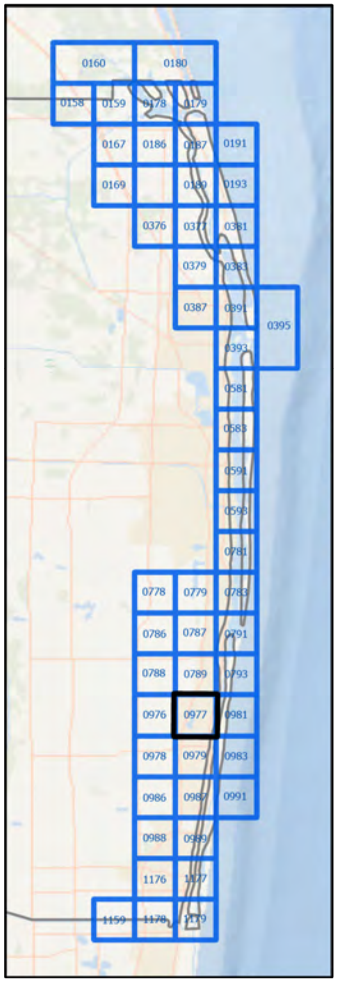
Calculated Difference (ft)

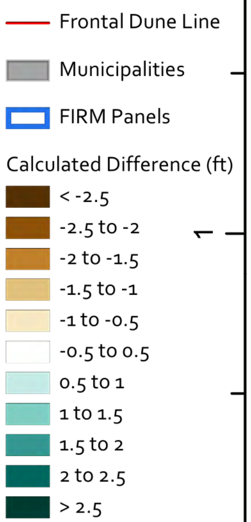
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

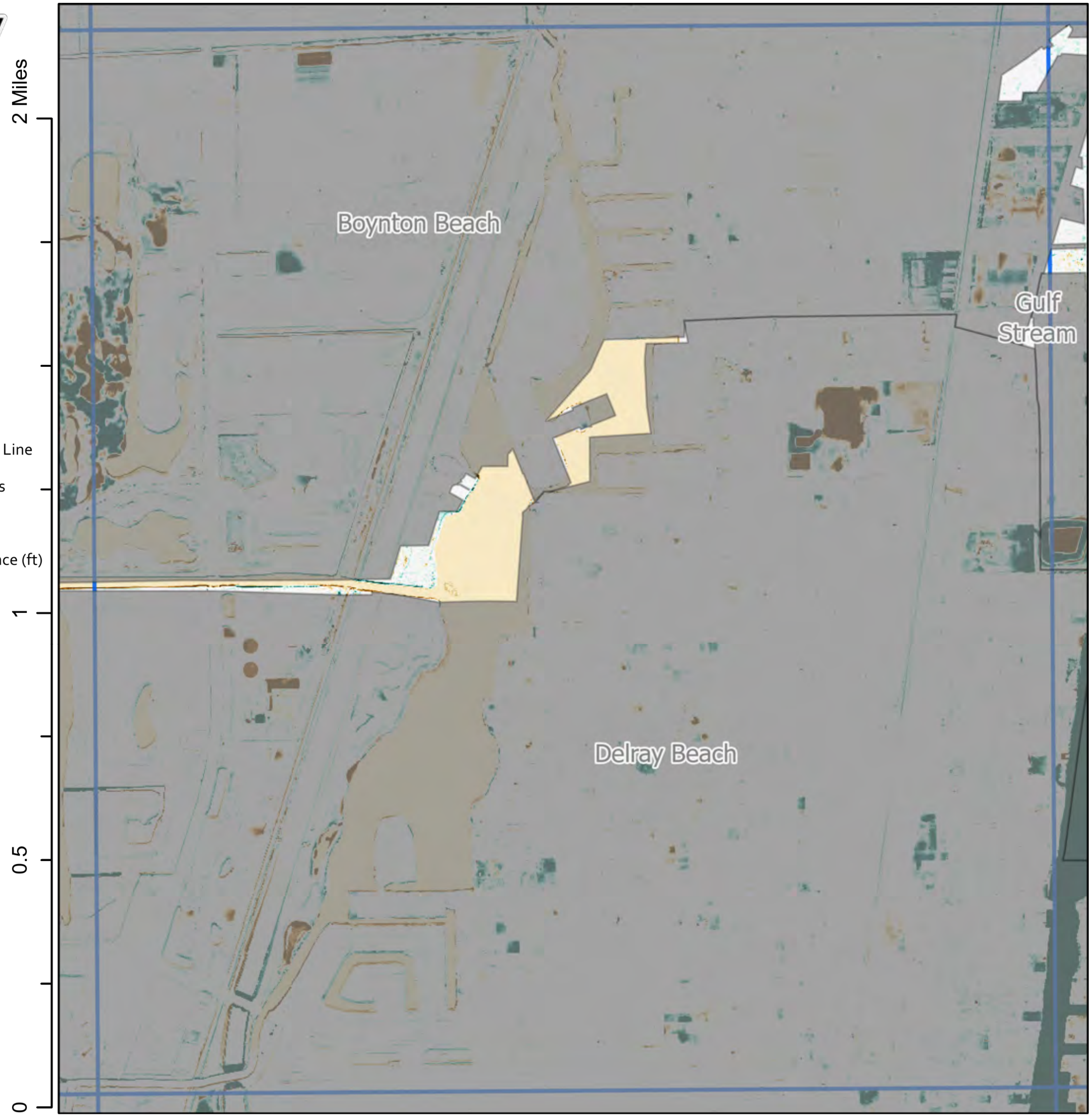


Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0977

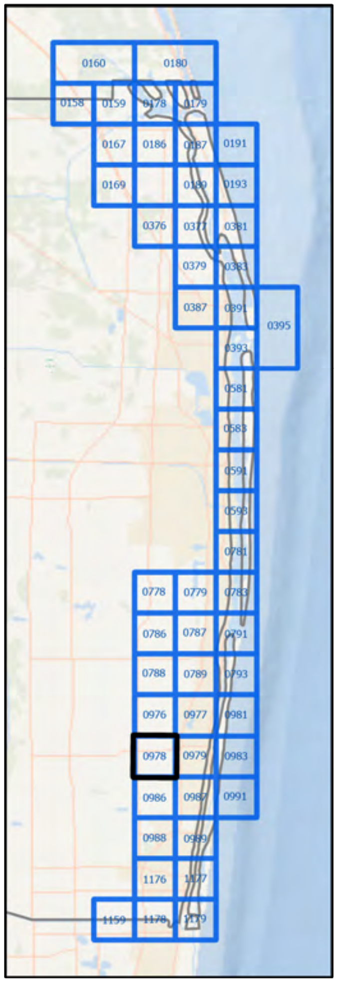






Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0978



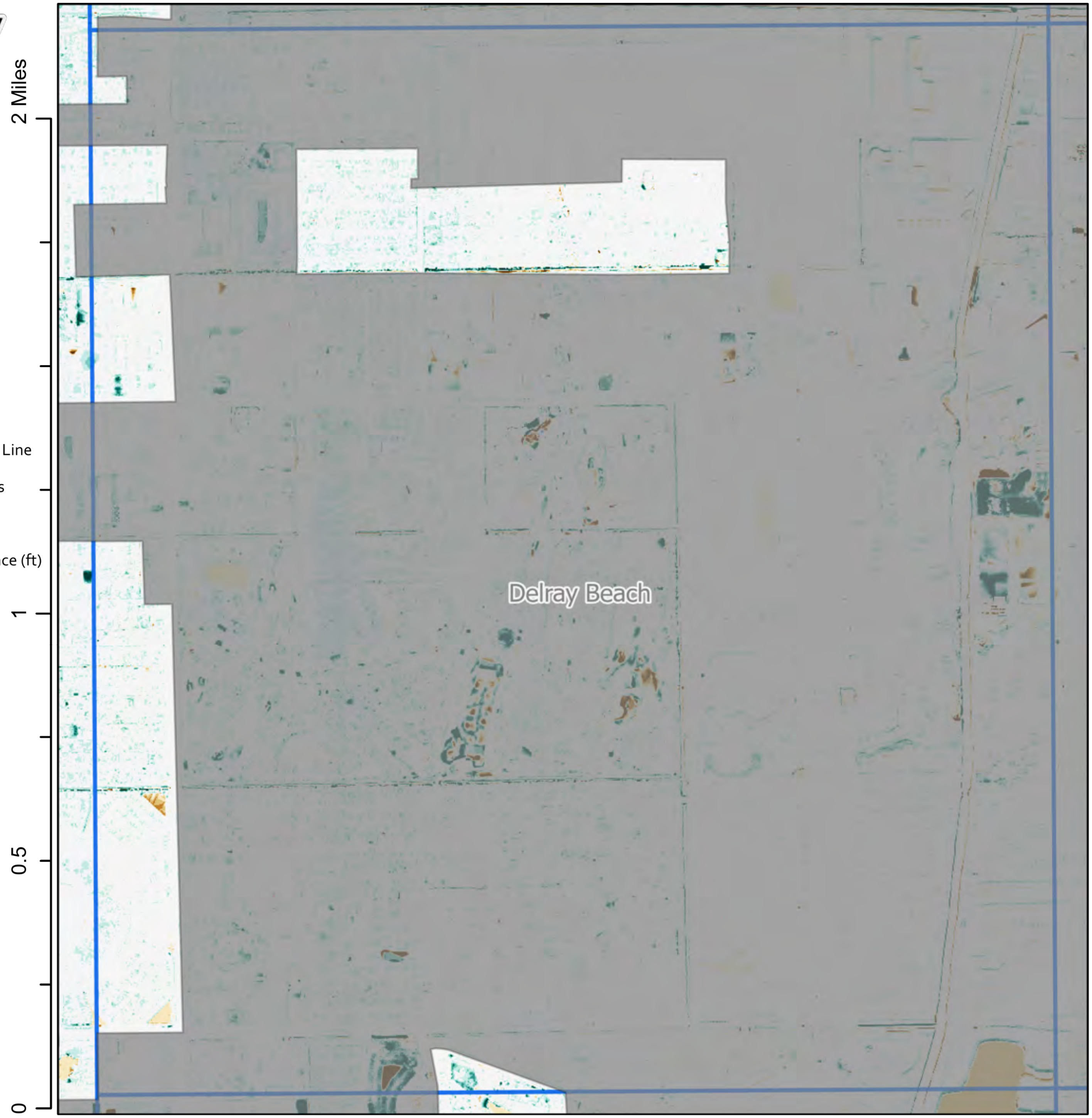
Frontal Dune Line

Municipalities

FIRM Panels

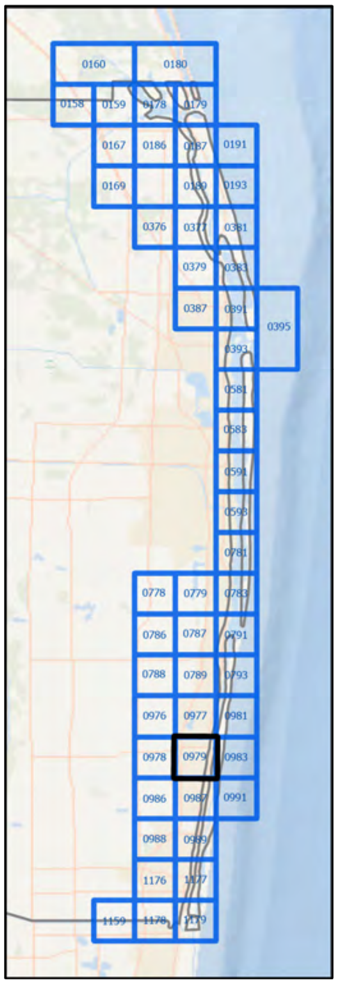
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

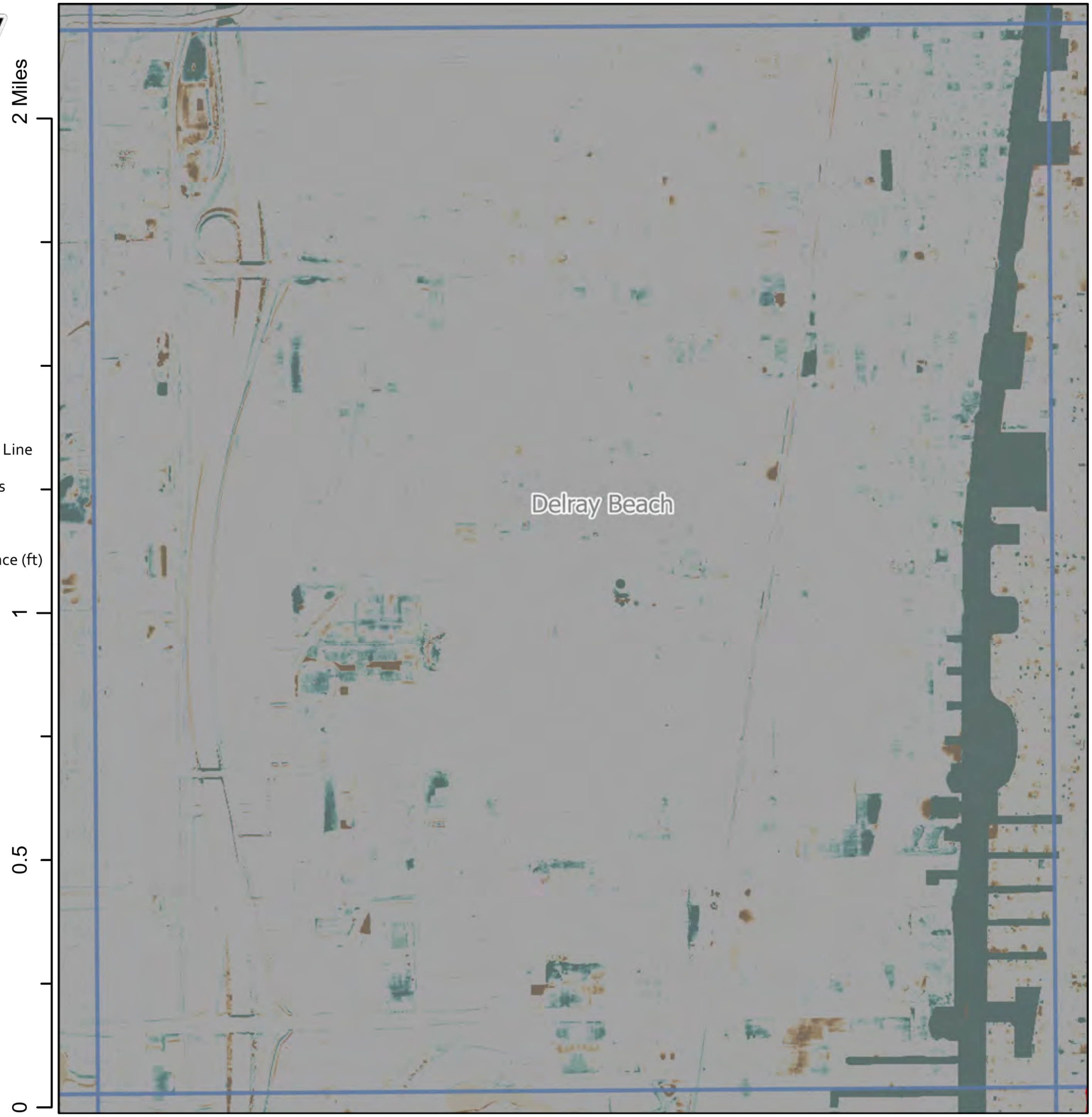
FIRM Panel: 0979



- Frontal Dune Line
- Municipalities
- FIRM Panels

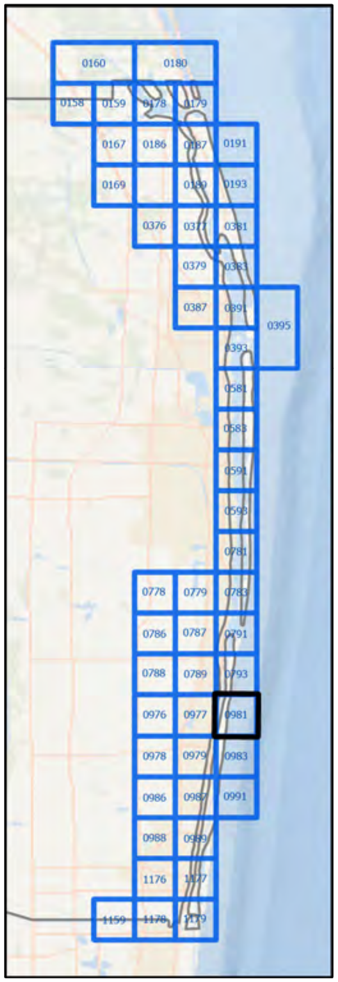
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0981



Frontal Dune Line

Municipalities

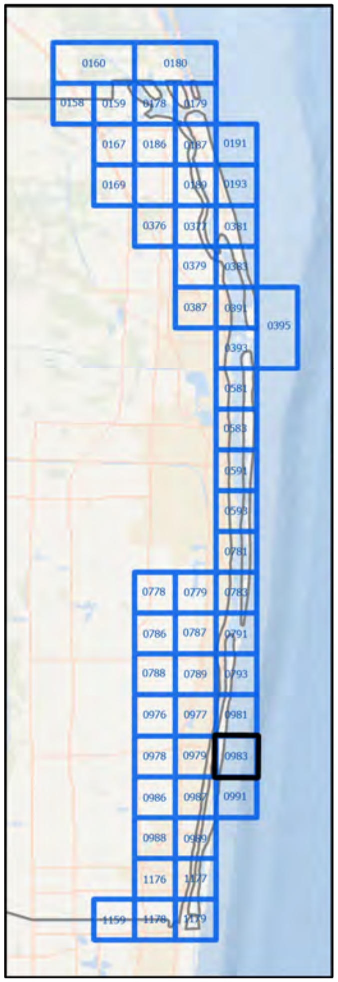
FIRM Panels

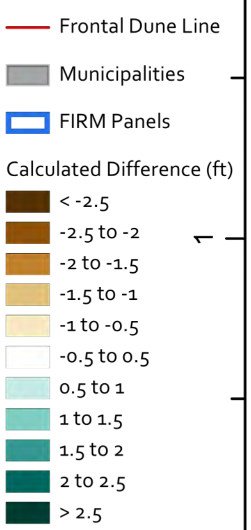
Calculated Difference (ft)

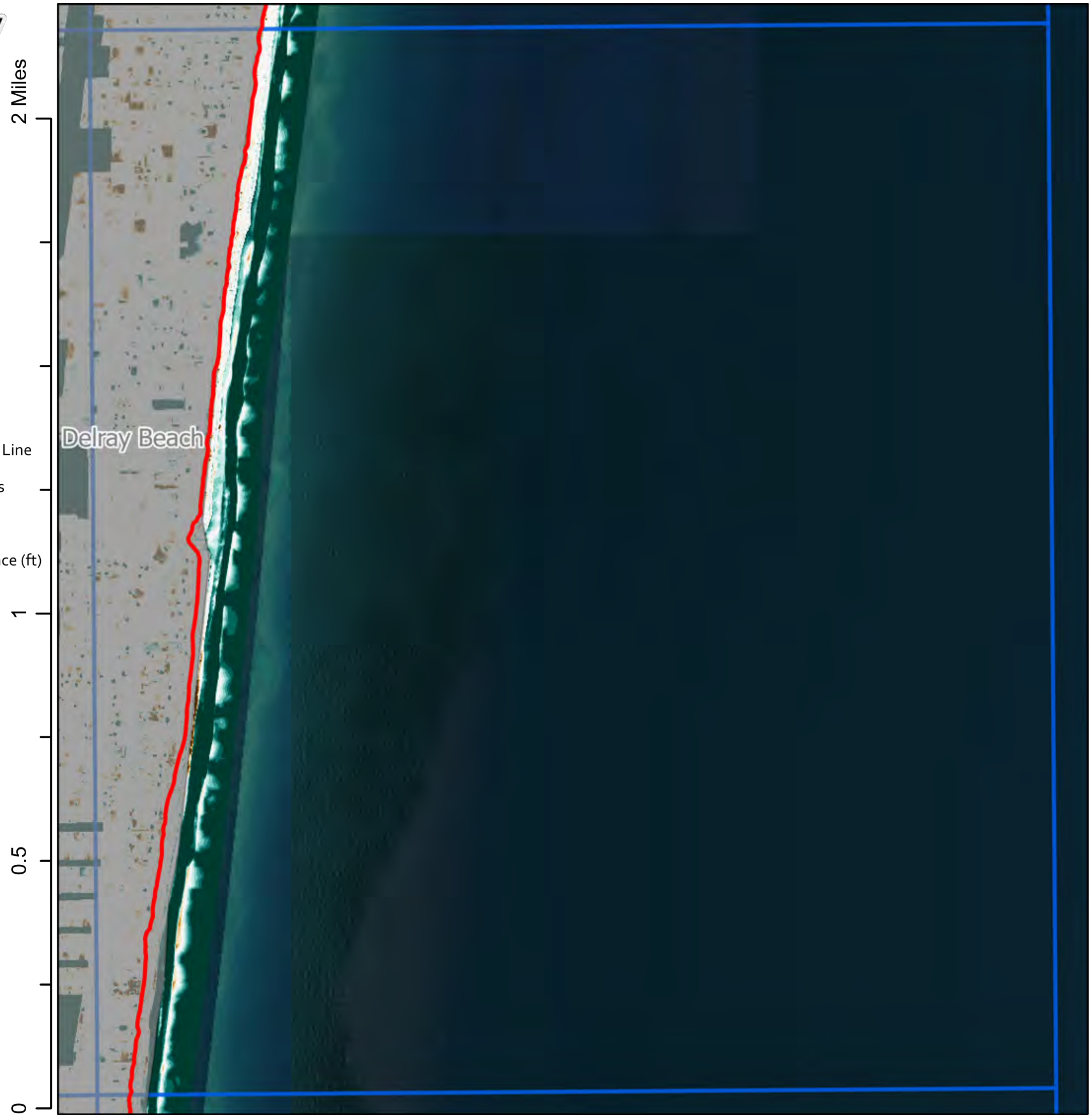
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5

Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0983

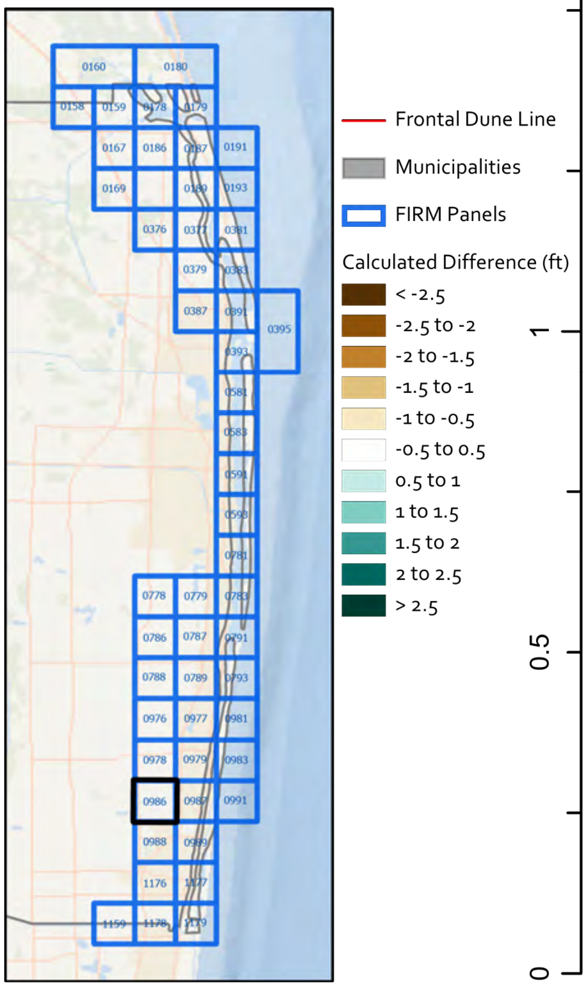


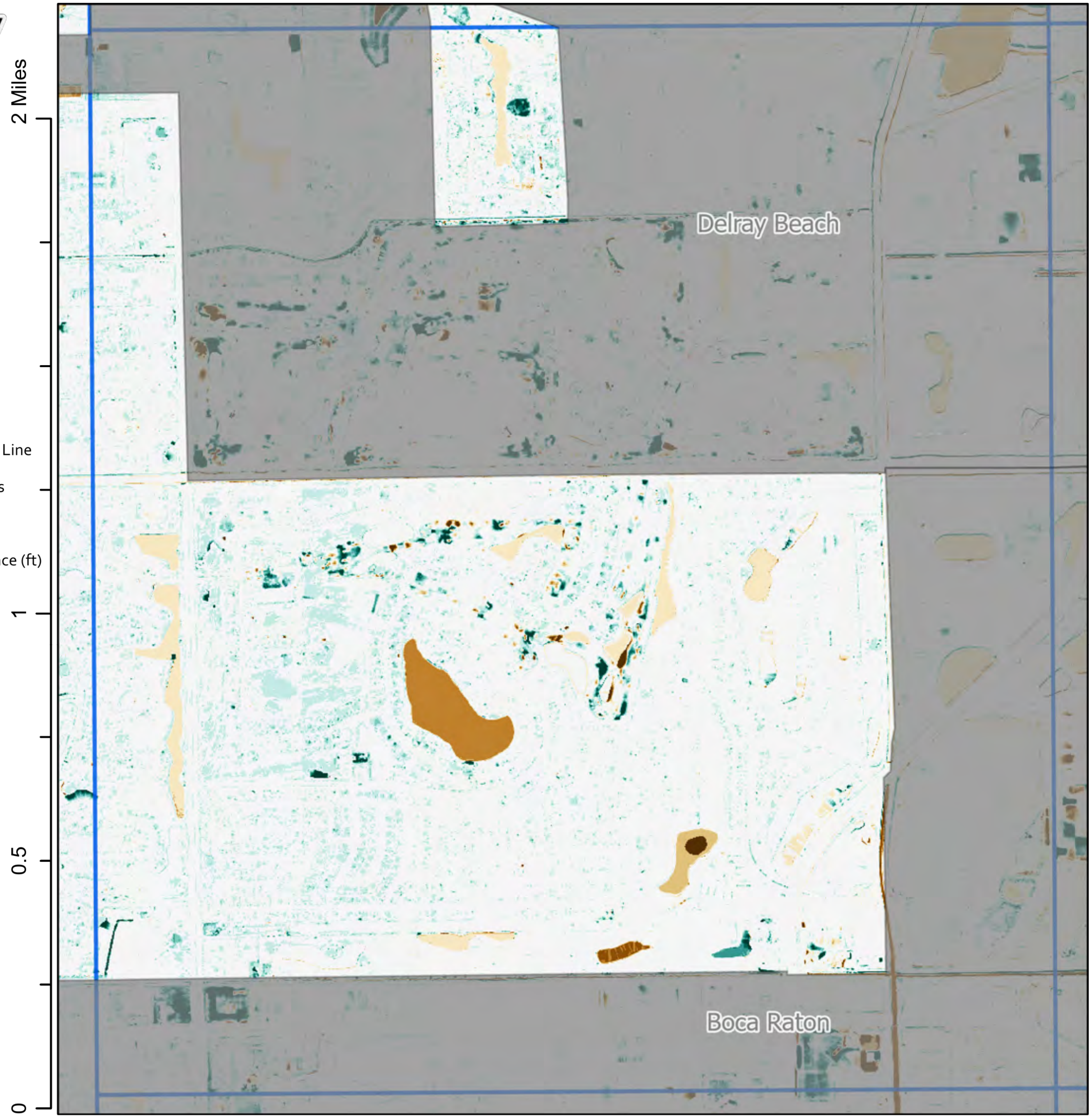




Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

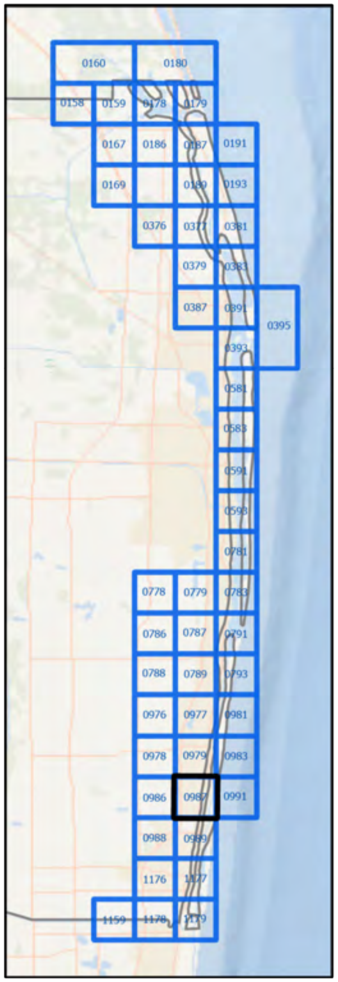
FIRM Panel: 0986





Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0987



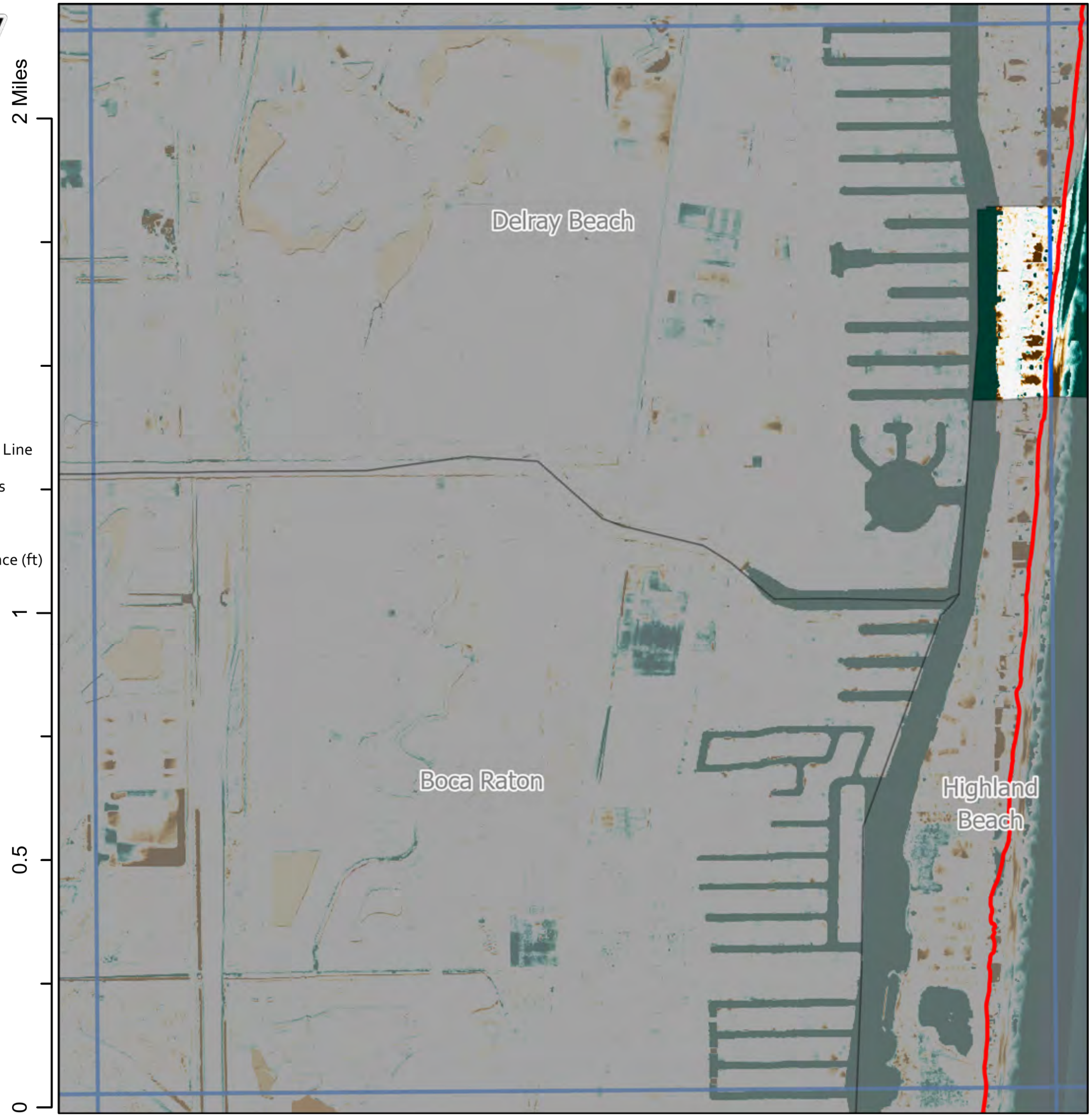
Frontal Dune Line

Municipalities

FIRM Panels

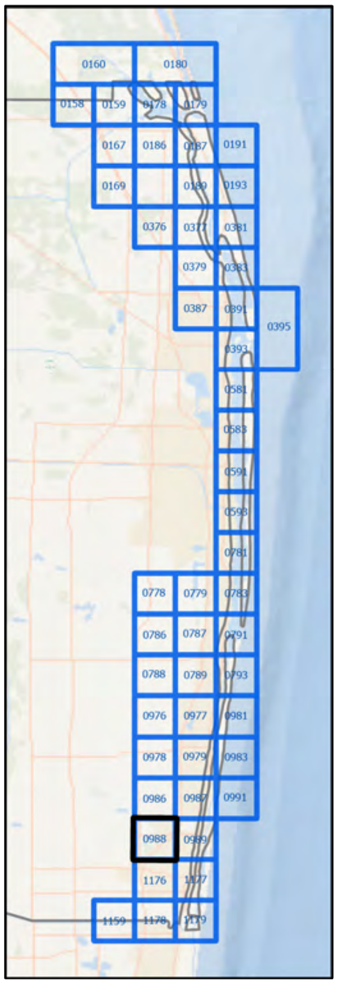
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0988



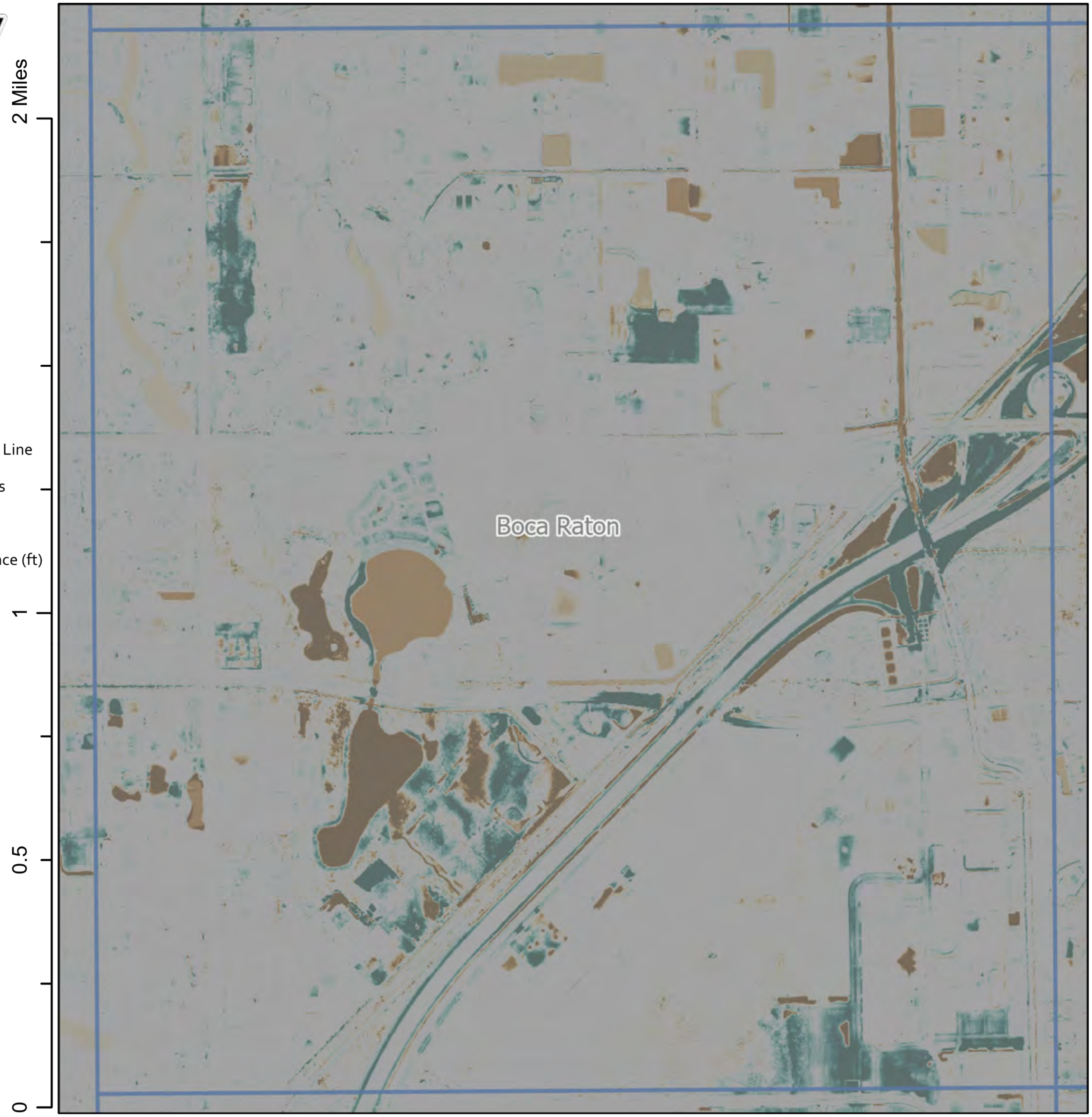
Frontal Dune Line

Municipalities

FIRM Panels

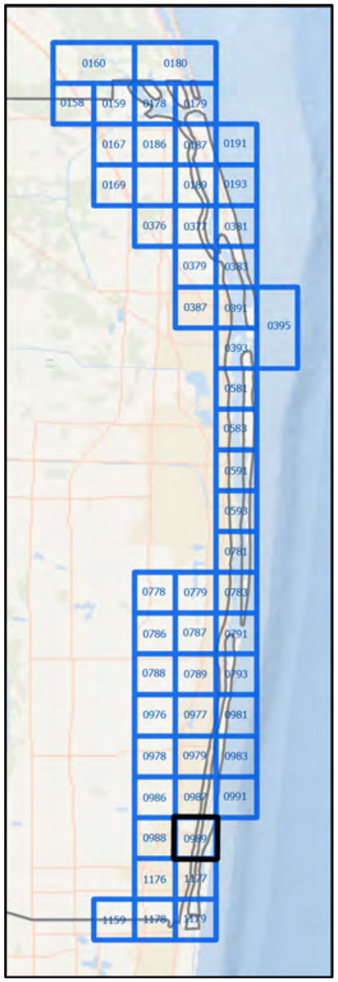
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 0989



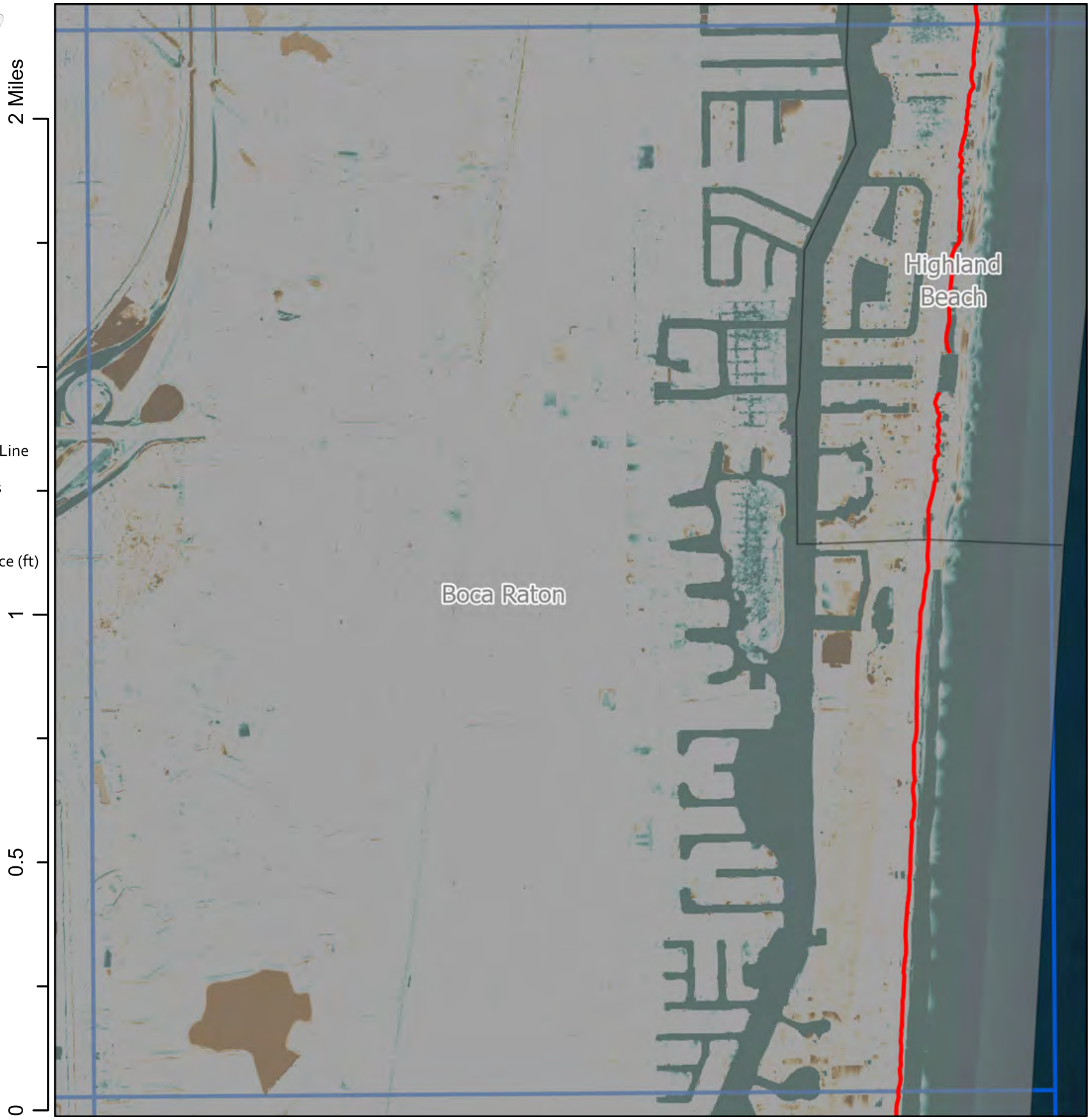
Frontal Dune Line

Municipalities

FIRM Panels

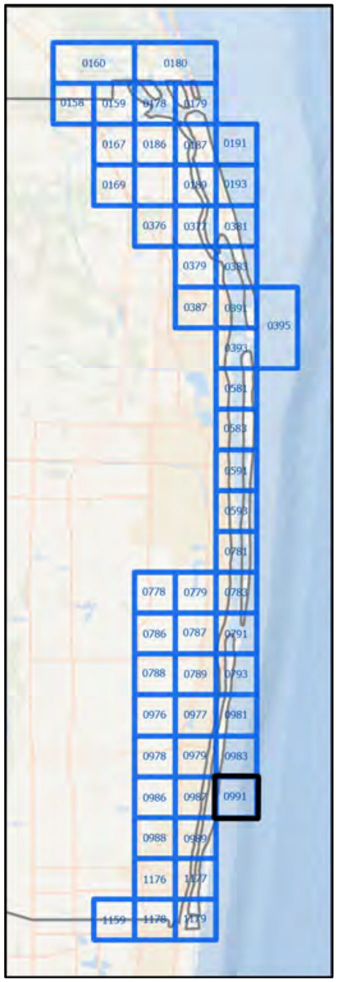
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

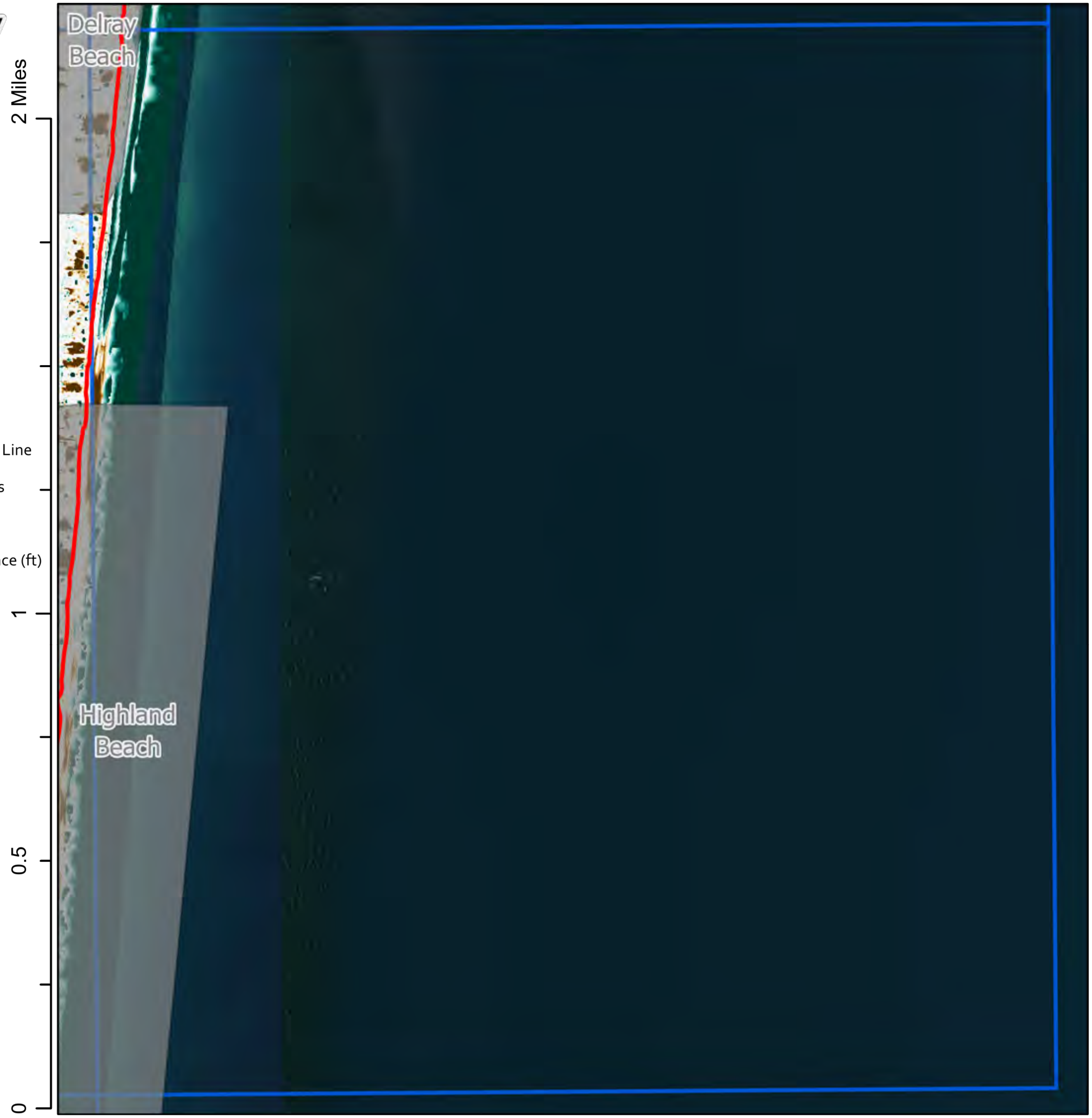
FIRM Panel: 0991



Frontal Dune Line
Municipalities
FIRM Panels

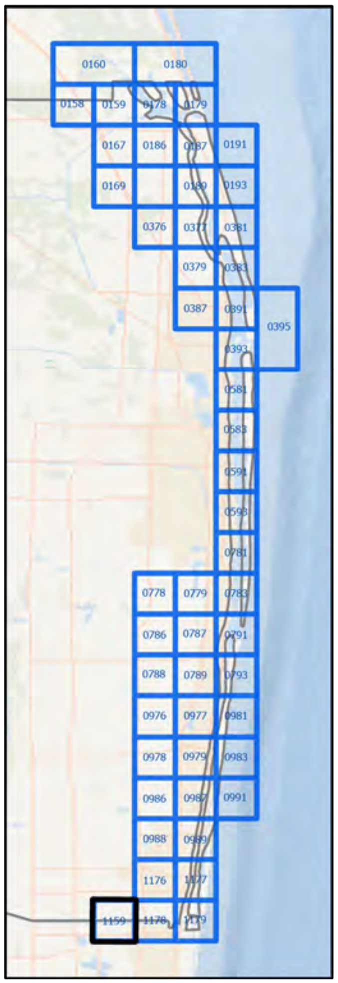
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 1159



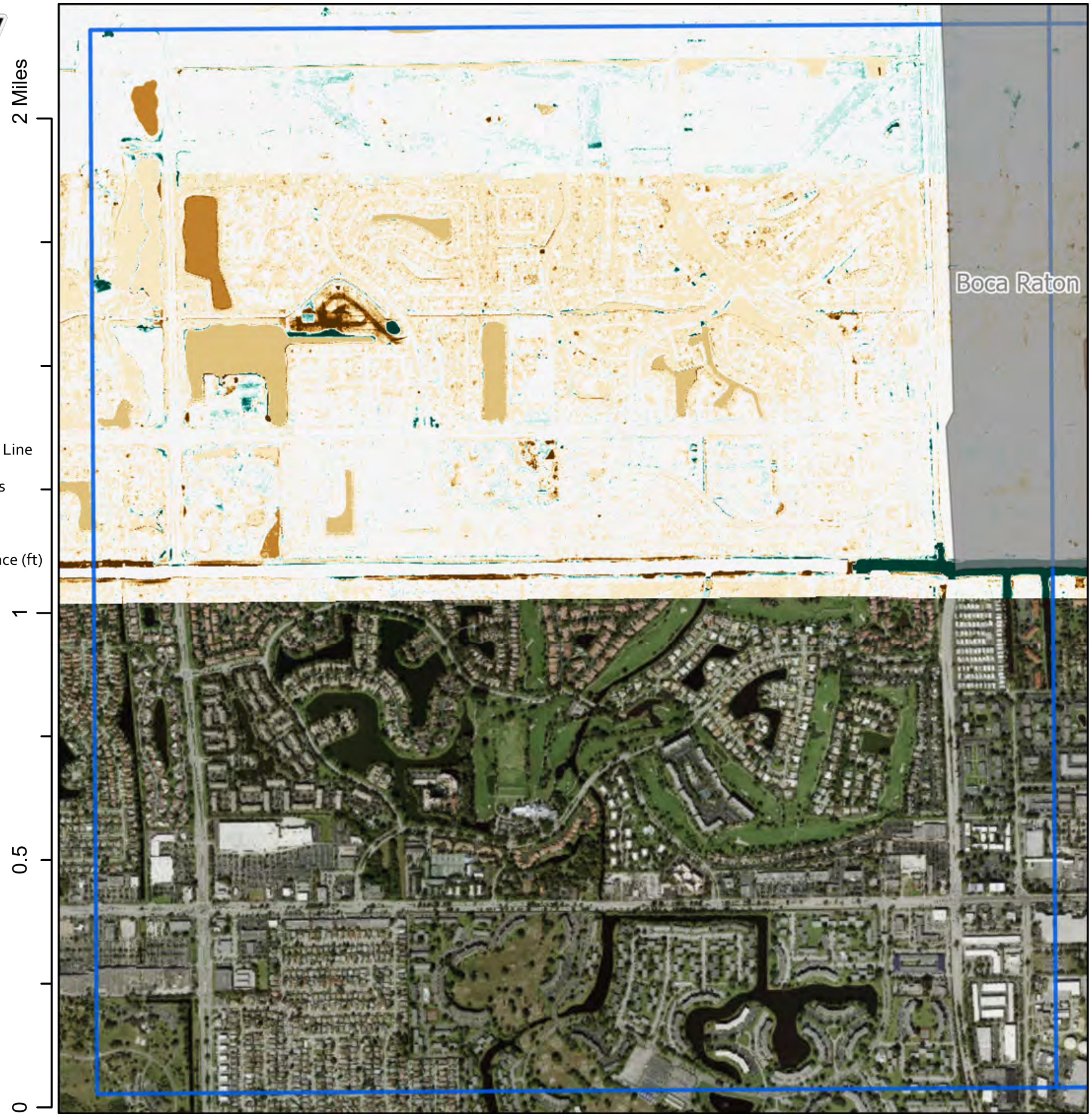
Frontal Dune Line

Municipalities

FIRM Panels

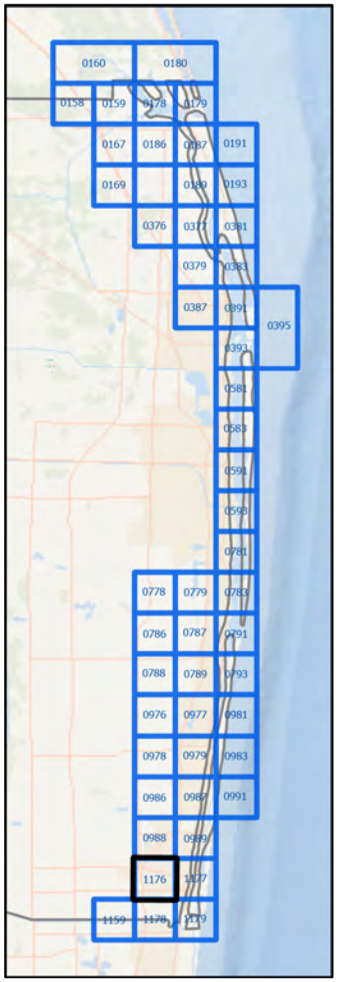
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

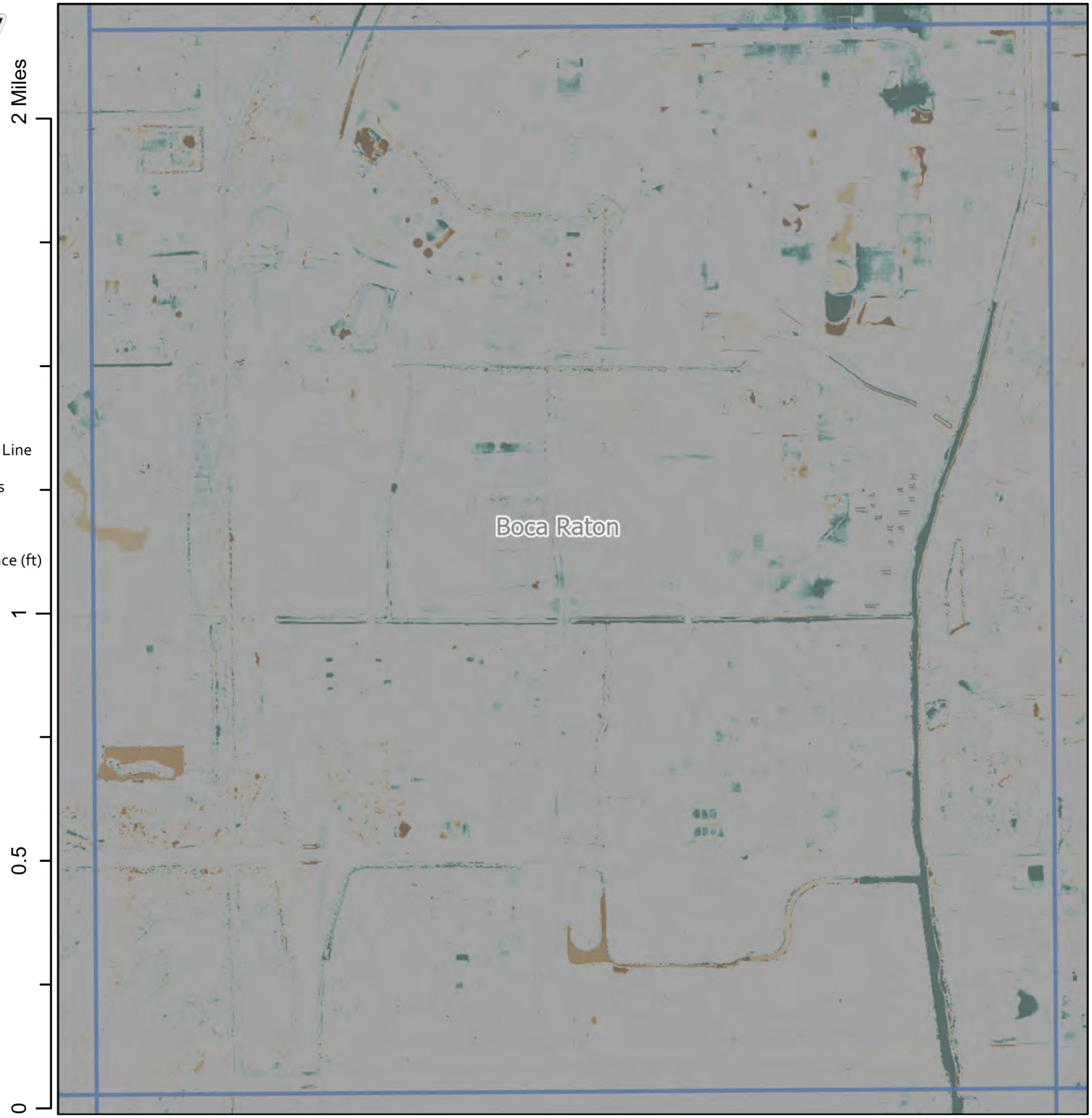
FIRM Panel: 1176



- Frontal Dune Line
- Municipalities
- FIRM Panels

Calculated Difference (ft)

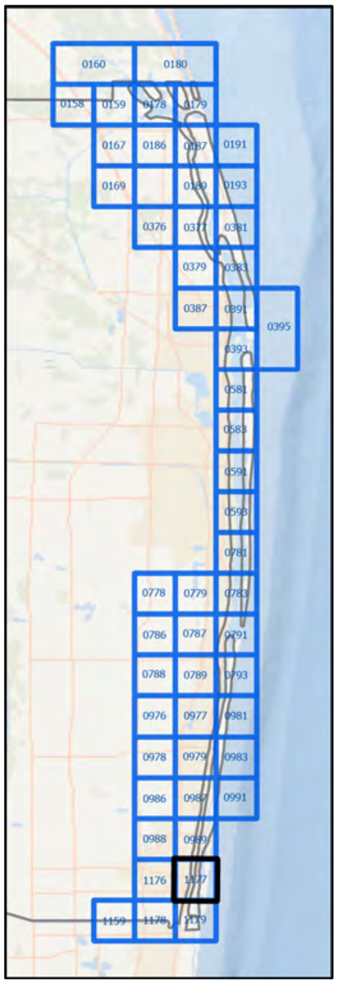
- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison

PBC LiDAR minus USACE DEM

FIRM Panel: 1177



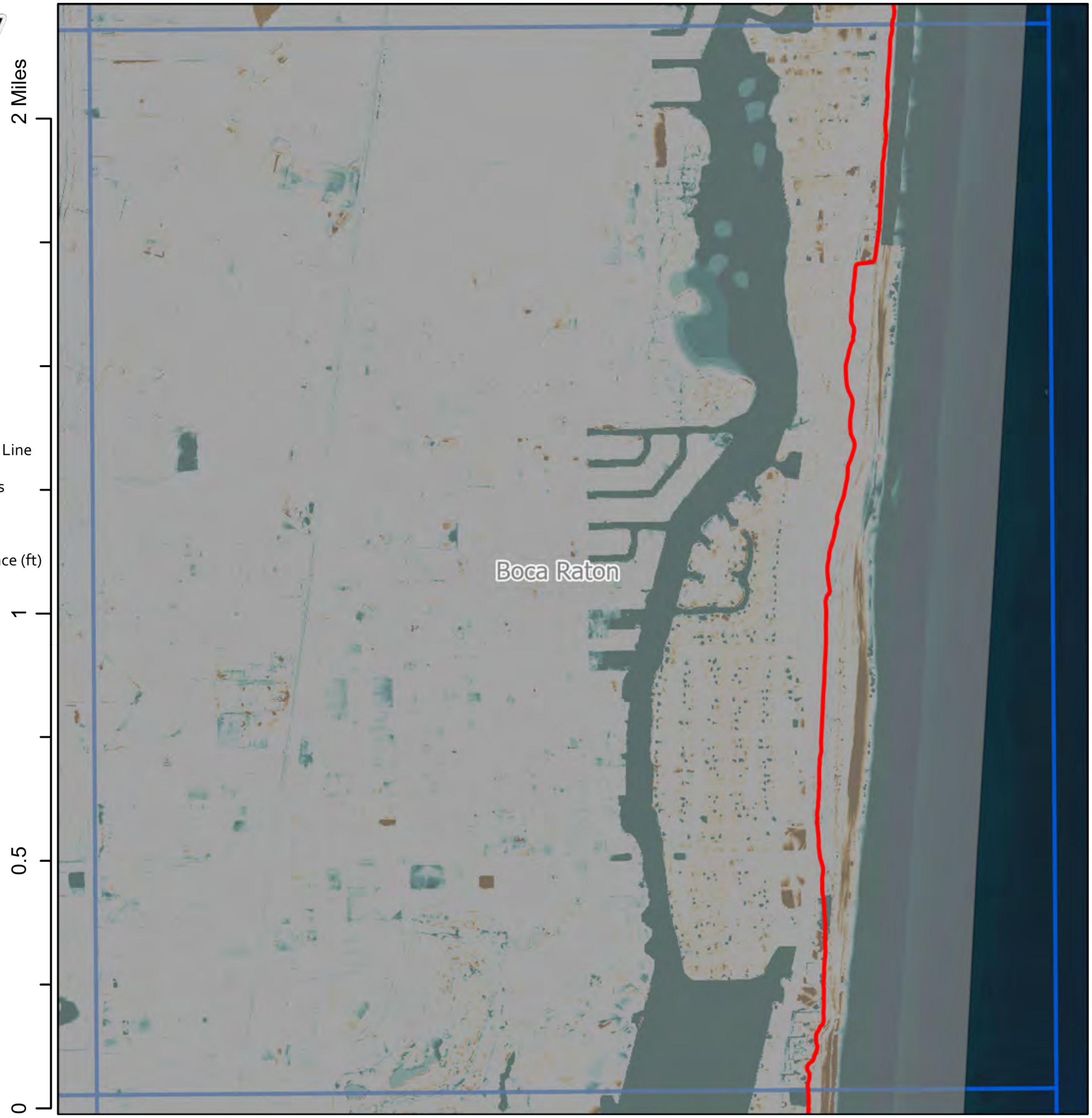
Frontal Dune Line

Municipalities

FIRM Panels

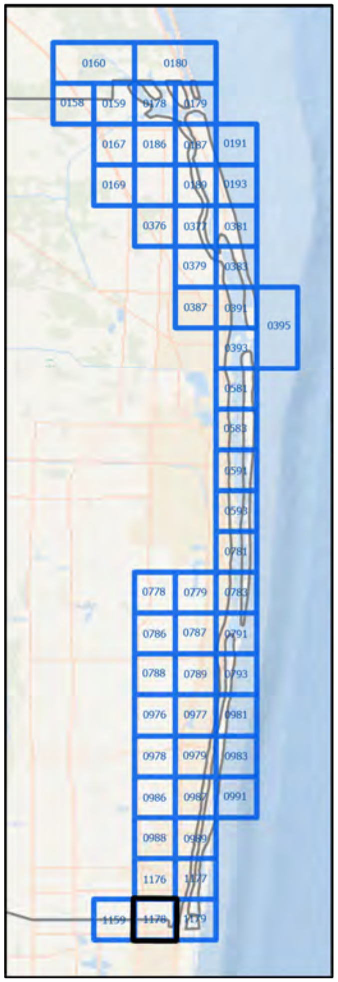
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

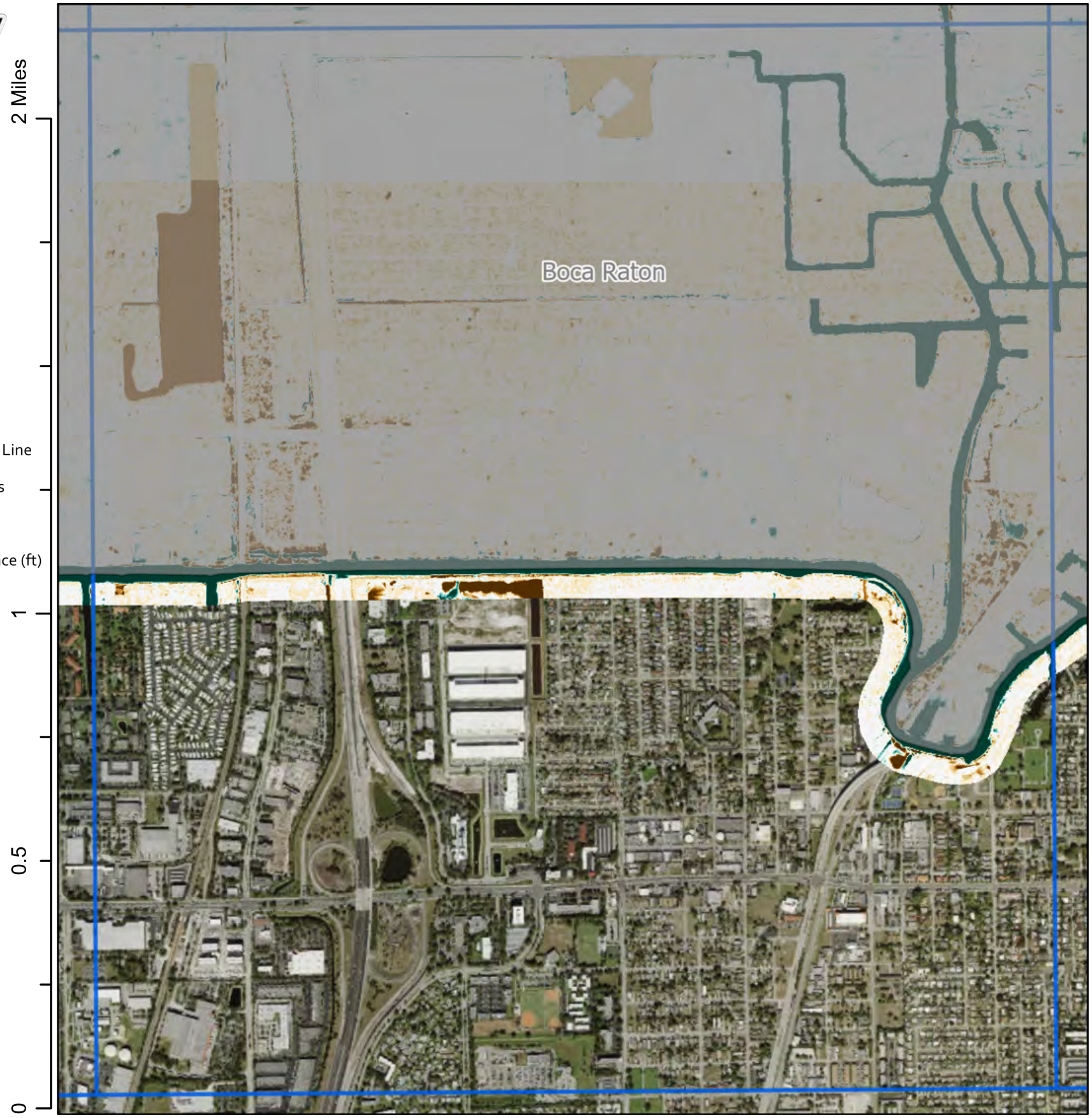
FIRM Panel: 1178



Frontal Dune Line
Municipalities
FIRM Panels

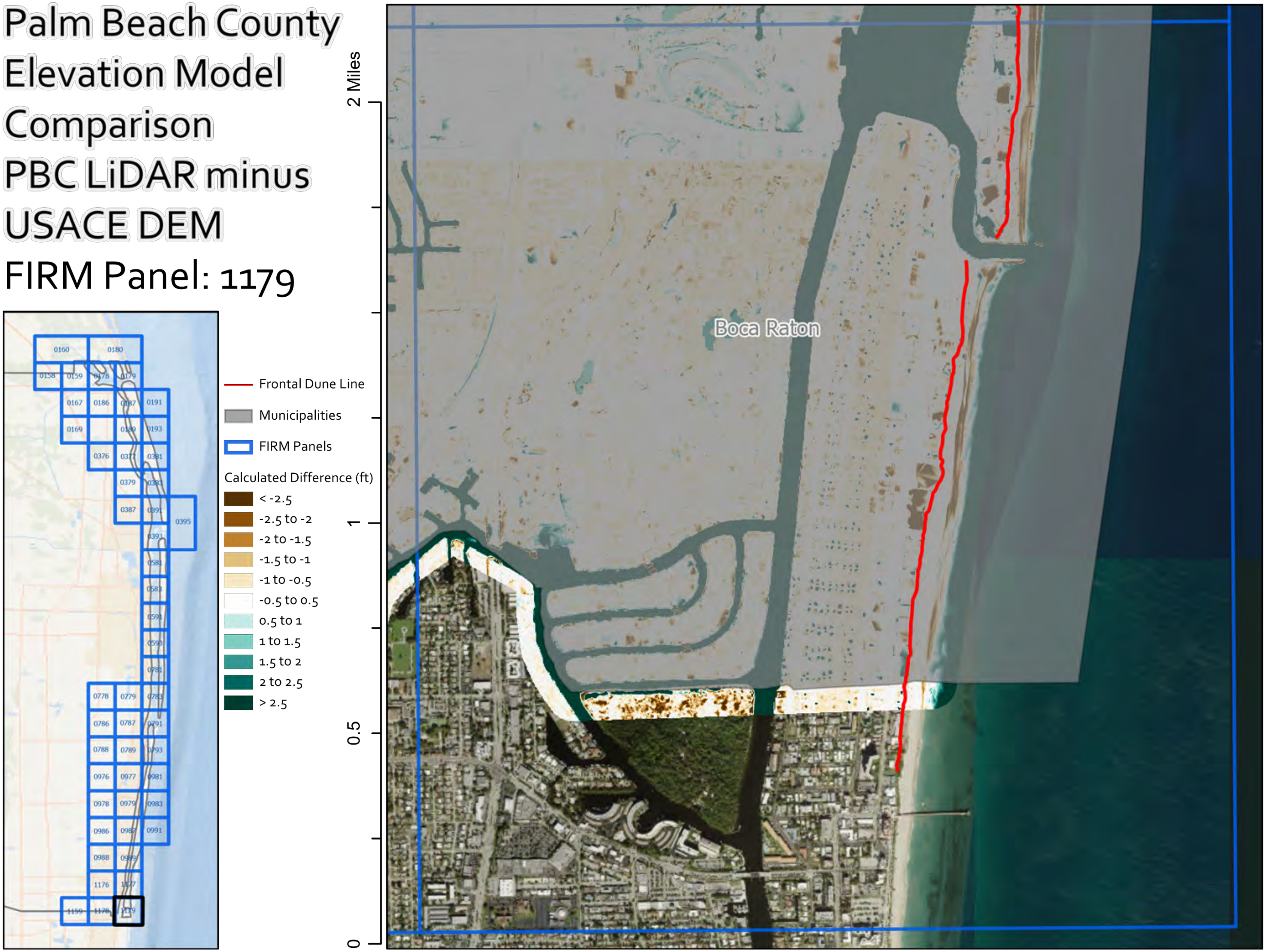
Calculated Difference (ft)

- < -2.5
- -2.5 to -2
- -2 to -1.5
- -1.5 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 1.5
- 1.5 to 2
- 2 to 2.5
- > 2.5



Palm Beach County Elevation Model Comparison PBC LiDAR minus USACE DEM

FIRM Panel: 1179

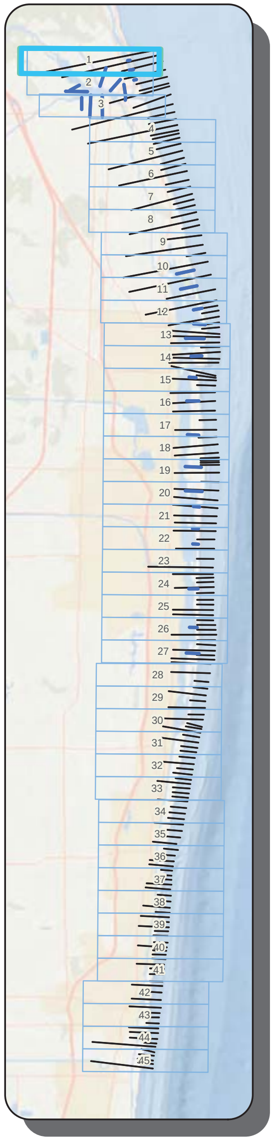


Appendix D

Palm Beach County WHAFIS Transects

Transect View

Page: 1



Change Since Last FIRM

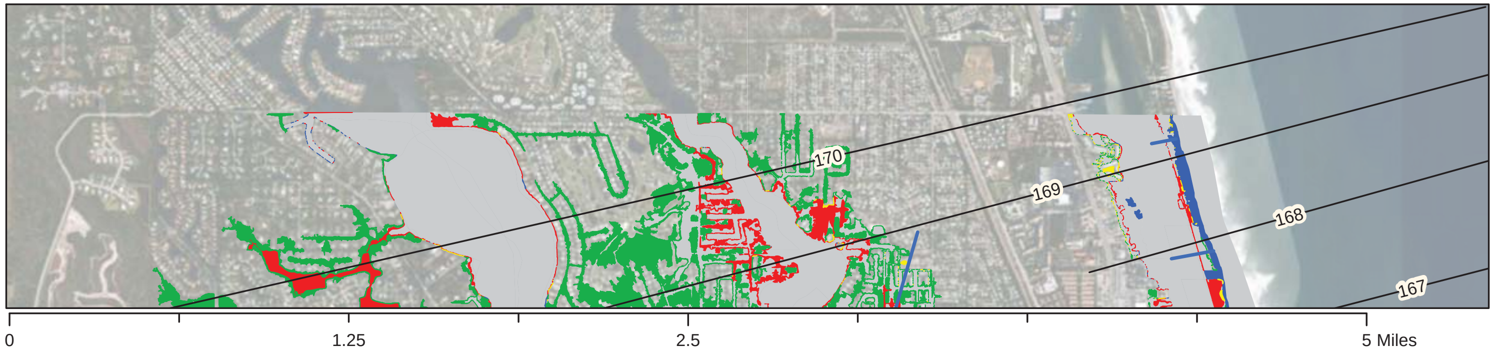
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

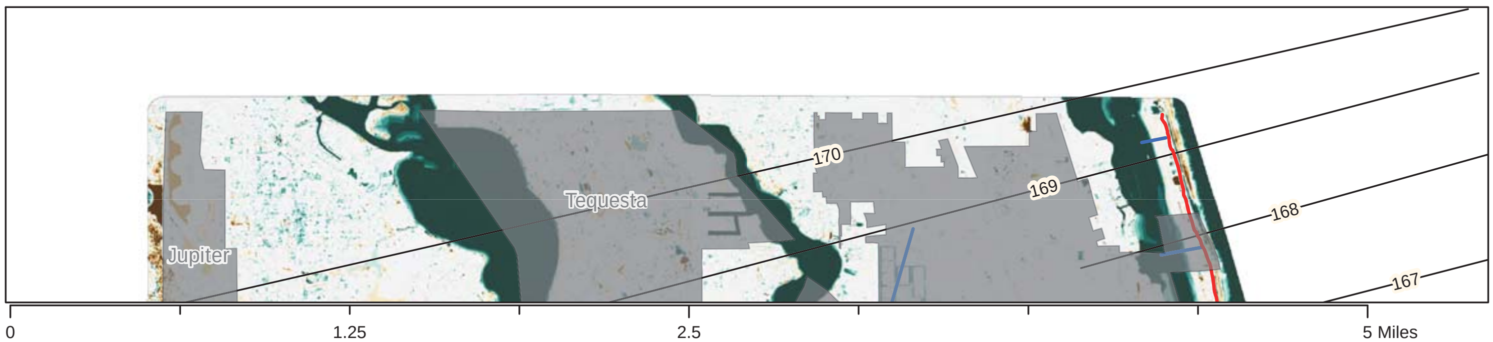
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

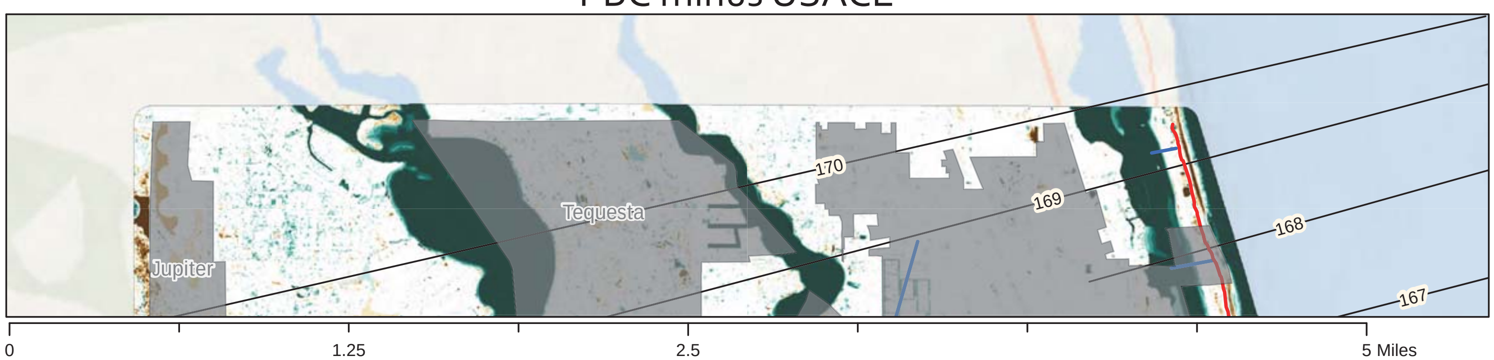
Change Since Last FIRM



PBC minus SWFLTB DEM

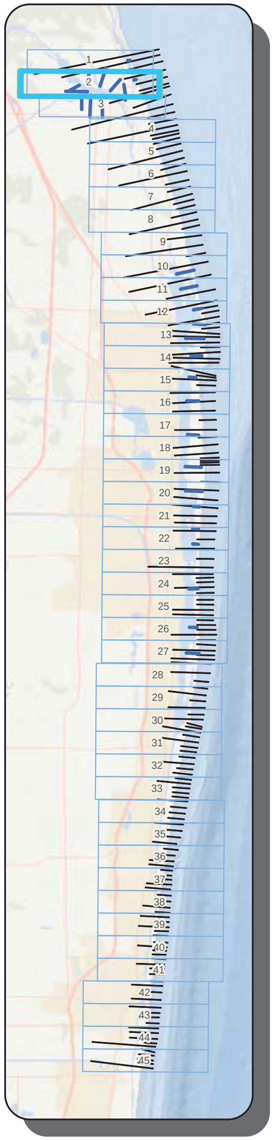


PBC minus USACE

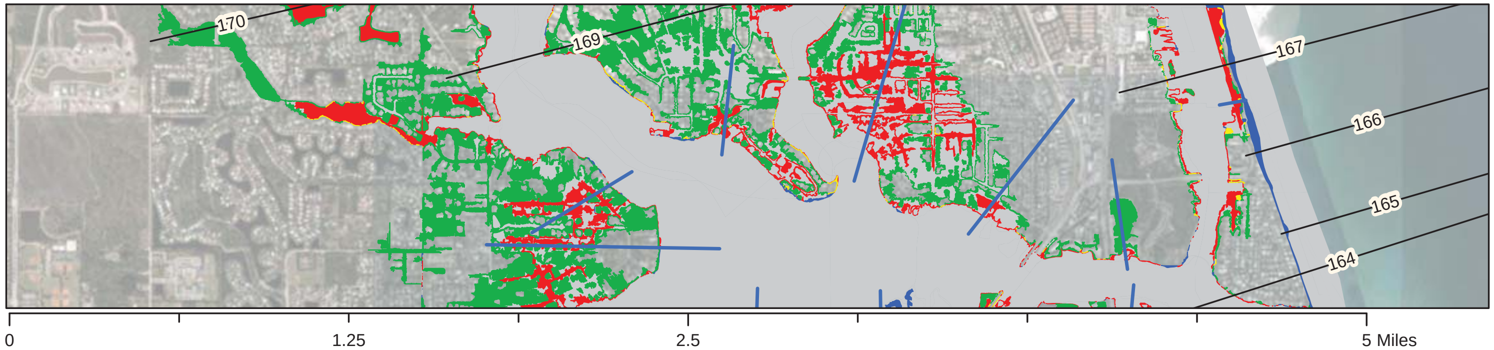


Transect View

Page: 2

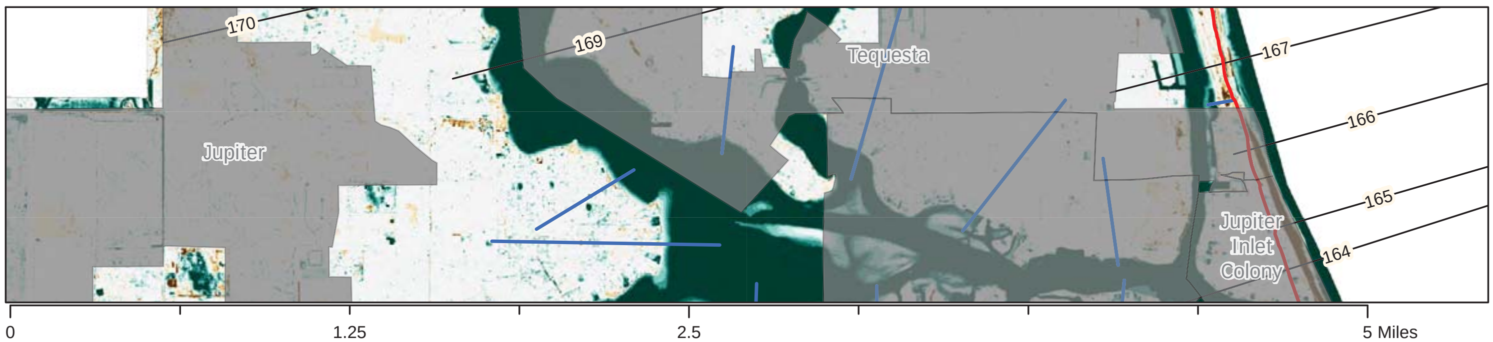


Change Since Last FIRM



Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

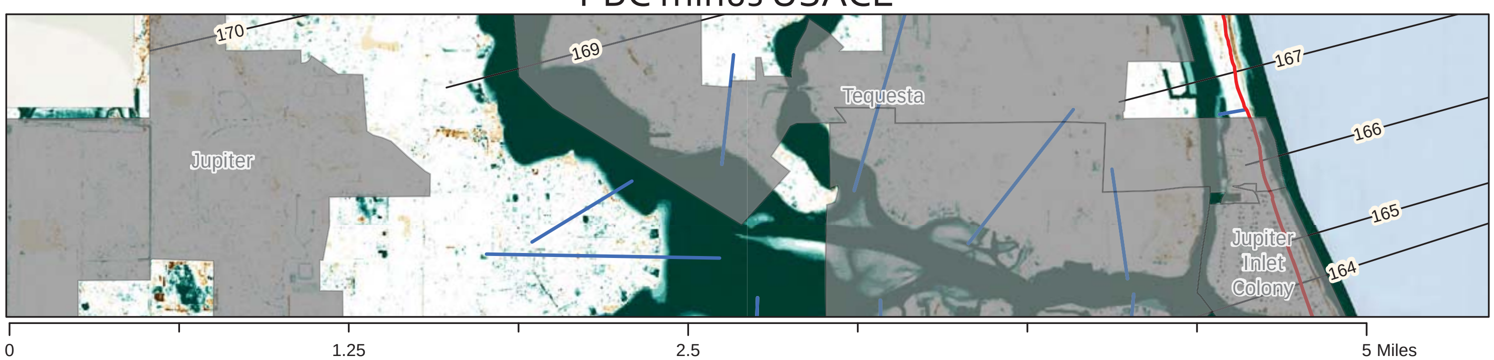
PBC minus SWFLTB DEM



- Frontal Dune Line
- Municipalities

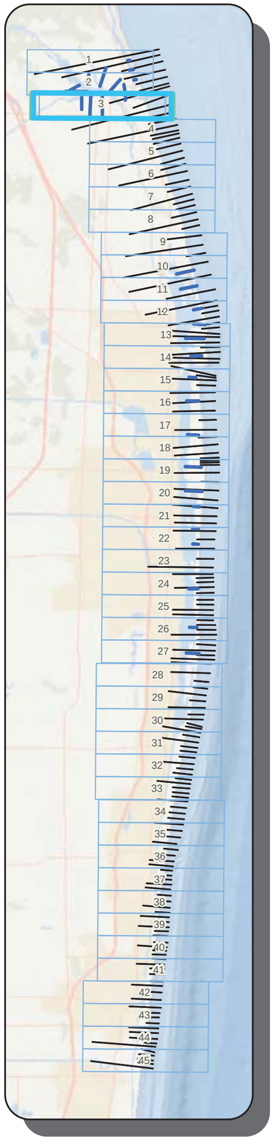
Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

PBC minus USACE

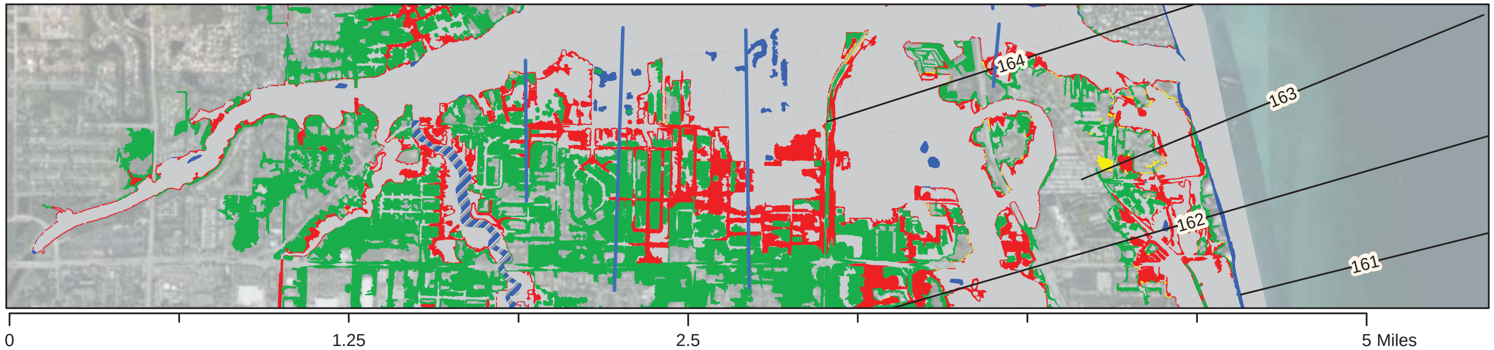


Transect View

Page: 3



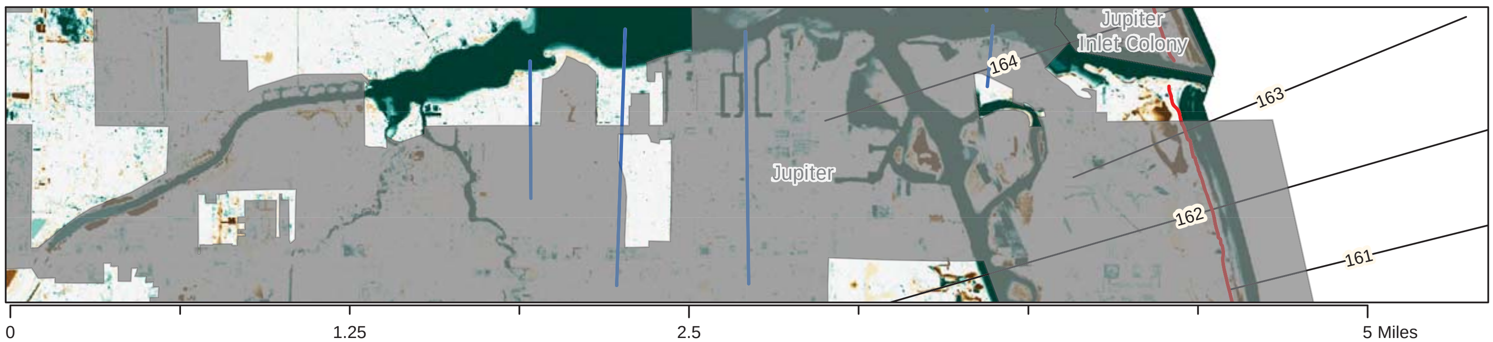
Change Since Last FIRM



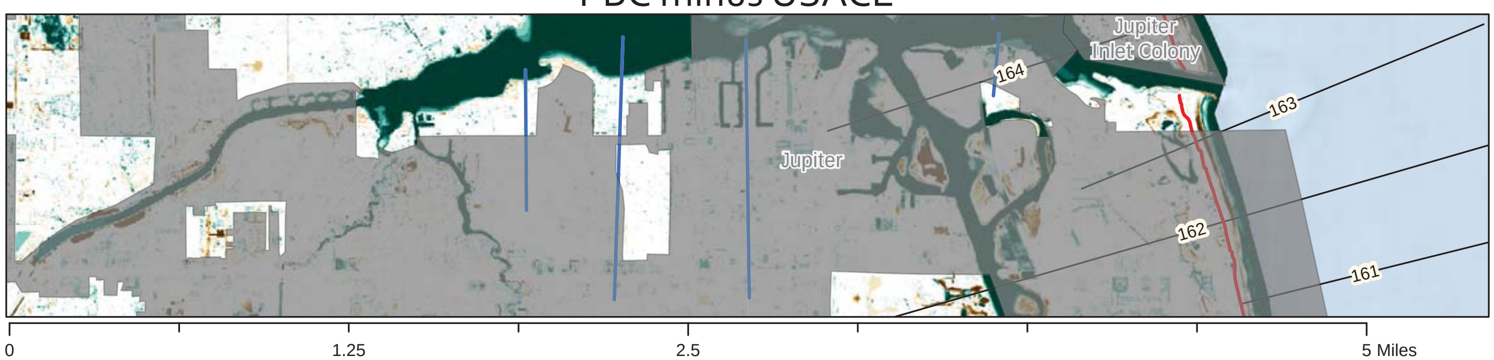
Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

PBC minus SWFLTB DEM



PBC minus USACE



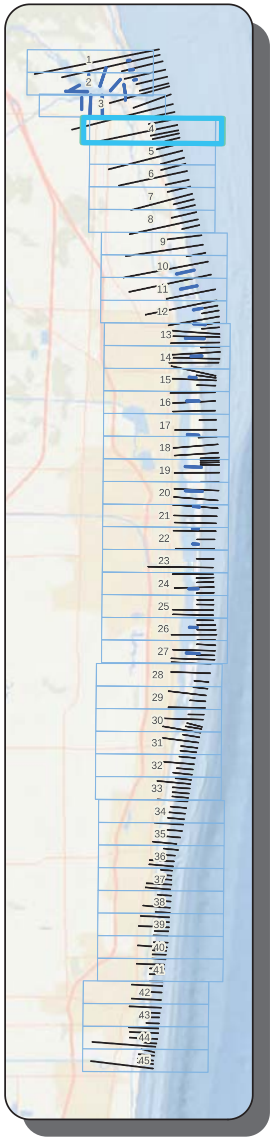
- Frontal Dune Line
- Municipalities

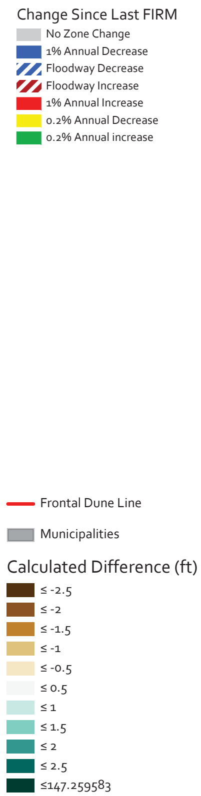
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

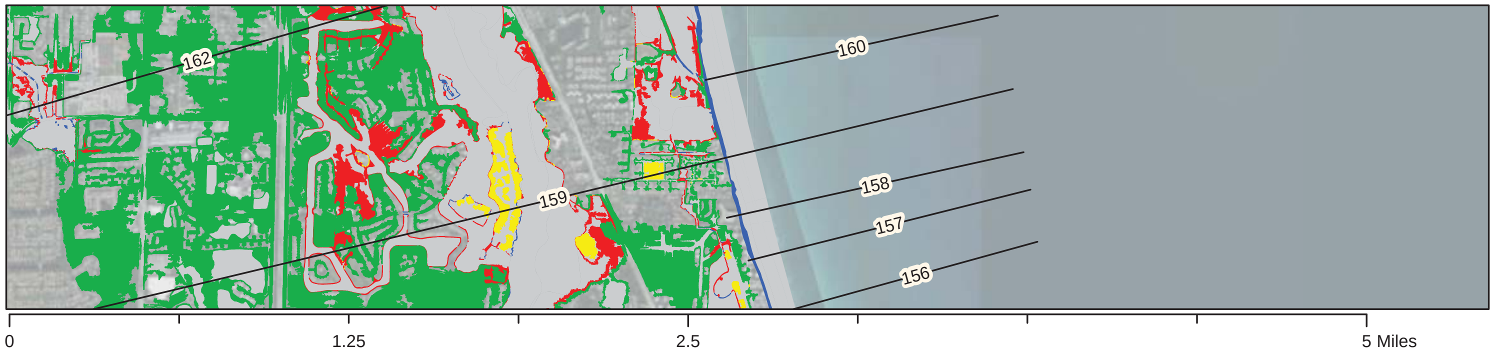
Transect View

Page: 4

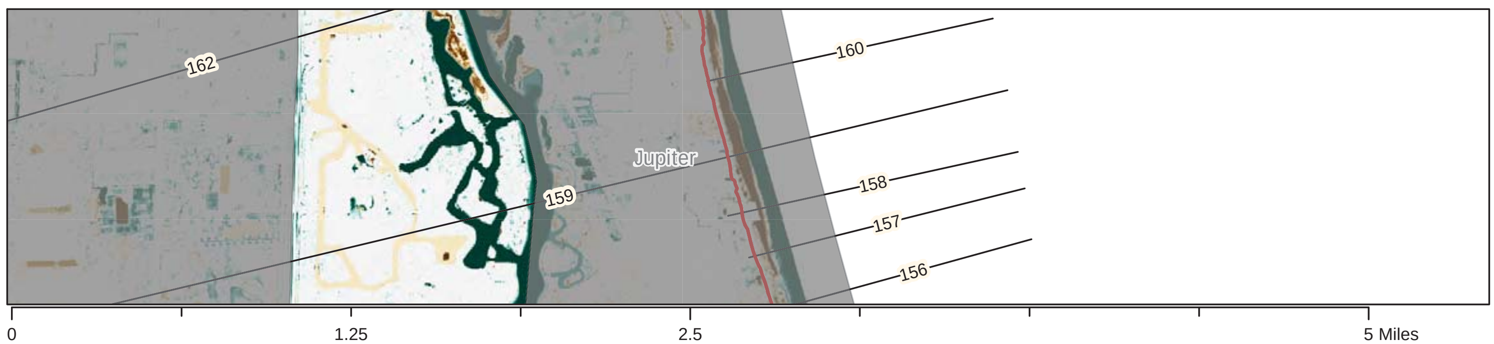




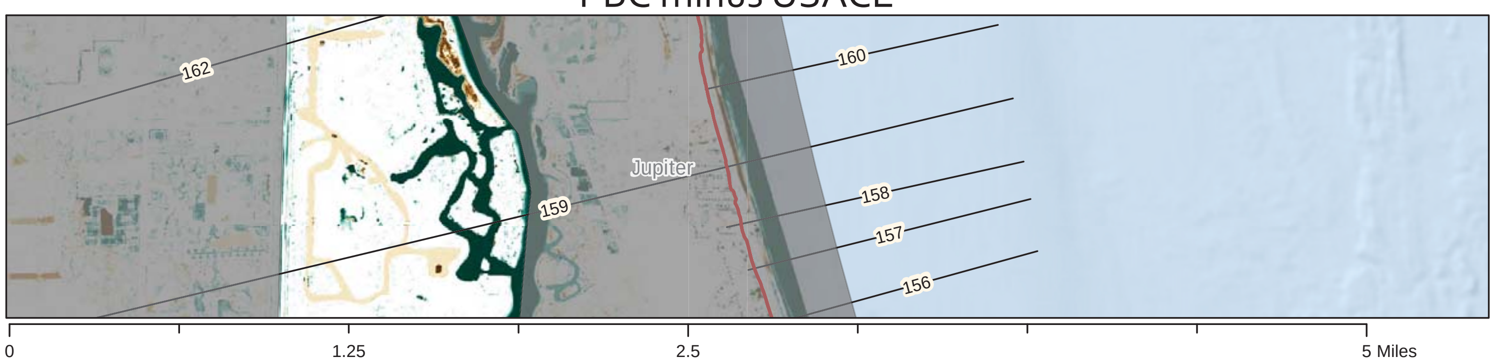
Change Since Last FIRM



PBC minus SWFLTB DEM

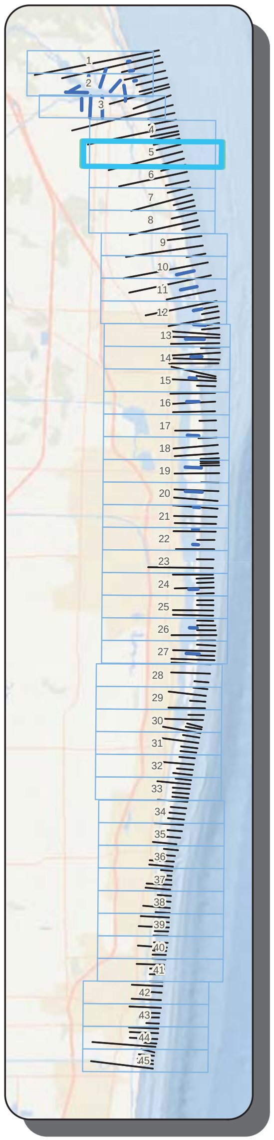


PBC minus USACE



Transect View

Page: 5



Change Since Last FIRM

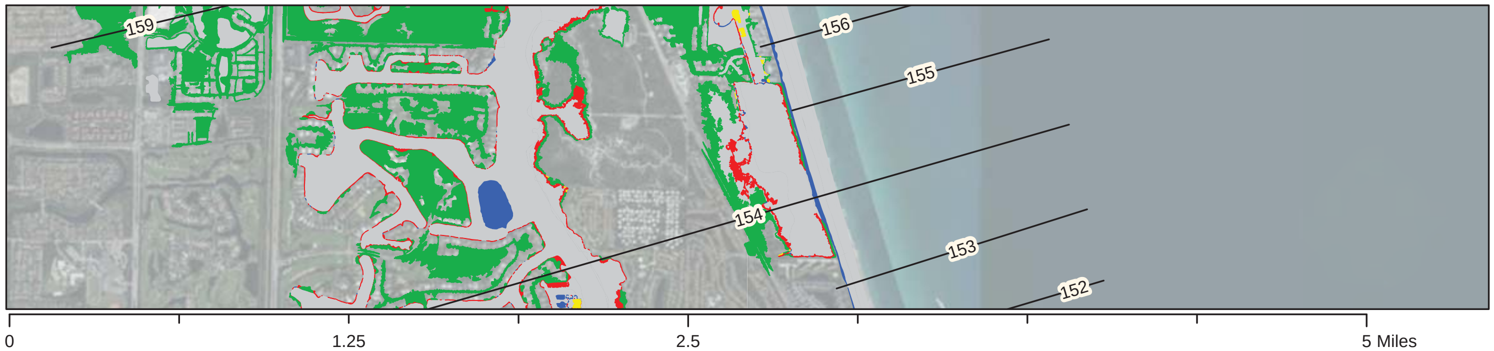
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

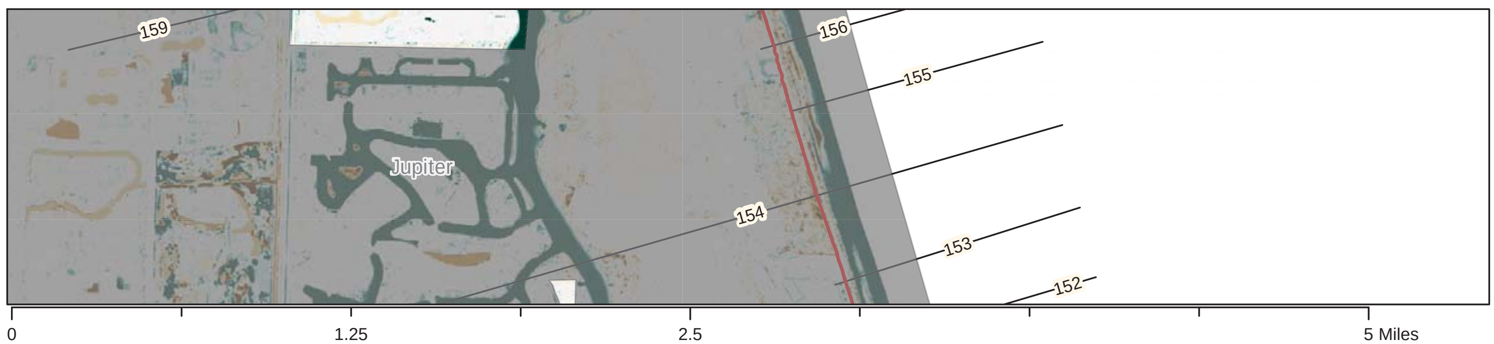
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

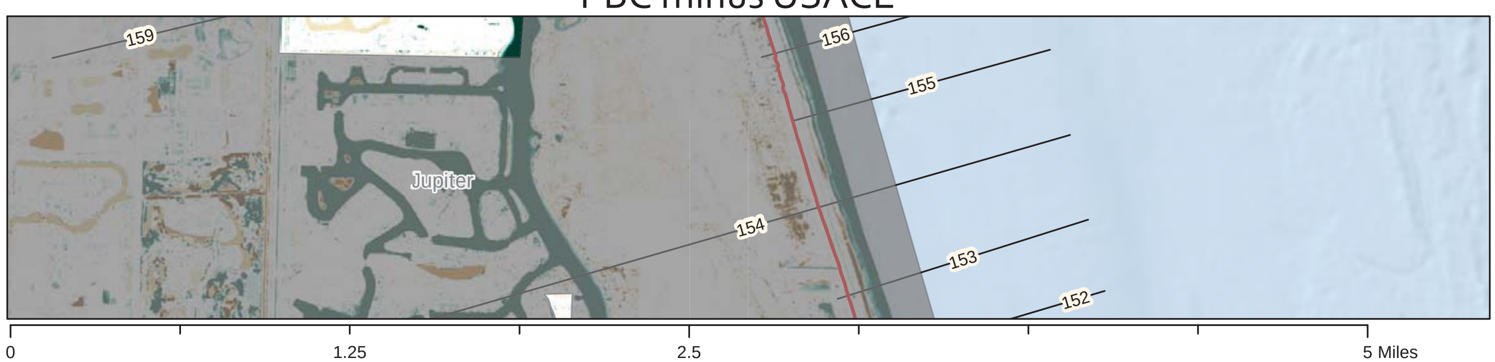
Change Since Last FIRM



PBC minus SWFLTB DEM

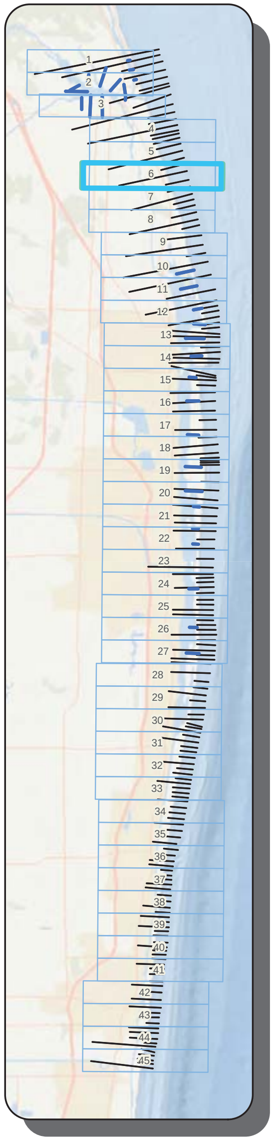


PBC minus USACE

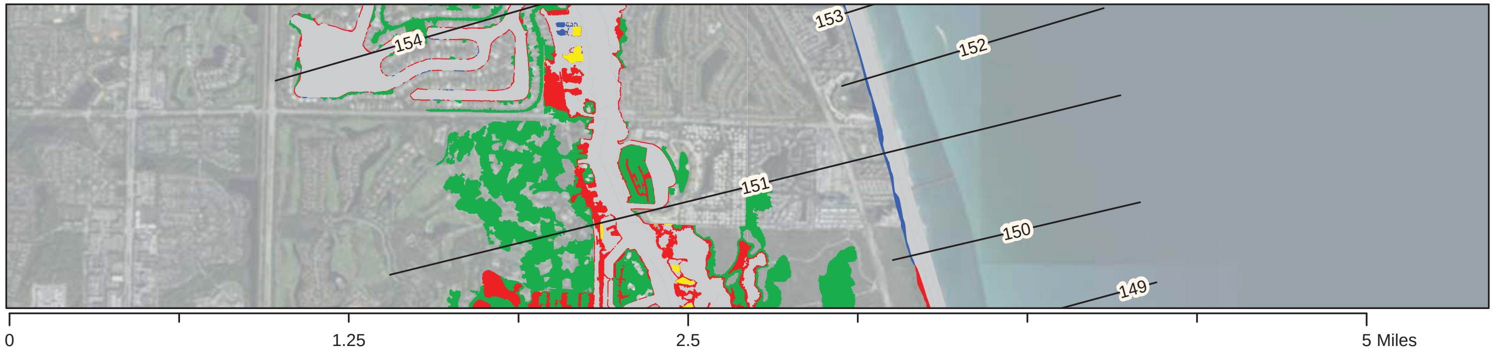


Transect View

Page: 6



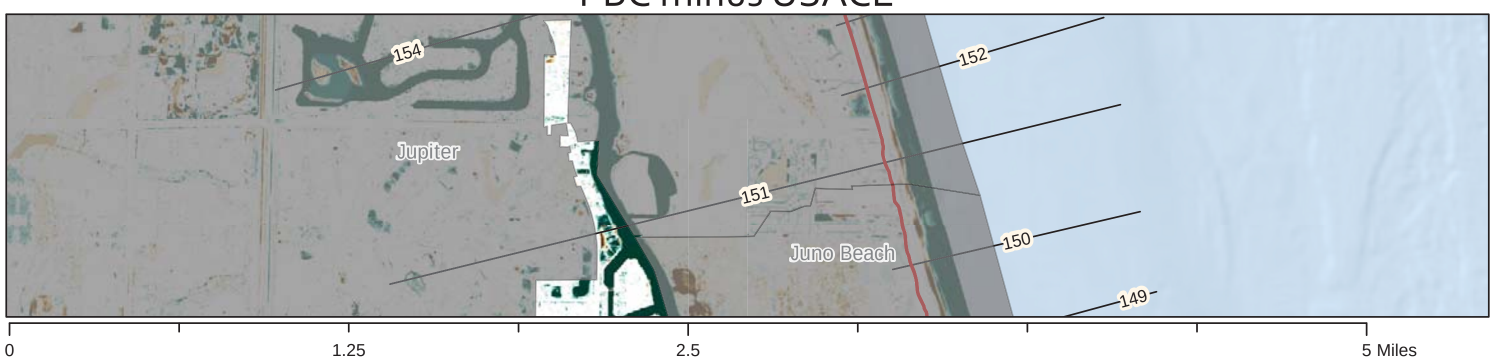
Change Since Last FIRM



Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

PBC minus SWFLTB DEM

PBC minus USACE

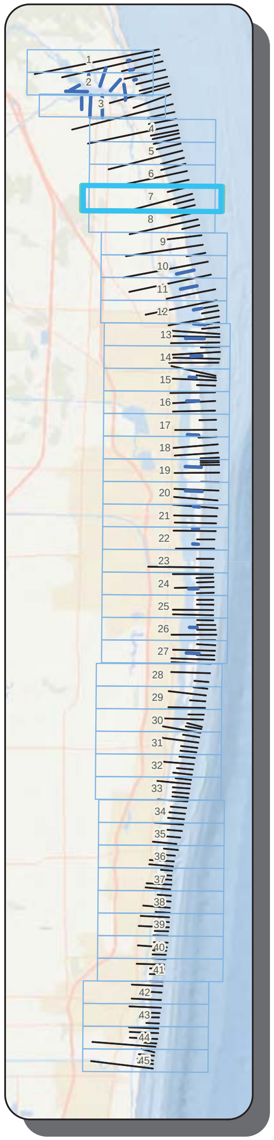


- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Transect View

Page: 7

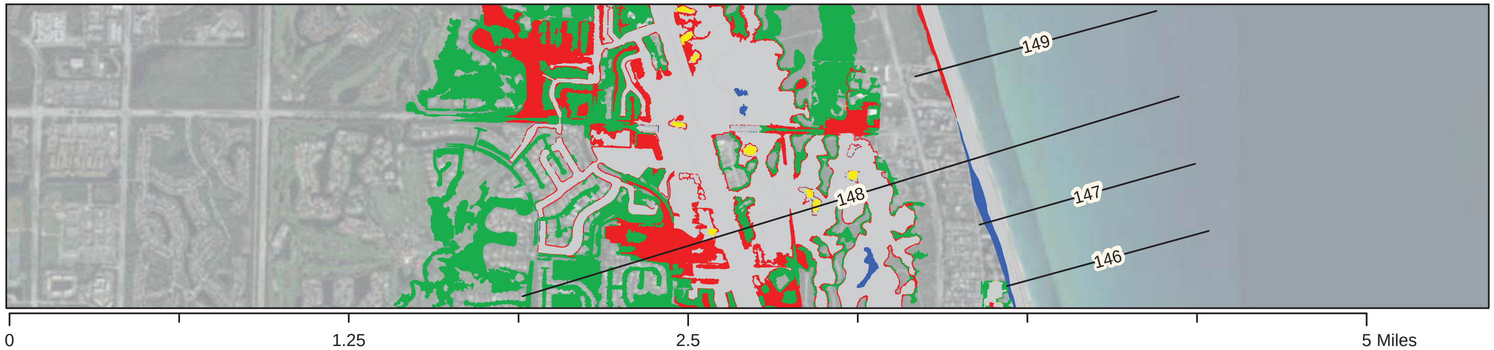


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM

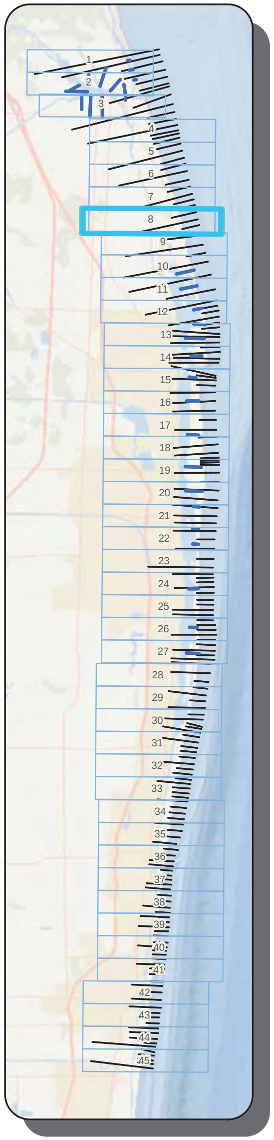


PBC minus SWFLTB DEM

PBC minus USACE

Transect View

Page: 8



Change Since Last FIRM

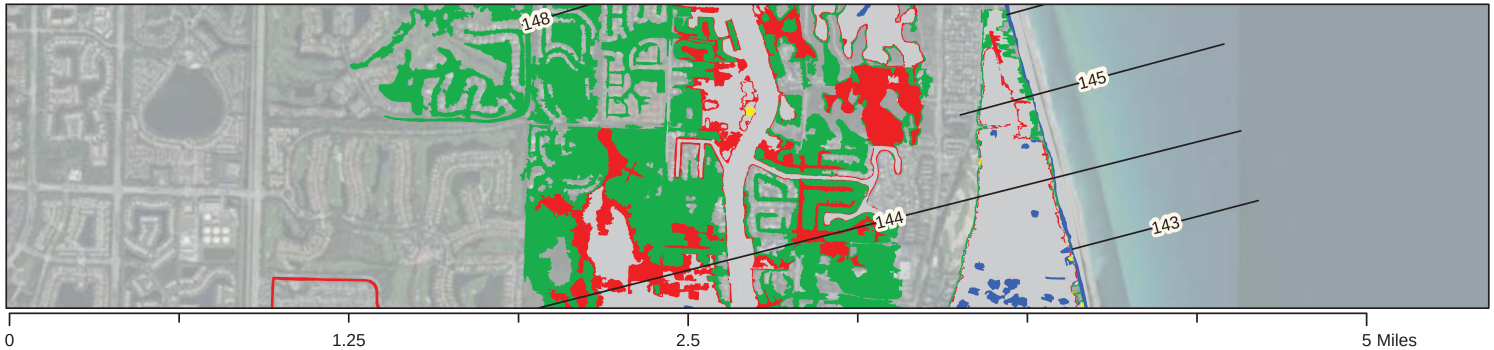
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

Calculated Difference (ft)

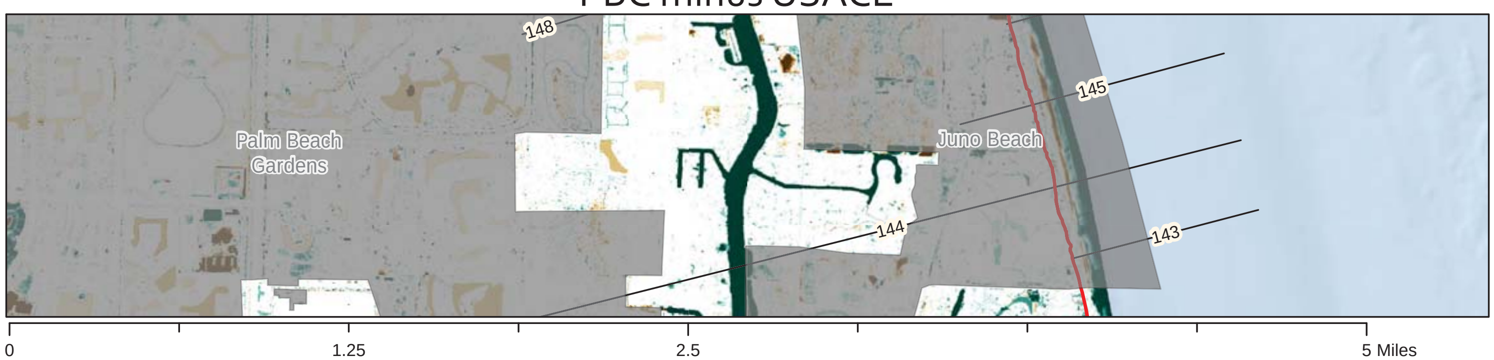
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



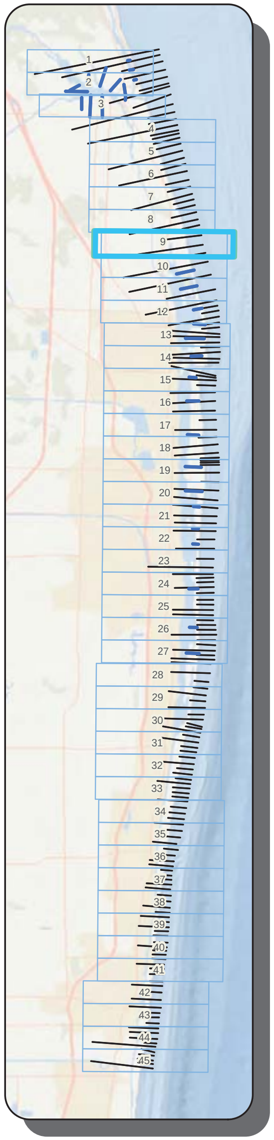
PBC minus SWFLTB DEM

PBC minus USACE



Transect View

Page: 9



Change Since Last FIRM

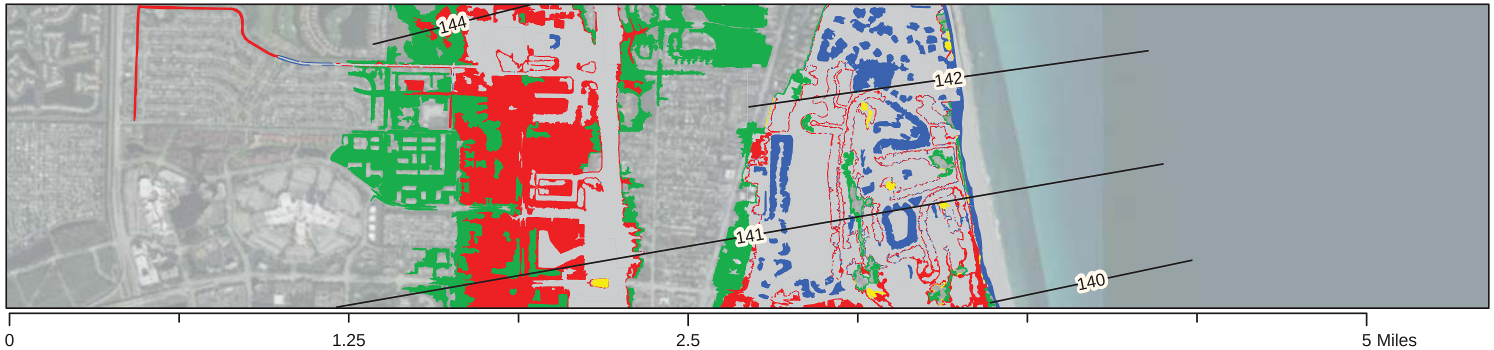
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

Calculated Difference (ft)

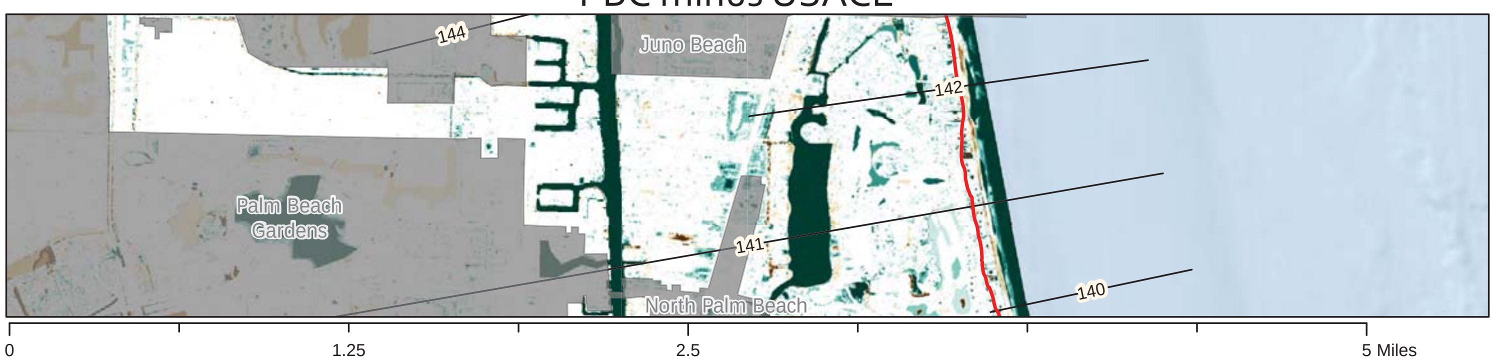
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



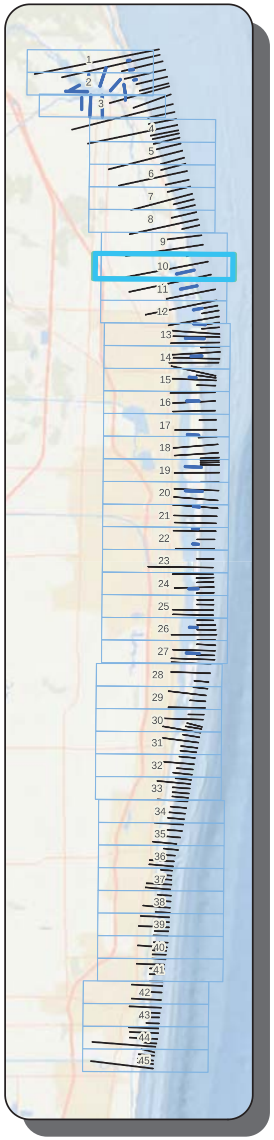
PBC minus SWFLTB DEM

PBC minus USACE



Transect View

Page: 10

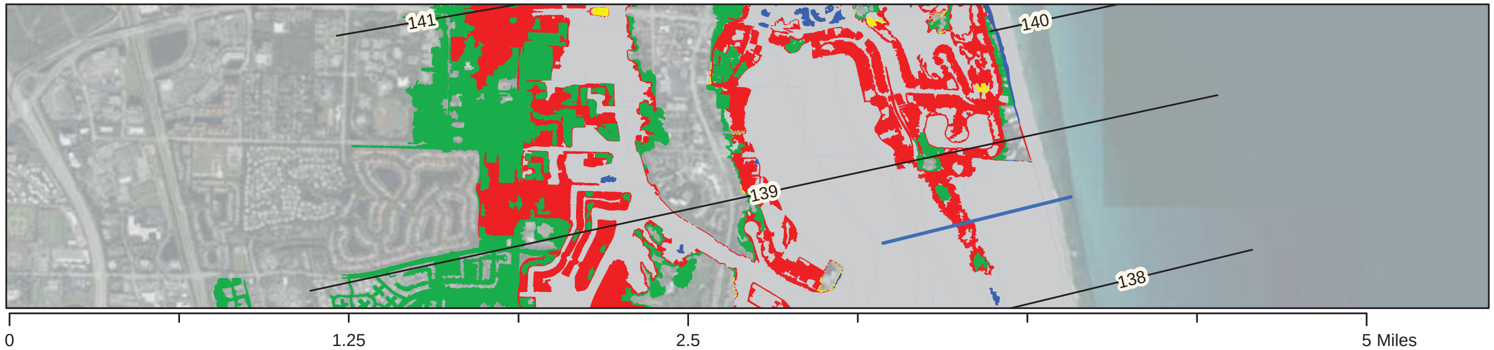


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

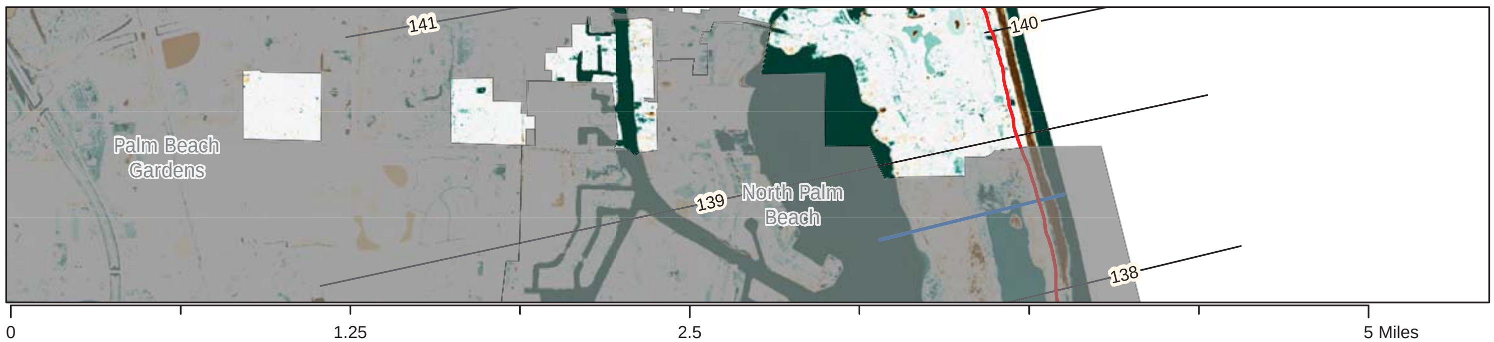
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

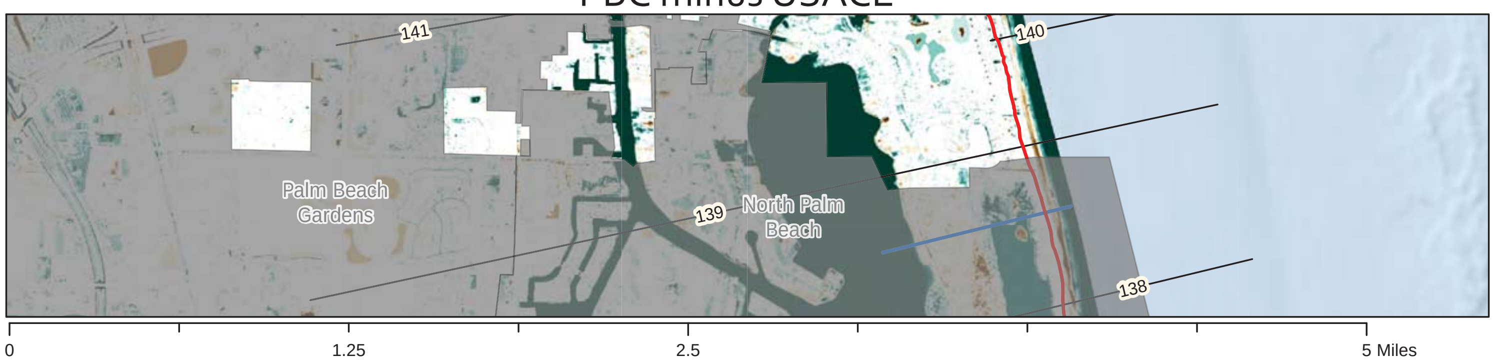
Change Since Last FIRM



PBC minus SWFLTB DEM

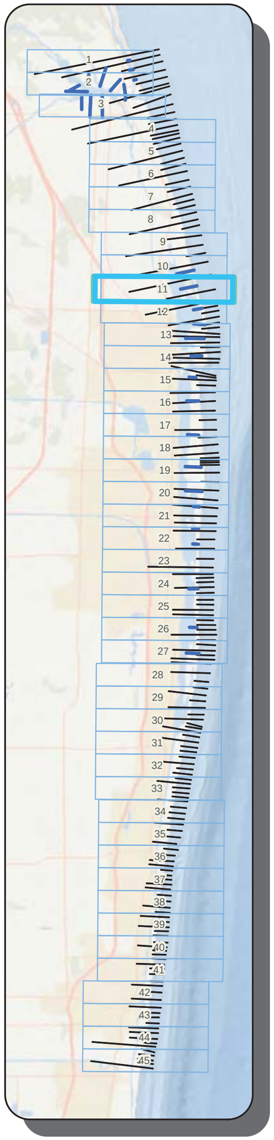


PBC minus USACE



Transect View

Page: 11

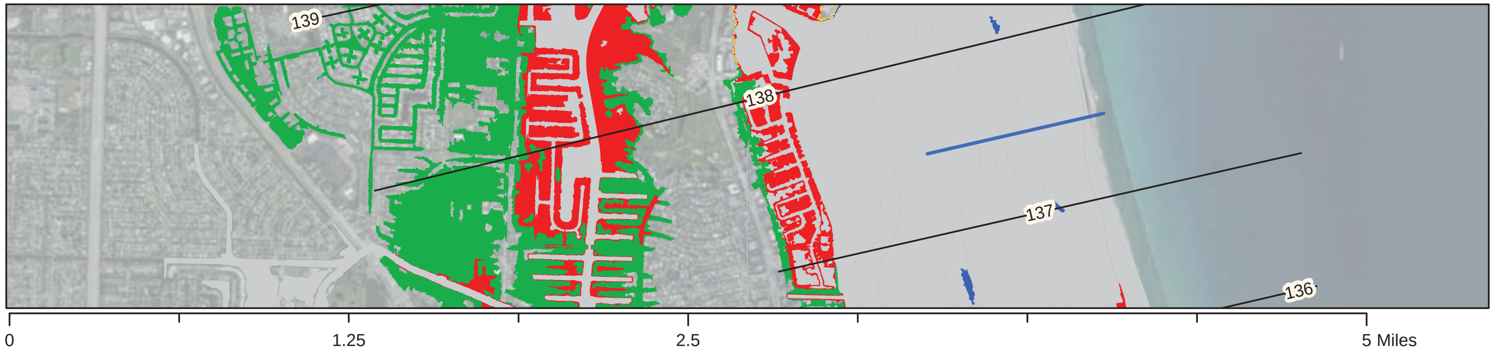


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

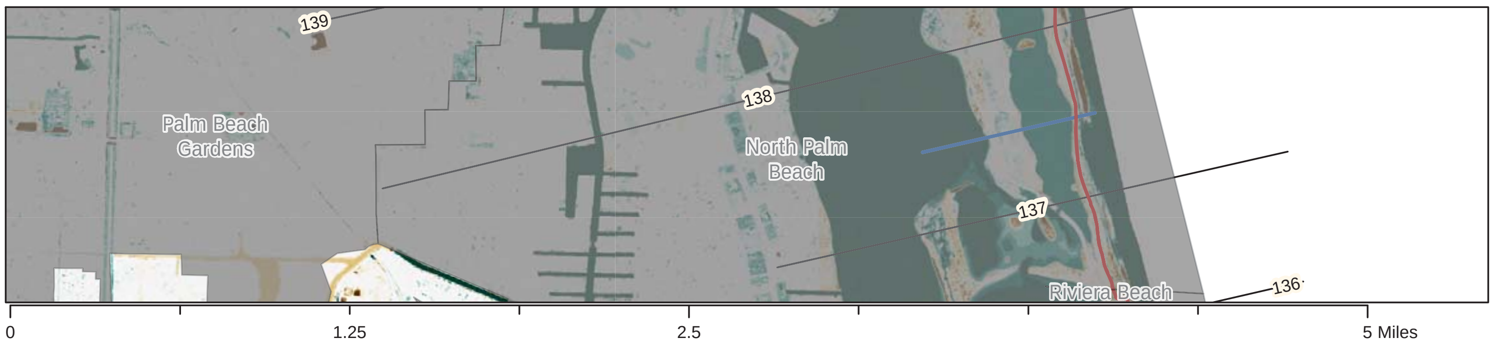
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

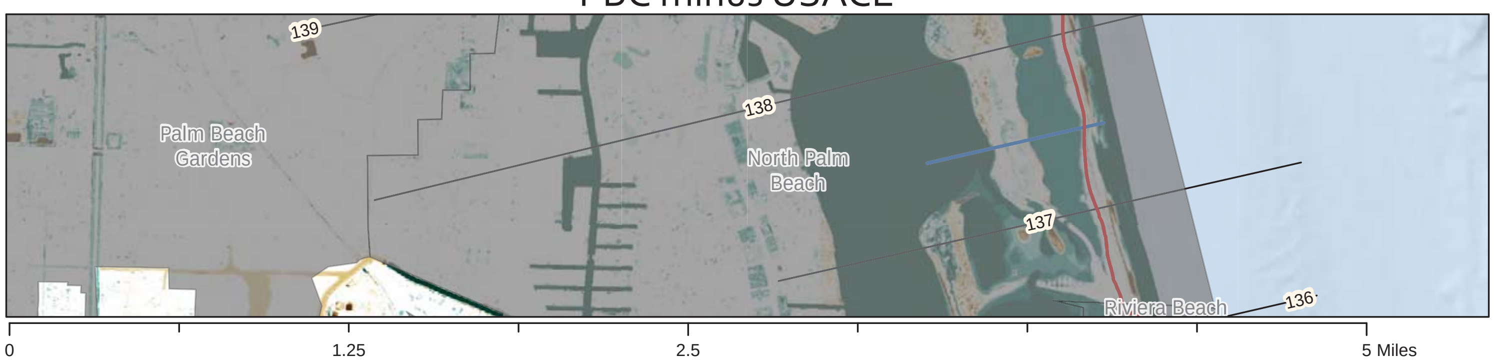
Change Since Last FIRM



PBC minus SWFLTB DEM

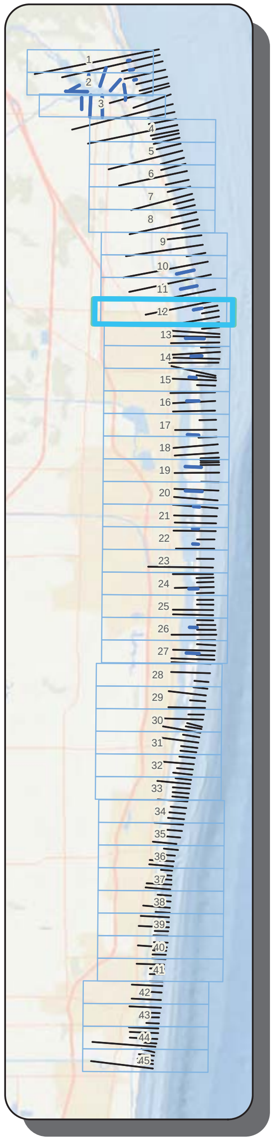


PBC minus USACE



Transect View

Page: 12

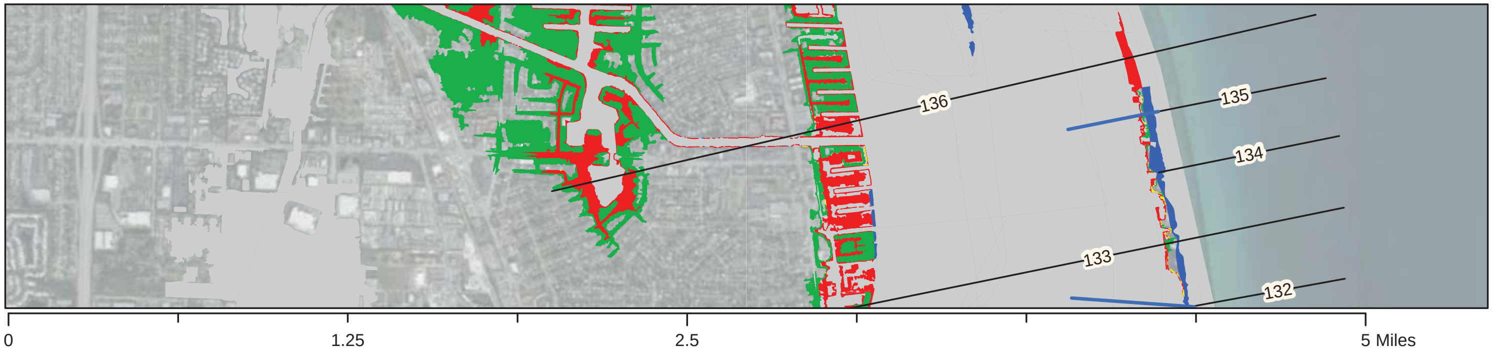


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

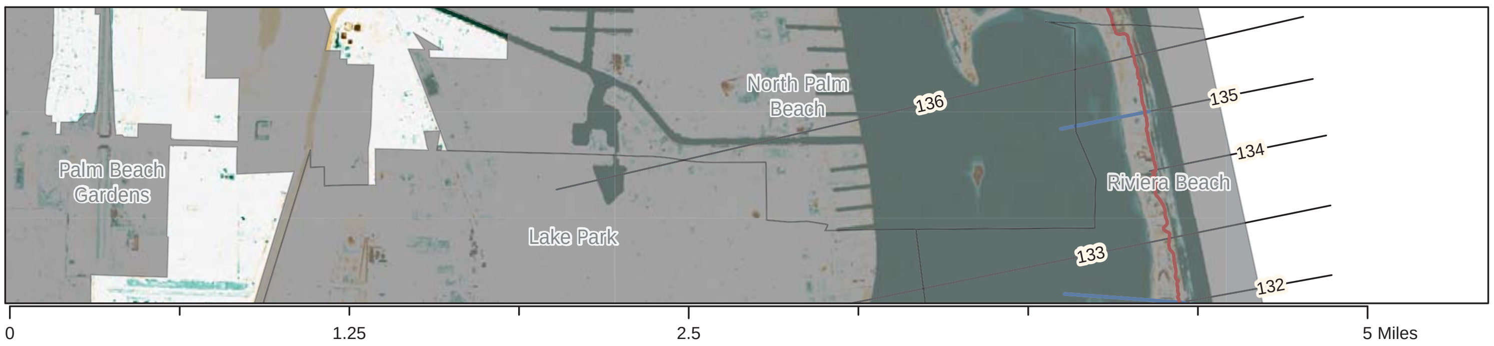
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

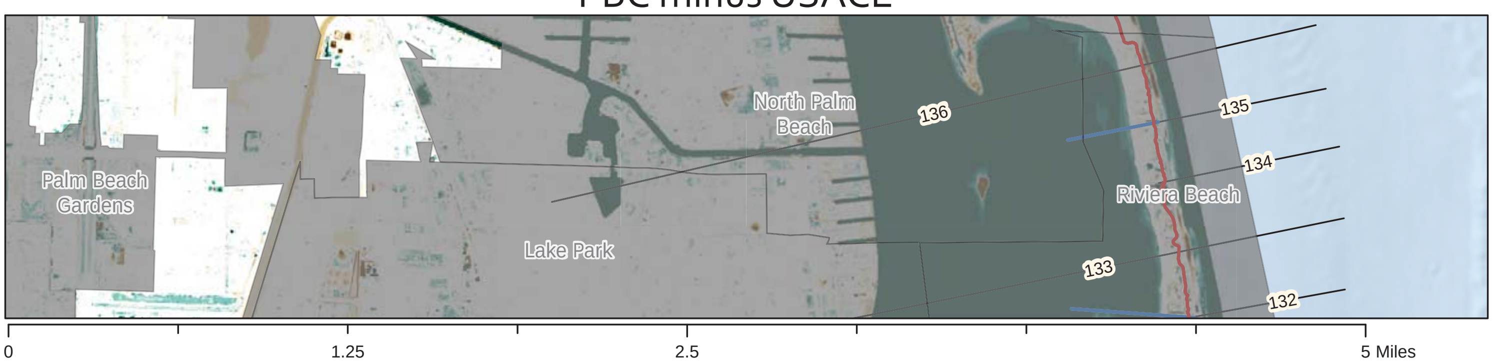
Change Since Last FIRM



PBC minus SWFLTB DEM

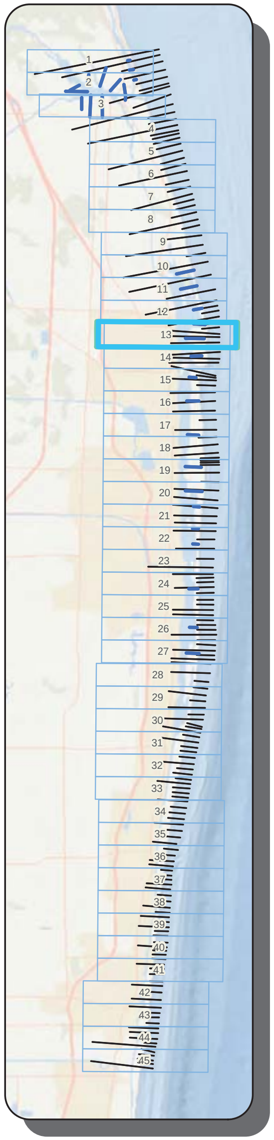


PBC minus USACE



Transect View

Page: 13

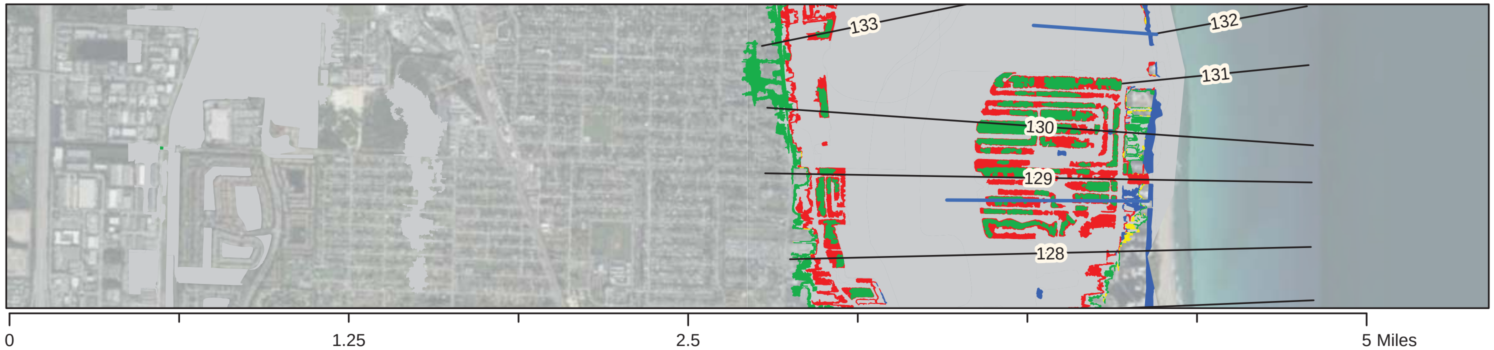


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

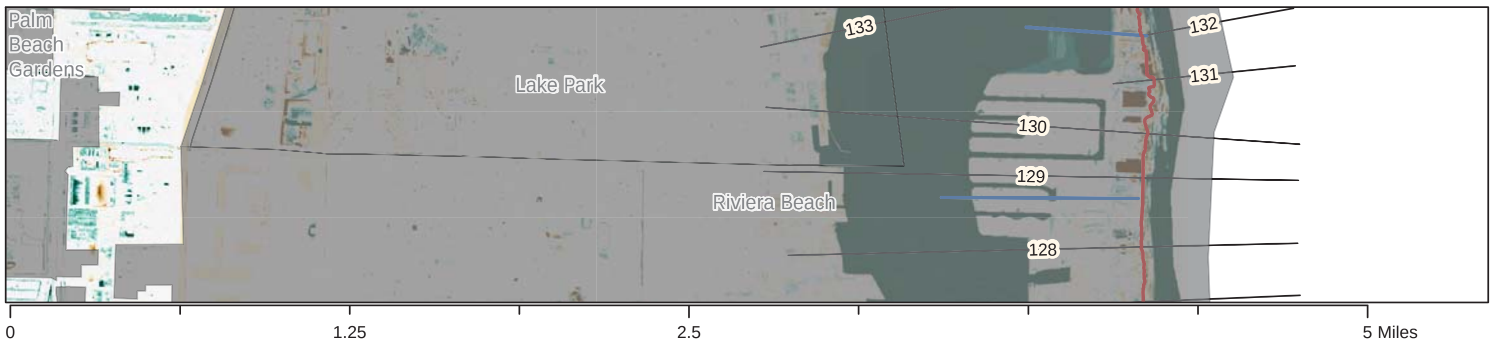
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

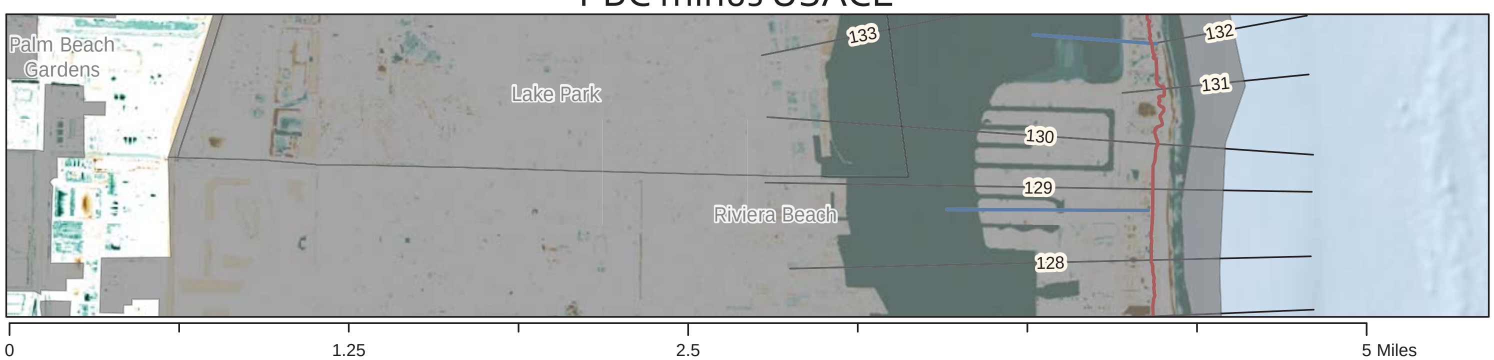
Change Since Last FIRM



PBC minus SWFLTB DEM

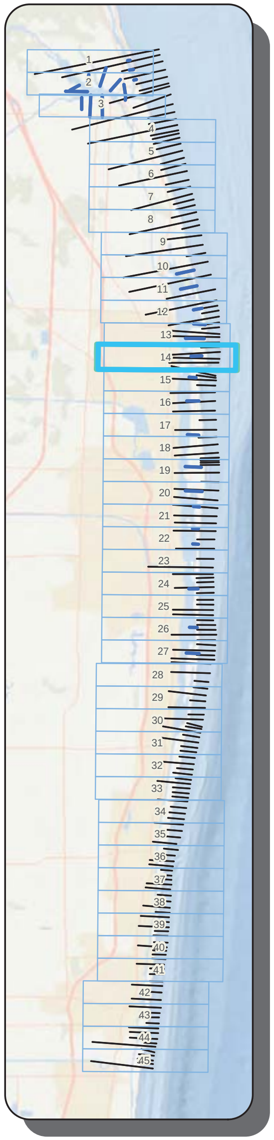


PBC minus USACE



Transect View

Page: 14

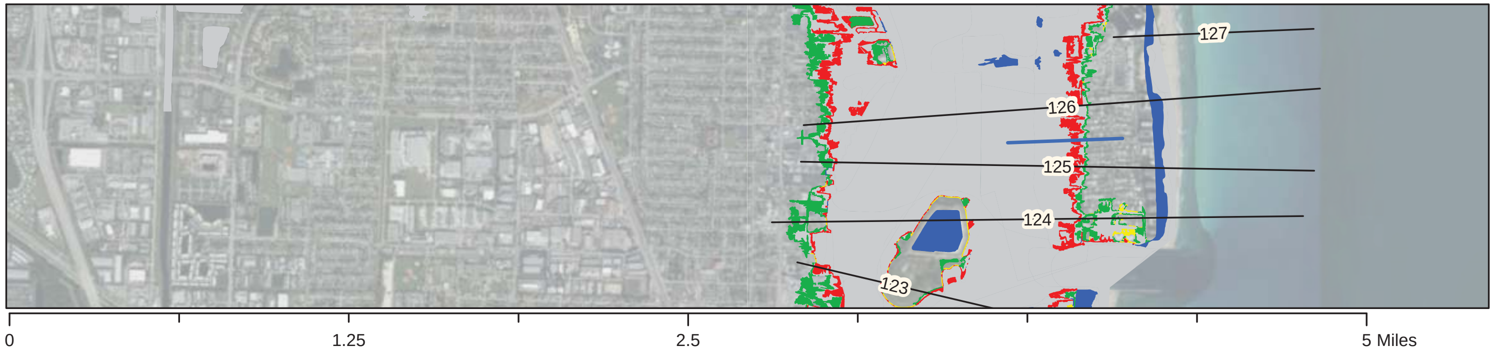


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

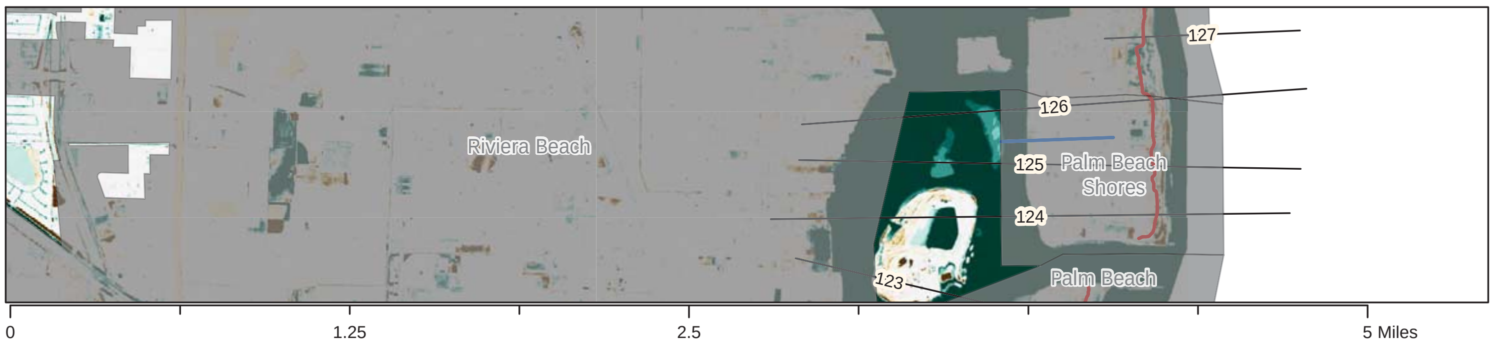
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

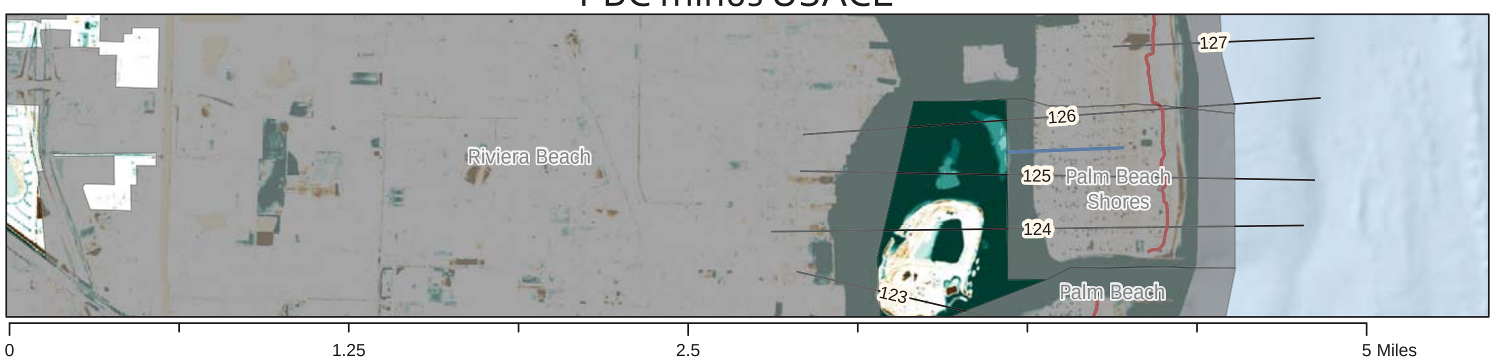
Change Since Last FIRM



PBC minus SWFLTB DEM

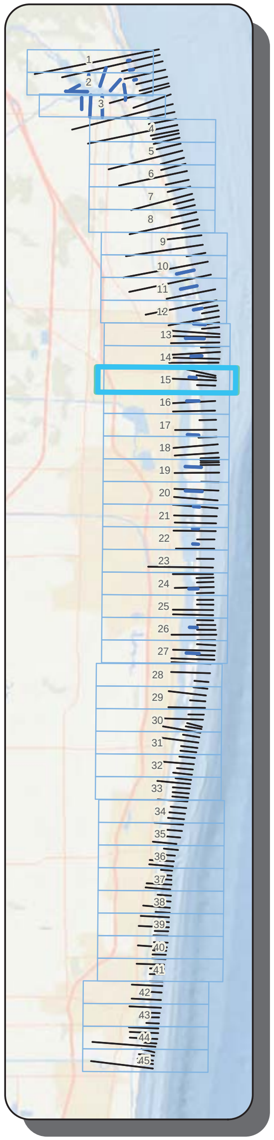


PBC minus USACE



Transect View

Page: 15



Change Since Last FIRM

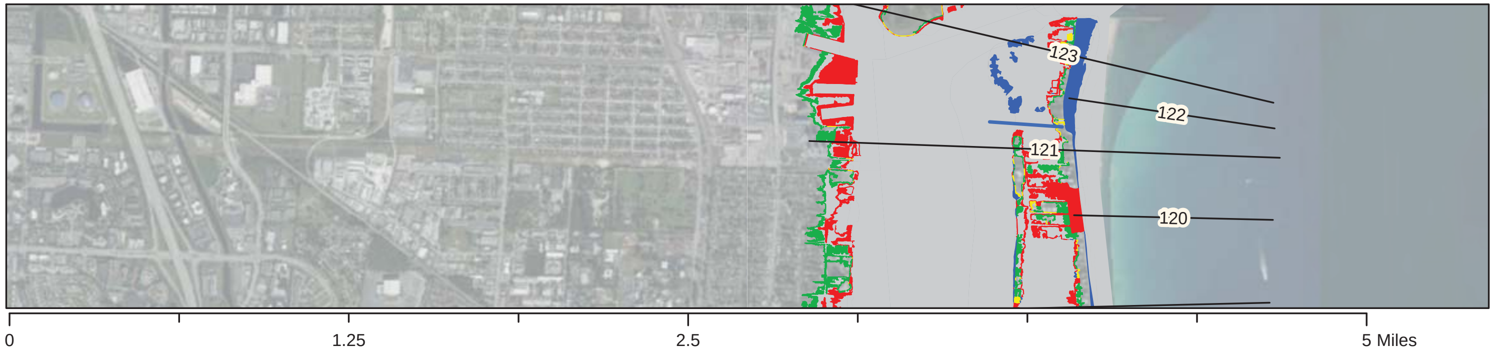
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

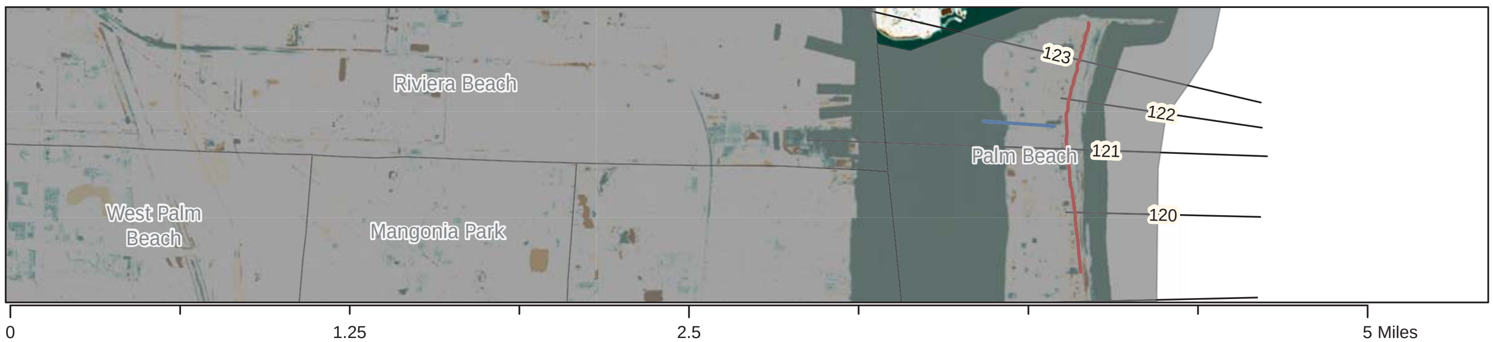
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

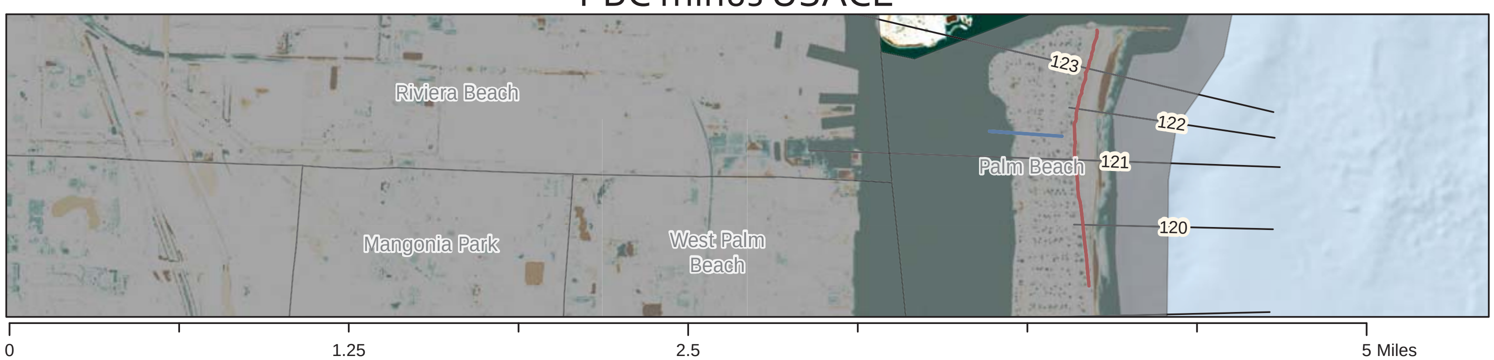
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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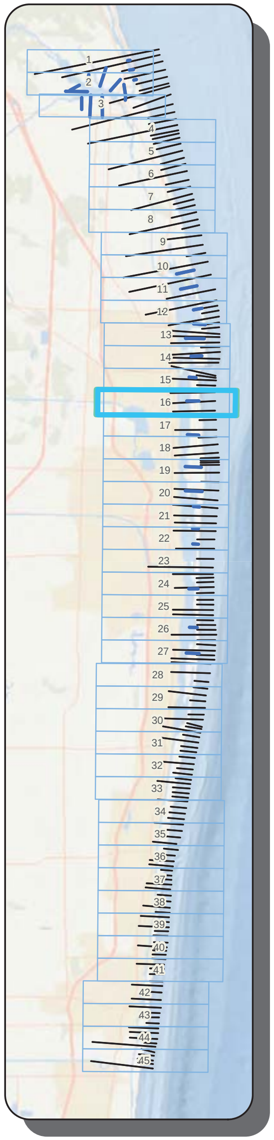
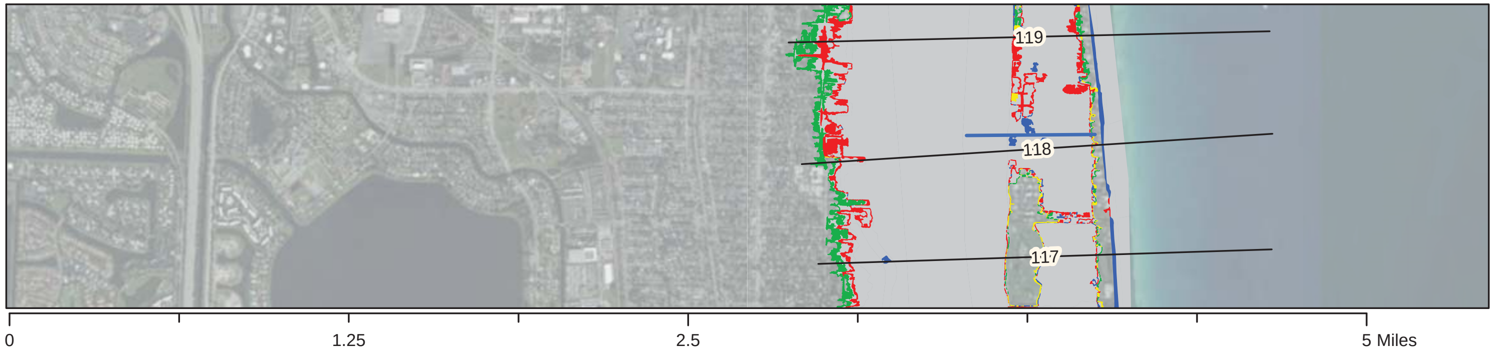


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

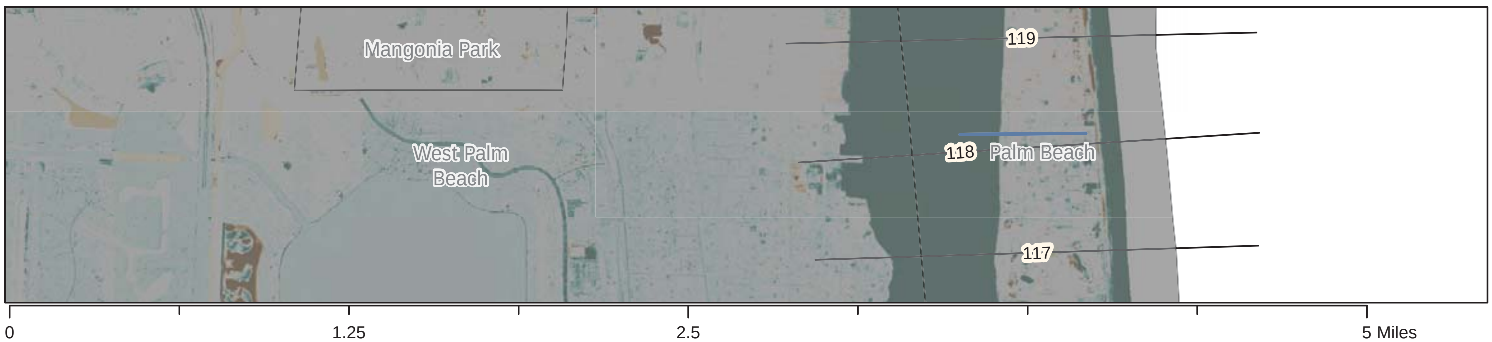
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

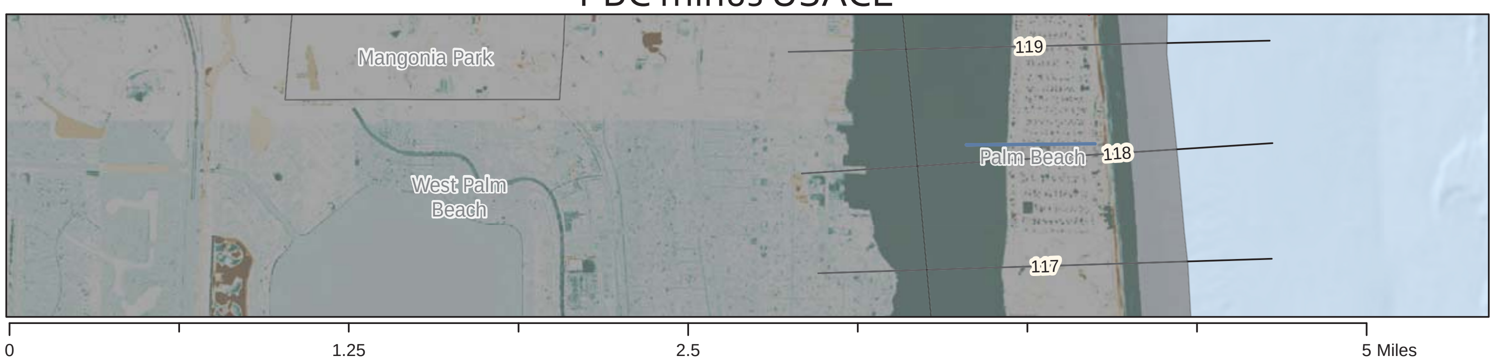
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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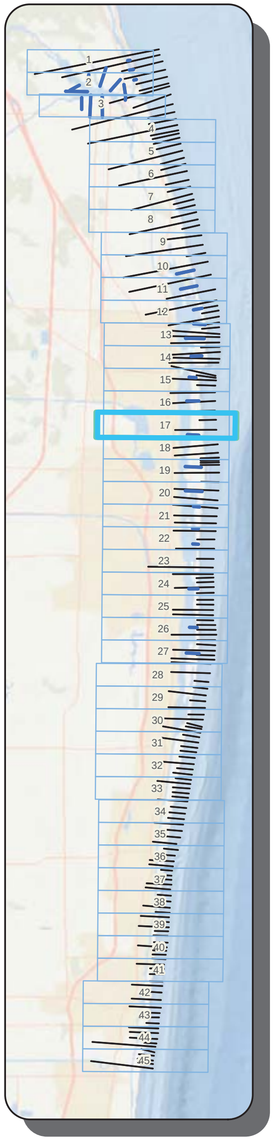

Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

Calculated Difference (ft)

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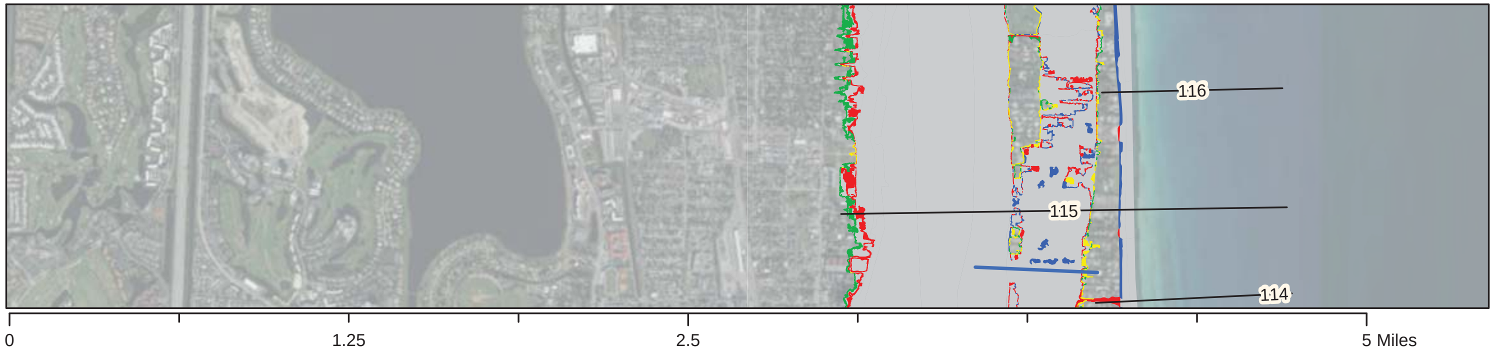
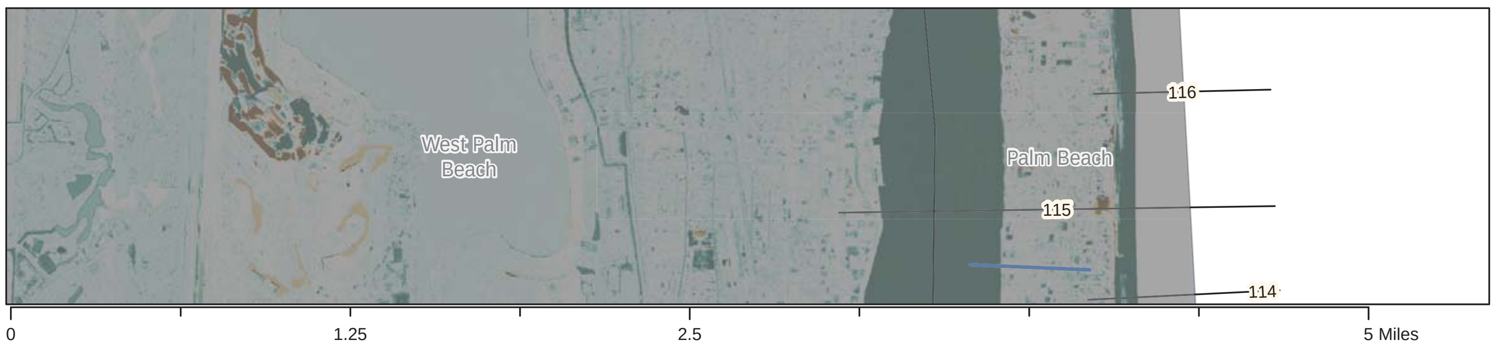
- ≤ 2
- ≤ 2.5
- ≤147.259583

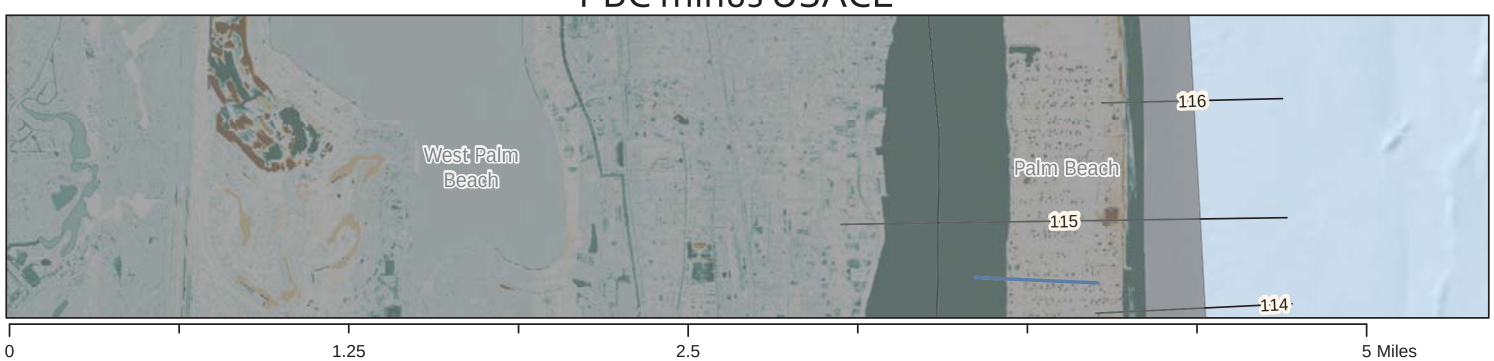
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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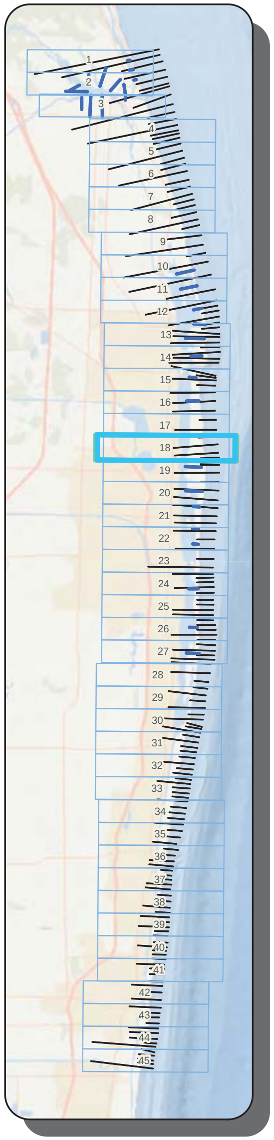

Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
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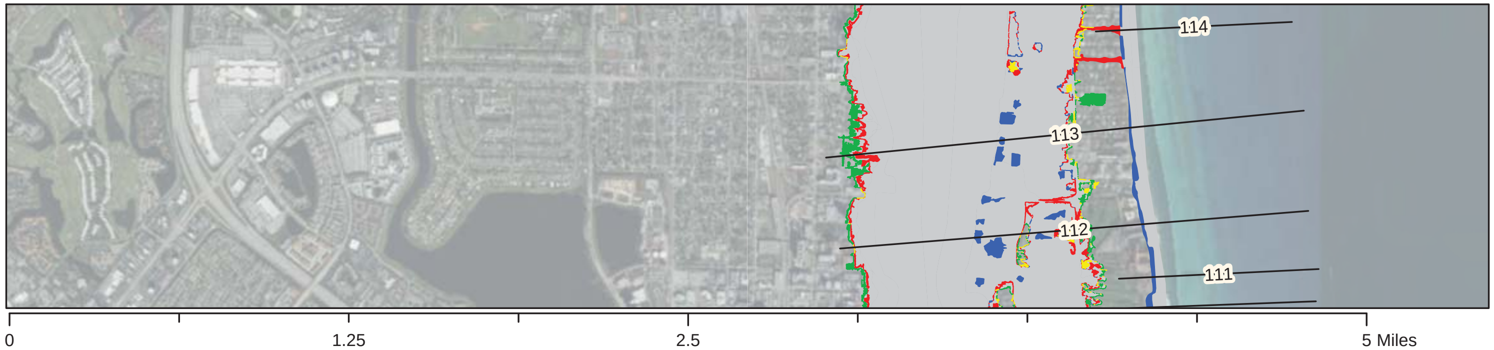
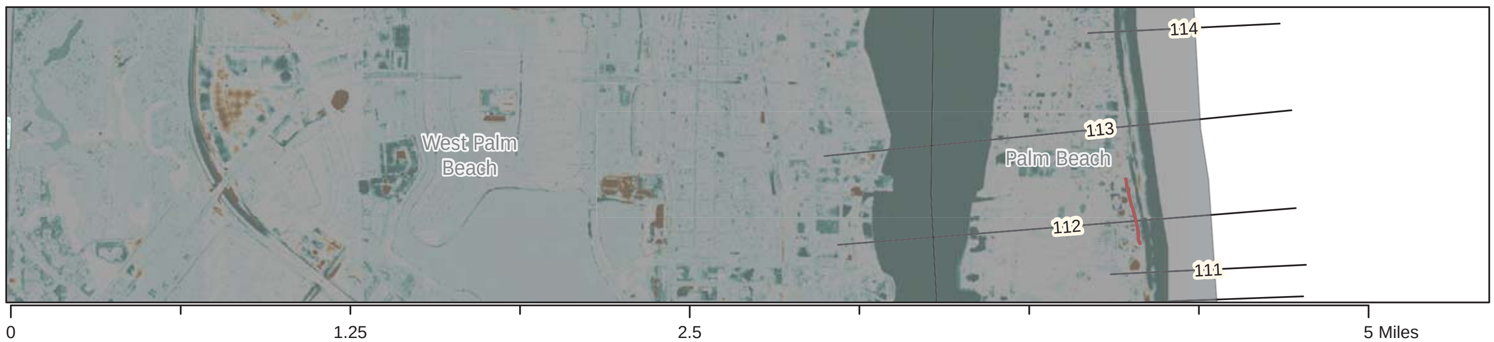
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE

Transect View

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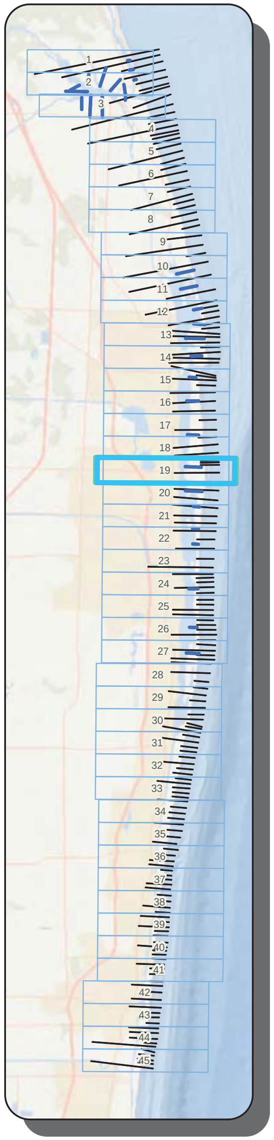

Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

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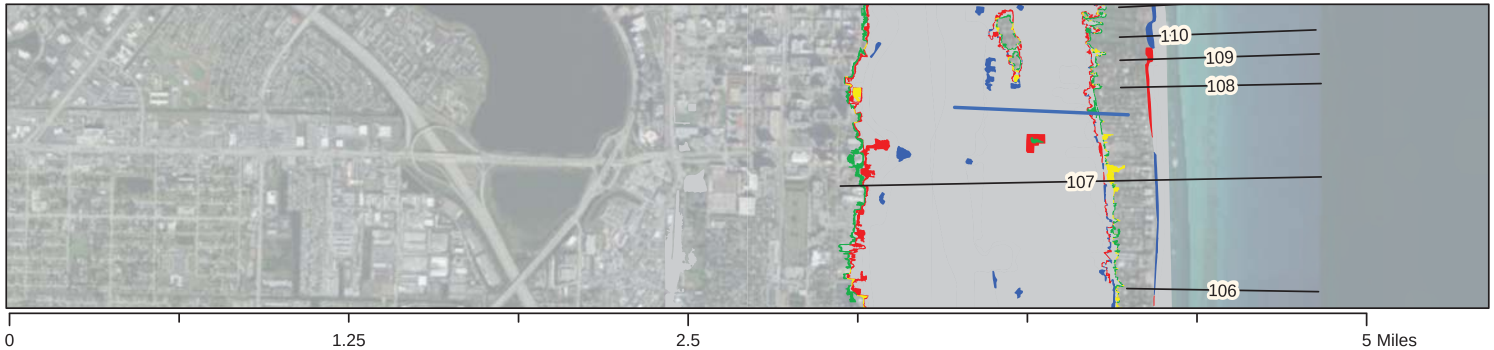
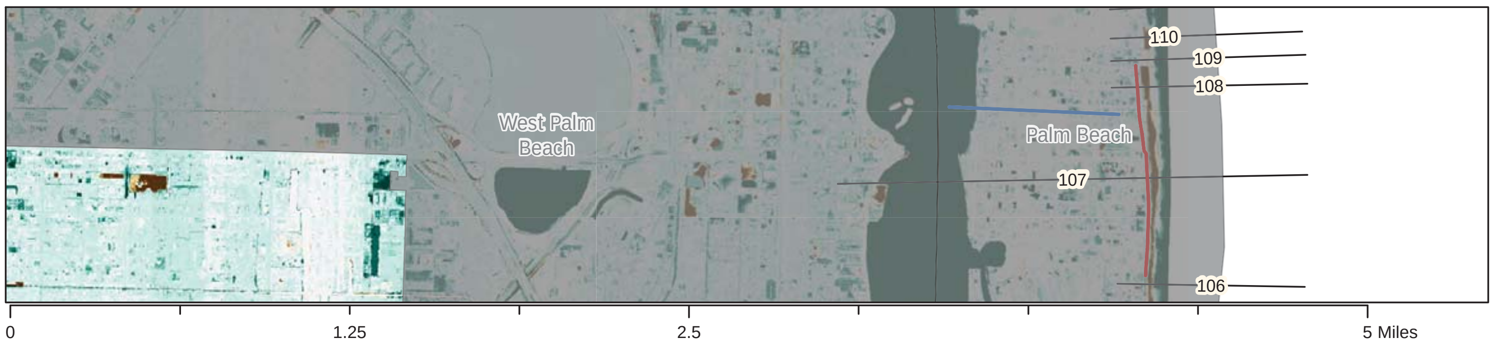
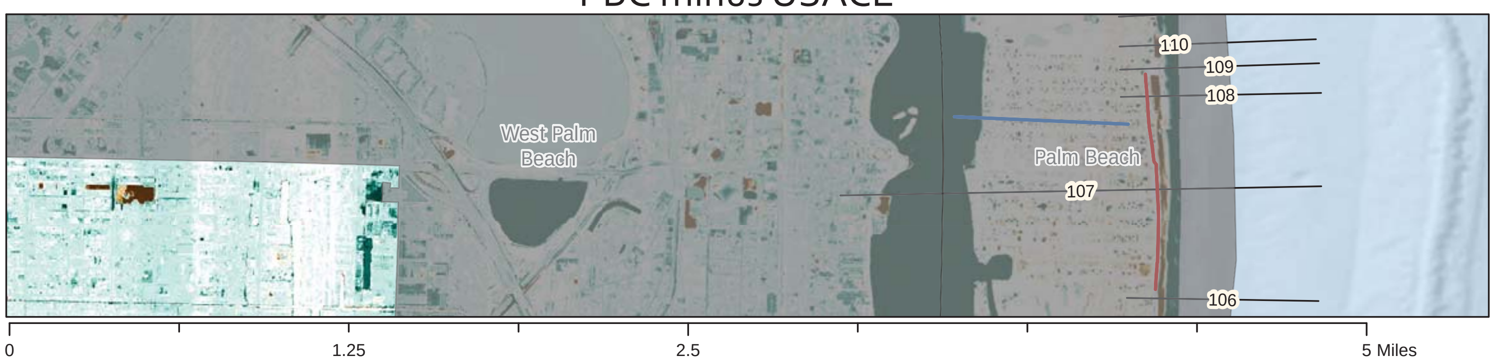
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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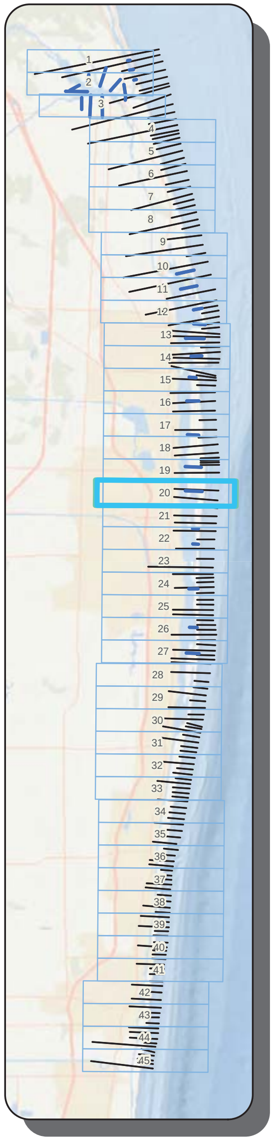

Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

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- Municipalities

Calculated Difference (ft)

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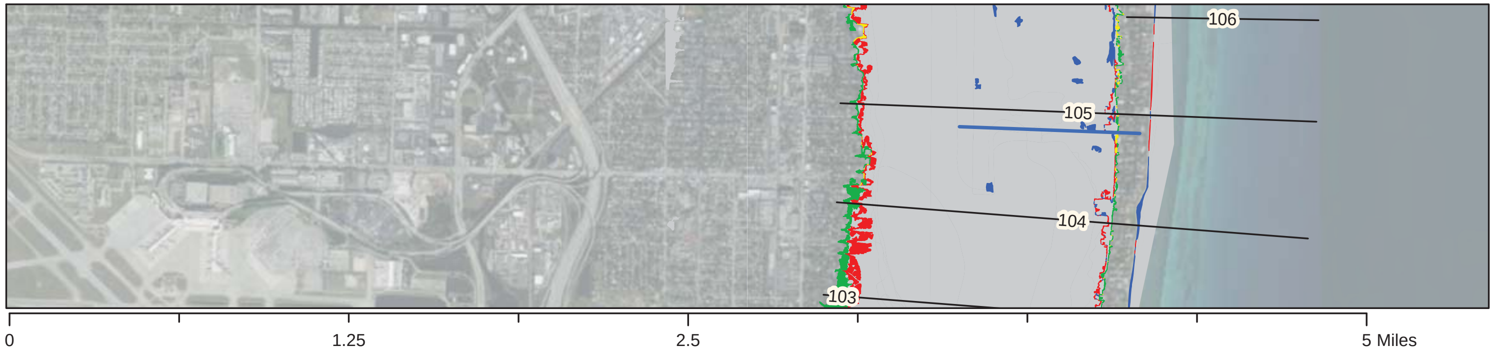
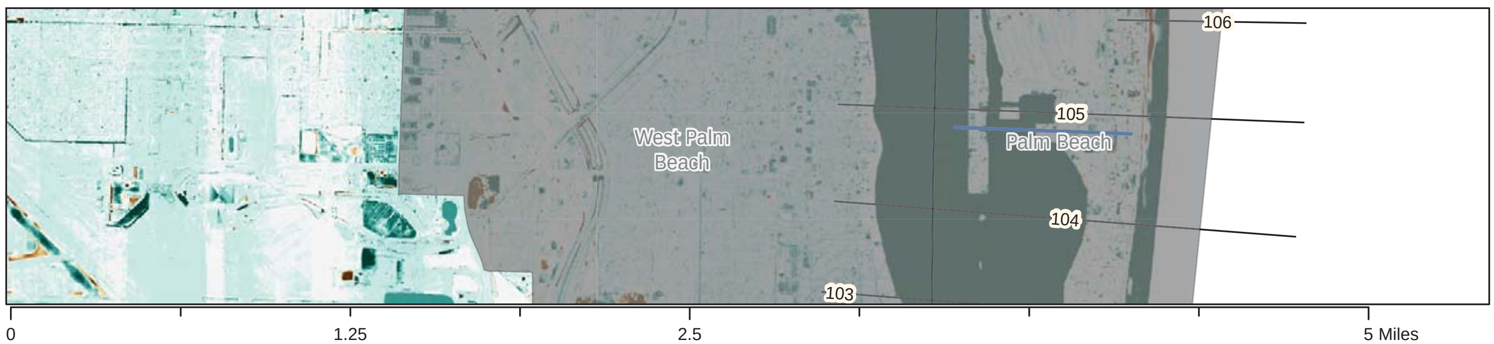
- ≤ 2.5
- ≤147.259583

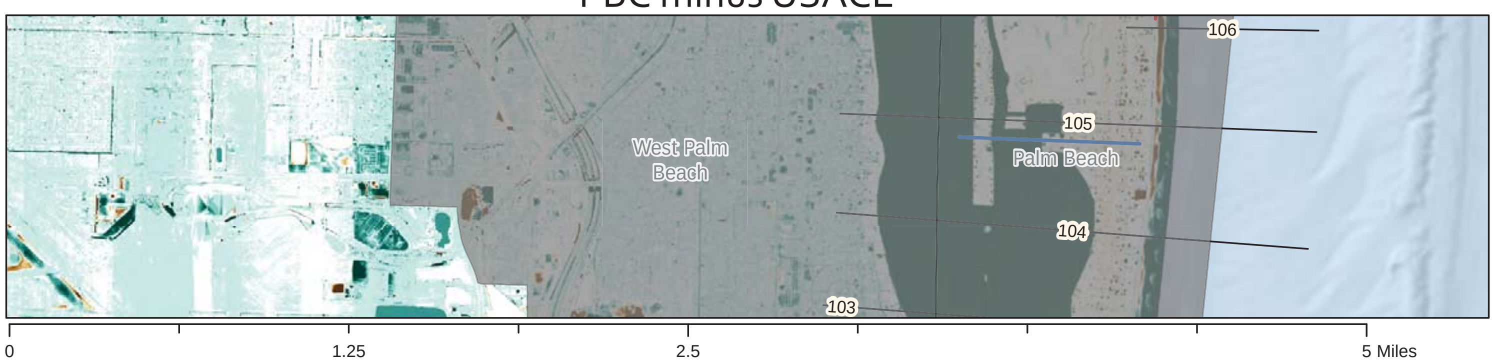
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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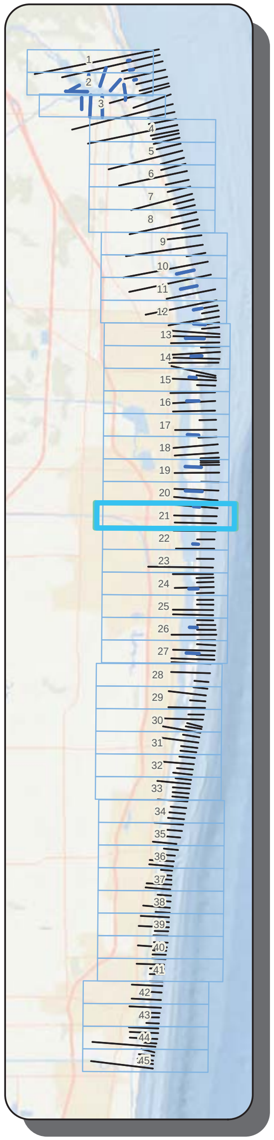

Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

Calculated Difference (ft)

- ≤ -2.5
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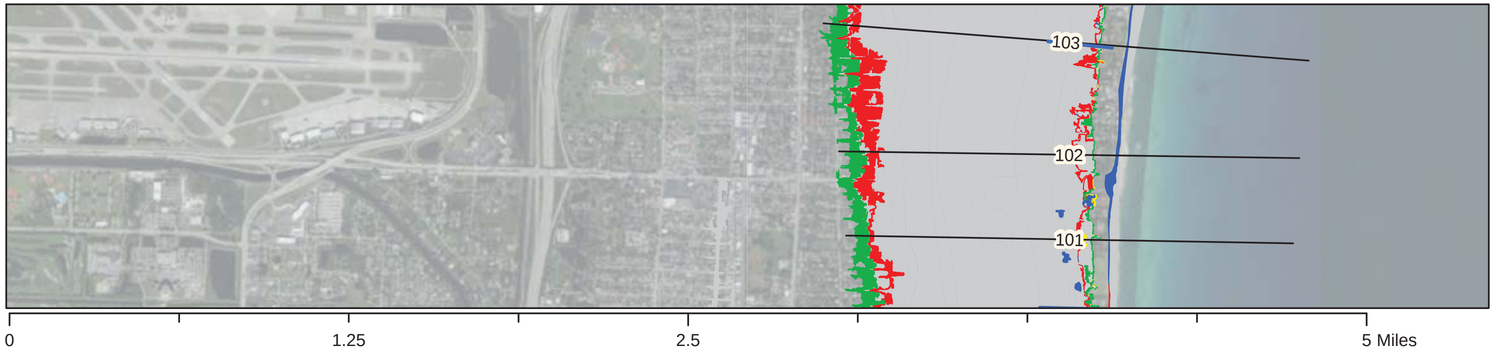
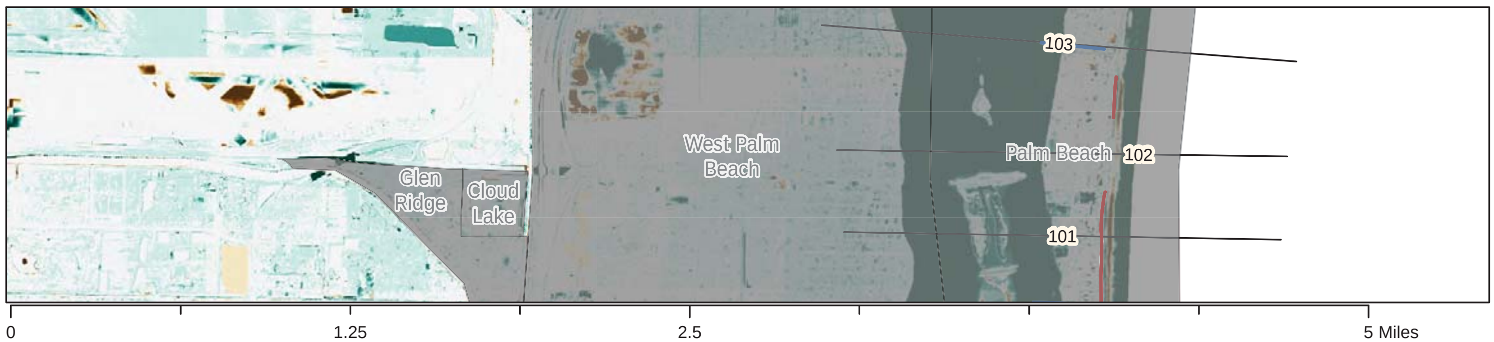
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE

Transect View

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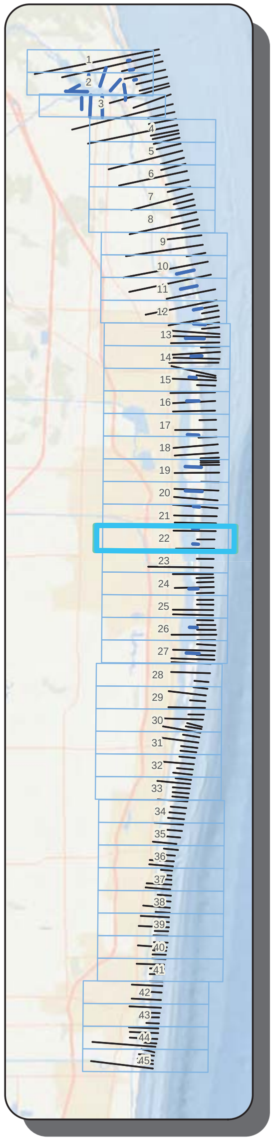

Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
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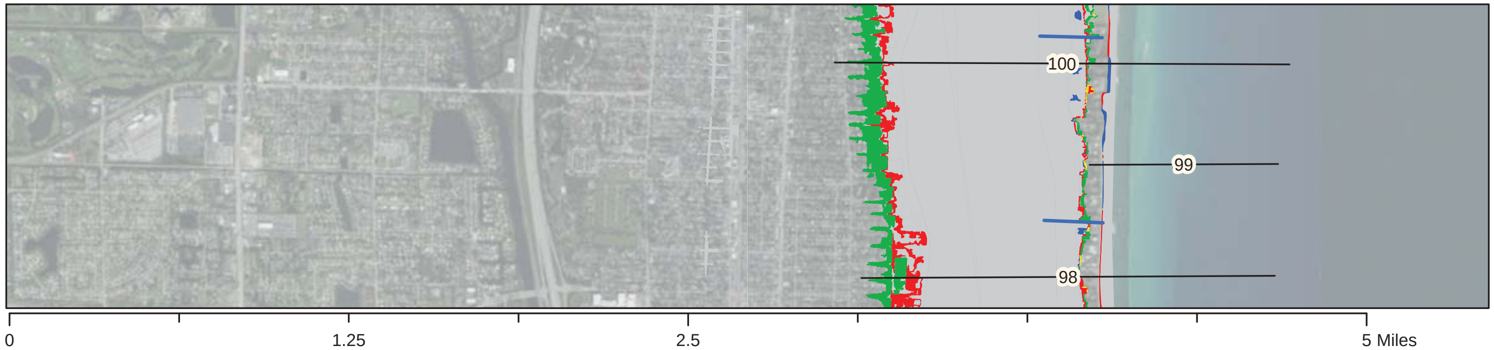
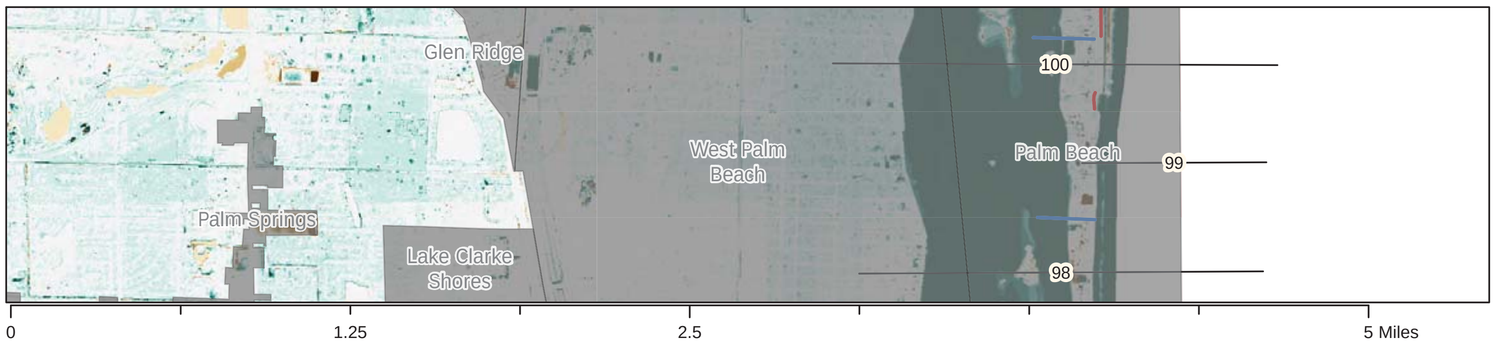
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE

Transect View

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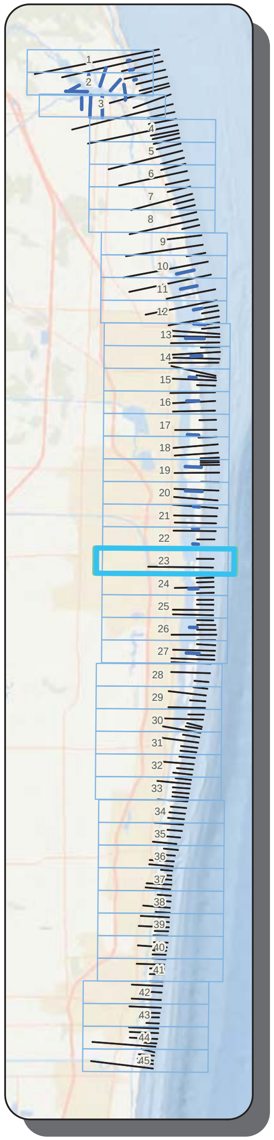

Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
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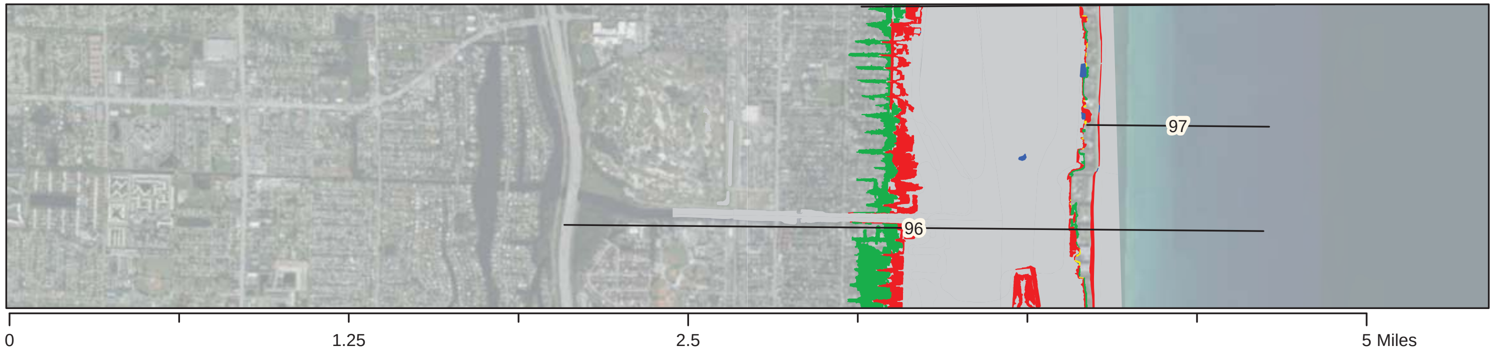
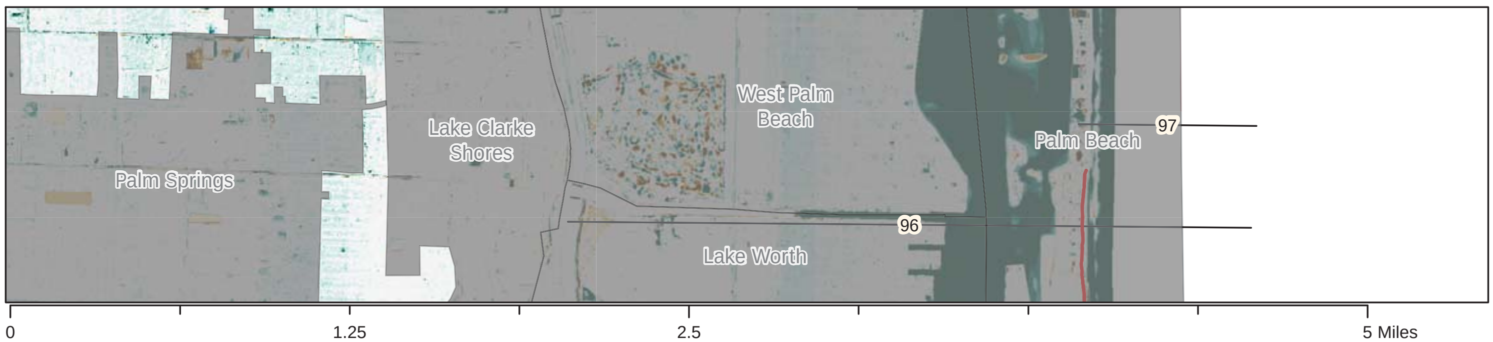
- ≤ 2.5
- ≤147.259583

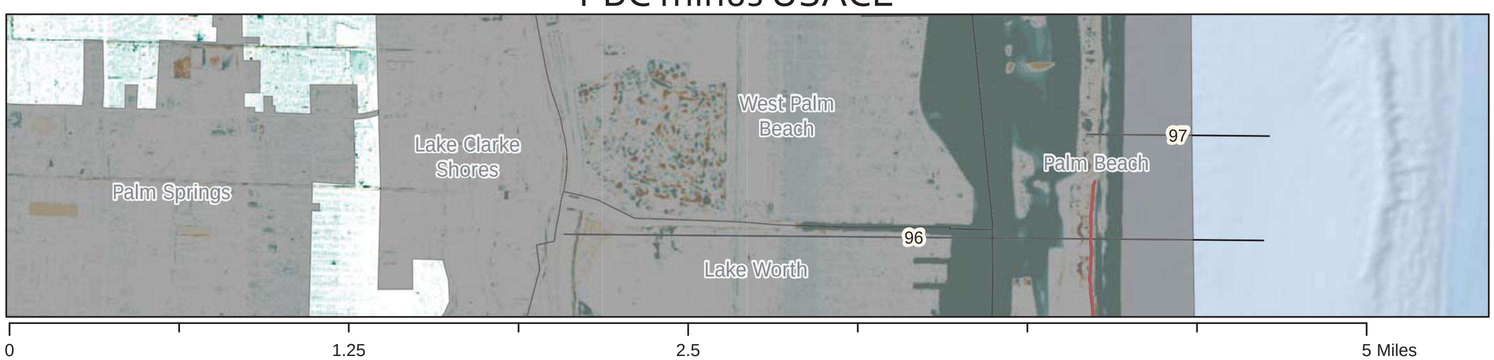
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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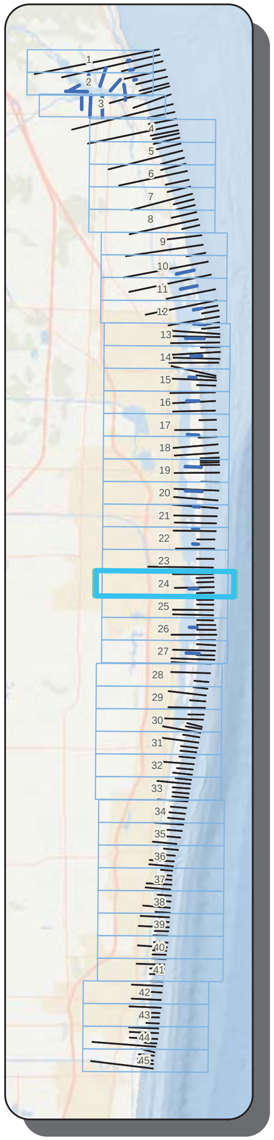

Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
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- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
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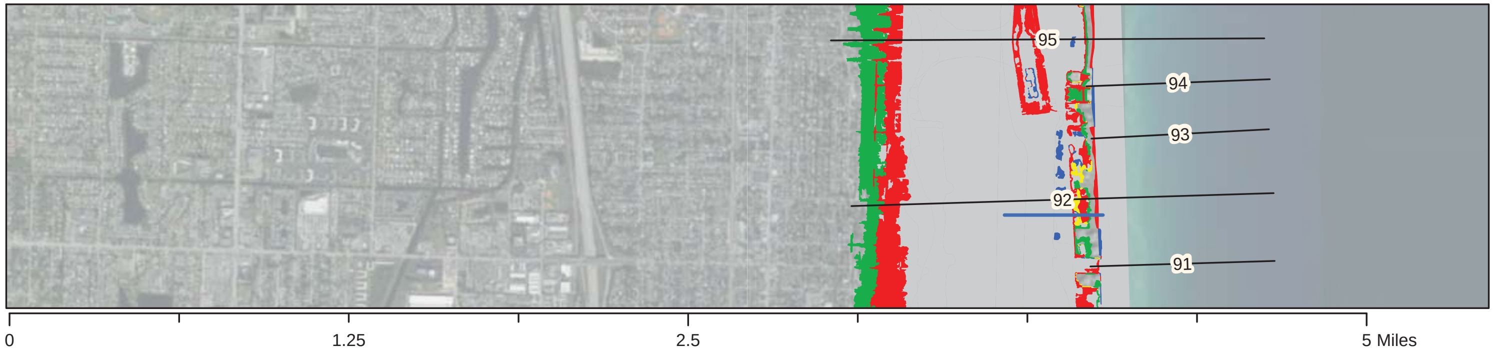
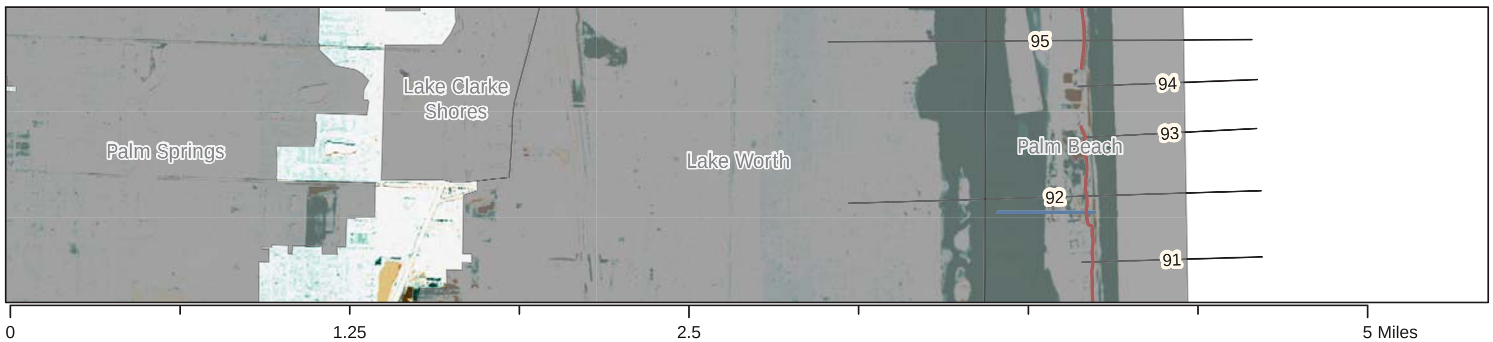
- ≤ 2.5
- ≤147.259583

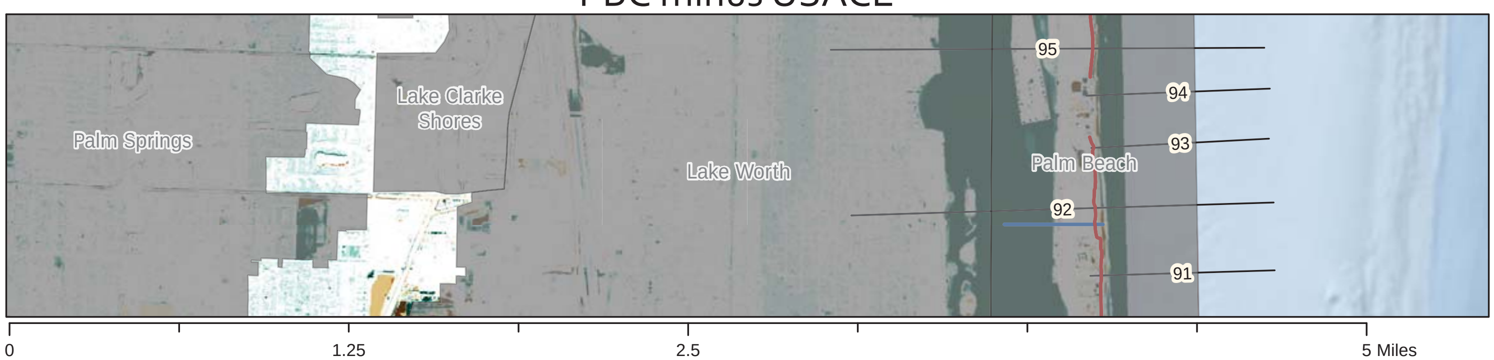
Change Since Last FIRM



PBC minus SWFLTB DEM

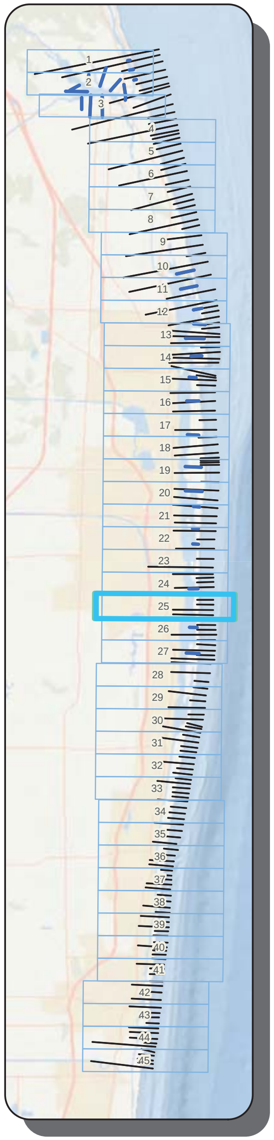


PBC minus USACE



Transect View

Page: 25



Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
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- Frontal Dune Line
- Municipalities

Calculated Difference (ft)

- ≤ -2.5
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- ≤ 1.5
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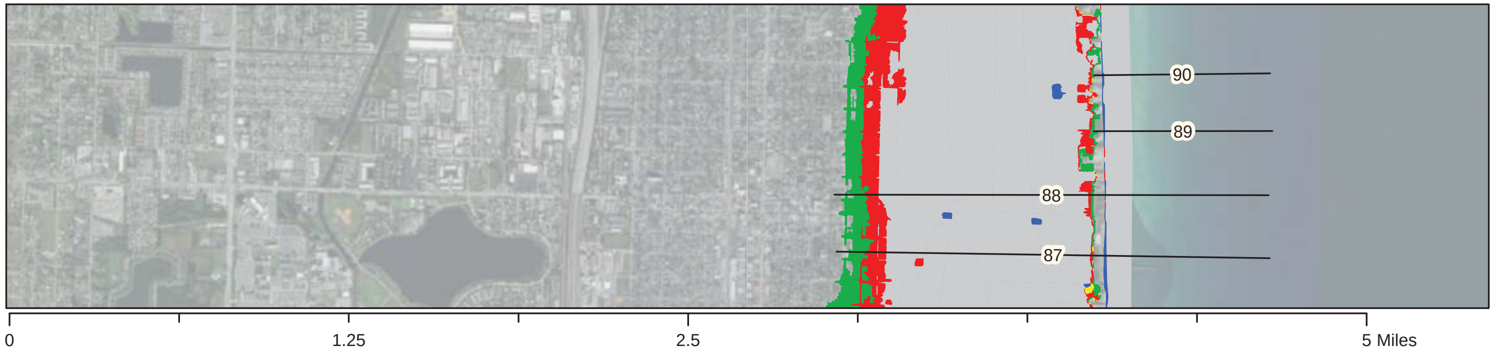
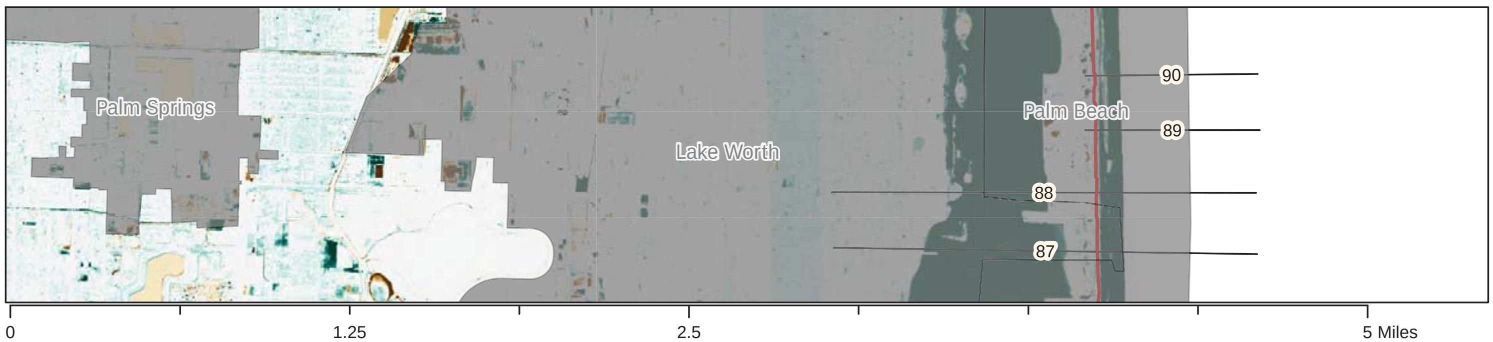
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE

Transect View

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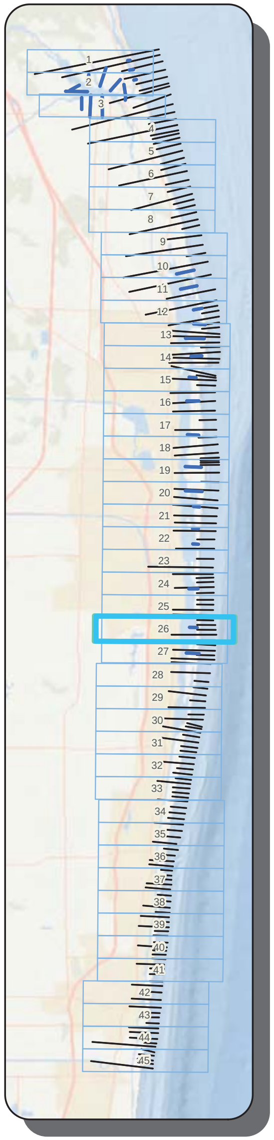

Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
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- 1% Annual Increase
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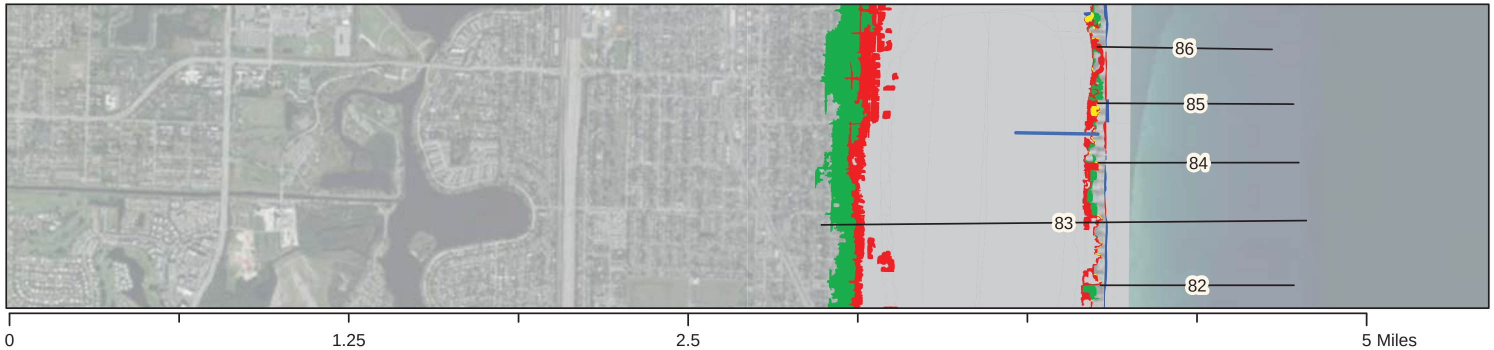
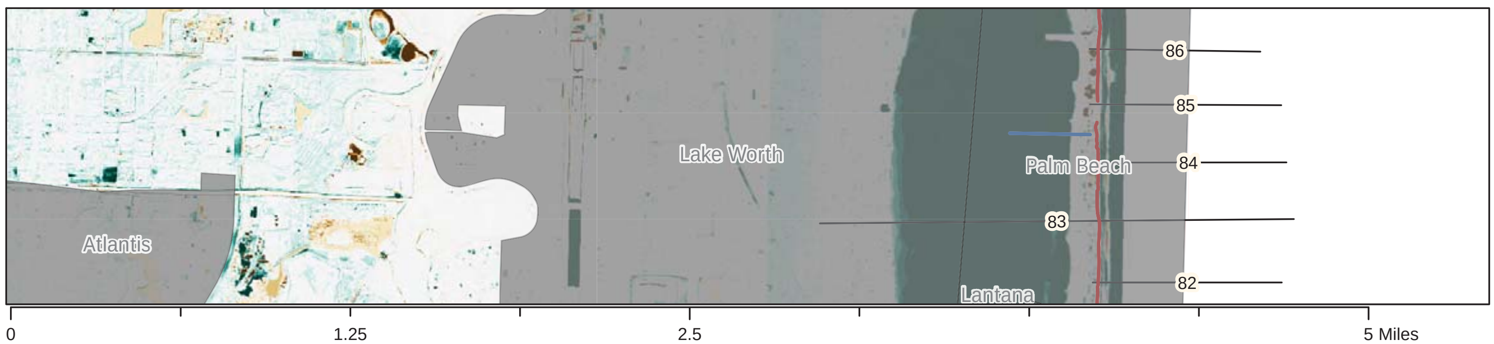
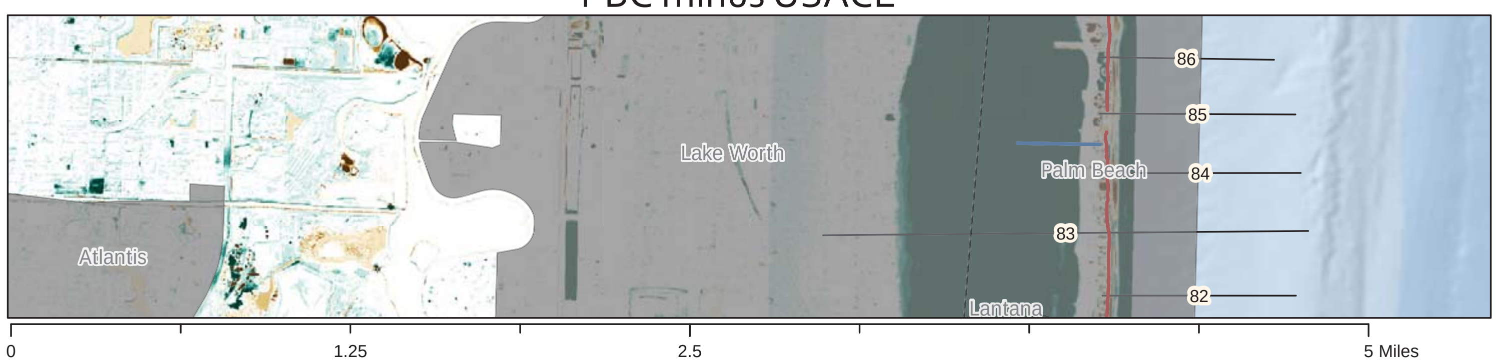
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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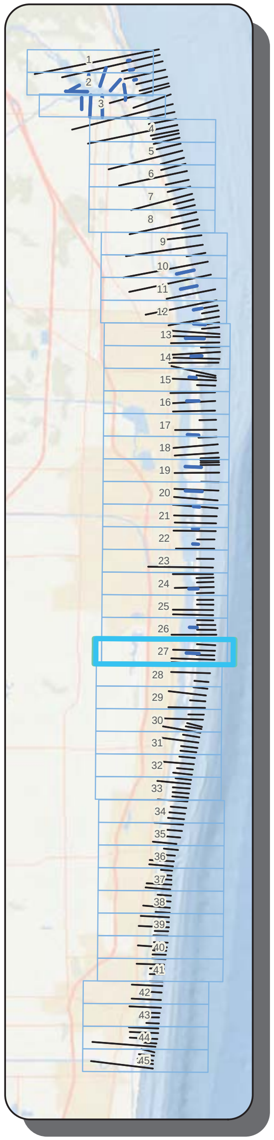

Change Since Last FIRM
- No Zone Change
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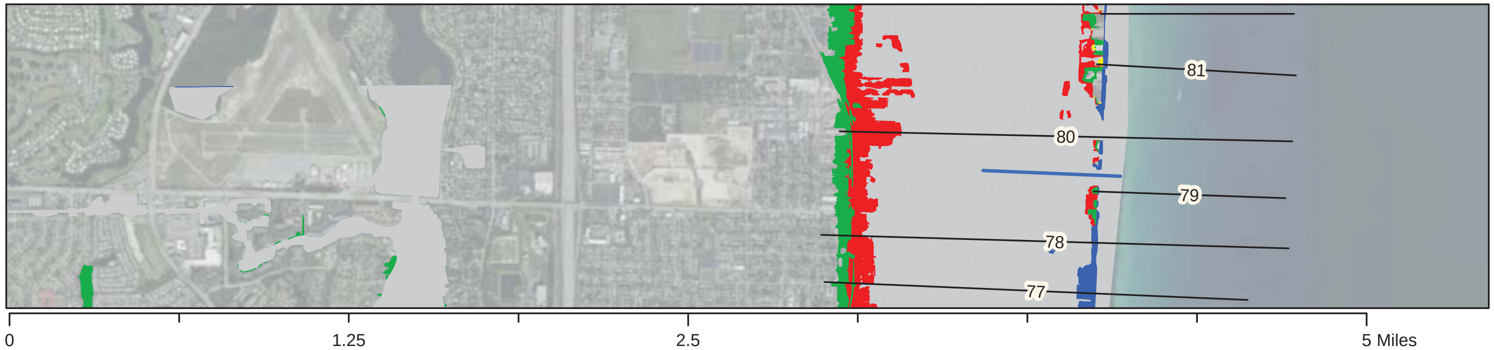
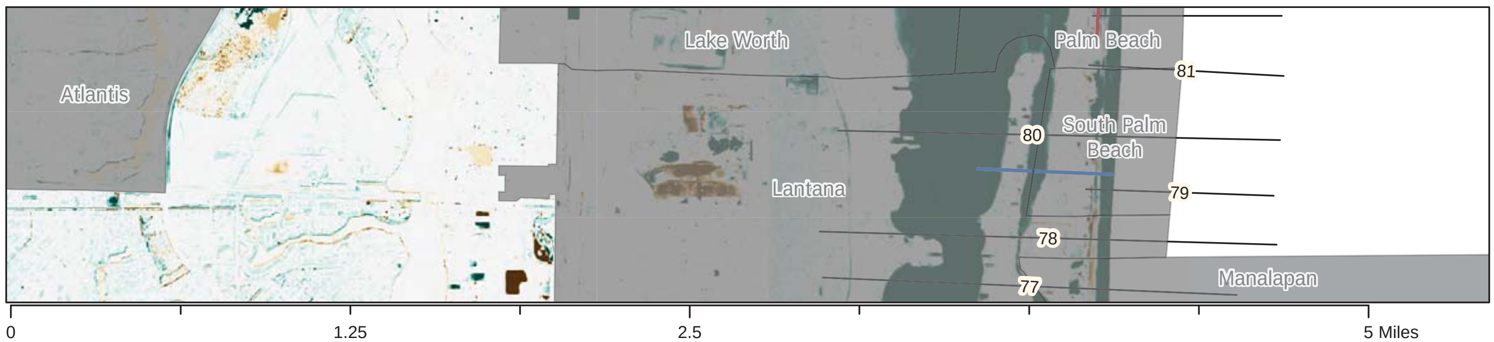
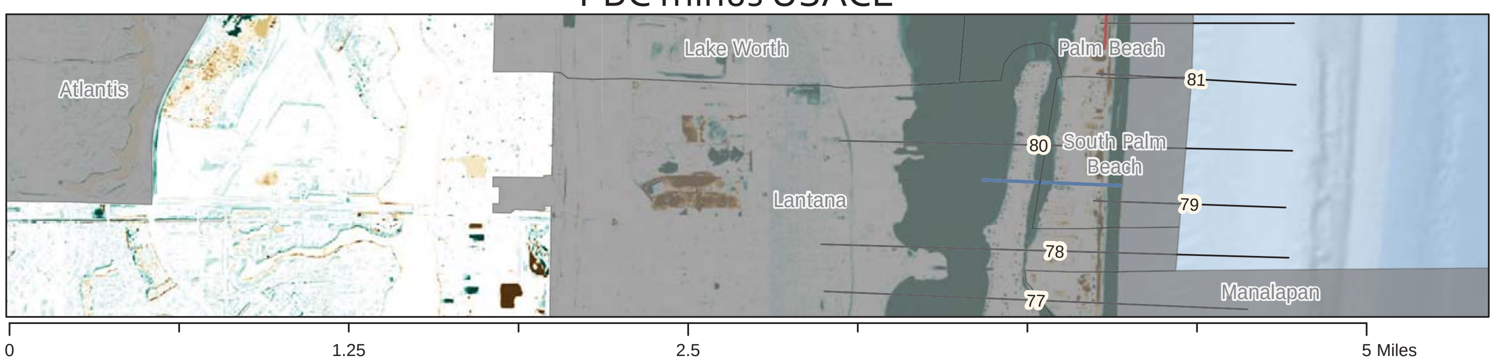
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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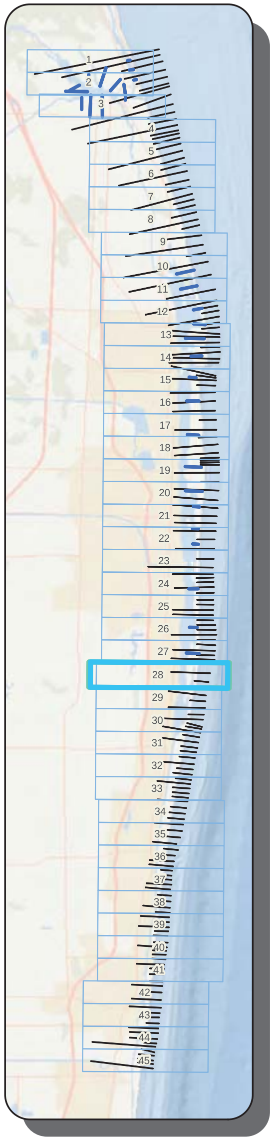

Change Since Last FIRM
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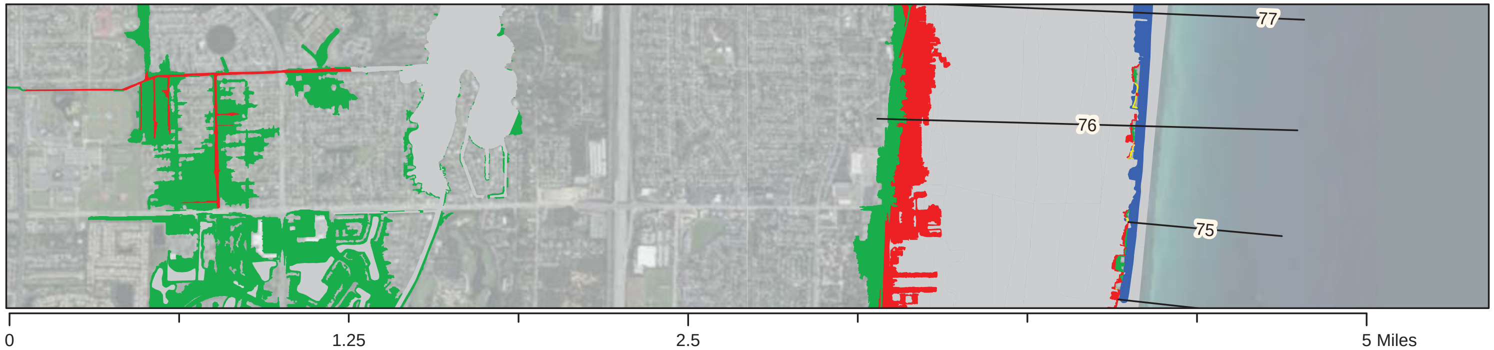
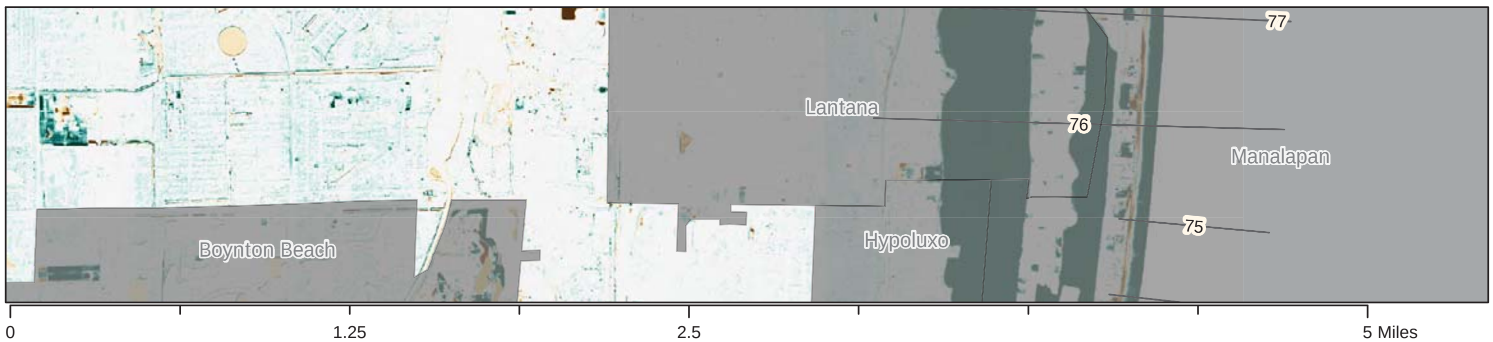
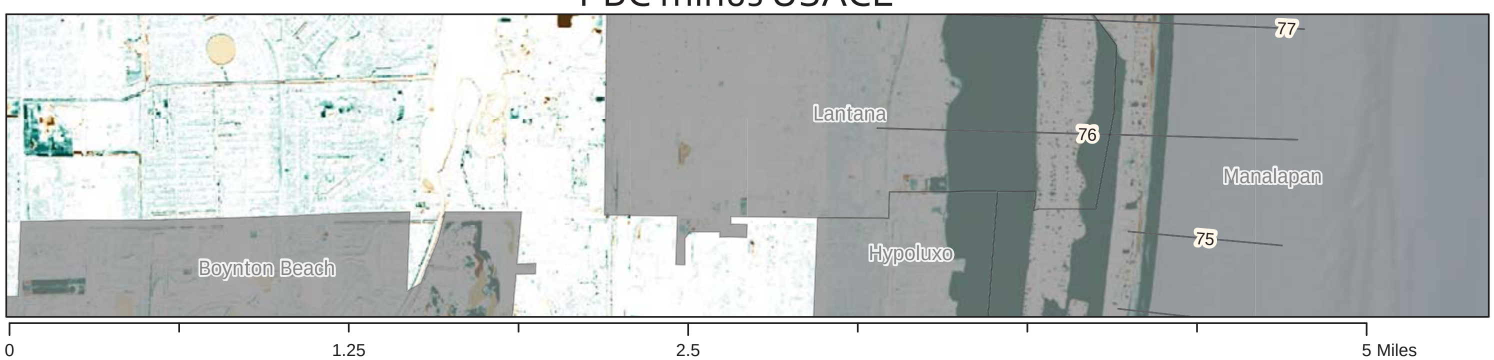
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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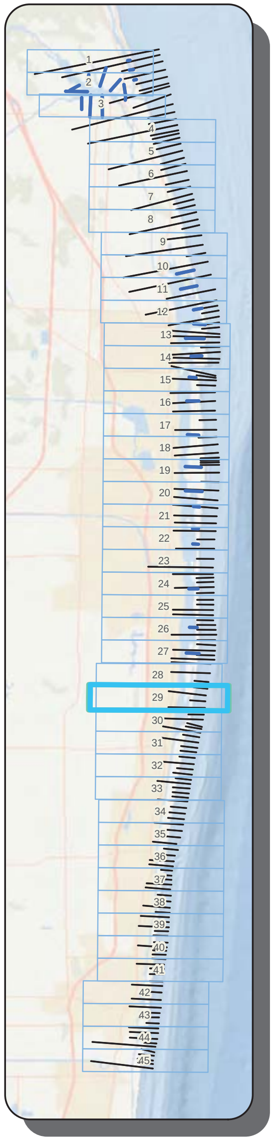

Change Since Last FIRM

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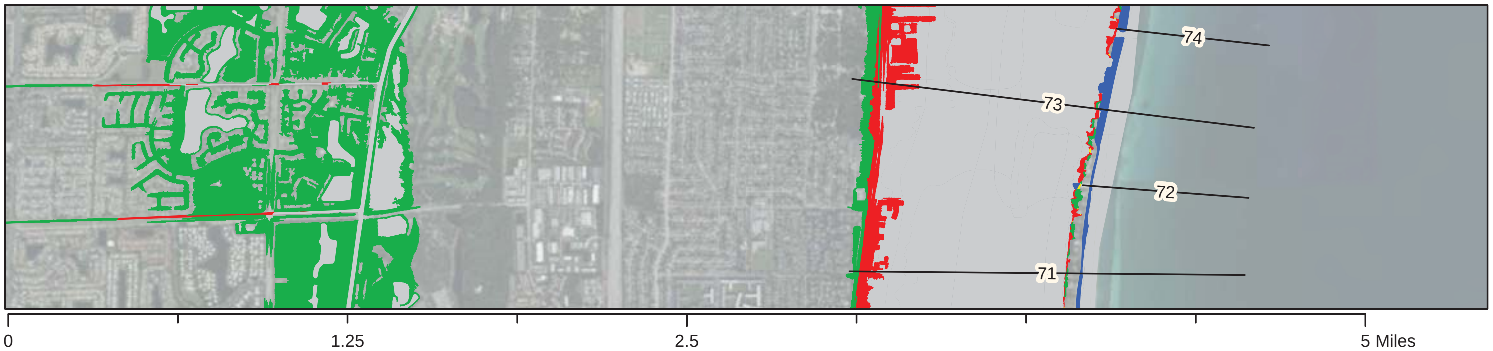
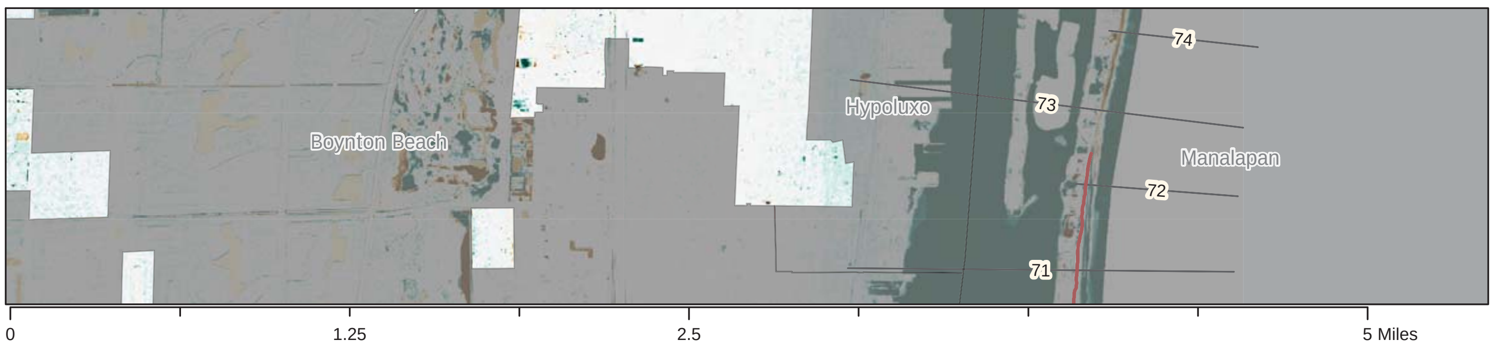
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

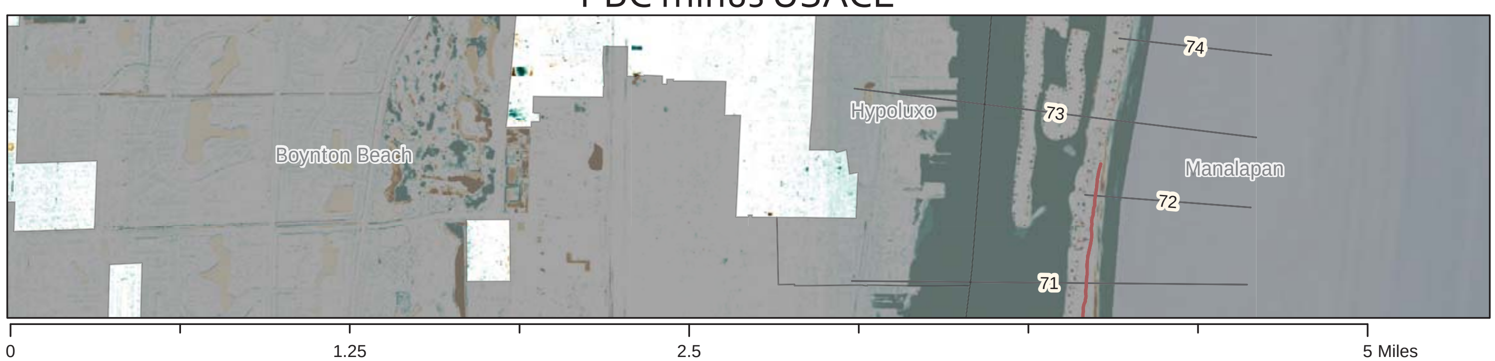
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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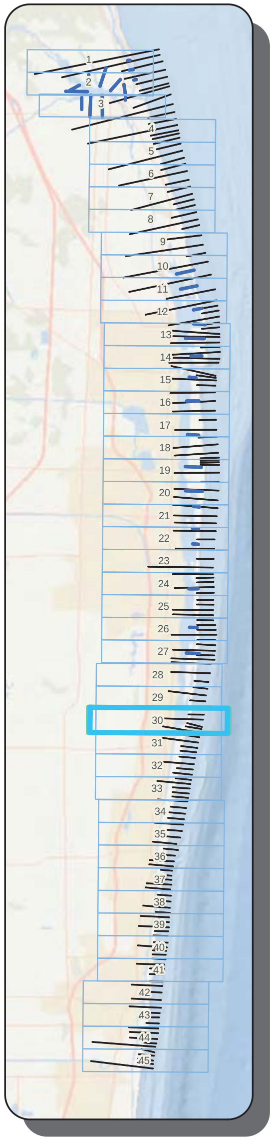
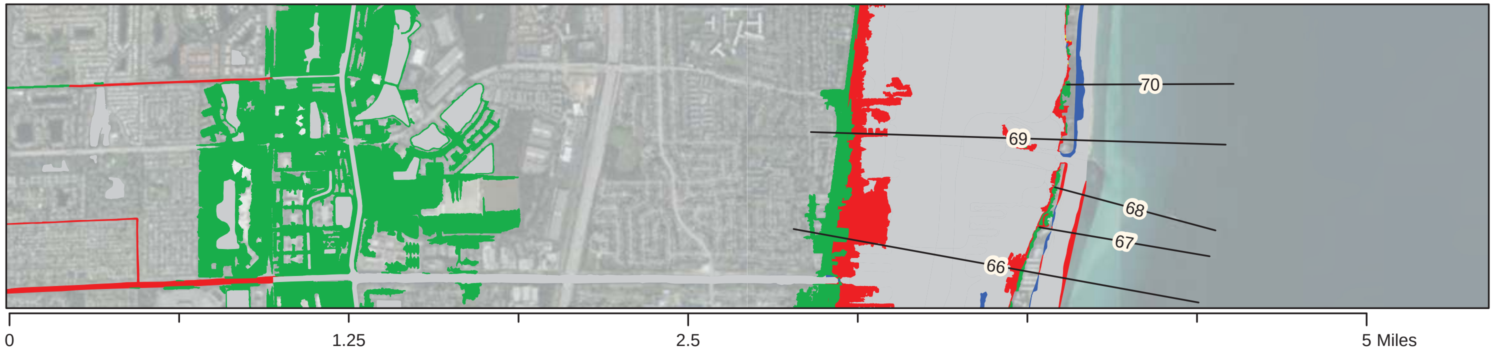


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

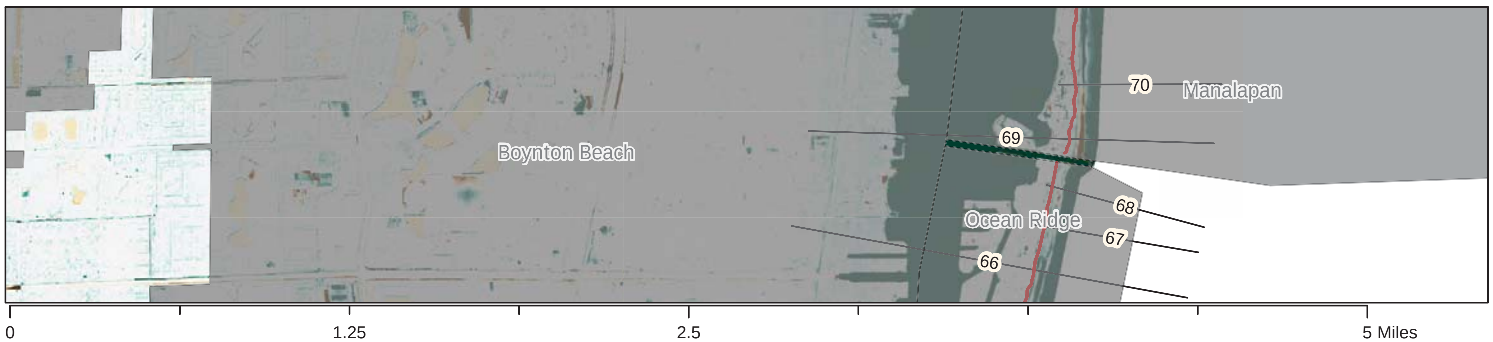
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

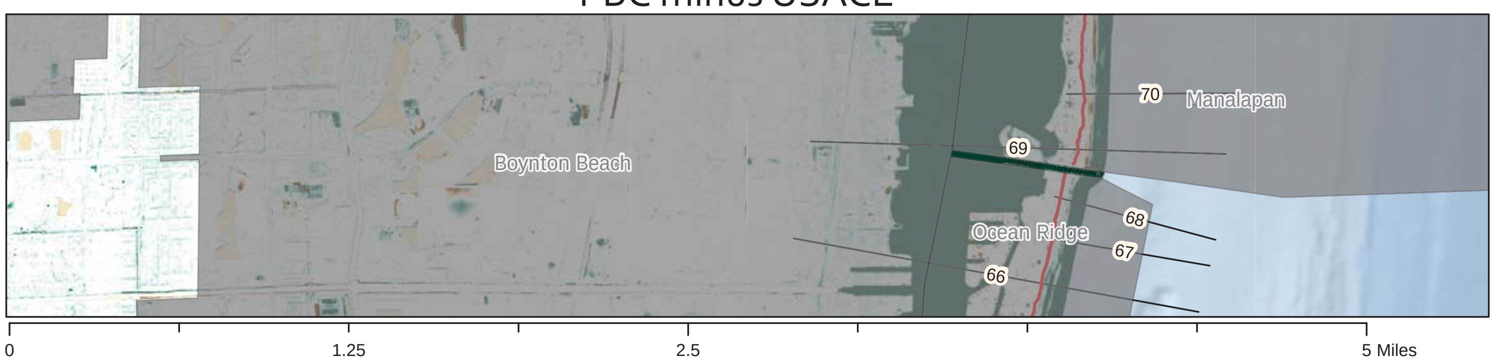
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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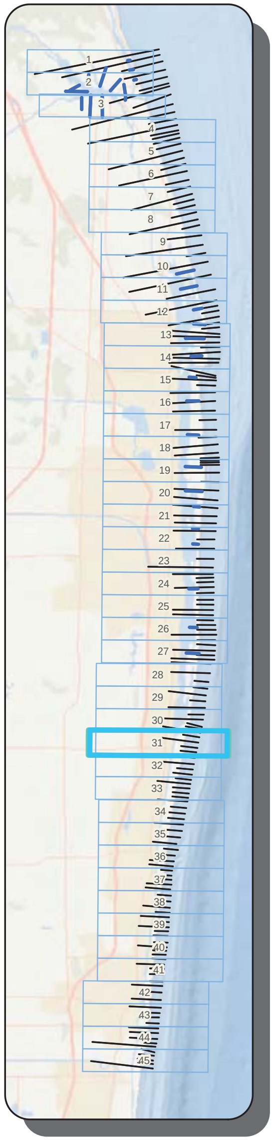


Change Since Last FIRM

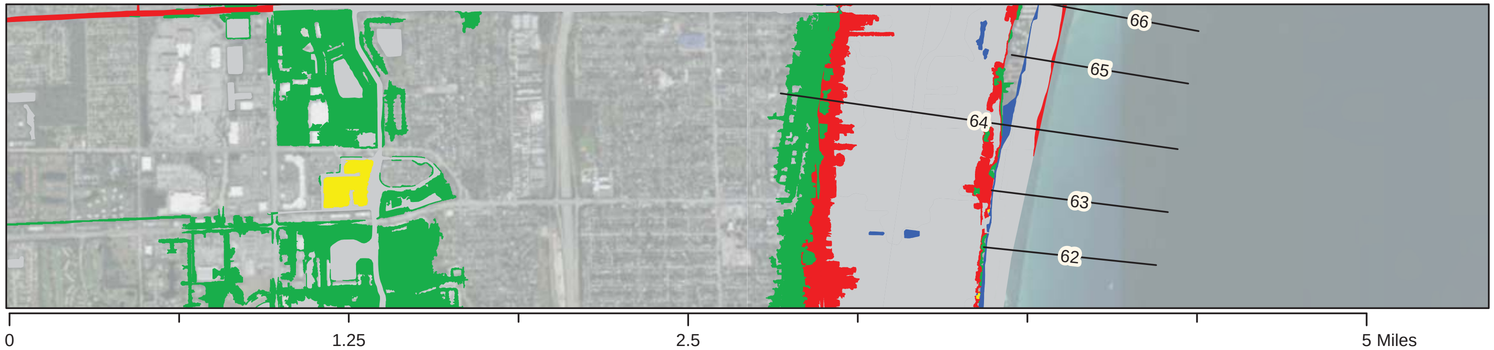
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

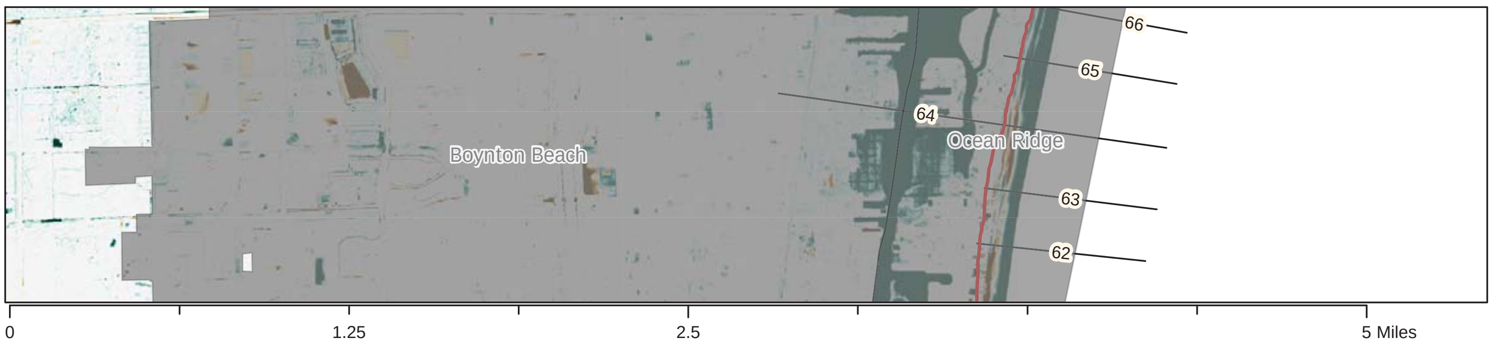
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

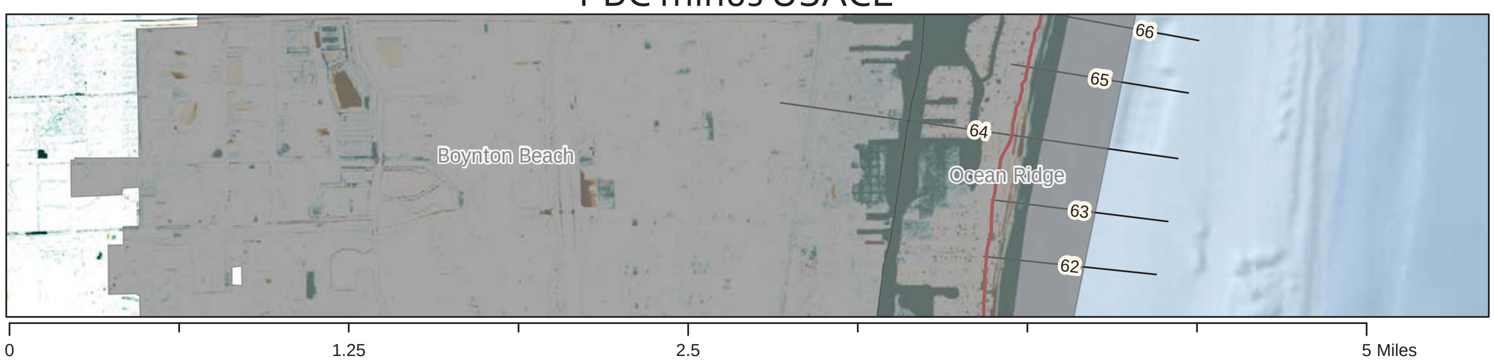
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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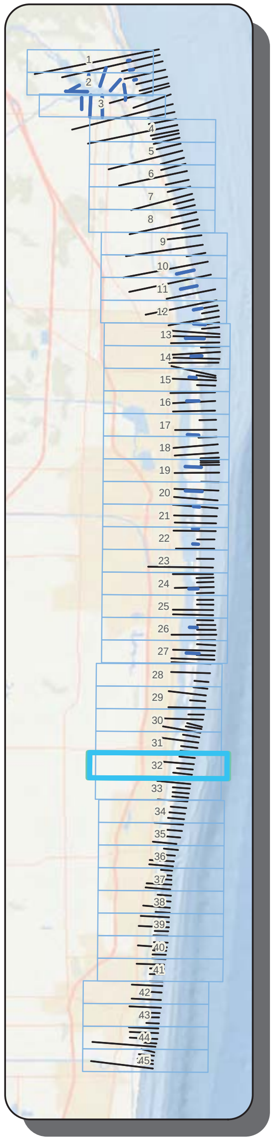
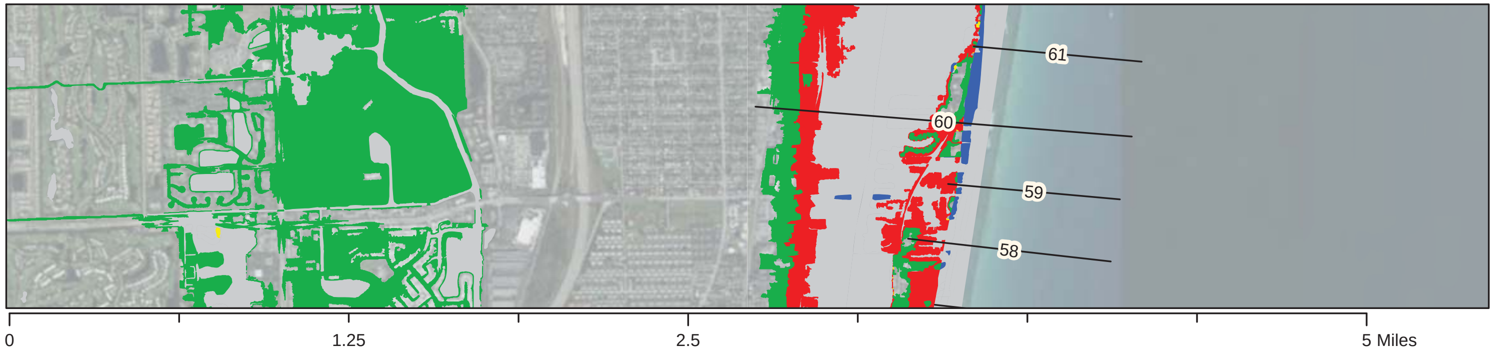
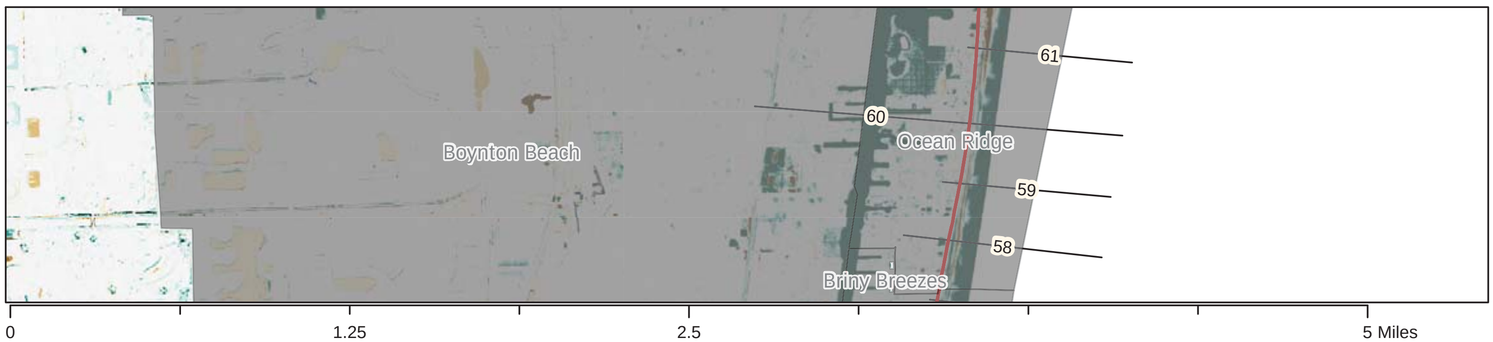


Change Since Last FIRM



Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

PBC minus SWFLTB DEM



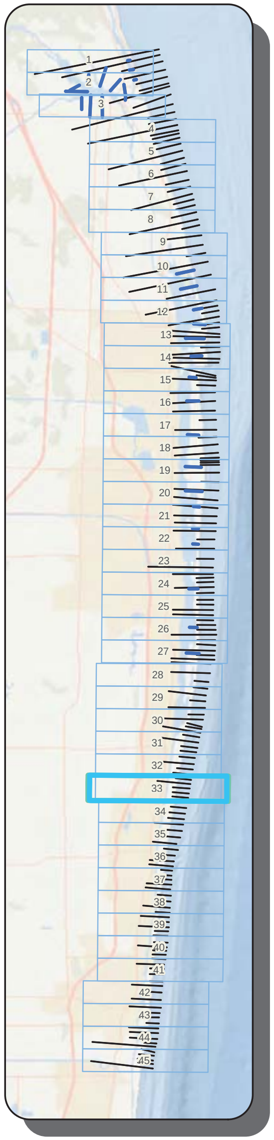
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

PBC minus USACE

Transect View

Page: 33



Change Since Last FIRM

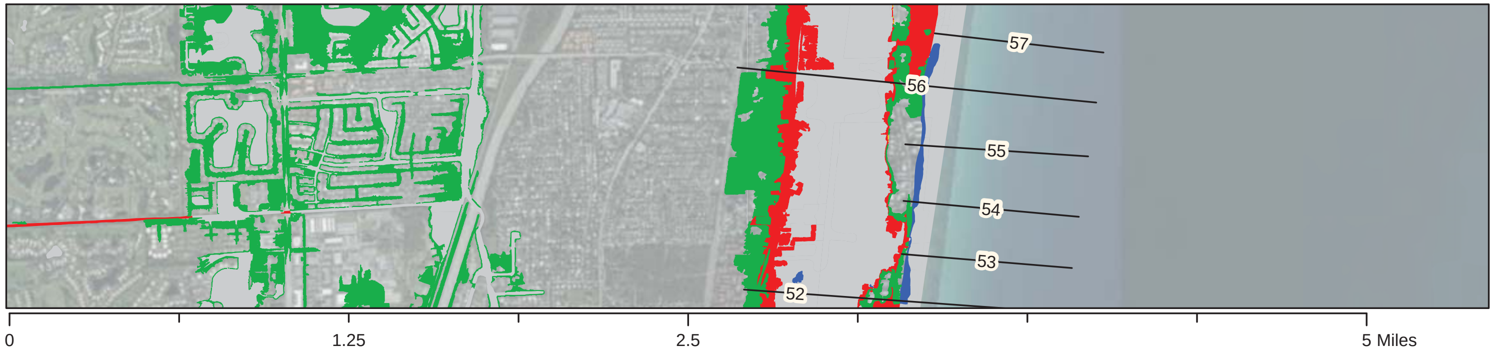
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

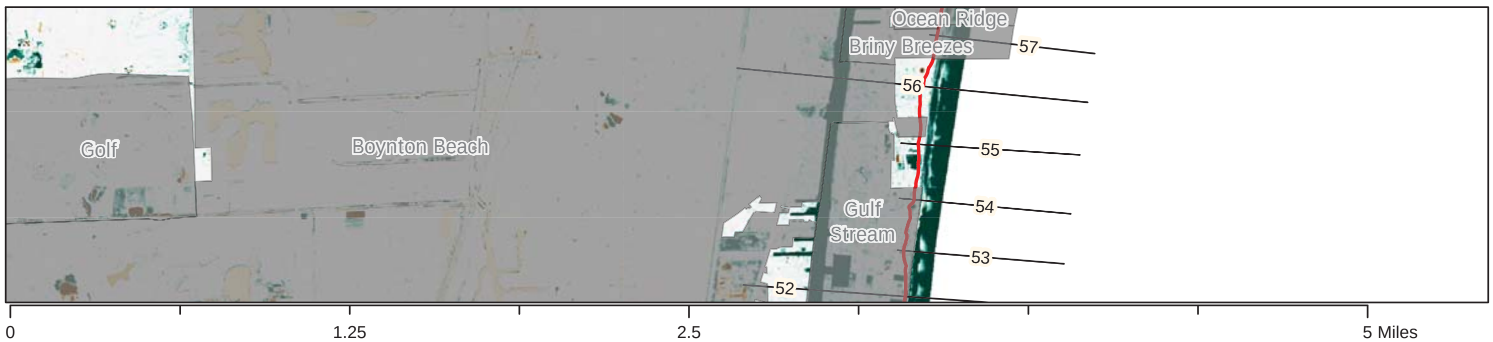
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

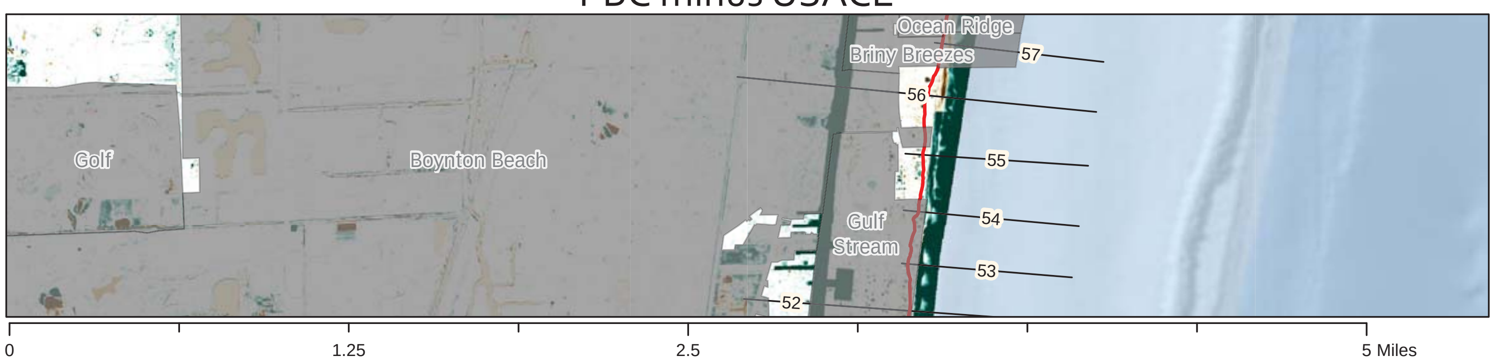
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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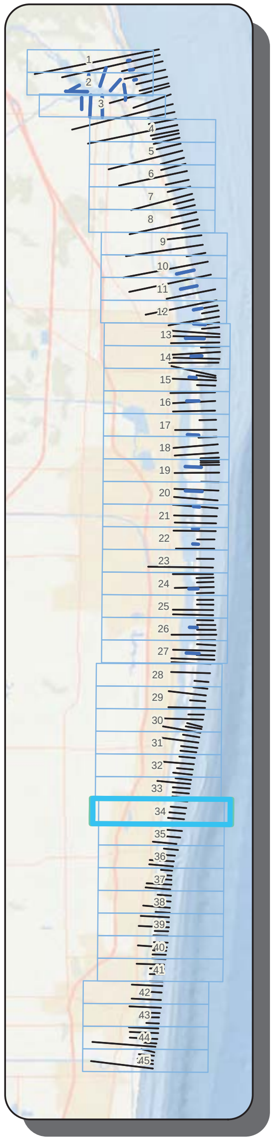
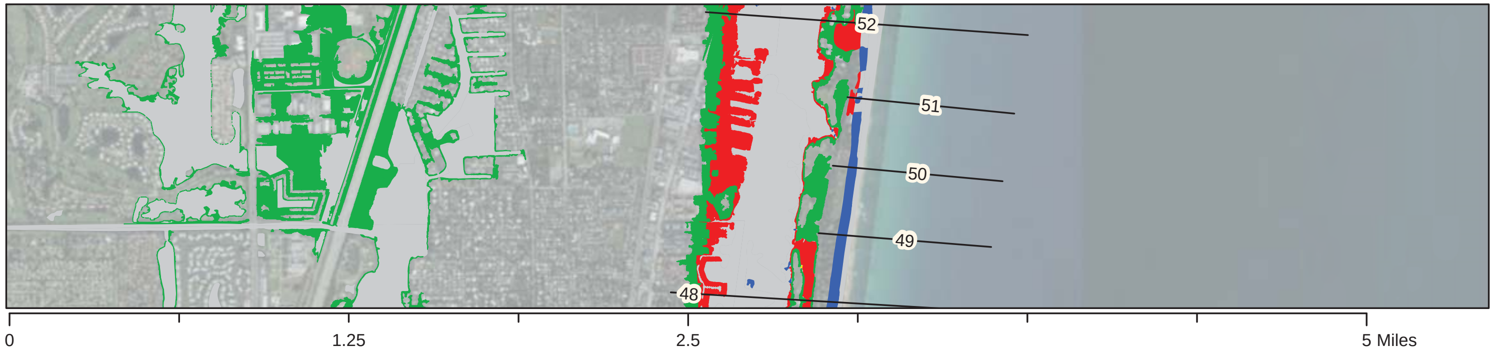


Change Since Last FIRM

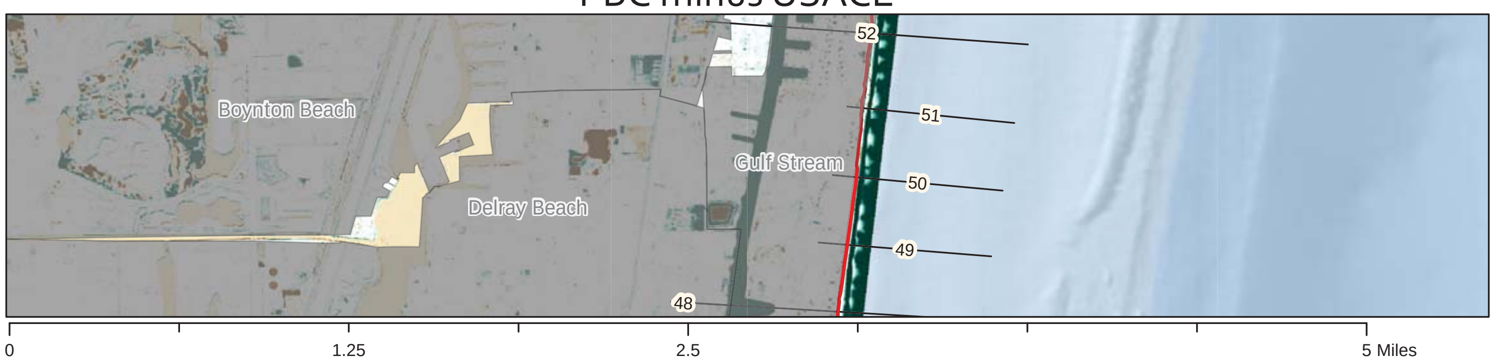


Change Since Last FIRM

- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

PBC minus SWFLTB DEM

PBC minus USACE



- Frontal Dune Line
- Municipalities

Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Transect View

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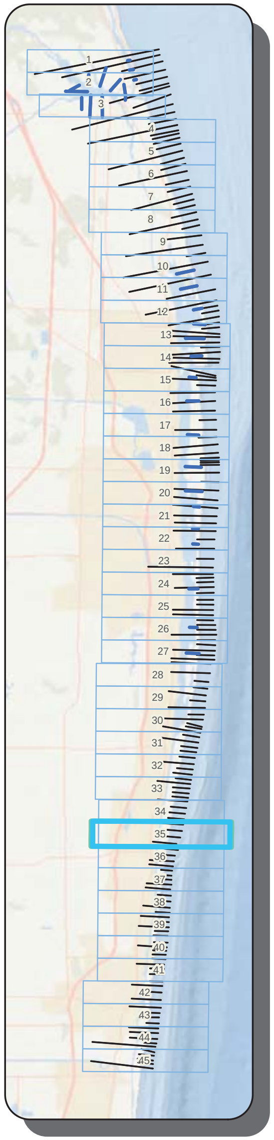


Change Since Last FIRM

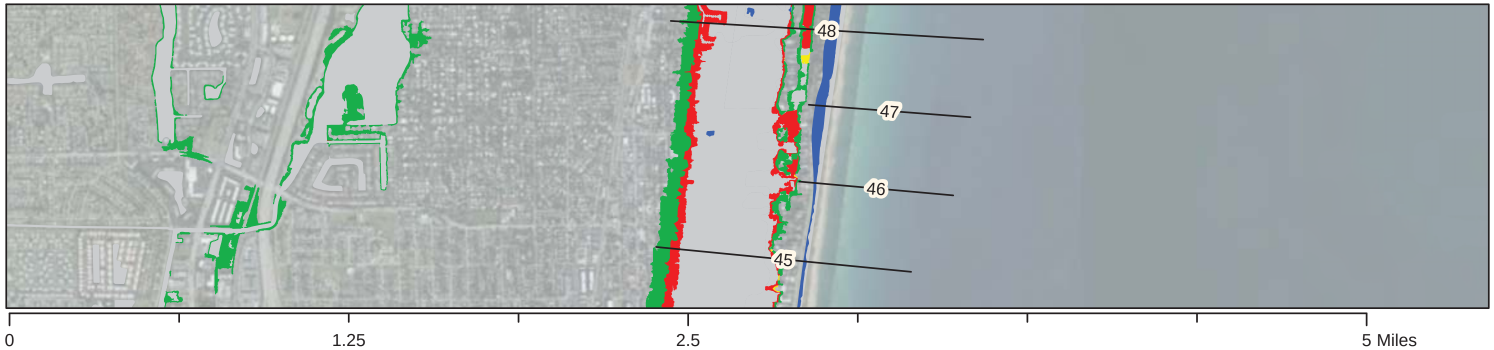
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

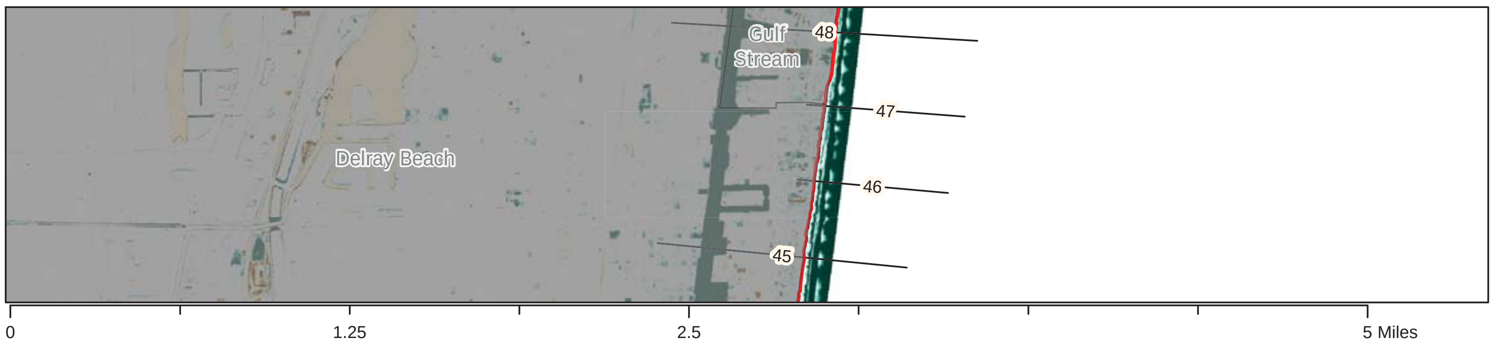
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE

Transect View

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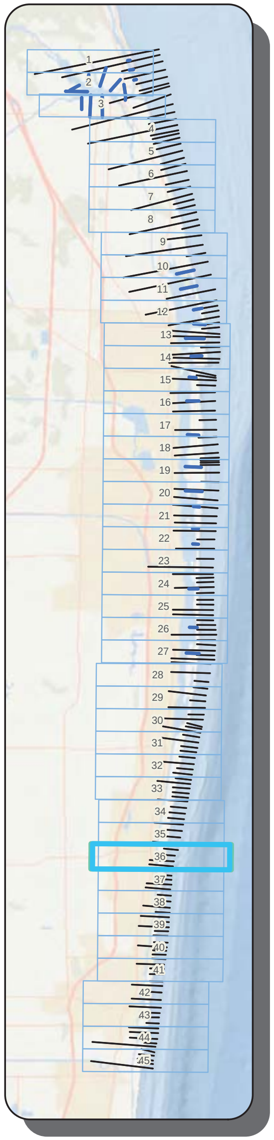


Change Since Last FIRM

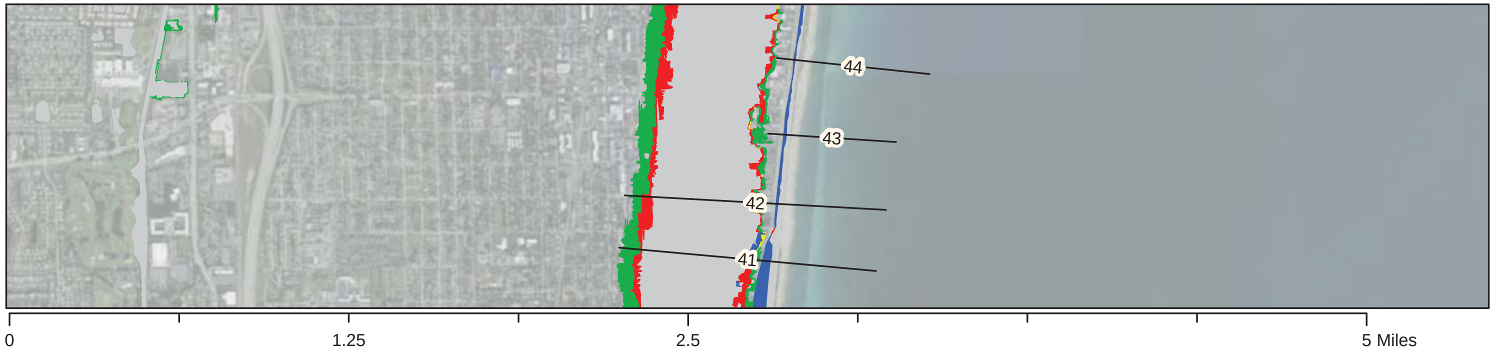
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

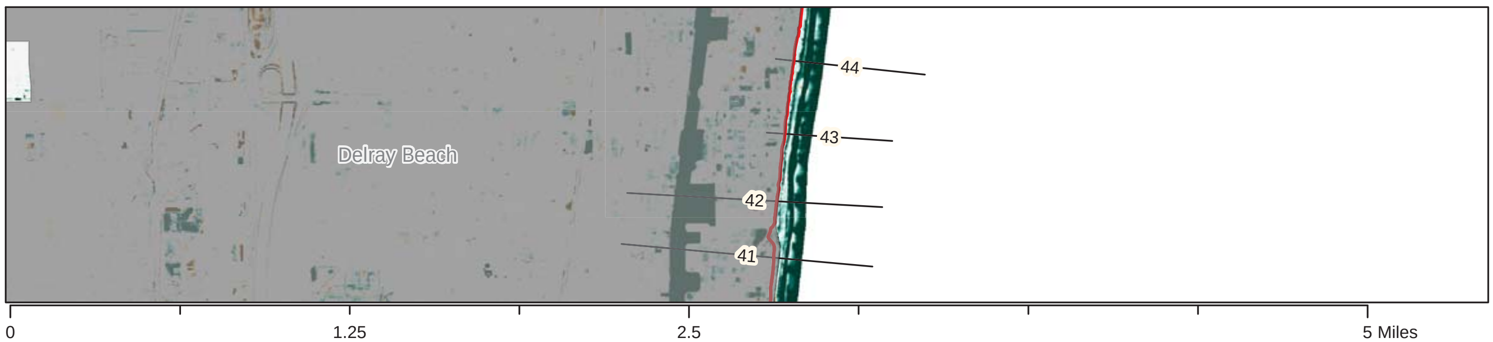
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

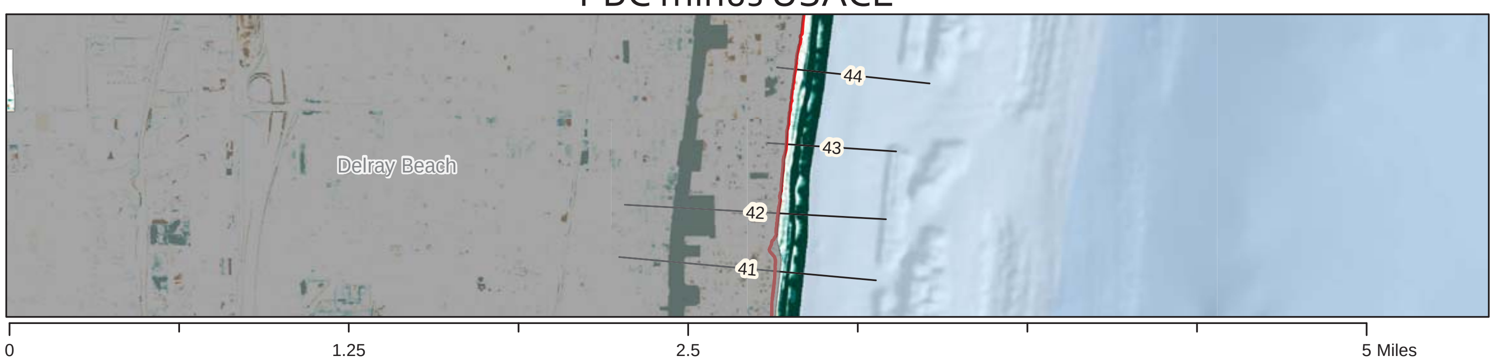
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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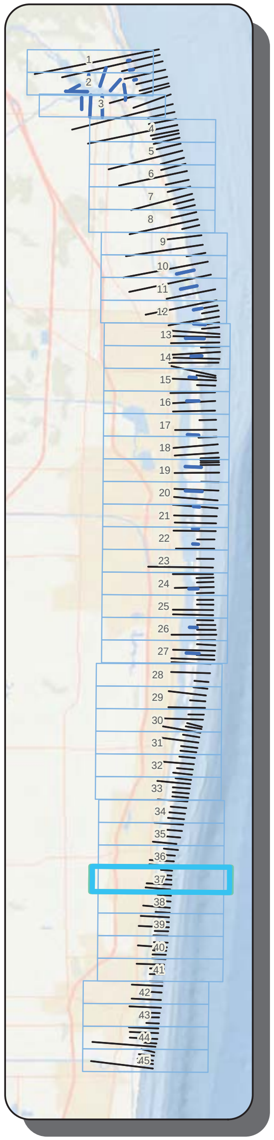
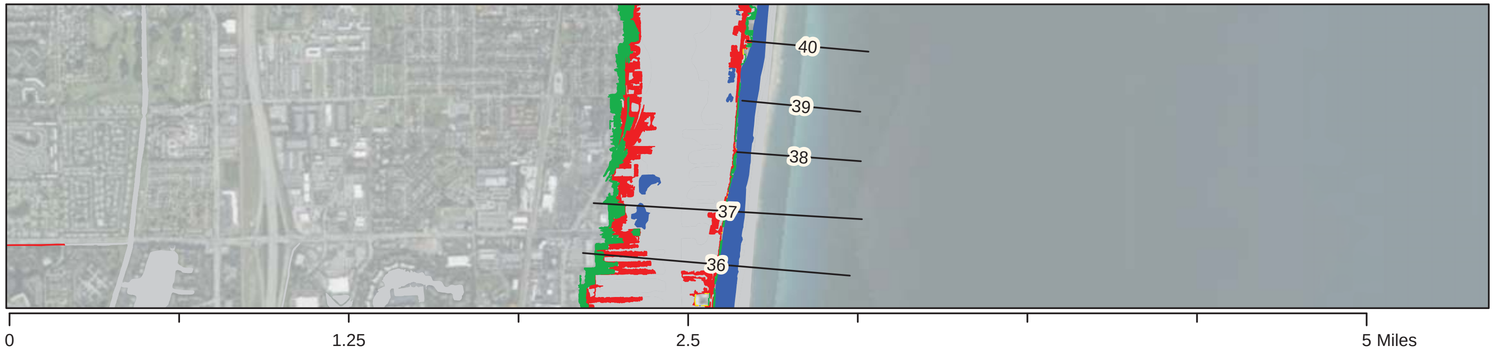


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

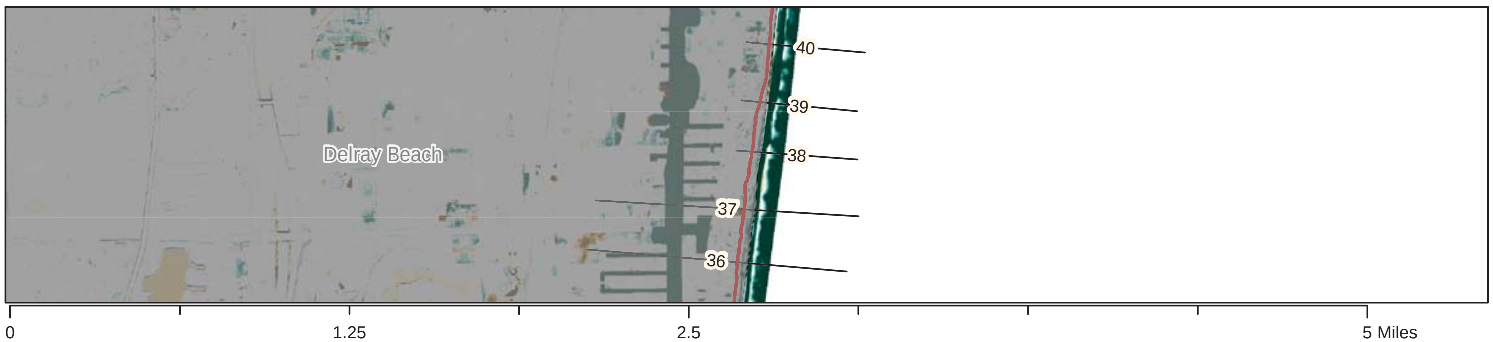
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

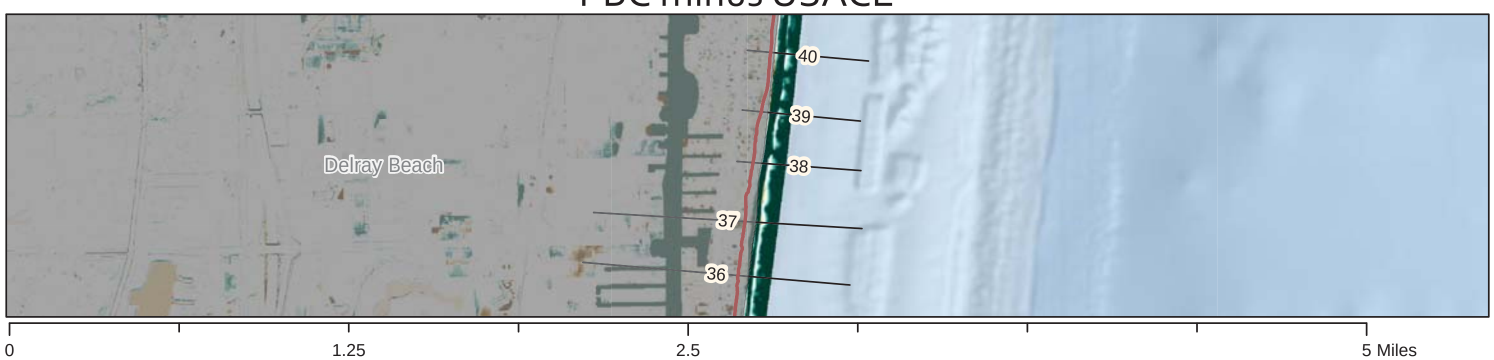
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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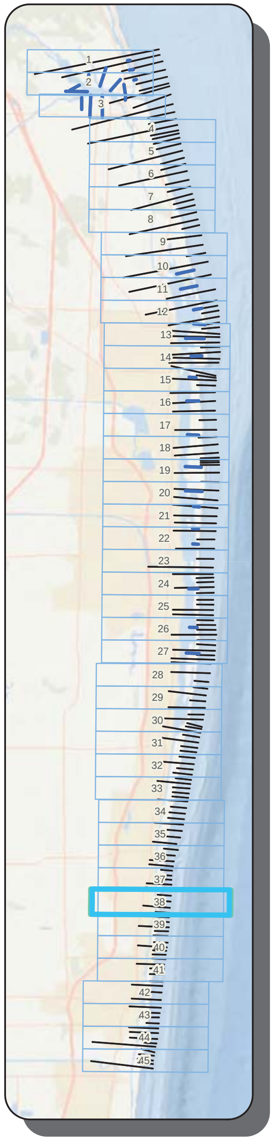
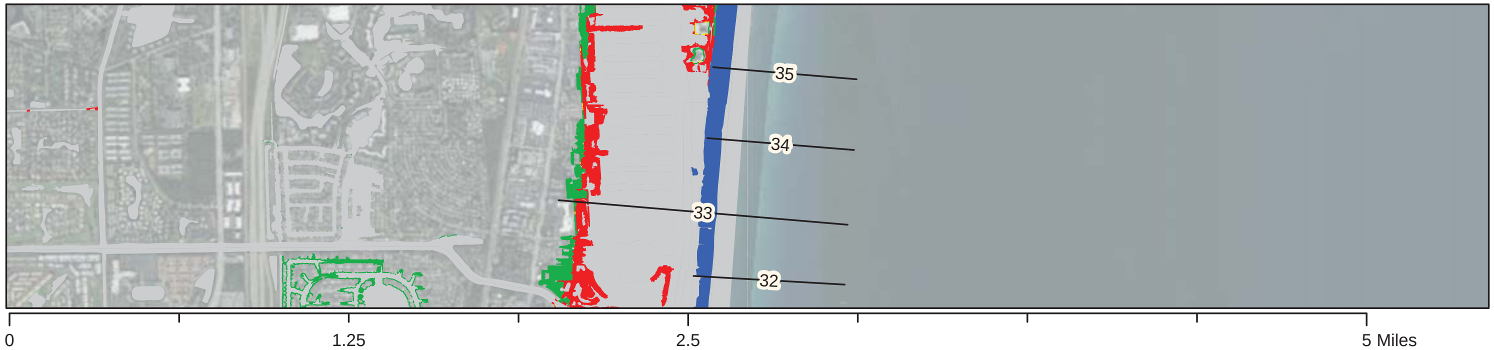


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

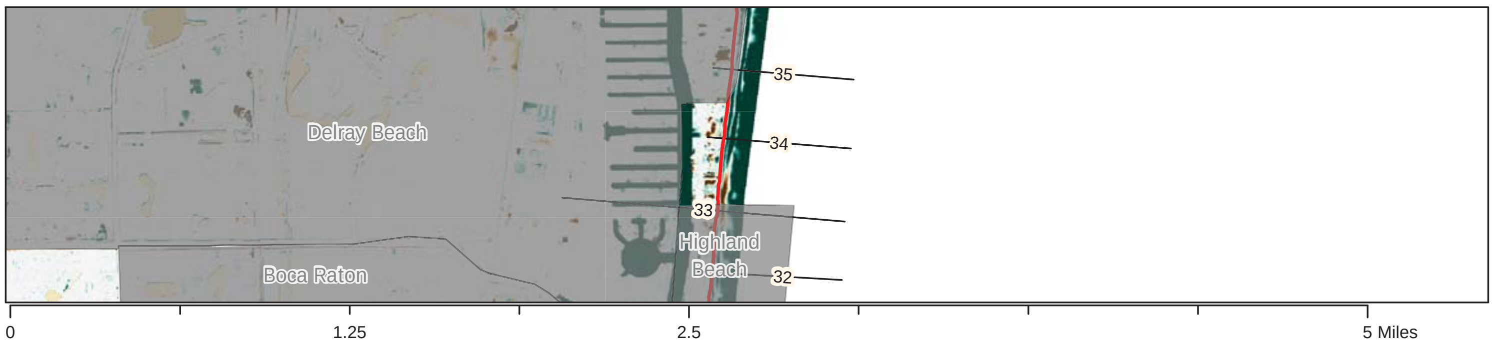
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

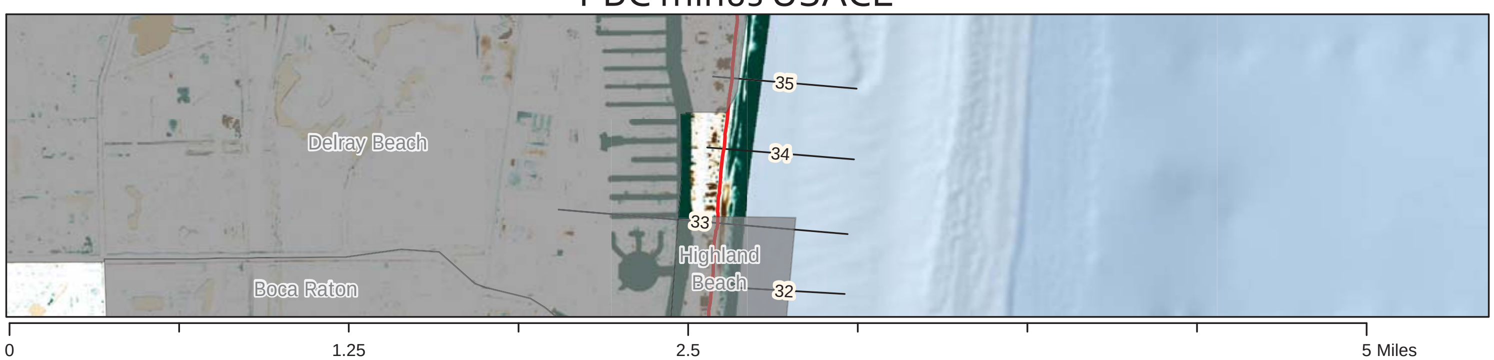
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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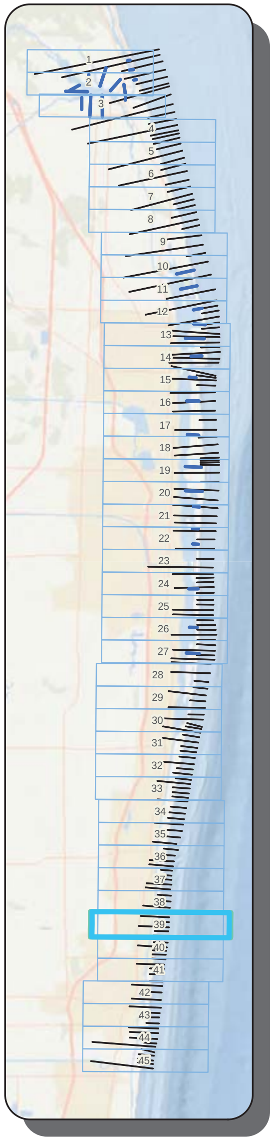
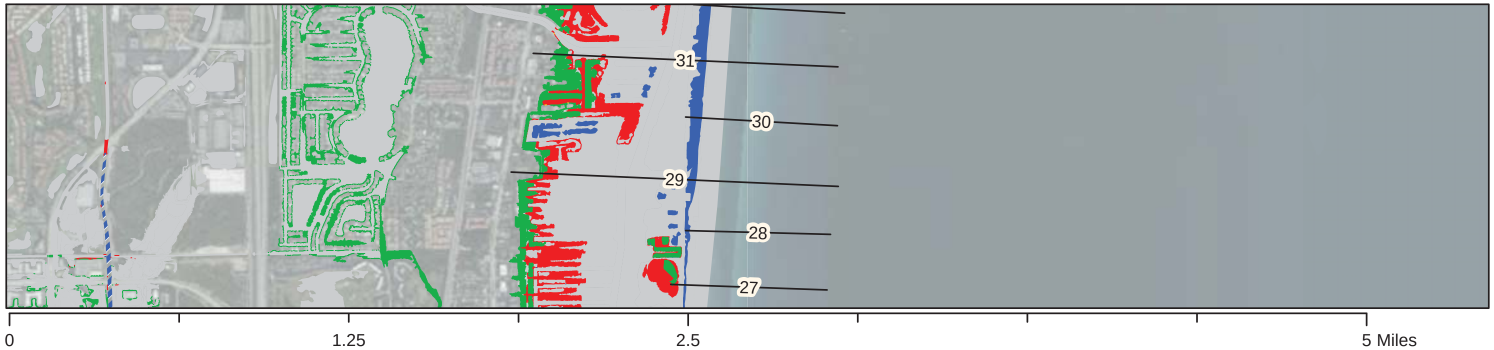


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

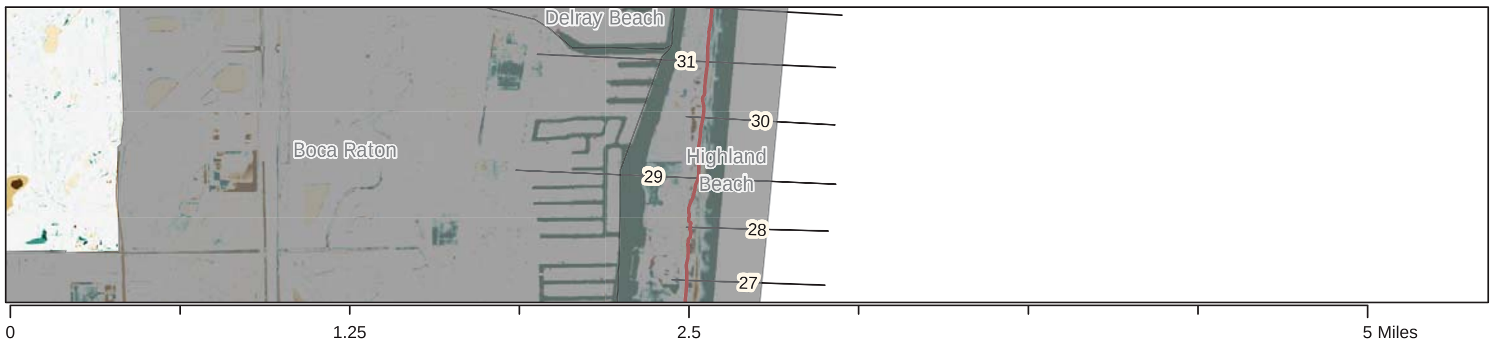
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE

Transect View

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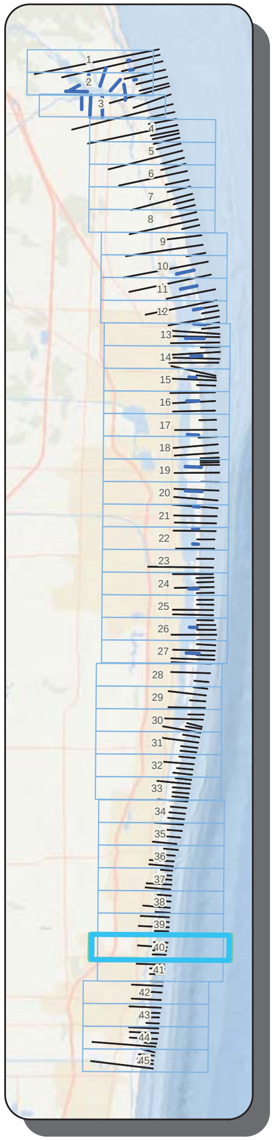


Change Since Last FIRM

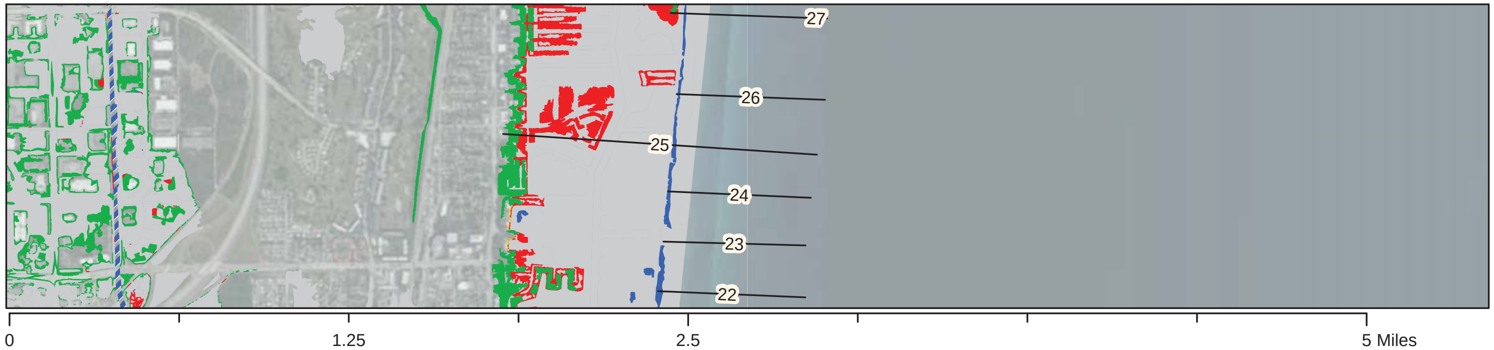
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

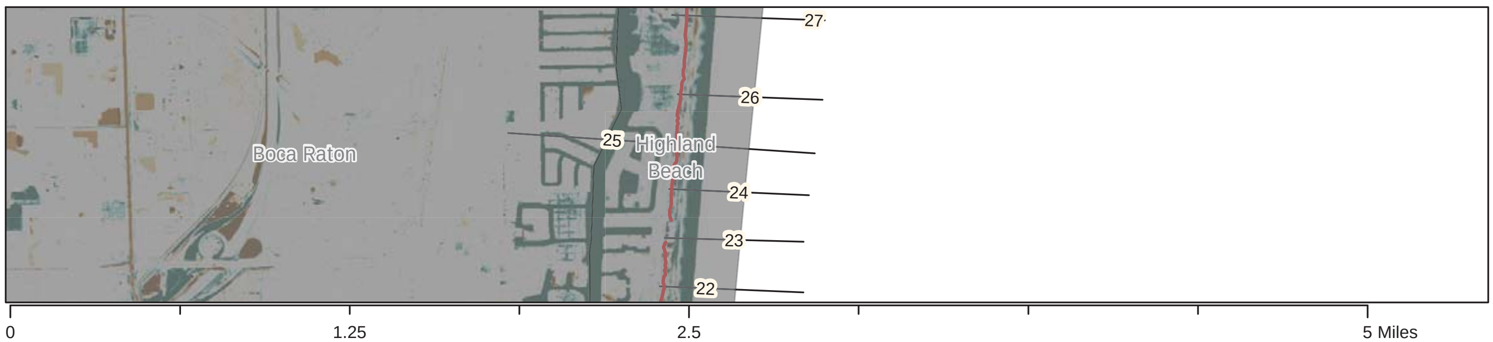
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

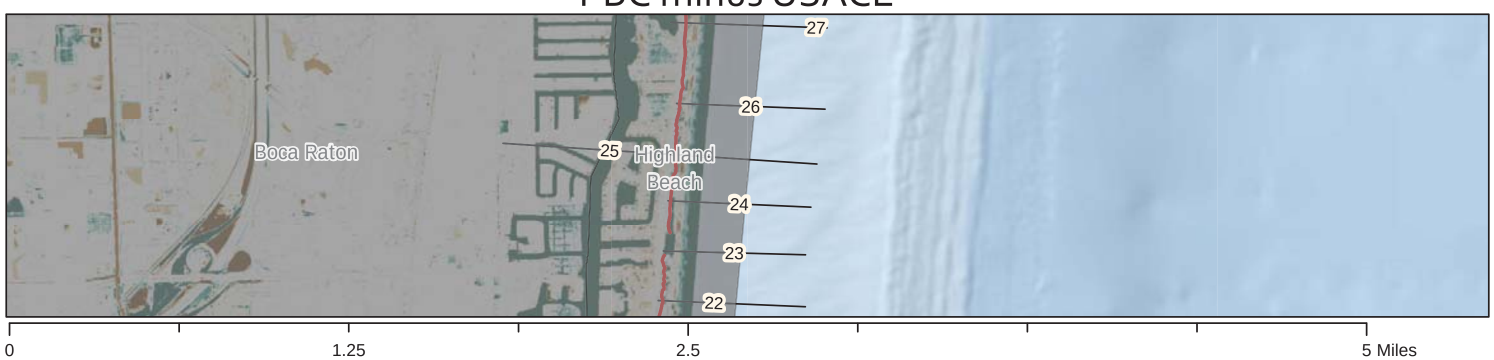
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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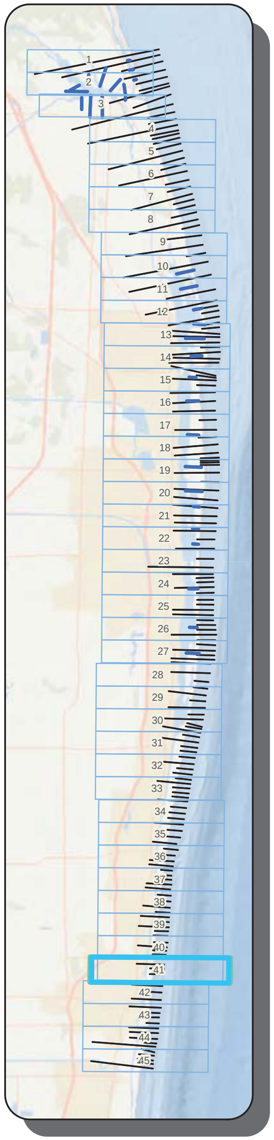
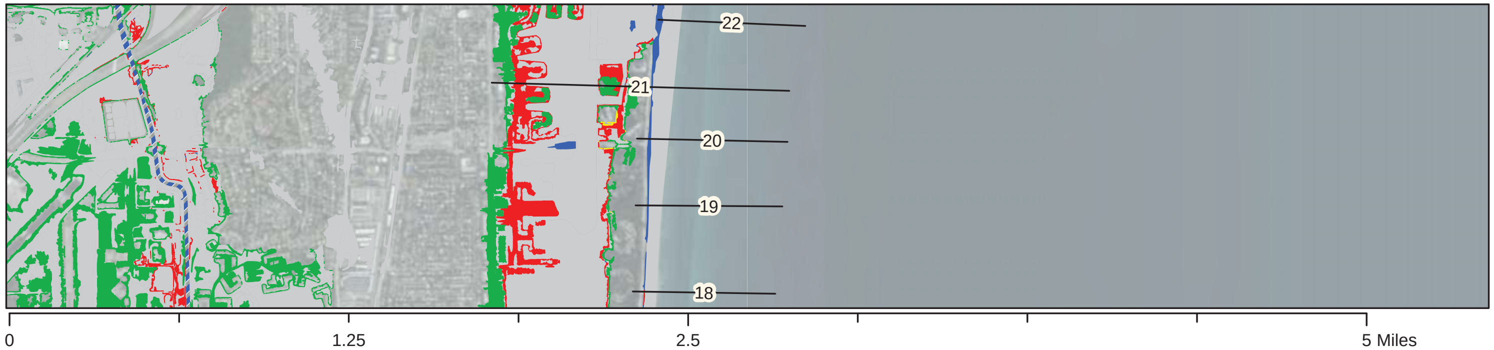


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

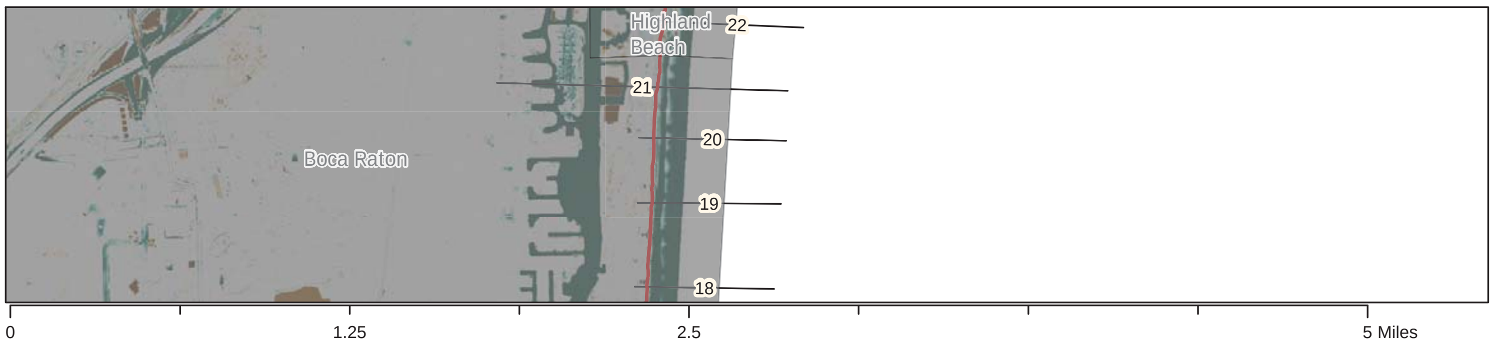
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

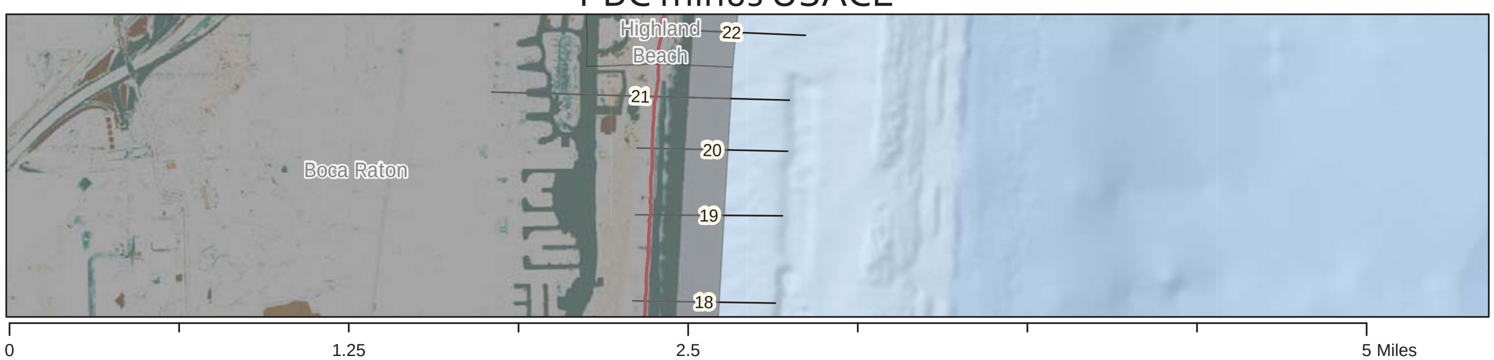
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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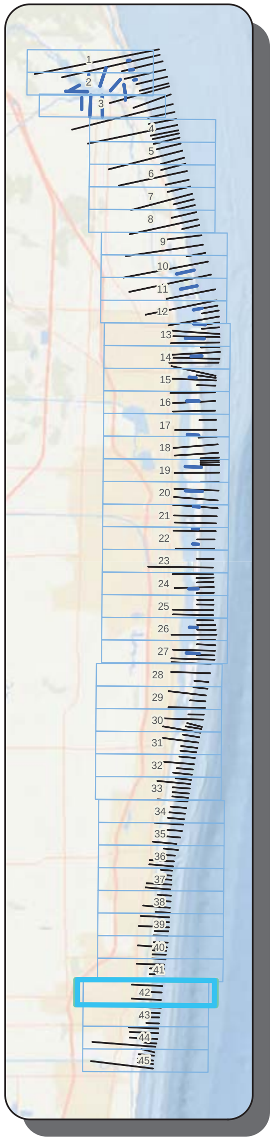


Change Since Last FIRM

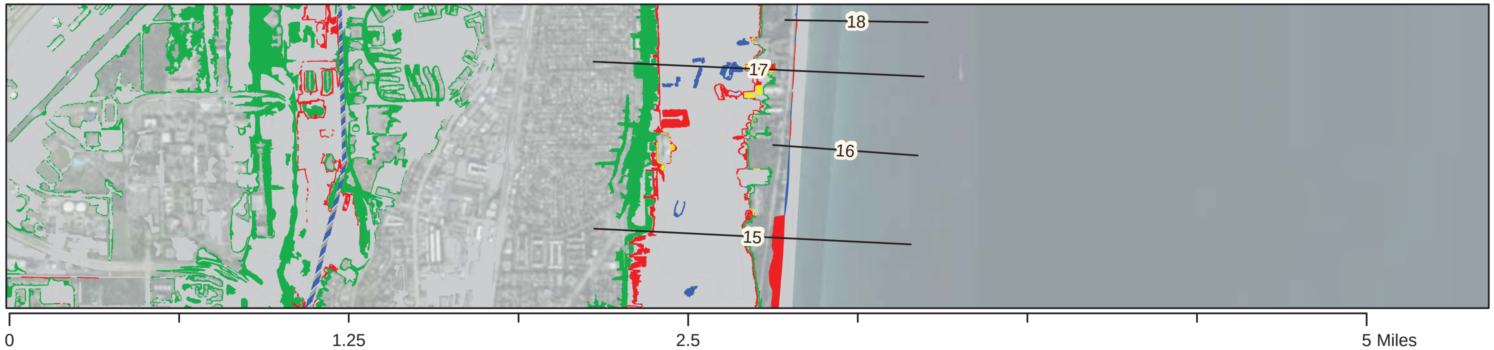
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

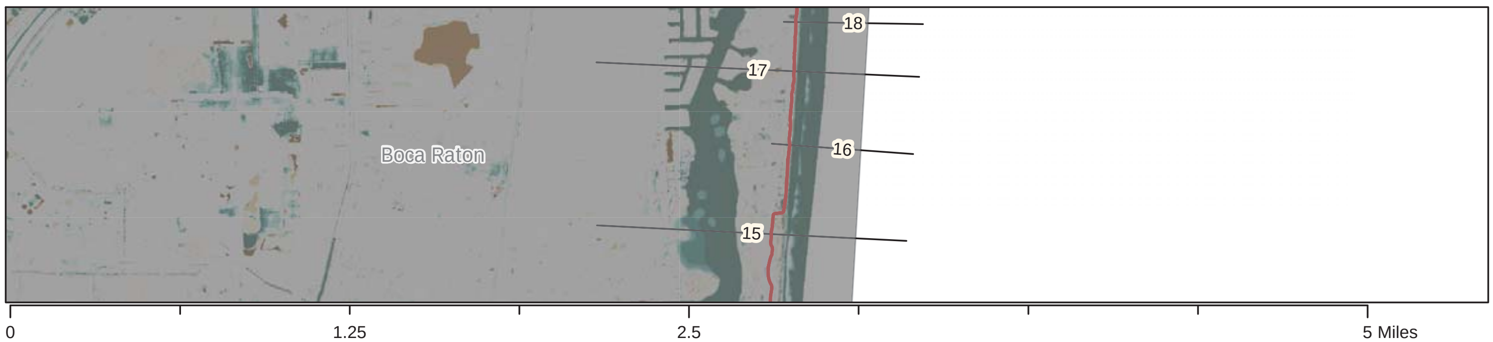
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

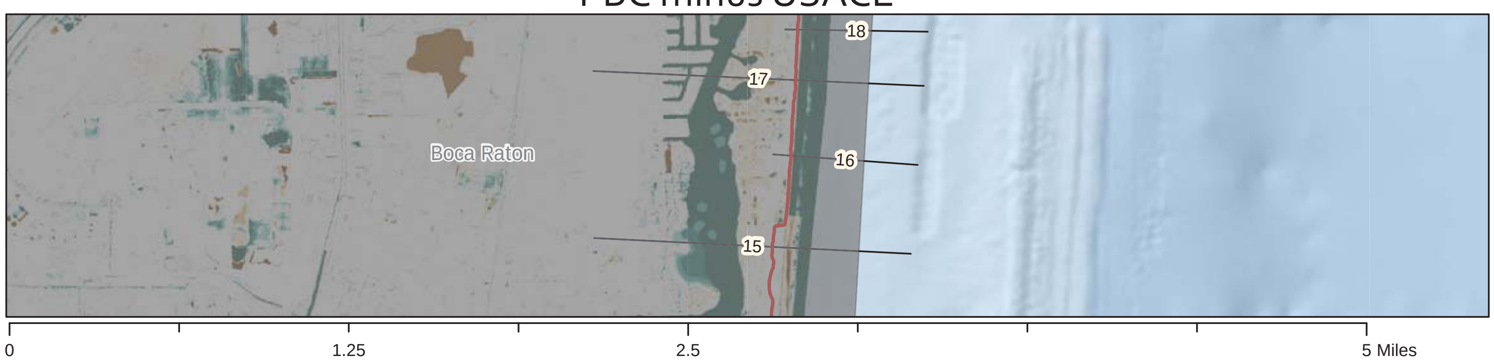
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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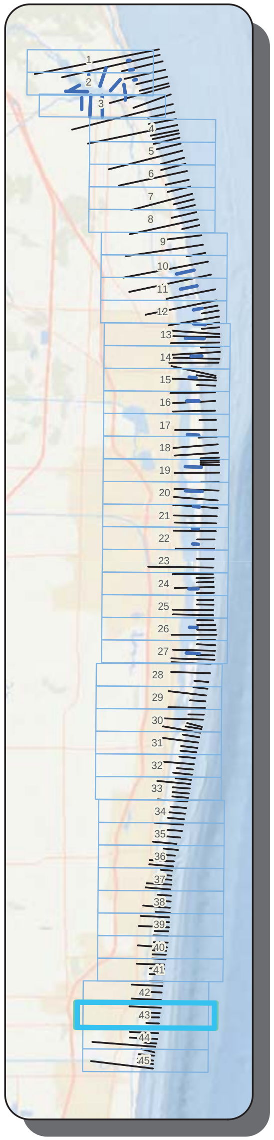


Change Since Last FIRM

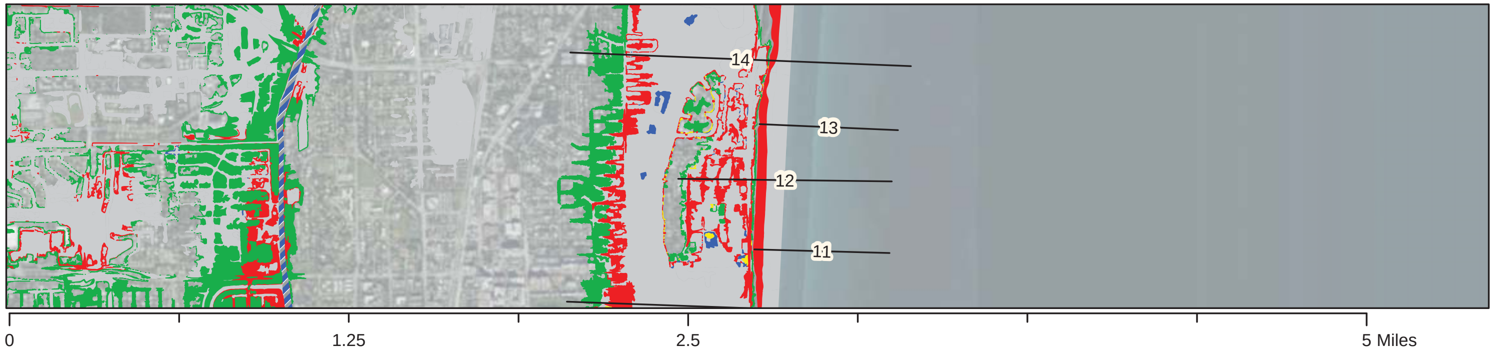
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

- Frontal Dune Line
- Municipalities

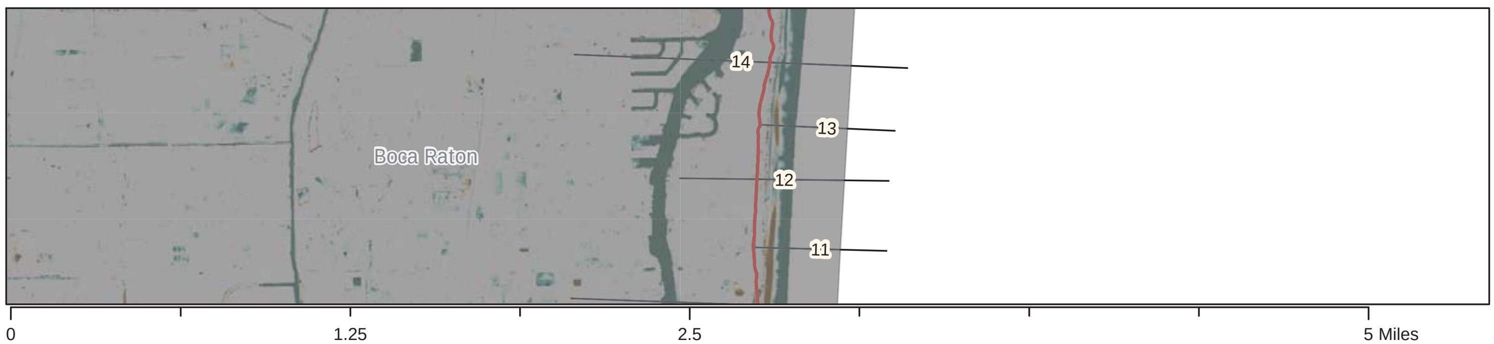
Calculated Difference (ft)

- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

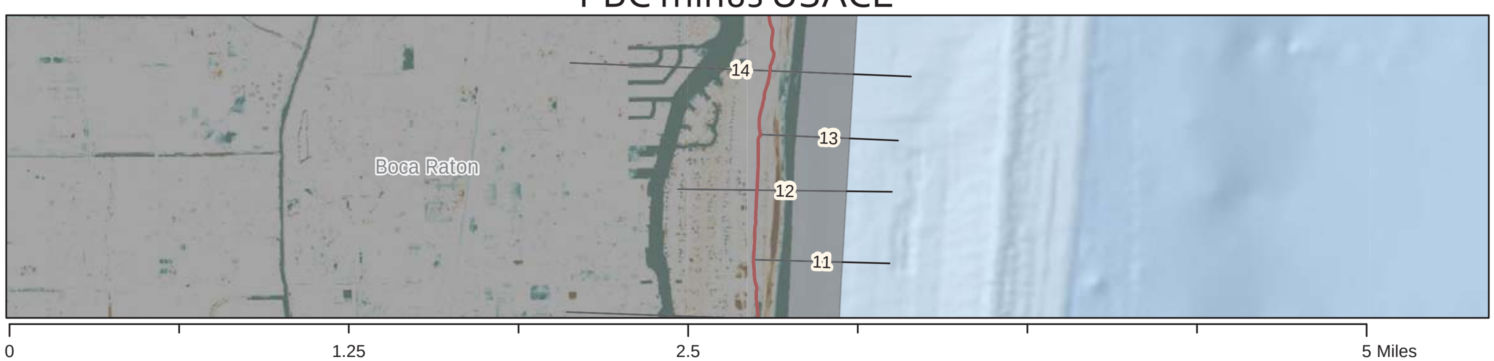
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



Transect View

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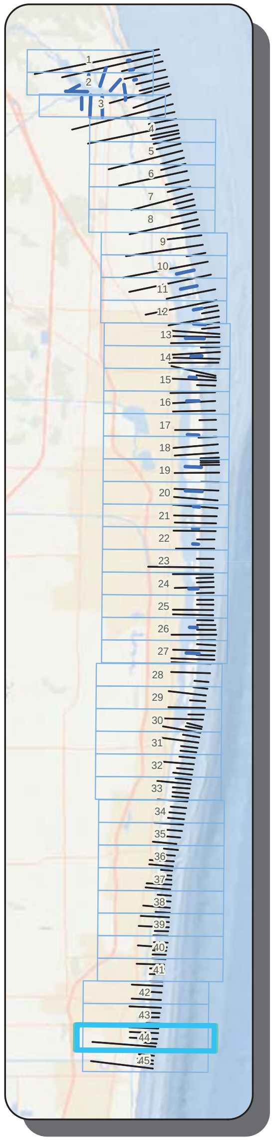
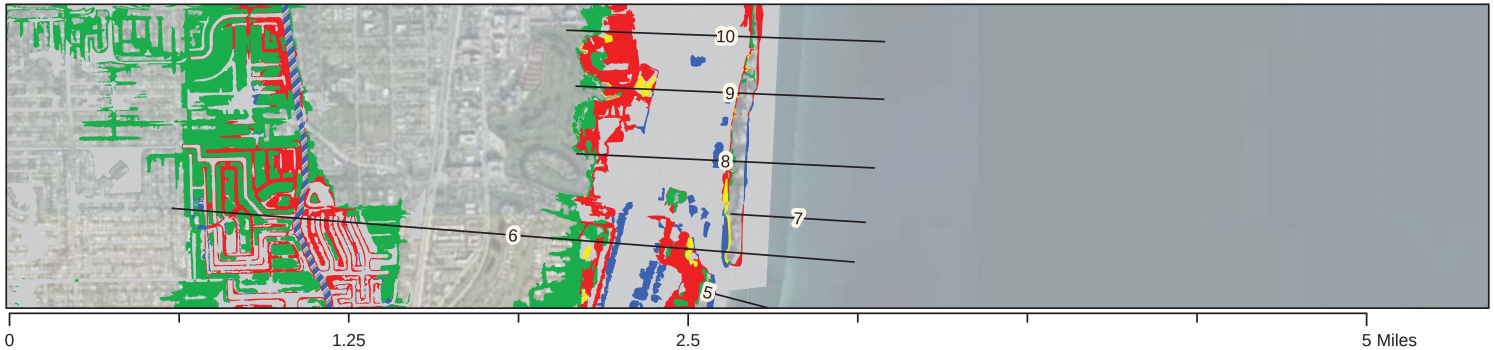


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

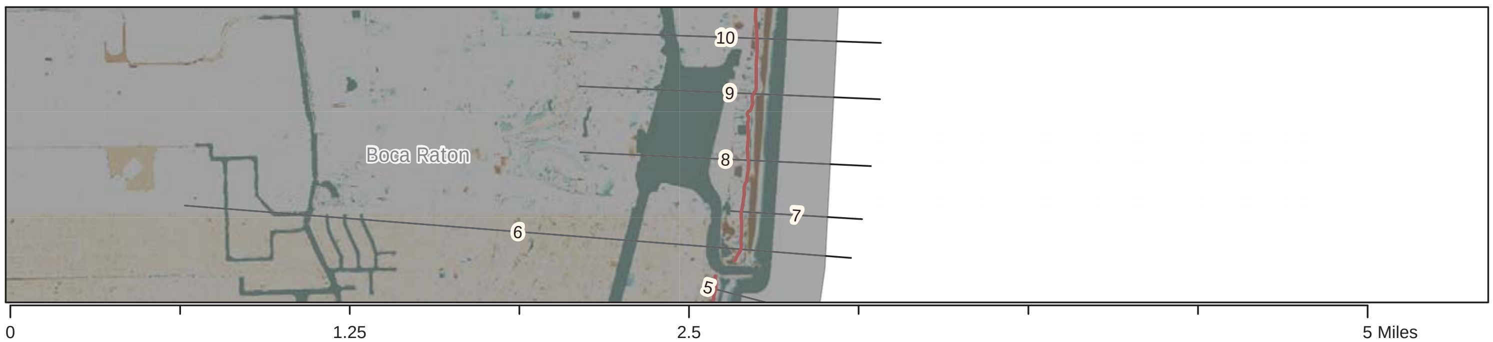
- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

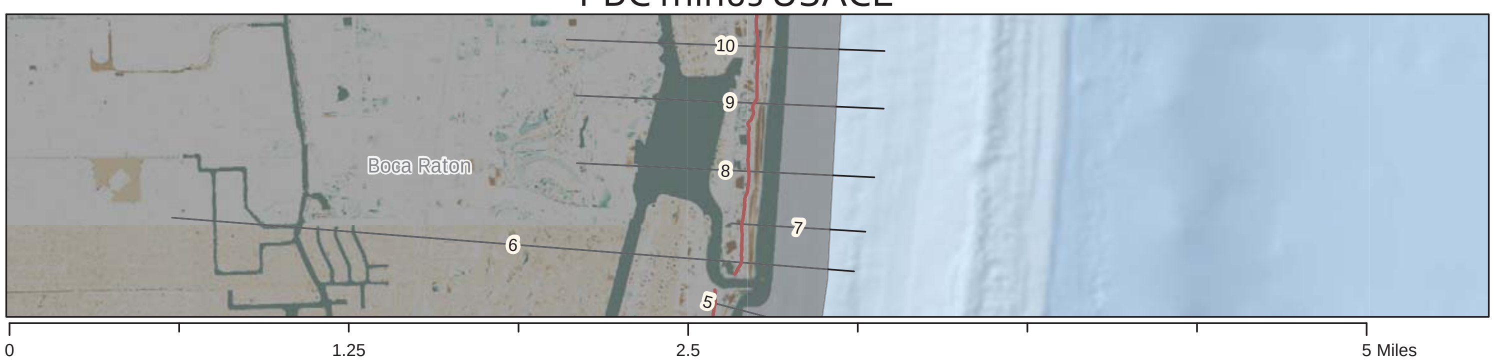
Change Since Last FIRM



PBC minus SWFLTB DEM



PBC minus USACE



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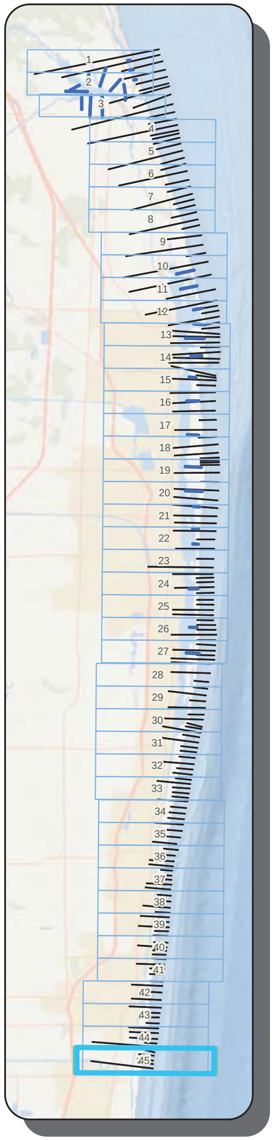
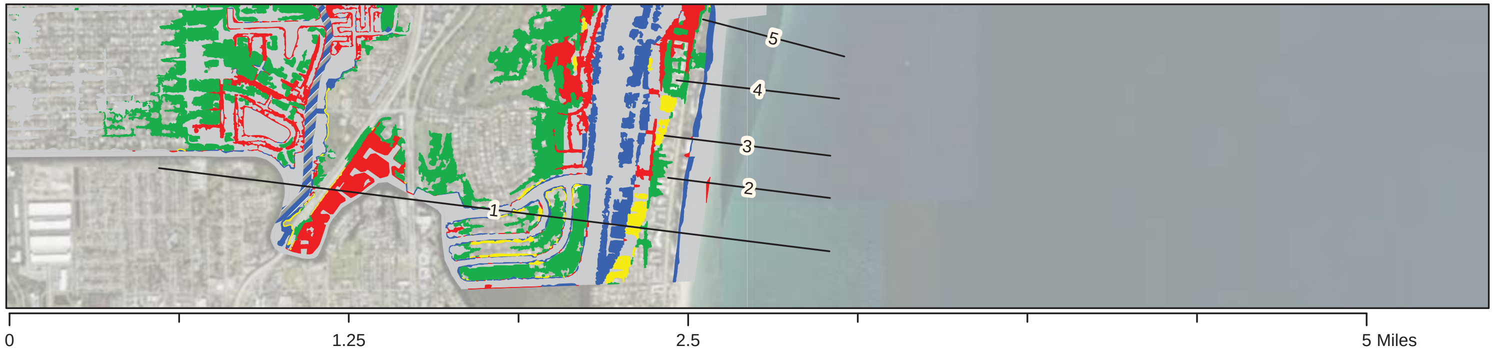
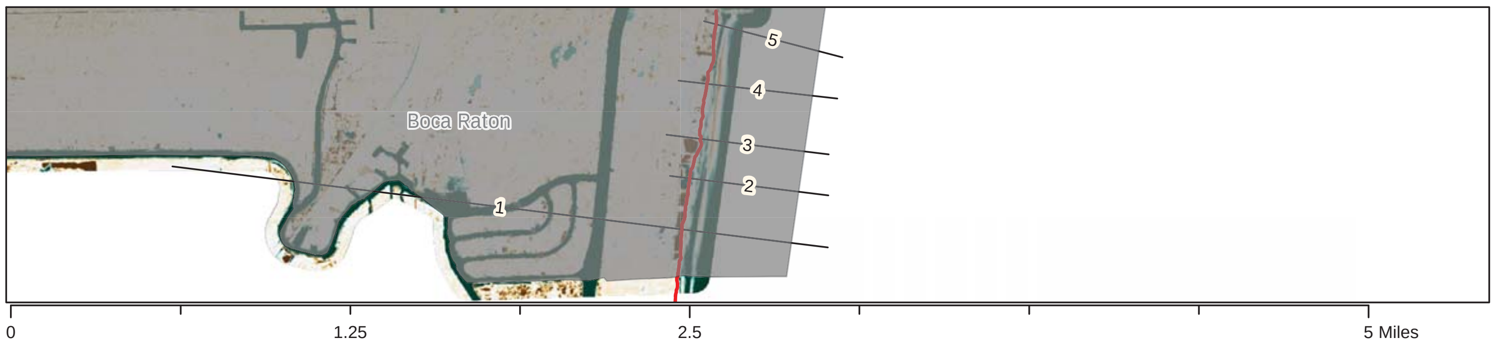


Change Since Last FIRM
- No Zone Change
- 1% Annual Decrease
- Floodway Decrease
- Floodway Increase
- 1% Annual Increase
- 0.2% Annual Decrease
- 0.2% Annual increase

Change Since Last FIRM



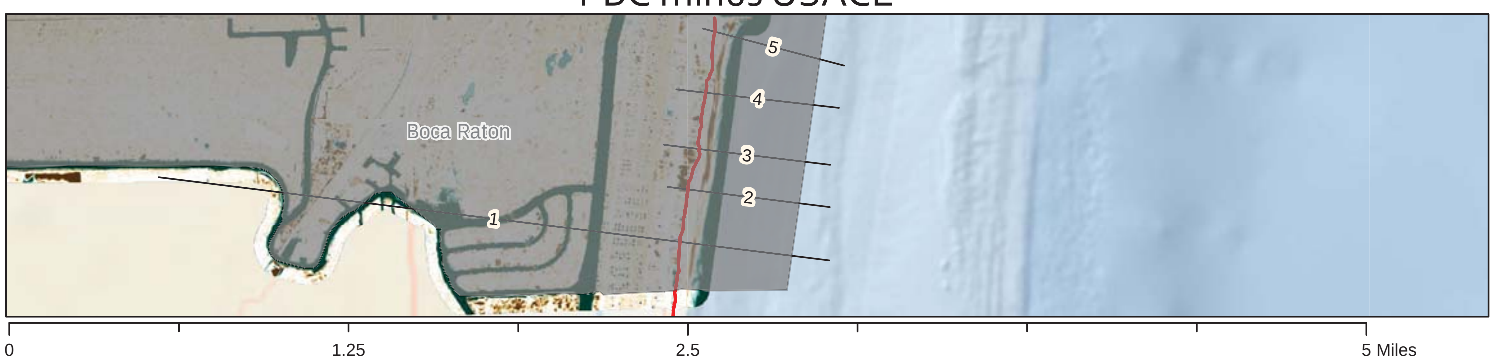
PBC minus SWFLTB DEM



- Frontal Dune Line
- Municipalities

Calculated Difference (ft)
- ≤ -2.5
- ≤ -2
- ≤ -1.5
- ≤ -1
- ≤ -0.5
- ≤ 0.5
- ≤ 1
- ≤ 1.5
- ≤ 2
- ≤ 2.5
- ≤147.259583

PBC minus USACE



Appendix C

B.
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Review & Evaluation of FEMA's Coastal Flood Risk Study

Data and Documents Review Technical Memorandum (Deliverable 4.1)
Task Order #1778-01

October 1, 2020 | 13134.201.R3.Rev0

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Review & Evaluation of FEMA's Coastal Flood Risk Study

Data and Documents Review Technical Memorandum (Deliverable 4.1)
Task Order #1778-01

Prepared for: **Prepared by:**

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13134.201.R3.Rev0

Z:\Shared With Me\QMS\2020\Reports_2020\13134.201.R3.Rev0_PBC FEMA Review - Document Review - 2020-10-01 (Del 4.1).docx

Revision	Date	Status	Comments	Prepared	Reviewed	Approved
Rev A	5/1/2020	Draft	County review	DS	OK	DS
Rev B	8/18/2020	Draft	Comments incorporated	DS	GT	DS
Rev 0	10/1/2020	Final		DS	GT	DS

Executive Summary

The National Flood Insurance Program (NFIP) is a federal program that provides flood insurance to property owners within participating communities. Palm Beach County and a number of its communities participates in the program. The Federal Emergency Management Agency (FEMA) is responsible for administering the NFIP and as such periodically updates information on the flood hazards. The updated information is incorporated into FEMA's Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRM) for a given study area.

FEMA is in the process of updating the FIS for the South Florida Study Area with the Coastal Flood Risk Study (SFL study), which was intended to reevaluate the coastal flood hazard originating from the Atlantic Ocean. Palm Beach County, along with Broward, Miami-Dade, and Monroe Counties, is located within the SFL study area. FEMA's study leveraged coastal numerical modeling and analyses to better define the coastal flood risks associated with storm surge. The document review presented herein was intended to identify specific elements of the study that may have misrepresented the water levels and mapping results with respect to Palm Beach County. The major elements are summarized below.

Validation Storm Selection

- Validation of the Simulating WAves Nearshore + ADvanced CIRCulation (SWAN+ADCIRC) model was based on five historical hurricanes; Betsy (1965), David (1979), Andrew (1992), Georges (1998), and Wilma (2005). Inclusion of these storms within the model validation may not have been appropriate given the magnitude of storm surge generated, the regional extents of the surge, the locations of gage measurements, and limited measured data. FEMA's statements within the documents also cast doubt as to the appropriateness of the selected storms.
- Inclusion of other validation storms in addition to (or in substitution of) those selected by FEMA should be considered. For example, Hurricanes Frances and Jeanne (2004) are potential storms that should be considered for the following reasons.
  - The storms provide a basis for representing storm surges along the Atlantic coastline of the study area, specifically within Palm Beach County.
  - The storms were used to validate the SWAN+ADCIRC model for FEMA's East Coast Central Florida (ECCFL) coastal study (2014). Inclusion of these storms within the SFL study may help improve agreement at the study area boundaries (Martin and Palm Beach county line).

SWAN+ADCIRC Model Validation

- Model validation did not account for the location of measured data with respect to the distances from storm tracks, the type of measured data (e.g. hydrographs and high water marks (HWM)), or the timing between measured and modeled peak water levels. Failure to do so may have negatively affected model validation and uncertainties and resulted in water levels that are not representative.
- Hurricane Wilma was the only common validation storm considered for both the SFL and ECCFL studies. The same water level gages were not used in both studies, which FEMA did not provide justification. The average difference of modeled water levels for the SFL study within the 60-mile segment of coastline common between the studies was 64% greater than the ECCFL study. The ECCFL study ultimately eliminated Hurricane Wilma to improve the model's capability to reproduce non-exiting storm conditions and because of increased uncertainty in the wind and pressure fields for exiting storms. Despite this, Hurricane Wilma was included in the SFL study.

Statistical Stillwater Elevations (SWEL)

- Model uncertainty was evaluated and used to statistically estimate the 1% SWEL within the study area. In developing inputs for the coastal hazard analysis, FEMA concluded that the 1% SWEL were high in some areas because of the model "uncertainty term and the combined storm frequency curves" for east and west coast storms used to define the 1% SWEL (Table 1.1, Reference #14). Review of FEMA's reports for the ECCFL study revealed that FEMA excluded west coast (exiting) storms citing that "exiting storms have a minimal effect on the low-frequency water levels" and "the presence of other uncertainties which influence the modeling results to a larger degree." FEMA reported that the influence of west coast storms on the SFL study was 0.25 feet (3 times greater than the ECCFL study) but opted to include them regardless.
- At the study area boundary between the SFL study and ECCFL study, discrepancies in the 1% SWEL were identified by FEMA. The 1% SWEL for the SFL study were higher by "1.7 feet along the open coast, 2.0 feet in the Intracoastal Waterway, and 2.0 to 4.2 feet up the Loxahatchee and North Fork Loxahatchee Rivers" (Table 1.1, Reference #12). FEMA identified a transition area and applied adjustments lowering the 1% SWEL within the northern 5 miles of the County to align the studies. Refinement to FEMA's approach to consider the entirety of Palm Beach County in adjusting the 1% SWEL appears justified. The alternate approach presented herein, if adopted by FEMA, would result in lower 1% SWELs within the County.

Coastal Hazard Analysis

- Revisions to the 1% SWEL may affect FEMA's evaluation of dune response.
- Review of FEMA's analysis and inspection of open coast transects suggested there may be opportunities to improve the consistency of the mapping of the VE Zone throughout Palm Beach County and to reflect the potential for wave overtopping and the landward limit of moderate wave action.
- FEMA's analysis of sheltered water (inland) transects excluded transects within the Lake Worth Lagoon south of the East Ocean Avenue bridge in Lantana to avoid inconsistencies in mapping Base Flood Elevations (BFE) along the eastern shoreline of the Lake Worth Lagoon. The inconsistencies were attributed to the larger starting wave conditions extracted from the SWAN+ADCIRC model results which appeared to be localized outliers as compared to the other areas of the lagoon. FEMA opted to rely on sheltered water transects within the lagoon to the north for mapping purposes as opposed to reviewing the SWAN+ADCIRC modeling to resolve the outlying starting wave conditions.

Subsequent tasks will review the model setups, inputs, outputs, and other data provide by FEMA to delve beyond the level of detail contained in FEMA's documents; this will provide Palm Beach County additional information and details regarding FEMA's SFL study.

Table of Contents

Tables

Figures

1. Introduction

The National Flood Insurance Program (NFIP) is a federal program that provides flood insurance to property owners within participating communities. Palm Beach County and a number of its communities participates in the program. The Federal Emergency Management Agency (FEMA) is responsible for administering the NFIP and as such periodically updates information on the flood hazards. The updated information is incorporated into FEMA's Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRM) for a given study area.

FEMA is in the process of updating the FIS for the South Florida Study Area with the Coastal Flood Risk Study (SFL study), which is intended to reevaluate the coastal flood hazard originating from the Atlantic Ocean. Numerous documents have been generated by FEMA (and its mapping partner) for the updated SFL study, which are based on published FEMA guidelines as outlined in Table 1.1.

Palm Beach County, along with Broward, Miami-Dade, and Monroe Counties, is located within the South Florida Study Area. The documents in Table 1.1 were reviewed by Baird with respect to their applicability and appropriateness to Palm Beach County. The document review presented herein summarizes elements of the study that may warrant the County's attention. Elements are correlated to respective FEMA documents by the reference numbers assigned in the table below. The discussion is organized into the following broad categories.

- Validation Storm Selection
- SWAN+ADCIRC Model Validation
- Statistical Stillwater Elevations (SWEL)
- Coastal Hazard Analysis

It should be noted that the discussion herein does not attempt to document all elements that were considered during our review nor does it attempt to provide resolutions to these elements, but rather provides information intended to improve the accuracy, consistency, and reliability of FEMA's SFL study in simulating water levels and mapping flood risks. Task 5 will review the model setups, inputs, outputs, and other data provided by FEMA to delve beyond the level of detail contained in FEMA's documents; this will provide the County additional information and details. Coastal analysis and modeling to evaluate the impact and sensitivity of the elements on FEMA's overall SFL study is beyond Baird's scope of work.

Table 1.1: List of FEMA Documents.

FEMA Document			Date	Description	Reference #
SFL Coastal Study Documents					
Coastal Discovery Report			Apr 2015	Presents available data and information considered by FEMA for inclusion in the updated coastal study.	[1]
Intermediate Data Submittal (IDS) Reports					
	#1	Section 1 - Technical Approach	Nov 2014	Introduces the major technical study components contained in IDS Report #1, Sections 2-7.	[2]
		Section 2 - Digital Elevation Model (DEM)	Mar 2016	Discuss topographic and bathymetric data sets, DEM development, and creation of the finite element model mesh utilized in the SWAN+ADCIRC modeling, WHAFIS modeling, and coastal hazard analyses.	[3]
		Section 3 - Validation Storm Selection	Feb 2015	Presents wave and water level data sets and the methodology applied to develop the studys validation storm suite for the SWAN+ADCIRC modeling.	[4]
		Section 4 - Study Area & Site Reconnaissance	May 2015	Details site reconnaissance performed and the procedure followed to identify coastal structures and to delienate the primary frontal dune (PFD).	[5]
		Section 5 - JPM-OS Probablistic Model Development	Jun 2015	Documents the storm climatology and initial probabilistic model development.	[6]
		Section 6 - Tropical Analysis & Forcing Development	Feb 2015	Presents the methodology applied to develop wind and pressure fields as inputs to the SWAN-ADCIRC modeling.	[7]
		Section 7 - Hydrodynamic & Wave Model Development	Jan 2016	Details the wave and hydrodynamic storm surge model and mesh development methods.	[8]
	#2	Section 1 - Wave & Hydrodynamic Model Validation	Feb 2017	Describes the methodology and results of the wave and hydrodynamic modeling validation.	[9]
		Section 2 - JPM-OS	Oct 2016	Describes development of the representative stor set and associated annual recurrance rates (return period) of storms.	[10]
	#3	Section 1 - Production Runs	Jun 2018	Describes the SWAN+ADCIRC modeling of the synthetic storms developed as part of the JPM-OS analysis. The modeling resulted in total maximum water levels and wave conditions for return period storms.	[11]
		Section 2 - Low-Frequency Analysis	Jul 2018	Documents the methodology used to define still water elevations (SWEL) throughout the SWAN+ADCIRC modeling domain for low-frequency (2-, 1-, and 0.2-percent-annual-chance) storm events.	[12]
		Section 3 - Regional Fequency Analysis of Tide Gage Water Levels	Jul 2019	Documents the methodology used to define still water elevations (SWEL) throughout the SWAN+ADCIRC modeling domain for high-frequency (50-, 20-, 10-, and 4-percent-annual-chance) storm events.	[13]
	#4,5	Coastal Hazard Analysis	Oct 2019	Decribes the analyses of overland wave propagation, wave runup, wave overtopping, coastal structures, storm induced erosion used to define special flood hazard araes (SFHA) and delineate flood zones boundaries.	[14]
Preliminary Flood Insurance Study (FIS)			Dec 2019	Summarizes the general framework of the study, engineering methods considered in the study, and mapping methods.	[15]
Preliminary Flood Insurance Rate Map (FIRM) Panels			Dec 2019	Maps depicting SFHA, flood zones, and base flood elevations (BFE) resulting from the study. Maps provide a level of detail that individual building and parcels can be identified.	[16]
FEMA Guidance Documents					
Atlantic Ocean & Gulf of Mexico Coastal Guidelines Update			Feb 2007	Technical guidance governing the breadth of the modeling and analysis for coastal study updates.	[17]
Guidance for Coastal Flood Hazard Analysis & Mapping (CFHAM)					
	Sheltered Waters		Feb 2008	Guidance for analyzing flood harzards (primarily 1-percent-annual chance- storm events) within sheltered water areas.	[18]
	Overland Wave Propagation		Nov 2015	Guidance on applying the WHAFIS model, defining input parameters, and interpreting model results.	[19]
	Erosion		Feb 2018	Guidance on methods available to estimate profile changes for erodible shorelines due to storm events.	[20]
	Coastal Floodplain Mapping		Nov 2019	Guidance on delineating coastal flood zones and defining BFE's.	[21]
	Coastal Water Levels		May 2016	Guidance on extracting stillwater level (SWL) data from measured water levels and on determining SWL where storm surge processes dominate.	[22]
	Coastal Structures		Nov 2019	Guidance on methods available to analyze the stability and effects of coastal structures during the 1-percent-annual-chance storm event.	[23]
	Coastal General Study Considerations		Nov 2019	Guidance provides an overview of coastal flooding processes and describes general considerations for FEMA coastal flood hazard studies.	[24]
	Determination of Wave Characteristics		Feb 2019	Guidance on determining wave characteristics that are required for a coastal hazard analysis.	[25]
Wave Height Analysis for Flood Insurance Studies (WHAFIS)					
	WHAFIS Technical Documentation Version 3.0		Sep 1988	User manual for the WHAFIS model.	[26]
	Supplementary WHAFIS Documentation Version 4.0		Aug 2007	Supplemental information for a later version of the WHAFIS model.	[27]

2. Validation Storm Selection

Coastal storm events can result in elevated water levels known as storm tides. Storm surge is the difference between storm tides and underlying astronomical tides and is affected by the combined effects of waves, currents, and water levels, among other factors. The FEMA SFL study utilized a coupled wave model and hydrodynamic model (SWAN+ADCIRC model) to simulate coastal storm surge. The SWAN spectral wave model was used to develop the offshore and nearshore wave climate, while the ADCIRC hydrodynamic model simulated currents and water levels. Coupling of the models allows for wave-induced water level changes and its effects on storm surge to be accounted for simultaneously during model simulations. The SWAN+ADCIRC model requires that a model mesh be developed for the study area and a subsequent validation "demonstrates satisfactory model performance – without consistent bias to underestimate or overestimate water levels" [2]. Thus, validation requires selection of representative storm events, which is detailed in FEMA's Intermediate Data Submittal (IDS) Report 1, Section 3 [4].

The following storms were selected by FEMA to validate the SWAN+ADCIRC model; storm tracks are shown in Figure 2.1.

- Hurricane Betsy (1965)
- Hurricane David (1979)
- Hurricane Andrew (1992)
- Hurricane Georges (1998)
- Hurricane Wilma (2005)

FEMA's SFL study identified the following criteria to guide the selection of validation storms [4]:

- Storms that made landfall within the project area, exited within the project area, or bypassed near the study area.
- Storms that resulted in significant surge (approximately greater than 3 feet) within the project area.
- The availability of water level data points available for each storm and their spatial distribution throughout the study area.
- The density of wave data points available for each storm and their spatial distribution throughout the study area. (It should be noted that this criterion was later eliminated from the study given the lack of wave data near the study area).
- Storms occurring between 1950 and 2014 and that passed within 200 nautical miles of Miami, Florida. 1950 represents the year of implementation of more sophisticated storm data collection techniques.
- Storms with central pressures of 980 millibars or lower at landfall, land exit, or at the point of closest approach to the study area. Extra-tropical systems were not included.
- Storms that increase the spatial distribution of storm surge validation over the study. In other words, ensuring the model is equally valid for all parts of the study area.
- Historical significance of the storm (i.e. storms identified by local residents as major events impacting the study area).

In summarizing its basis for selecting validation storms, FEMA defined one basis as being "water level records are available at more than 15 stations" [4]. This was inferred as FEMA's threshold for satisfying its criteria regarding availability of water level data and spatial distribution throughout the study area (3rd bullet in the list above). According to the information presented, National Oceanic Atmospheric Administration (NOAA), United States Army Corps of Engineers (USACE), United States Geological Survey (USGS), and South Florida Water Management District (SFWMD) stations within the study area were evaluated. Figures presented by FEMA cross-reference the available stations with respect to the selected storm events. NOAA's Key West station, a data point (not a time series) from NOAA's Miami Beach station, and four USGS stations in Broward County were identified for Hurricane Betsy in 1965. NOAA's Key West station and six SFWMD stations throughout the east coast of the study area were identified for Hurricane David in 1979. The available stations for Hurricanes Betsy and David were less than the 15-station threshold and highwater mark (HWM) data was not available to supplement the station data for either storm.

Subsequently, FEMA makes the following statements calling in to question the appropriateness of selected validation storms in performing the model validation of water levels.

- While Hurricanes Betsy, Andrew, and Wilma "produced significant surge" near the landfall locations, the storms "do not provide wide coverage of recent surge levels in the study area as they did not produce significant surge in southern Palm Beach or Broward Counties or in the Florida Keys" [9].
- With respect to Hurricane Betsy, "very little observed data are available for validation purposes" [9].
- "Inclusion of Hurricanes David and Georges recognized the need to evaluate multiple storms and storms with landfall locations that cover the study area. However, these storms do not represent ideal validation cases as their surge values occur well below the 1%-annual-chance levels targeted by the modeling effort" [9].
- FEMA stated that while NOAA's Key West station provides the longest record in study area and is "in a good location for storms that move through the Gulf of Mexico, the location of the Key West station does not make it a suitable station to capture the maximum surge levels for storms that impact the Atlantic coastline" [4].
- FEMA reported modeling challenges for Hurricane Andrew associated with "wind field development due to extremely strong winds, small-scale spatial variations (wind micro-structures), and failure of local recording stations" [9]. FEMA performed extensive sensitivity analyses on winds and storm tracks during model validation, but discrepancies were not resolved.

Inclusion of other validation storms in addition to (or in substitution of) those selected appears warranted in order to improve FEMA's model validation and representation of storm surge throughout the study area. FEMA should have included more recent storms with storm tracks adjacent but in close proximity to the study area, higher storm surge values, and greater spatial distribution of measured water level data. For example, Hurricanes Frances and Jeanne are potential storms that should be considered for the following reasons.

- The storms provide a basis for representing storm surges along the Atlantic coastline of the study area and in particular Palm Beach County. The hurricanes occurred more recently (September 2004) as compared to the selected storms and more robust measured water level data is available. The more northerly track of the hurricanes (Figure 2.2) would reduce the dependence on the Key West station while representing storm surges experienced in the northern portion of the study area.
- The storms passed within 200 nautical miles of Miami Beach. The hurricanes both made landfall immediately north of the study area in Martin County at similar locations as Hurricane David, which was a selected validation storm.
- The storms were of historical significance to the study area as reported by FEMA. The hurricanes resulted in "fatalities, property damage, power outages, and flooding across Palm Beach County" and that Hurricane Frances resulted in "approximately $34,000,000 in property damage in Miami-Dade County" [1].
- The storms passed closer to a location of measured wave data (NOAA's wave buoys located offshore of Cape Canaveral) than the other selected validation storms. It is anticipated that the hurricanes would provide an opportunity to perform validation of modeled wave conditions, which was not possible for the selected storms (see Section 3).

- The storms were used to validate the SWAN+ADCIRC model for FEMA's East Coast Central Florida (ECCFL) coastal study (2014). Inclusion of Hurricanes Frances and Jeanne as validation storms for the SFL study would likely provide added value in improving agreement with the ECCFL study (see Section 4).

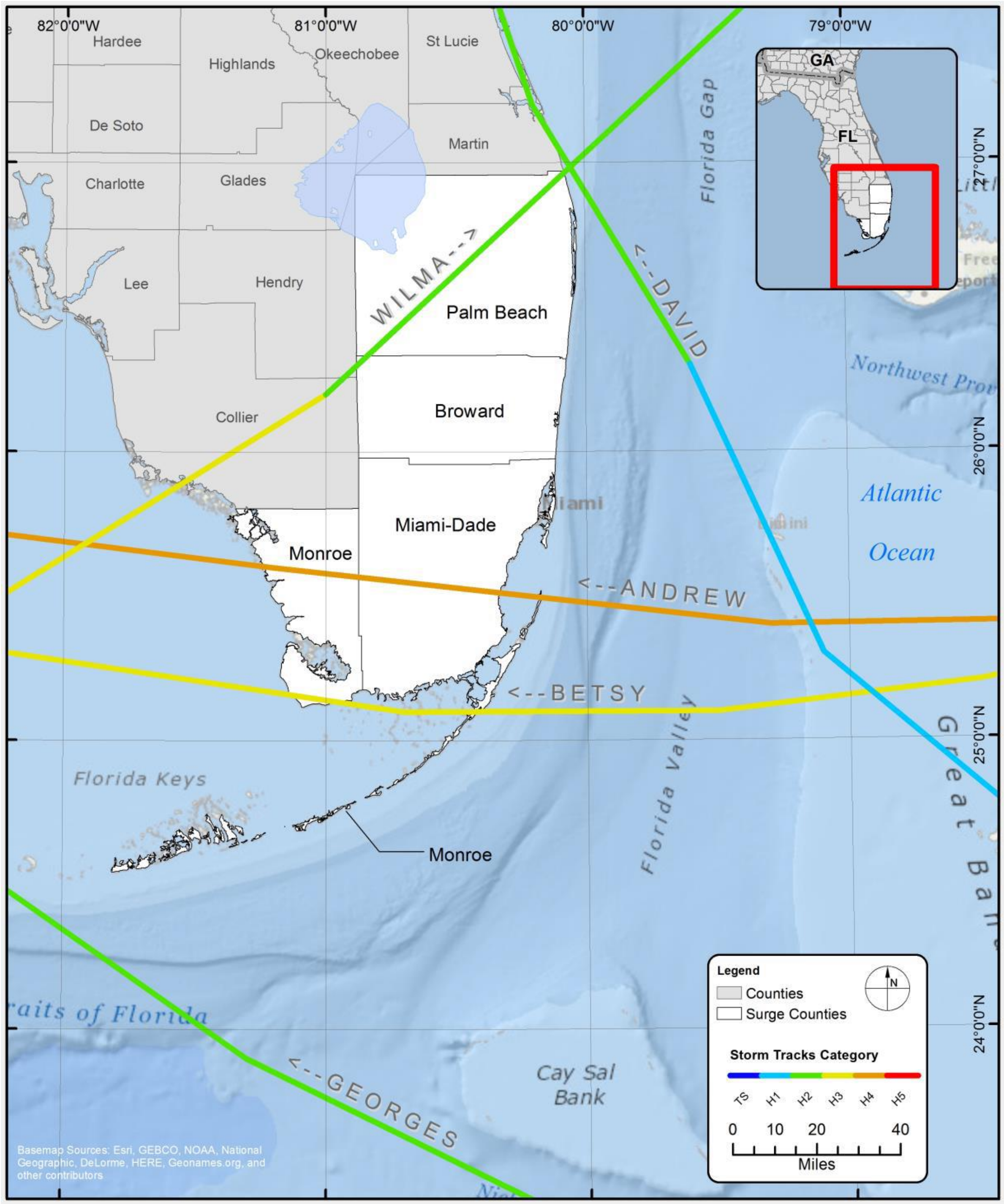


Figure 2.1: Tracks of selected Validation Storms (FEMA, 2015; [4]).

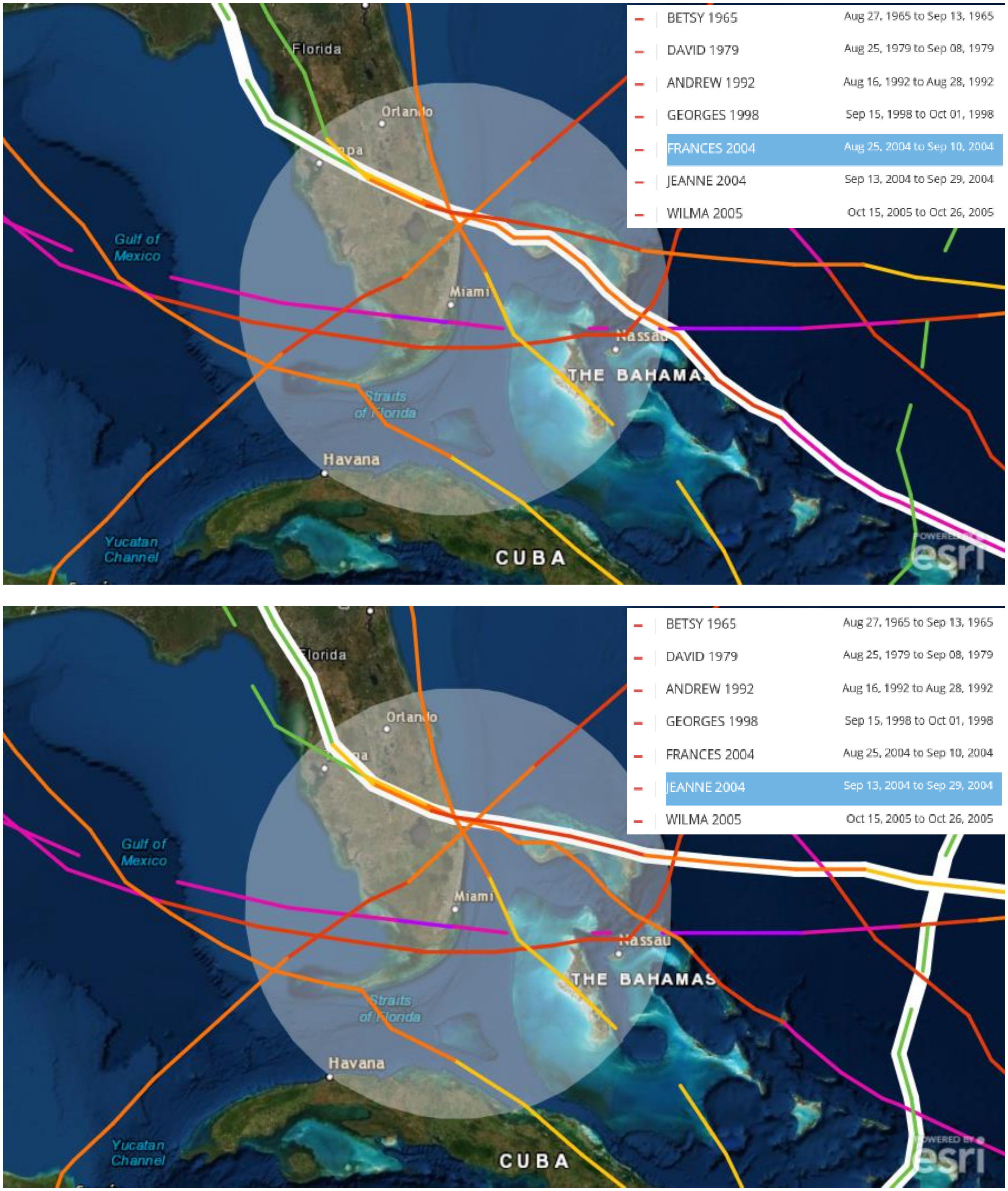


Figure 2.2: Tracks of Validation Storms compared to 2004 Hurricanes (screen capture NOAA, 2020). Hurricanes Frances (top) and Jeanne (bottom)

3. SWAN+ADCIRC Model Validation

As noted in Section 2, the SWAN+ADCIRC model requires validation to "demonstrate satisfactory model performance (waves and water levels) via comparison of model results with available measured data" [9]. FEMA reports that a "lack of measured [wave] data precludes validation of the SWAN+ADCIRC model within the study area" and relies on wave validation performed as part of FEMA's 2014 ECCFL study among others. Thus, the model validation effort of the SFL study primarily focuses on water levels.

Two types of water level data are considered within the model validation; hydrograph data from gage measurements and highwater marks (HWM) from post-storm survey measurements. Figure 3.1 shows the locations of available water level data for the five validation storms selected by FEMA. The symbols and color scale assigned to the data locations indicate whether the modeled water elevation is above/below the measured water elevation and the magnitude of the difference between the two. It should be noted that water level data is not available at all locations for each storm.

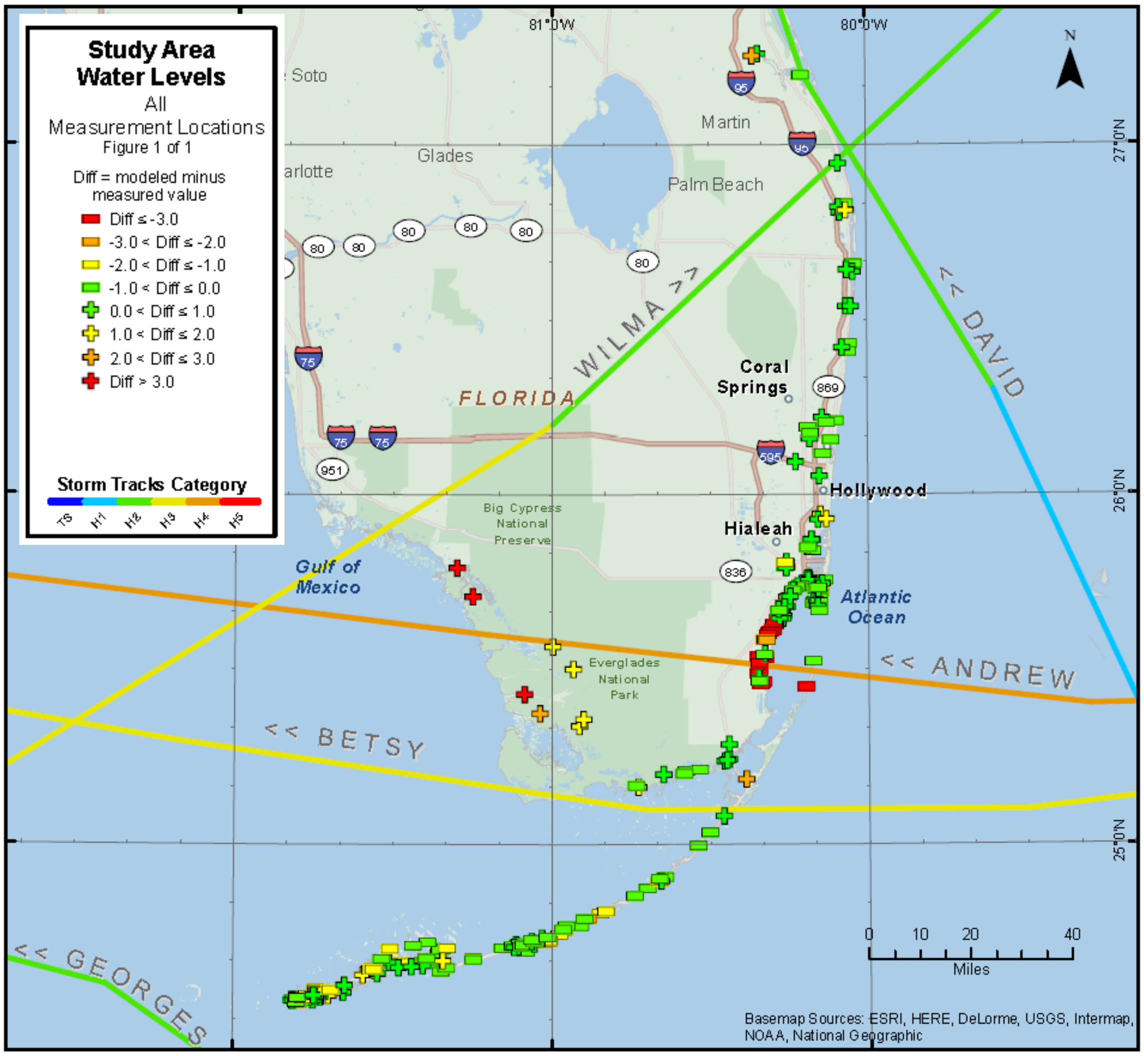


Figure 3.1: Stations with Measured HWM and Hydrograph for All Storms (FEMA, 2017; [9]).

Figure 3.2 compares modeled and measured peak water levels while providing additional detail regarding the storm and type of measurement. Solid symbols and "x" indicate peak water levels obtained from hydrographs; open symbols indicate HWM.

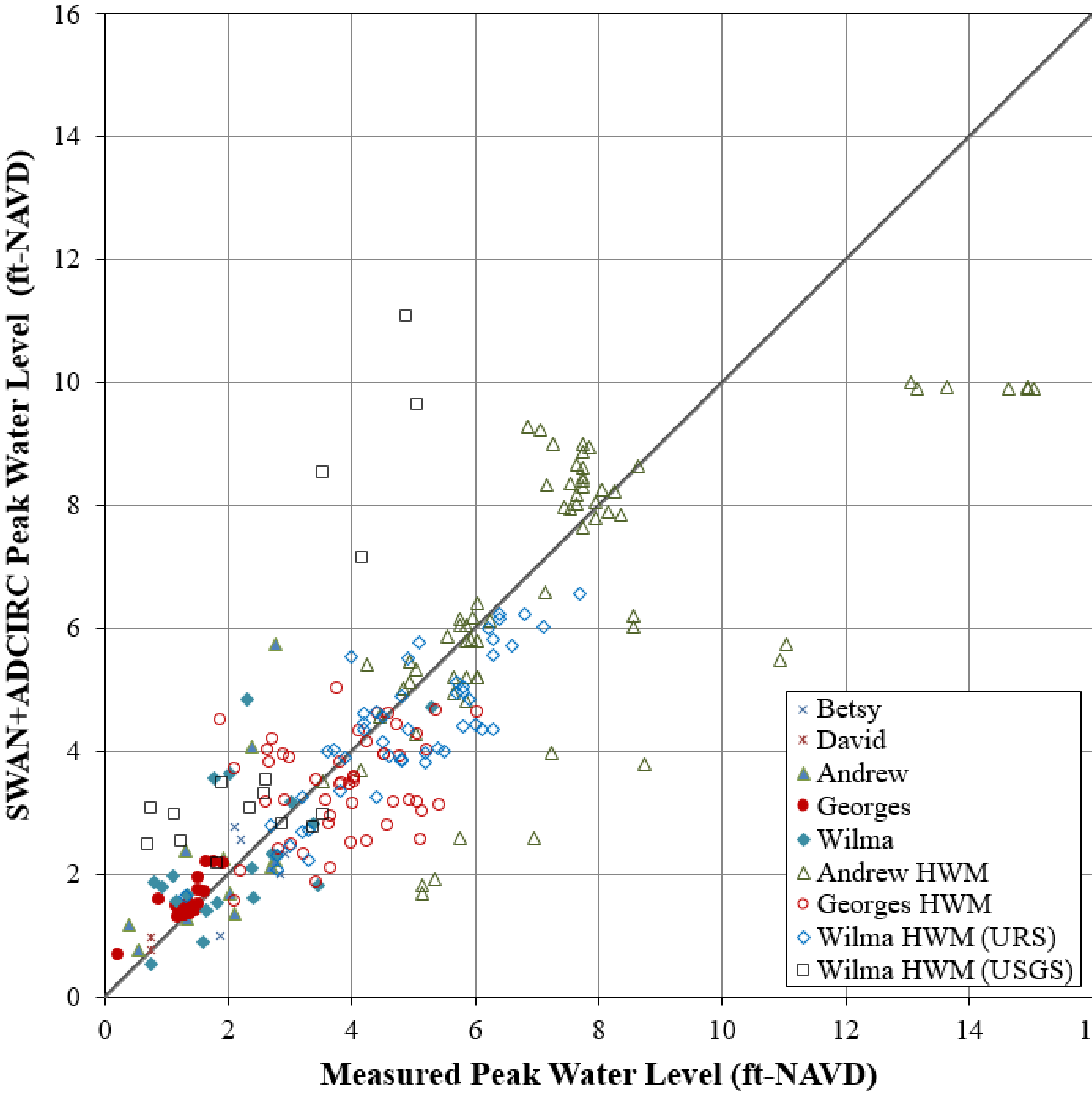


Figure 3.2: Measured-to-Modeled Peak Water Level Comparison for All Storms (FEMA, 2017; [9]).

The following observations were made from Figure 3.1 and Figure 3.2 suggesting that the proximity of measured water levels to the storm track, the gage locations, and the reliability of measured data are important to consider in the model validation.

- There was greater difference between modeled and measured water levels along the coastlines of Biscayne Bay in Miami-Dade County and Everglades National Park in Monroe County as compared to elsewhere in the study area (Figure 3.1). The modeled water levels range 2 to 3+ feet above/below the measured data. These differences are primarily associated with Hurricane Andrew in Miami-Dade County and Hurricane Wilma in Monroe County.

- The modeled water levels agree more closely with measured hydrograph data at lower water levels as compared to higher water levels (Figure 3.2). This is most evident for Hurricanes Andrew and Wilma as shown by the increased clustering of data point along the black, diagonal line at the lower left corner of the figure as compared to moving toward the upper, right corner. Lower water levels generally indicate less influence from storm surge.
- The modeled water levels agree more closely with the measured hydrograph water level data as compared to the measured HWM data (Figure 3.2). This is shown by the increased clustering of data points along the black, diagonal line for hydrograph data (solid symbols) as compared to the increased scatter for the HWM data (open symbols). This may be related to the inherent lower level of accuracy and/or lower reliability of HWM data collected manually during post-storm damage assessments as well as model uncertainty in simulating higher water levels (i.e. storm surge) where HWM are typically collected.

3.1 Proximity of Measured Water Levels to Storm Track

As storm surge decreases to zero due to distance from a storm event or as the storm tracks away from a particular location, changes in water levels are primarily governed by astronomical tides. While it is acknowledged that the extensive model validation resulted in reasonable agreement with measured astronomical tides, less favorable agreement with measured water levels during the simulated validation storm events suggests that the coastal processes associated with storm surge may not be sufficiently represented by the SWAN+ADCIRC model. This concept is highlighted by comparing hydrographs for a given location with a variety of storm tracks. Figure 3.3 shows the hydrograph for the SFWMD S44_T (DBKey 06675) gage in northern Palm Beach County with the green arrows indicating the peak water levels during Hurricanes Andrew (top), Georges (middle), and Wilma (bottom).

- The gage was located further from the storm tracks of Hurricanes Andrew and Georges and as such the influence of storm surges are expected to be less. The modeled and measured water levels are in better agreement for these storms (differences of -0.06 and 0.21 feet, respectively).
- The gage was located closer to the storm track of Hurricane Wilma. The modeled water level was overestimated 1.81 feet based on the measured data, which indicates that the model over predicted storm surge.

The model validation presented by FEMA is based on the difference between the maximum modeled and maximum measured water levels for the storm event but does not consider the timing (or phasing) of the maximum water levels during the storms. Disregard to the phase shift in the water levels can result in the misrepresentation of the model validation and thus the dynamic influence of storm surge. Figure 3.4 shows the hydrograph for the SFWMD S37A_T (DBKey 06651) gage in Broward County during Hurricane Wilma. The measured peak water level (green arrow) was 1.59 feet, NAVD88, while the modeled peak (purple arrow) was 0.88 feet, NAVD88, which resulted in a difference of -0.71 feet as reported by FEMA. The modeled water level was approximately -1 feet, NAVD88 at the time of the measured peak, which indicates a difference of approximately 2.59 feet. Differences between modeled and measured peak water levels is the basis for quantifying model bias to over- or underestimate storm surge and model uncertainty; the difference in this instance was approximately 3.5 times greater than reported. The model peak water level reported by FEMA was consistent with the high tides the 2 days prior and the day after the storm suggesting that the model simulated limited (if any) storm surge.

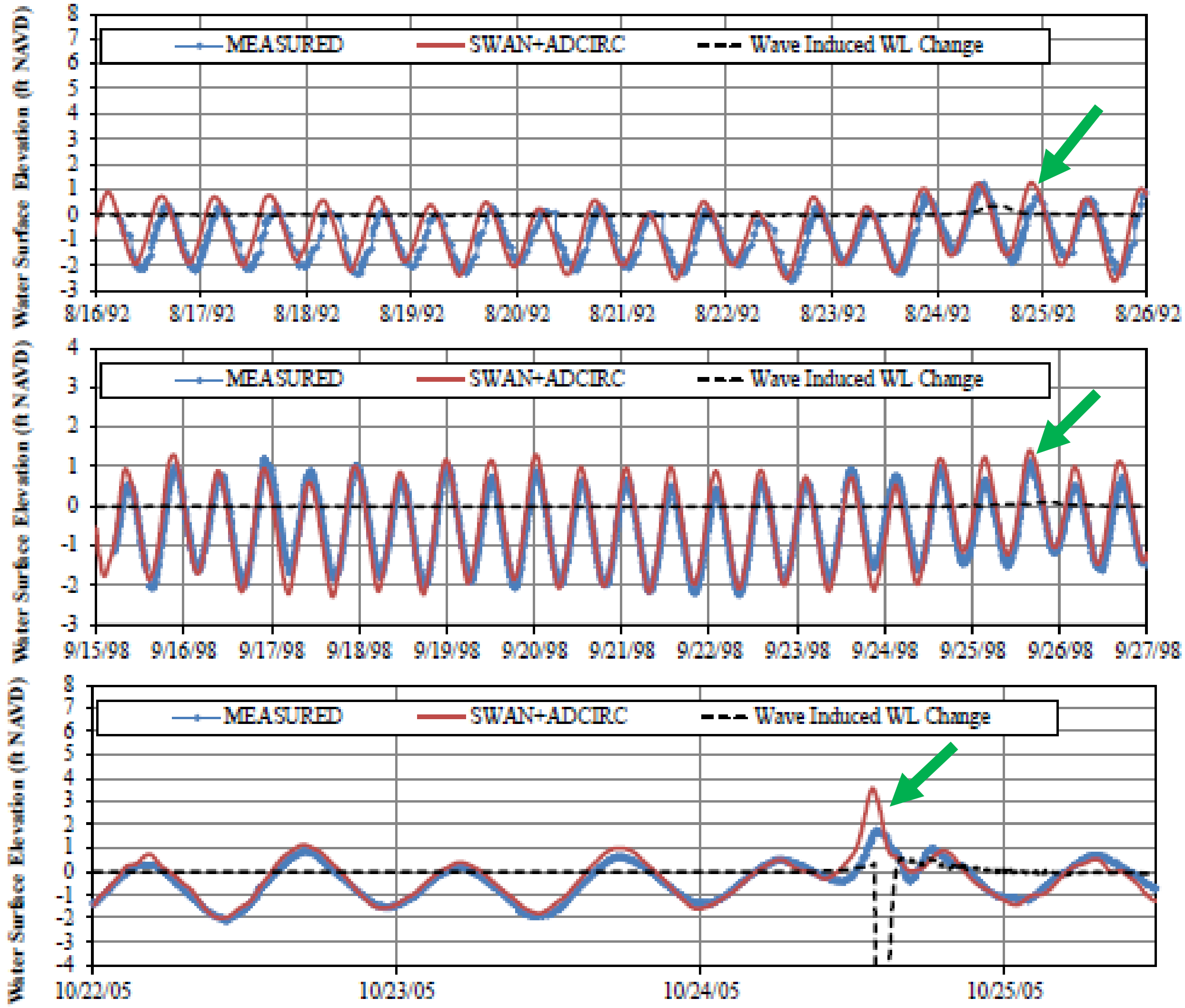


Figure 3.3: Hydrograph for Station S44_T located in northern Palm Beach County (FEMA, 2017; [9]). Hurricanes Andrew (top), Georges (middle), and Wilma (bottom).

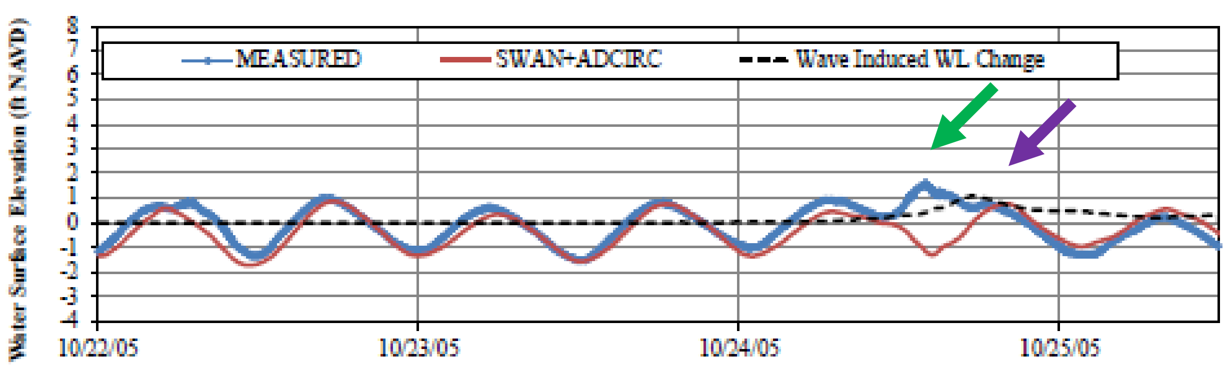


Figure 3.4: Hydrograph for Station S37A_T located in Broward County (FEMA, 2017; [9]). Hurricane Wilma.

3.2 Gage Selection

The location of the gages selected for comparison with modeled water levels can influence the model validation. Hurricane Wilma was identified as a storm for validating the SWAN+ADCIRC models for both the SFL study and the ECCFL study. The ECCFL study includes Atlantic coastline between Martin and Brevard Counties, but the model domain extended south into Palm Beach County. A comparison of the storm's peak water levels at the gages along a 60 mile segment of coastline (northern Martin County line to Highland Beach in Palm Beach County) common between the studies is shown Table 3.1. The gages are organized from north to south.

- The same gages were not included in both studies. The ECCFL study did not include gages S44_T, S155_T, and S41_T, while the SFL study did not include S46_T. Exclusion of gage S46_T is of particular importance as the gage is located within the Loxahatchee River on the oceanside of SFWMD's water control structure for the C-18 canal. The Loxahatchee River is where FEMA reported the greatest differences between the modeled 1% stillwater elevations for the ECCFL and SFL study; 2.0 to 4.2 feet [12] (see Section 4). The 1% stillwater elevation was higher for the SFL study, which suggests that the difference for Hurricane Wilma may have been greater than the 1.21 feet as reported for the ECCFL study validation at gage S46_T.
- The modeled water level was an average of 0.57 feet and 0.94 feet higher than the measured levels for the ECCFL and SFL studies, respectively. The average difference associated with the SFL study was 64% greater than the ECCFL study. An average of the differences was used by FEMA to report whether the model validation tended to over or under predict water levels (i.e. model bias). In this comparison, the positive averages indicated that the models for both studies tended to overestimate storm surge within this segment of coastline during Hurricane Wilma.
- The ECCFL study ultimately eliminated Hurricane Wilma from the model validation citing "improvement of the capability of the [model]…to reproduce non-exiting storm conditions within the project area," as well as "increased uncertainty in the wind and pressure fields for exiting storms" [12].
- Discrepancies between measured peak water elevations for the studies were noted, but was likely attributed to rounding.

Table 3.1: Hurricane Wilma Peak Water Elevations – ECCFL vs. SFL studies.

		Hurricane Wilma Peak Water Elevations (feet, NAVD88)					
		ECCFL Study			SFL Study		
Gage	County	Measured	Modeled	Difference*	Measured	Modeled	Difference*
S49_T	Martin	2.28	4.60	2.32	2.30	4.85	2.55
STL_STPT	Martin	2.33	1.93	-0.40	2.37	2.09	-0.28
S46_T	Palm Beach	0.68	1.89	1.21	-- Not Included --		
S44_T	Palm Beach	-- Not Included --			1.76	3.57	1.81
S155_T	Palm Beach	-- Not Included --			1.34	1.65	0.31
S41_T	Palm Beach	-- Not Included --			1.12	1.98	0.86
S40_T	Palm Beach	1.20	0.36	-0.84	1.16	1.56	0.40
	Average:			**0.57**			**0.94**

*Difference = Modeled - Measured

3.3 Model Uncertainty and Bias

The SWAN+ADCIRC model validation did not distinguish between the reliability of the types of measured water level data; hydrographs versus HWM. FEMA reports that model validation of storm water levels "generally consider hydrograph data superior to high water marks which record only the water level magnitude as noted and measured on structures following a storm" [9]. FEMA guidelines state that water level "gage observations are more reliable" than high water marks [18]. The model validation was based on 244 measured peak water levels (58 from hydrographs and 186 from HWM) and their differences compared to the model simulations. Model uncertainty (or model skill) is quantified as the standard deviations of the differences. The uncertainty for all 244 was 1.54 feet as reported by FEMA. The uncertainty associated with the hydrographs was 0.81 feet as compared to 1.68 feet for the HWM. This indicates that the model uncertainty was skewed by the uncertainty of the less reliable HWM, which was 2 times greater than the hydrograph uncertainty. FEMA made no adjustments during the model validation to account for the reliability of the measurement types.

Review of the model uncertainty and bias for each of the counties and with respect to the validation storms provides insight on the spatial variability of the uncertainty (see Table 3.2).

- The model uncertainty within Palm Beach County was the lowest of the four counties and 60% less than the uncertainty for the overall study area. The greatest uncertainties occurred within Miami-Dade and Monroe Counties, which were attributed to Hurricanes Andrew and Wilma, respectively.
- Hurricanes Andrew and Wilma resulted in a model uncertainty of 2.00 feet and 1.41 feet, respectively, for the SFL study. Hurricane Wilma was omitted from the model validation for the ECCFL study having had resulted in an uncertainty of approximately 1.0 foot.
- The lowest uncertainties for storms were associated with Hurricanes Betsy and David, but the validations were limited to 4-5 gages that were available for each of these storms. For each of the storms, one of the gages was NOAA's Key West station. However, FEMA reported that the NOAA Key West gage is not suitable "to capture the maximum surge levels for storms that impact the Atlantic coastline" [4].
- Model bias was assessed by FEMA to determine whether the model validation tends to over or under predict water levels. Bias was represented by FEMA as the average of the differences between modeled and measured peak water levels. The average of the overall study area reported by FEMA was -0.25 feet, which FEMA explained as a slight model bias of under predicting water levels. Within Miami-Dade County, the average was -0.52 feet which can be largely attributed to the landfall of Hurricane Andrew in Miami. Within Palm Beach County, the average was +0.25 feet suggesting an over prediction of modeled water levels. No adjustments were made by FEMA to account for spatial variability of model bias within the study area or the influence of the apparent outlier (Miami-Dade County).

Table 3.2: Model Uncertainty and Bias.

County	Uncertainty* (feet)	Bias (feet)
Palm Beach	0.63	0.25
Broward	0.64	0.05
Miami-Dade	1.84	-0.52
Monroe	1.36	-0.15
Overall	1.54	-0.25

Validation Storm	Uncertainty* (feet)	Bais (feet)
Betsy (1965)	0.72	-0.26
David (1979)	0.13	0.07
Andrew (1992)	2.00	-0.65
Georges (1998)	0.99	-0.24
Wilma (2005)	1.41	0.09
Overall	1.54	-0.25

*Uncertainty = model skill

4. Statistical SWEL

Following validation, the SWAN+ADCIRC model was used to simulate water surface elevations throughout the study area during 392 synthetic storms that were selected by FEMA using the Joint Probability Method – Optimal Sampling (JPM-OS) approach. At each model node for each storm, the maximum water surface elevation (WSE) was recorded along with recurrence interval of the storm. This information along with the model uncertainty estimated during model validation (see Section 3) were used as inputs to the SURGE_STAT program, which generated the statistical stillwater elevations (SWEL) for each node within the SWAN+ADCIRC model domain. A major contribution in identifying FEMA's special flood hazard areas (SFHA) was the 1% SWEL. Thus, considerations with respect to the development of the 1% SWEL are presented below.

4.1 JPM-OS Approach and Assumptions

The Joint Probability Method (JPM) with Optimal Sampling (OS) is a well-established, widely applied and standardized mathematical approach for the estimation of low frequency storm surge elevations in regions impacted by hurricanes. The JPM-OS method was applied to the SFL study and is cited as FEMA's preferred method based on the agency's 1988 publication on Coastal Flooding Hurricane Storm Surge Model [10]. The following approaches and assumptions presented in the JPM-OS report [10] warrant further consideration regarding their appropriateness in accurately estimating storm surge within the study area.

- New advances in methodology for describing long duration hurricane climatology and joint probability for estimation of low probability inundation are now routinely applied. For example, stochastic Monte Carlo modelling approaches whereby synthetic track sets based on historical hurricane climatology that capture the full randomness and variability in hurricane track paths and intensity/scale characteristics are now routinely applied for storm surge studies around the globe. FEMA applied a Monte Carlo approach for a coastal study in North Carolina (2008) and approved use of this method in FEMA Guidance No. 8-12 (2012). The SFL study utilized a Monte Carlo approach in accounting for tides within the study area to "provide more efficient solutions for problems that have high dimensionalities" [10]. Justification was not provided for the combination of JPM-OS and Monte Carlo approaches for storm surge and tides, respectively, as opposed to a single more advanced approach.
- FEMA reported that storm forward speed is considered of less importance as compared to a storm's pressure and radius based on FEMA's Mississippi coastal study in 2008. As such, the probability distribution for forward speed was less discretized (i.e. more coarsely resolved) as compared to other storm parameters. The profile of the continental shelf may affect the relative "importance" of storm parameters within the model. The Gulf coast of the study area has a wider, shallower, and flatter shelf that has greater similarity to the Mississippi coast as compared to the Atlantic coast with a narrower, deeper, and steeper shelf. The relative importance of the parameters to and within the SFL study area was not demonstrated, rather was pre-assumed. FEMA noted challenges during the model validation for Hurricane Andrew on the Atlantic coast, which were presumed related to wind field asymmetry and storm track but never resolved (see Section 2). The pre-assumed "importance" of parameters appears to have justified the use of a symmetric wind field for the Holland B parameter, which may have inaccurately accounted for wind field asymmetry due to a storm's forward speed and its interaction with the narrower, steeper Atlantic continental shelf.
- The JPM-OS approach assumed statistical stationarity across the study area. While this may be a reasonable assumption given the relative short duration of observed data compared to the number of low frequency events, differences in the adopted distributions applied to adjacent study areas (e.g. ECCFL study) will result in discontinuities at the boundaries of the study (see Section 4.4).
- FEMA reported that the ADCIRC model was employed for several reasons, one of which was the model "can simulate the momentum [interactions] associated with tidal conditions" [12] and storm surge. An

example of the effect of momentum interactions is that the inland extent of flood may reduce when storm surge arrives at a coast during the period of a falling tide. The dynamic modeling of tides and storm surge was not considered by FEMA in defining the synthetic storms to represent the optimized storm set, but rather only included during the modeling of the optimized storm set itself.

- The Gulf and Atlantic coastlines within the study area face nearly opposite directions. As such, FEMA performed separate JPM-OS analyses for the two coasts and allowed the SWAN+ADCIRC model parameters to be adjusted to reflect the coastal processes unique to the coasts improving model validation. Thus, landfalling storms were modeled using different SWAN+ADCIRC parameters as compared to exiting storms for the same coast. This approach was different from the approaches for the ECCFL and Southwest Florida (SWFL) coastal studies, where landfalling and exiting storms were modeled within a single JPM-OS analysis. The effects of this approach on the model validation was not documented by FEMA and warrants additional analysis to quantify its effects on the 1% SWEL.
- The meteorological optimization evaluated the influence of the synthetic storms on the 1% SWEL and removed storms that did not significantly contribute to the 1% SWEL. The optimization evaluated storm surge by assuming a constant mean sea level (i.e. tides were not included). Subsequently, a tidal optimization was completed using a Monte Carlo approach to randomly assign a start date to the remaining synthetic storms. The tidal optimization accounted for the timing of storms with respect to the tide cycle (e.g. high and low tides). The meteorological optimization did not account for the momentum interactions of storm surge and tide in initially screening the storms, and the tidal optimization may have potentially resulted in under sampling the more extreme storms contributing to the 1% SWEL. Under sampling of the extreme storms can cause the "tail" of the statistical distribution of the extremal analysis to steepen, thereby overpredicting water levels (i.e. higher water levels) for low frequency storm events (see Section 4.3).
- The dates for FEMA's tidal optimization were based on a selected 3-month period during the peak of the Atlantic hurricane season (August to October). The 3-month period during 2015 was identified by comparing the tide histogram over the long-term between 1985 and 2015 at several locations. Inspection of the tidal range histograms suggests that the 2015 period may have overrepresented the larger tidal ranges at each of the locations, which contributes to the 1% SWEL defined by FEMA. The histogram presented by FEMA at the Lake Worth Pier is shown in Figure 4.1; the overestimated larger tides for the 2015 period increased the mean tide range approximately 0.10 feet as compared to the long-term period.

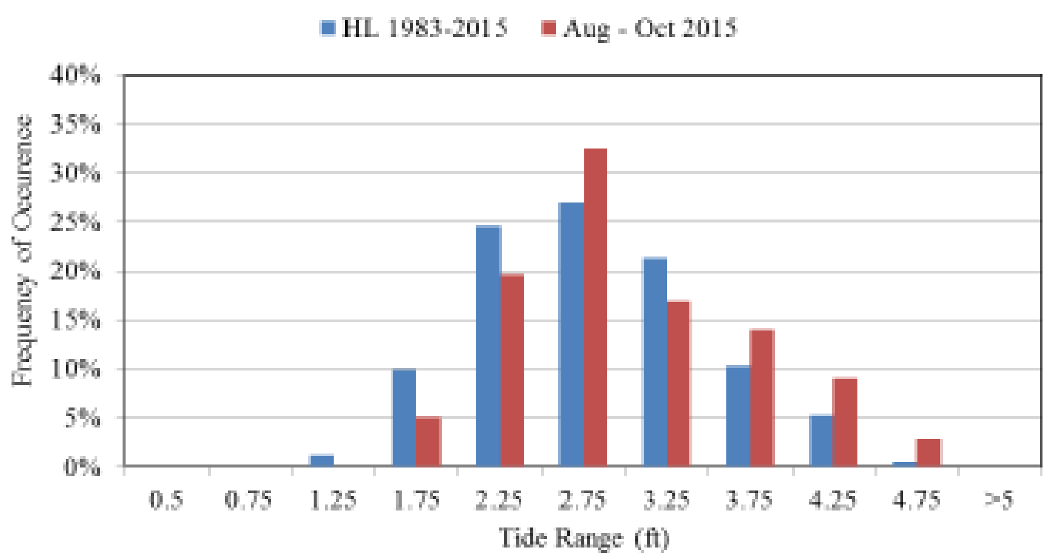


Figure 4.1: Tidal Range Histogram – Lake Worth Pier (FEMA, 2016; [10]).

4.2 Model Mesh

The SWAN+ADCIRC model requires that model grids (meshes) be developed to define bathymetric/topographic elevations as well as to define storm forcing parameters (e.g. winds and pressure fields) throughout the study area. FEMA states “for each new SWAN+ADCIRC model mesh, validation must demonstrate satisfactory model performance” [2]. FEMA’s evaluation of model performance for the SFL study focused on water surface elevations (e.g. 1% SWEL).

FEMA’s mesh for defining bathymetric and topographic features had a coarser resolution offshore and a finer resolution onshore (Figure 4.2). Finer mesh (close nodal spacing) is required to more accurately describe inland water bodies, channels, canals, and land/water interfaces. FEMA reported that along the Intracoastal Waterway (ICW) and adjacent canal systems, the mesh “included channels at least 30-feet wide…such that at least one element spanning the channel remains wet when the water level lies at or above low tide level” [8], while channels narrower than 30 feet were excluded.

Based on initial review of 1% SWEL as reported by FEMA (Figure 4.3), the following locations within Palm Beach County were identified as areas that may warrant further consideration with respect to the developed model mesh. The buildup of water, and equally the exchange of water, may be the result of the coastal processes below, but FEMA’s model mesh will need to be reviewed in greater detail.

- Southern Lake Worth Lagoon: The highest 1% SWEL values were simulated within the southern portion of the Lake Worth Lagoon immediately interior of South Lake Worth Inlet (a.k.a. Boynton Inlet). This may be attributed to the exchange of water through the inlet, northerly winds (likely during landfalling hurricanes) forcing water within the lagoon south to the constriction of the ICW, or a combination thereof.
- Northern Lake Worth Lagoon: The next highest 1% SWEL values occur at the northern portion of the lagoon. Lake Worth Inlet (a.k.a. Palm Beach Inlet) is located further away as compared to the situation at the southern portion of the lagoon, but the inlet is wider and deeper improving its ability to exchange water with the Atlantic Ocean. Southerly winds (likely during exiting hurricanes and after the passing of landfalling hurricanes) forces water into the constricted ICW and tributary canals.
- Loxahatchee River: The river’s major tidal connection is through Jupiter Inlet, with some influence from the narrow ICW to the north and south. FEMA reported that the greatest discrepancy (ranging from 2.0 to 4.2 feet) between 1% SWELs for the SFL and ECCFL studies occurred within the river (see Section 4.4).

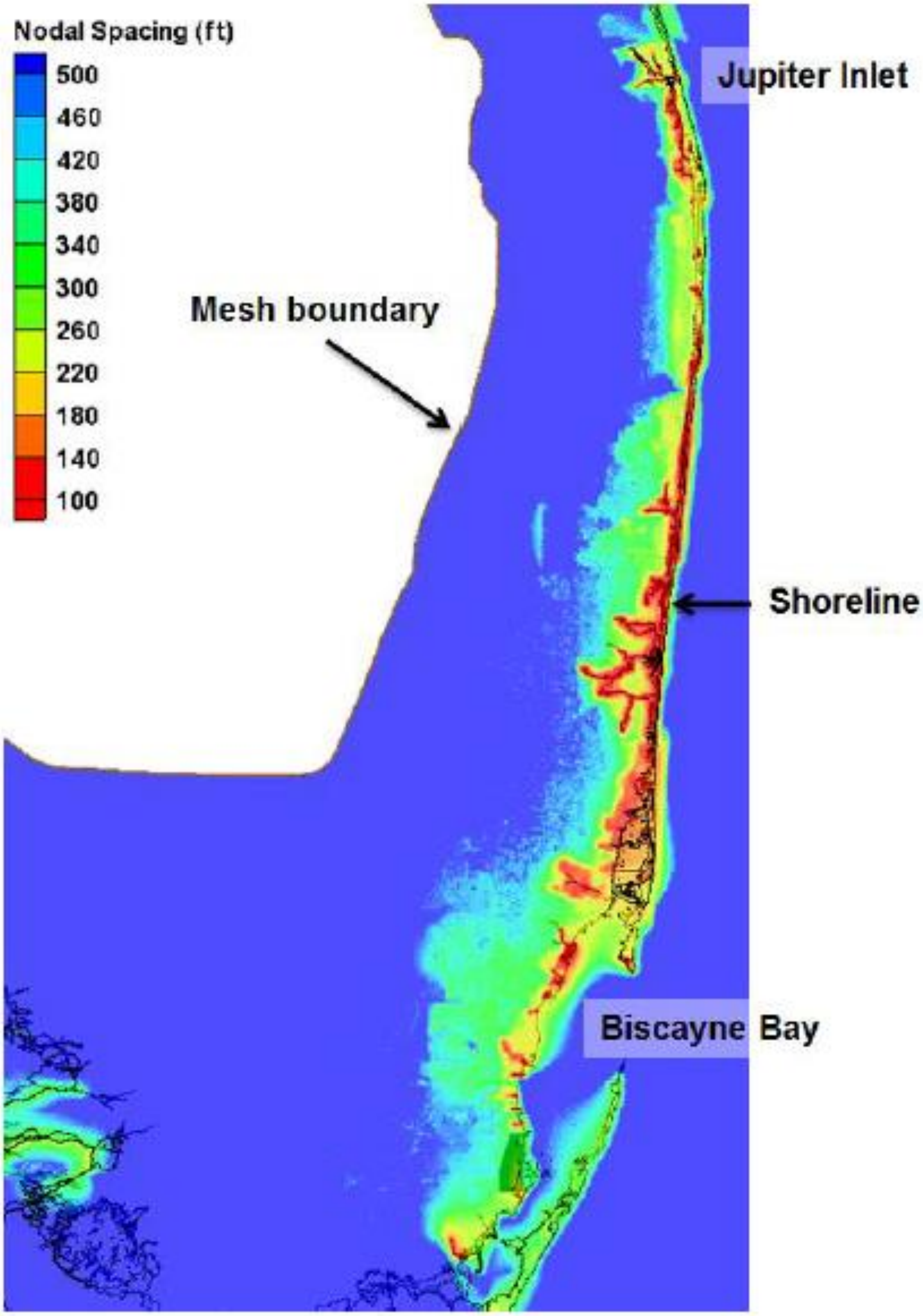


Figure 4.2: SWAN+ADCIRC Model Mesh – Nodal Spacing (FEMA, 2016; [8]).

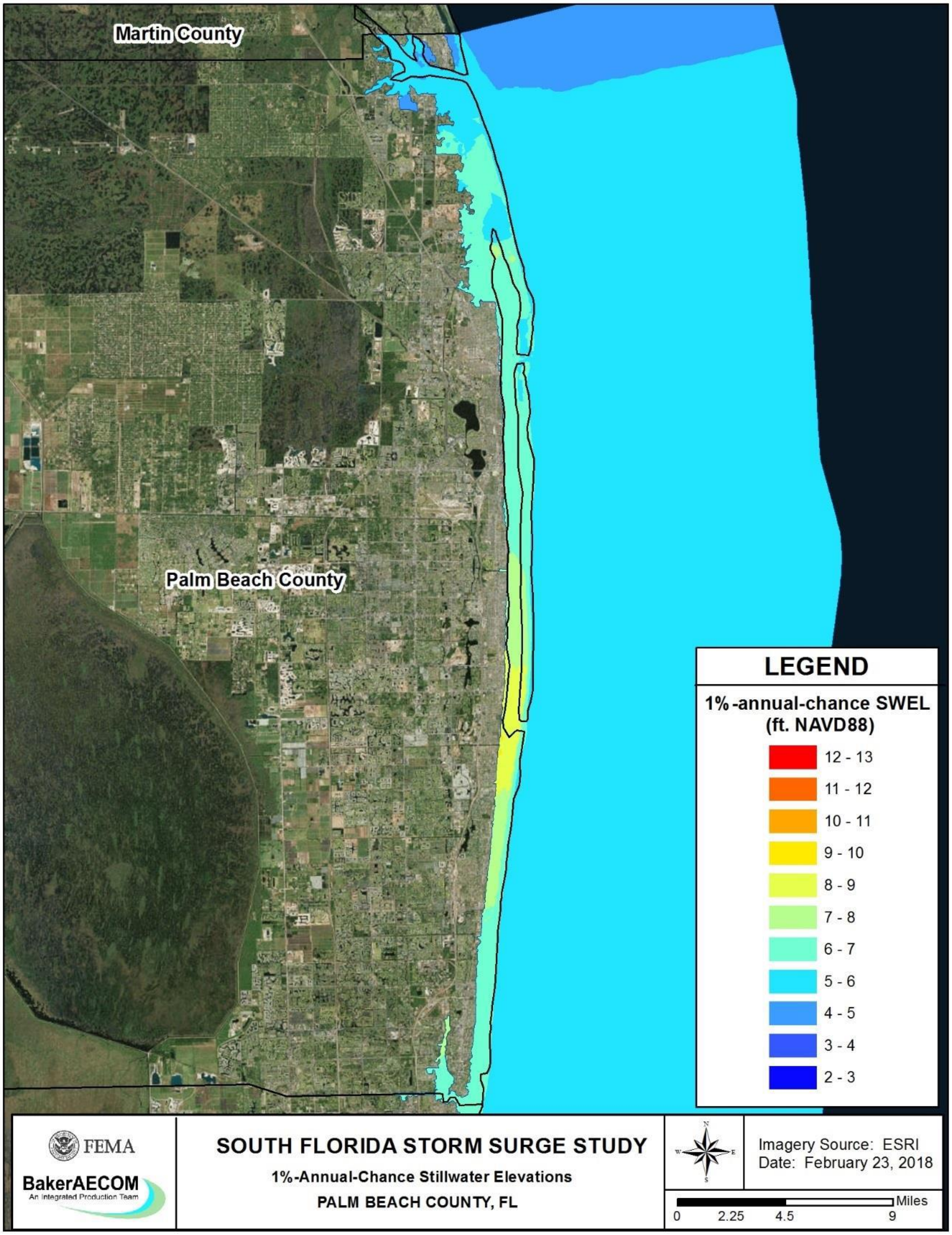


Figure 4.3: 1% SWEL – Palm Beach County (FEMA, 2018; [12]).

4.3 1% SWEL

The 1% SWEL is considered by FEMA as the major factor to define the inland extent of coastal special flood hazard areas (SFHA) when overlaid on digital elevation models (DEM). The water surface elevation (WSE) for each synthetic storm within the optimal sampling dataset is recorded at each of the nodes within the model mesh. The maximum WSE and model uncertainties are used as inputs to the SURGE_STAT program that generates return frequency curves at each model node.

The total model uncertainty is comprised of two terms; model skill and the planetary boundary layer terms. A larger model uncertainty results in return frequency curves that yield higher 1% SWEL.

- Model Skill term "represents the variations in water surface elevations due to lack of modeling accuracy as a result of approximations in physical processes" [12]. This term is reflected by the model uncertainty presented in Section 3.3. The model skill term was estimated at 1.54 feet and was applied uniformly throughout the modeling domain which includes Palm Beach County, along with Broward, Miami-Dade, and Monroe Counties. No distinction was made to account for the potential spatial variability within the study area.
- Planetary Boundary Layer (PBL) term "represents the variations in water surface elevations due to a range of departures from the real behavior of hurricane wind and pressure fields that are not well represented by the planetary boundary layer" [12]. FEMA assumed a PBL term of 1.17 feet based on FEMA's Mississippi coastal study in 2008 for which the same wind and pressure field methodologies and sources for data generation were applied. FEMA reported "increased uncertainty in the wind and pressure fields for exiting storms" [12], which suggests that FEMA's assumption may not have been applicable and that revaluation of the PBL term may have been warranted for the SFL study.

The SURGE_STAT program was utilized to define the 1% SWEL at each model node, but it was not until FEMA began its coastal hazard analysis (see Section 5) that potential issues were identified. The hazard analysis requires the 1% SWEL as well as the accompanying wave heights and periods associated with the 1% event. FEMA's methodology to define the wave parameters is to identify the synthetic storm with a WSE closest to the 1% SWEL and nine storms above and nine storms below the 1% SWEL. The wave parameters at the storms' peak water levels are then averaged. When FEMA's methodology was applied, the 1% SWEL were above the maximum WSE of the individual storms at model nodes which FEMA attributed to the model "uncertainty term and the combined storm frequency curves" in defining the 1% SWEL [14]. FEMA's methodology to define the wave parameters for the coastal hazard analysis was modified to reduce the number of storms included in the average, but no refinements were made to resolve the actual 1% SWEL throughout the study area. This indicates that the 1% SWEL may have been overestimated and was not sufficiently bracketed by the synthetic storms, which may have also been a relic of under sampling of the extreme events as part of the JPM-OS approach (see Section 4.1). Furthermore, FEMA reported that model nodes "in some areas" were affected by the situation but limited (if any) information was provided regarding the locations or spatial extents of the affected nodes.

4.4 SWEL Transition Areas and Adjustments

FEMA states that “having matching water levels across study area boundaries is considered desirable, so that the communities on either side of the boundary do not have widely differing base flood elevations” [12]. Base flood elevations are directly affected by the 1% SWEL and as such transition areas are sometimes incorporated in the 1% SWEL to achieve agreement between studies. FEMA states that “differences of 1 foot in magnitude at storm surge study boundaries are within typical range” and “are the result of differences in the model frameworks and model parameterizations” [12]. Differences at the boundaries of other FEMA coastal studies and FEMA’s respective transition areas are described below for context.

- The northern boundary on the Gulf coast of the SFL study abuts with the southern boundary of the Southwest Florida (SWFL) coastal study. This occurs at the Monroe and Collier county lines. At the boundary, the 1% SWEL for the SFL study were approximately 1.0 feet higher at the coastline and 0.5 feet higher inland as compared to the SWFL study. A narrow transition area was identified and the SFL study 1% SWEL were adjusted down to agree with the SWFL study.
- The northern boundary on the Atlantic coast for the SFL study abuts with the southern boundary of the ECCFL study. This occurs at the Palm Beach and Martin county lines. At the boundary, the 1% SWEL for the SFL study were higher by “1.7 feet along the open coast, 2.0 feet in the Intracoastal Waterway, and 2.0 to 4.2 feet up the Loxahatchee and North Fork Loxahatchee Rivers” [12] as compared to the ECCFL study. A 10-mile wide transition area was identified extending 5 miles north and south of the county line within which the SFL study 1% SWEL were adjusted down and the ECCFL study was adjusted up to achieve agreement.
- The northern boundary of the ECCFL study abuts with the southern boundary of the Georgia-Northeast Florida (GANEFL) coastal study. This occurs at the Brevard and Volusia county lines. At the boundary, the 1% SWEL for the ECCFL study were higher by 2.0 feet along the open coast and less than or equal to 0.5 feet in the Mosquito Lagoon as compared to the GANEFL study. An approximately 25-mile wide transition area was identified extending approximately 12 miles north and south of the county line within which the ECCFL study 1% SWEL were adjusted down to agree with the GANEFL study.

Justification for defining the 10-mile wide SFL study transition area was not provided by FEMA. The following presents a basis for redefining the transition area applied between the SFL and ECCFL studies that aligns with other FEMA studies.

- The differences at the study area boundary between the SFL and ECCFL studies were comparable on the open coast and 4 times larger within the Intracoastal Waterway (ICW) as compared to the differences reported at the northern boundary of the ECCFL study.
- The smaller adjustments at the northern boundary of the ECCFL were applied to the southern half (12 miles) of the 25-mile wide transition area. The transition area was defined to align with the limits of the Canaveral National Seashore.
- Assuming that the width of the SFL study transition area should be scaled to achieve a similar linear adjustment within the ICW as the ECCFL, the SFL transition area should have a redefined alongshore length of 48 miles, which is much greater than the 10-mile wide transition area used by FEMA. Assuming that the transition area is shifted south to align with the redefined adjustments applied within Palm Beach County as described below, the northern limit of the transition area would be approximately 3 miles north of the Palm Beach and extend south to include all of Palm Beach County (Figure 4.4).

FEMA presented a detailed discussion explaining the factors that contributed to the differences between the 1% SWEL for the SFL and ECCFL studies [12]. FEMA’s discussion did not explicitly state which water body was being analyzed, but it could be inferred that the discussion could be applicable to the open coast given the relatively close agreement of the values discussed. FEMA explained that differences in the SWELs were attributed to model uncertainty (0.80 feet), interpolation techniques in estimating mean sea level (MSL; 0.30

feet), and the inclusion of west coast (exiting) storms in the SFL study (0.25 feet). FEMA's explanation did not explicitly assign the differences to each of the studies nor did the summation of absolute adjustments equal any of the differences identified.

Review of FEMA's reports for the ECCFL study revealed that FEMA excluded west coast (exiting) storms from both the model validation for ECCFL study as well as the JPM-OS modeling. FEMA's explanation was that "exiting storms have a minimal effect on the low-frequency water levels" and "the presence of other uncertainties which influence the modeling results to a larger degree." The ECCFL study documented that inclusion of exiting storms increased the 1% SWEL by 0.08 feet. FEMA reported that the influence of west coast storms on the SFL study was 0.25 feet (3 times greater than the ECCFL study) but FEMA opted to include them regardless.

In the absence of re-performing the SWAN+ADCIRC modeling to explicitly resolve the differences noted by FEMA, the following presents a basis for more clearly redefining adjustments to the 1% SWEL by assigning differences to the respective FEMA studies (Table 4.1).

- The storm surge bias estimated within Palm Beach County (see Section 3.3) and the overestimated tidal optimization (see Section 4.1) were included to achieve agreement with the 1.70 feet difference along the open coast.
- This resulted in a 1.40 feet reduction in the 1% SWEL within the SFL study and an increase of 0.30 feet within the ECCFL study; as compared to FEMA's assumed even distribution of 0.85 feet reduction and 0.85 feet increase for the SFL and ECCFL studies, respectively.
- As such, there is a strong justification that at least 82% (40 miles) of the proposed redefined 48-mile transition area for the open coast and ICW be located within Palm Beach County. This redefined transition area would be located to include the entirety of Palm Beach County's 45-mile coastline and extend 3 miles north into Martin County (Figure 4.4).
- The redefined adjustments and transition area were based on values reported by FEMA. Additional analysis of the modeling may result in revisions to the refinements presented herein.

Table 4.1: 1% SWEL Adjustments along the Open Atlantic Coast.

Factor	1% SWEL Adjustments along Open Coast (feet)			
	FEMA		Redefined	
	ECCFL Study	SFL Study	ECCFL Study	SFL Study
As Explained				
Model Uncertainty		-0.80		-0.80
MSL	0.30		0.30	
West Coast Storms		-0.25		-0.25
Storm Surge Bias				-0.25
Tidal Optimization				-0.10
Adjustment as Assigned	0.30	-1.05	0.30	-1.40
Absolute Adjustment		1.35		1.70
Proportion of Adjustment	22%	78%	18%	82%
As Applied				
Application of Adjustments	0.85	-0.85	0.30	-1.40
Absolute Adjustment		1.70		1.70
Proportion of Adjustment	50%	50%	18%	82%

Figure 4.4: Redefined SFL and ECCFL Transition Area.

5. Coastal Hazard Analysis

The coastal hazard analysis considers processes governing the open coast and sheltered waters during extreme storm events at defined cross-shore transects. The open coast includes the Atlantic coastline within Palm Beach County; sheltered waters are associated with inland water bodies (e.g. Intracoastal Waterway, Loxahatchee River, and Lake Worth Lagoon). Transect location maps are provided in Appendix A.

5.1 Open Coast

The analysis along the open coast evaluates coastal erosion, wave runup, and overtopping. The SFL study analyzed 170 transects within Palm Beach County for each of the coastal processes to map the VE Zone. The analysis is summarized below [17].

- Coastal erosion was evaluated in terms of the dune response to a storm event; dune retreat or dune removal. The dune response was evaluated based on the volume of the dune "reservoir" seaward of the dunes landward crest and above the 1% SWEL. A dune reservoir greater than 540 square feet were assumed to retreat (erode), while dune reservoirs less than this amount were assumed to be removed. Eroded dune profiles were "constructed" based a FEMA's defined methodology. Changes to the 1% SWEL (see Section 4) may affect FEMA's evaluation of dune response and in turn mapping of flood zones. Additional review of the Wave Height Analysis for Flood Insurance Studies (WHAFIS) modeling and input parameters regarding the landward limit of the dune crest and "construction" of the eroded profiles may be warranted.
- The WHAFIS model was used to propagate the offshore wave conditions from outside the surf zone to the beach. The offshore wave conditions (wave height and period) associated with the 1% SWEL storm event were obtained from the SWAN+ADCIRC modeling (see Section 4.3). FEMA's analysis assumed that the direction of wave propagation was shore normal (perpendicular to shore), which is a requirement of the WHAFIS model as it does not account for wave refraction due to bottom interactions. Furthermore, FEMA analysis assumed that the peak wave height coincided with the peak water surface elevation. While not necessarily an incorrect assumption, FEMA did not provide justification for these assumptions and if inappropriate can result in an overestimation of the wave conditions (e.g. wave heights) at the beach.
- Based on the wave conditions at the beach, wave runup was analyzed using the RUNUP2.0 model, USACE Shore Protection Manual (SPM) or Technical Advisory Committee for Water Retaining Structures (TAW) methods. Coastal structures (e.g. seawalls) were identified and assumed to fail within Palm Beach County as FEMA reported that none of the structures were certified to withstand the 1% storm event.
- If the wave runup was identified to extend above a coastal structure or eroded dune profile, then wave overtopping and breaking wave heights were evaluated.
- FEMA defines the primary frontal dune (PFD) as the "continuous or nearly continuous mound or ridge of sand with relatively steep seaward and landward slopes immediately landward and adjacent to the beach and subject to erosion and overtopping from high tides and wave during major coastal storms. The inland limit of the primary frontal dune occurs at the point where there is a distinct change from a relatively steep slope to a relatively mild slope" [17]. FEMA guidance defines the area extending from offshore to the inland limit of the PFD along an open coast as a coastal high hazard area. Coastal high hazard areas are defined as a FEMA VE zone, which are at greater flood risk during coastal storms.
- FEMA guidance requires that the VE zone along the open coast be mapped according to the wave runup, wave overtopping, breaking wave height, or the PFD, whichever is most landward. Consistent mapping of the PFD, which is more often the most landward parameter, is important to consistently defining flood risks within the study area (e.g. barrier islands of Palm Beach County).

FEMA delineated the landward limit of PFD for the SFL study based on site reconnaissance and review of topographic surveys. Delineation of the PFD was reviewed for appropriateness and to confirm consistency throughout Palm Beach County. Inspection of FEMA's transects suggested that the PFD delineation was not consistent throughout the County in that the PFD limit was located further seaward relative to the beach profile in the southern portions of the County as compared to the northern portions. Lake Worth Inlet was identified as the demarcation where the mapping inconsistency occurred. Of the 170 open coast transects within the County, 123 were located south of the inlet and 47 to the north (Table 5.1). The PFD was delineated for 75% of the transects south of the inlet as compared to 98% to the north; the difference was attributed to the greater number of coastal structures (e.g. seawalls and revetments) south of the inlet. The more seaward delineation of the PFD south of the inlet is evident by the PFD being the defining the limit of the VE zone on 44% of the transects south of the inlet as compared to 87% to the north.

Example transects depicting the inconsistent PFD delineations south and north of the inlet are shown in Figure 5.1 and Figure 5.2, respectively. The pink dots in the figures represent FEMA's PFD locations. The PFD locations are seaward of the highest portion of the beach profiles (15-20 feet, NAVD88) south of the inlet (Figure 5.1), while they are located landward of the beach profiles' high point north of the inlet (Figure 5.2). Additional details regarding the open coast transects are provided in Appendix B.

Table 5.1: Primary Frontal Dune Analysis.

Coastline (Open Coast Transects)	# of Transects			% of Transects	
	Open Coast	PFD Delineated	VE Zone Defined by PFD	PFD Delineated	VE Zone Defined by PFD
South of Lake Worth Inlet (1 to 123)	123	92	54	75%	44%
North of Lake Worth Inlet (124 to 170)	47	46	41	98%	87%
Palm Beach County (1 to 170)	170	138	95	81%	56%

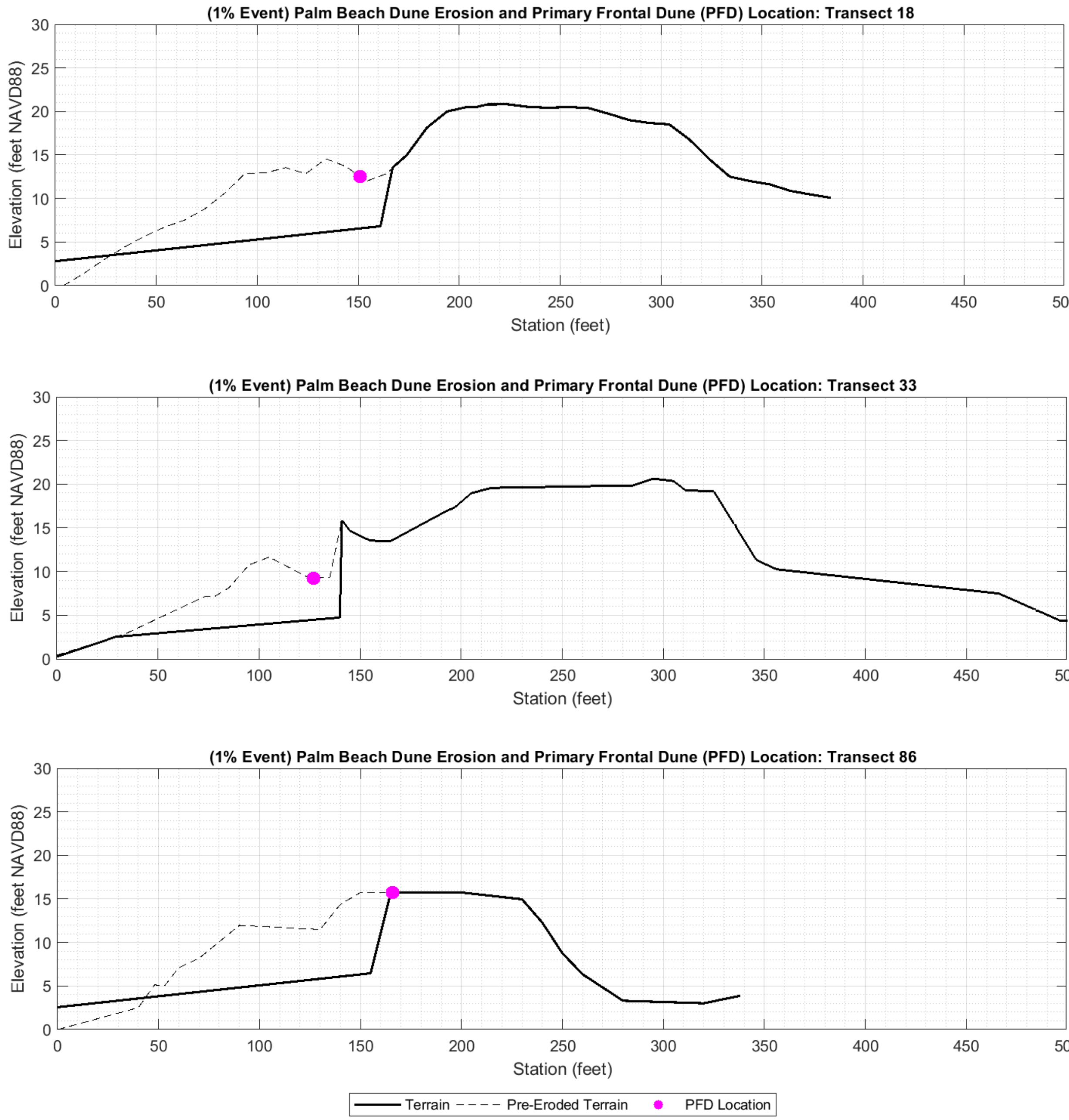


Figure 5.1: PFD - Transects 18, 33 and 86 South of Lake Worth Inlet (FEMA, 2019; [15]).

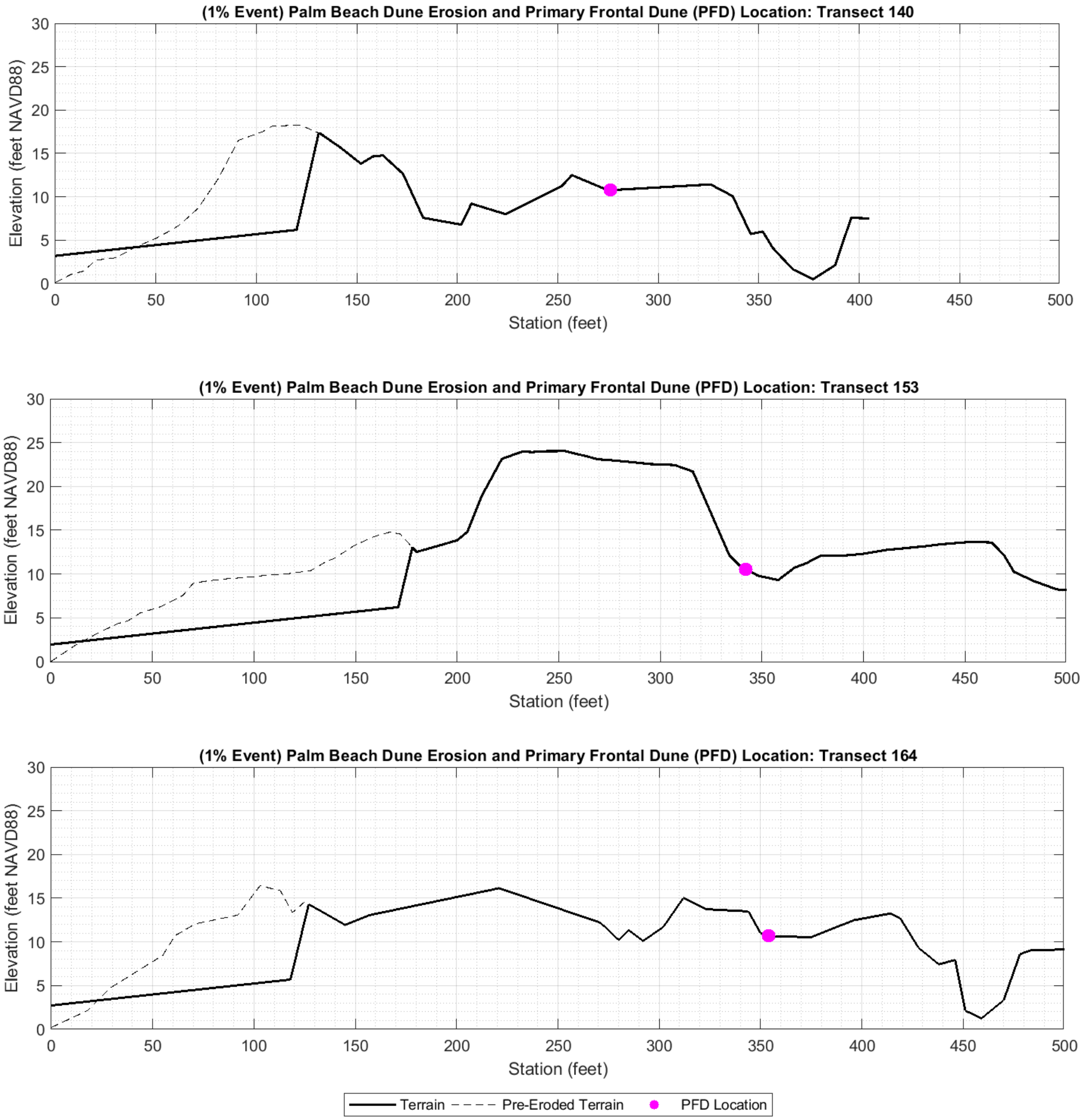


Figure 5.2: PFD - Transects 140, 153, and 164 North of Lake Worth Inlet (FEMA, 2019; [15]).

Based on review of the transects, the following was noted, which may require further consideration by FEMA in addition to a more consistent mapping of the PFD. Concepts presented below may have occurred at other transects in addition to those discussed herein.

- Transect 134: FEMA identified that dune removal would occur at the transect. FEMA's guidelines state that for dune removal "the profile is modified with a 1:50 seaward-dipping [slope] from the backside (landward) of the dune through the dune toe" [20]. The guidelines for defining the dune toe on the seaward face of the dune include "the junction between the relatively steep slope of the front dune and the noticeably flatter seaward region of the beach" or the elevation consistent with the local 10% SWEL [20]. The seaward-dipping slope of the eroded profile appears to have been specified at approximately 1:20, which is steeper than FEMA's guidelines (Figure 5.3). Assuming that the backside of the dune should be located within the limit of the PFD and FEMA's 1:50 slope suggests that the specified dune toe may warrant revaluation as depicted by the red dashed line in Figure 5.3. A dune toe assigned higher on the profile to align with FEMA's slope guidelines would result in a higher eroded profile which effects the wave runup and wave overtopping and potentially mapping of FEMA SFHA zones.

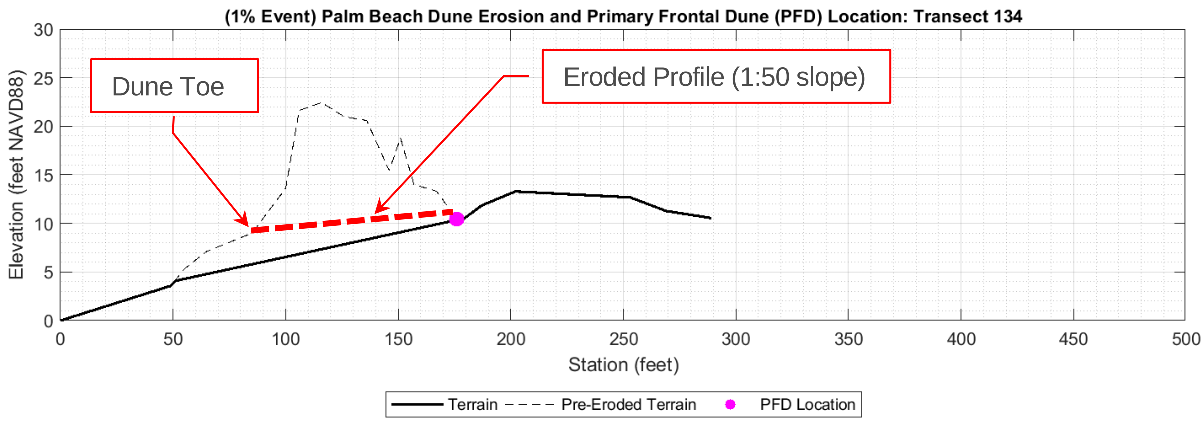


Figure 5.3: Dune Removal - Transect 134 (FEMA, 2019; [15]).

- Transect 136: Similar to Transect 134, FEMA identified dune removal for the transect and the eroded profile was specified steeper than the 1:50 FEMA guideline. A higher eroded profile associated with the dune toe specified at a higher elevation may reduce overtopping at the transect thereby having a significant effect on FEMA's mapping of the SFHA zone. This segment of coastline was mapped as an A0-1 Zone, which indicates sheet flow of water up to 1 foot across the dune during a 1% SWEL event.
- Transect 137 and 138: FEMA identified dune removal for the transects and the slope of the eroded profile was specified according to the FEMA guidelines (Figure 5.4). Inspection of the profile suggests that a dune toe at a higher elevation (+9 feet, NAVD88) may be justified. A higher dune toe would raise the elevation of the eroded profile (depicted by the red dashed line, Figure 5.4) and reduce wave runup and overtopping across the dune. This is the only segment of coastline within the County that the landward limit VE Zone was mapped based on the breaking wave height and the VE Zone extended across the barrier island into the Lake Worth Lagoon (Figure 5.5). Breaking waves across the barrier island may have implications further inland as larger waves within the lagoon may result in increased base flood elevations and in modifications to the delineated "limit of moderate wave action" along the lagoon's interior shorelines.
- Transect 147: The PFD was mapped within the pool of a single family residence (Figure 5.6). Revision to the PFD appears warranted to avoid this anomaly.
- Transect 158: A seawall is present, and the PFD was delineated. Within other segments of the County's coastlines (particularly south of Lake Worth Inlet) where seawalls were more prevalent, there appeared to be a tendency to not delineate the PFD and rely on the wave runup at a vertical structure to define the VE Zone. The presence of a seawall at this transect may warrant revaluation in defining the VE Zone to improve consistency throughout the County.

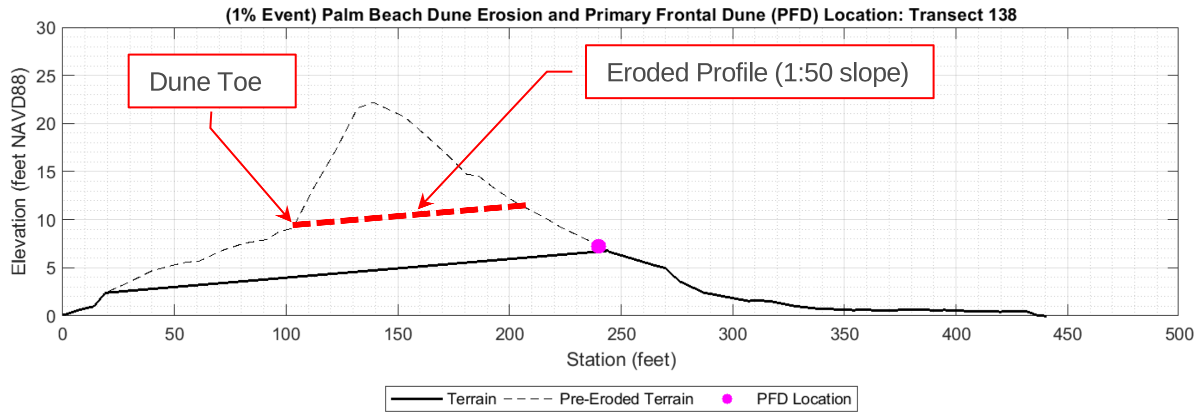


Figure 5.4: Dune Removal – Transect 138 (FEMA, 2019; [15]).

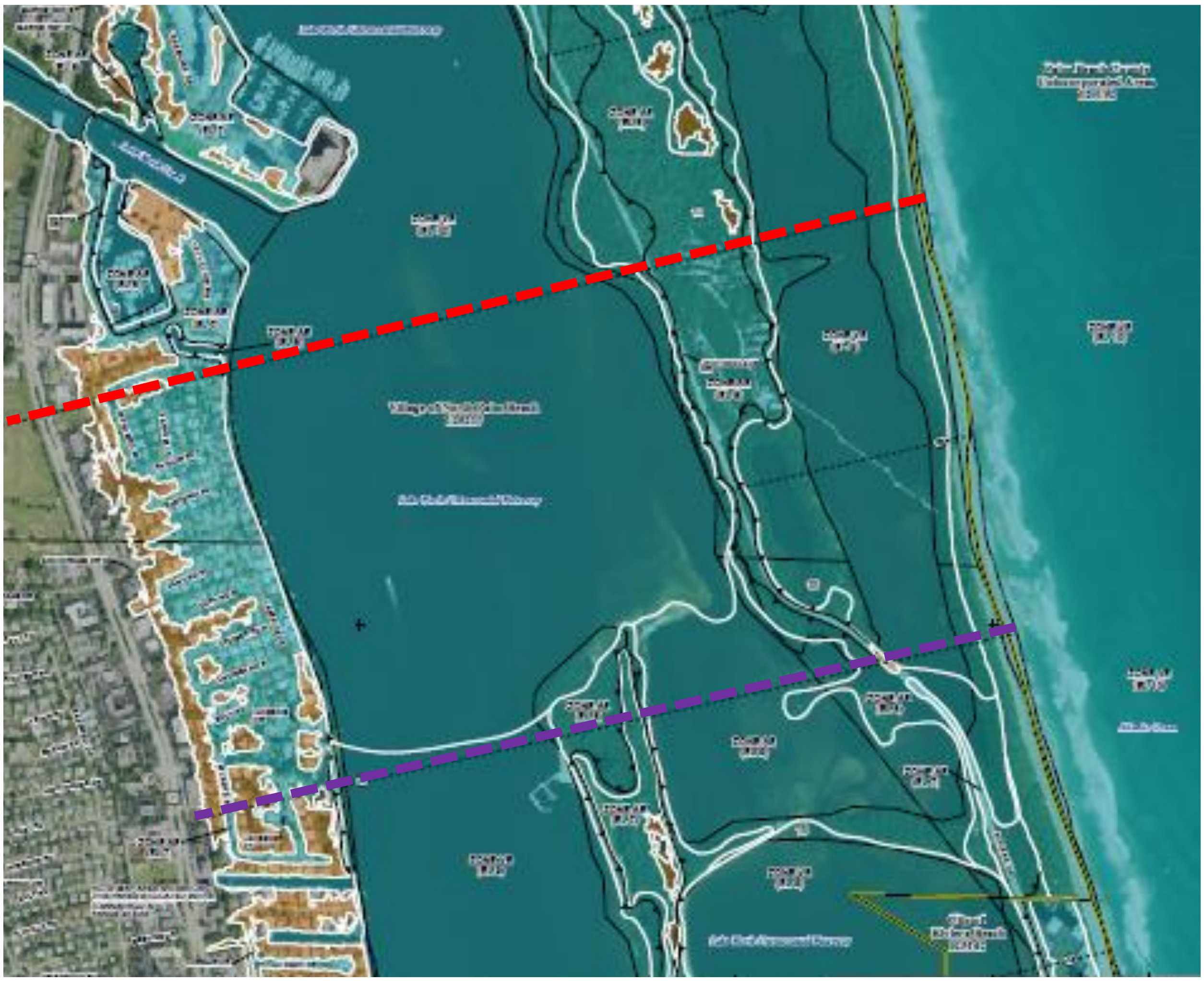


Figure 5.5: FIRM Panel 0383G (FEMA, 2019; [16]).
Transects 137 (purple) and 138 (red) highlighted by dashed lines.

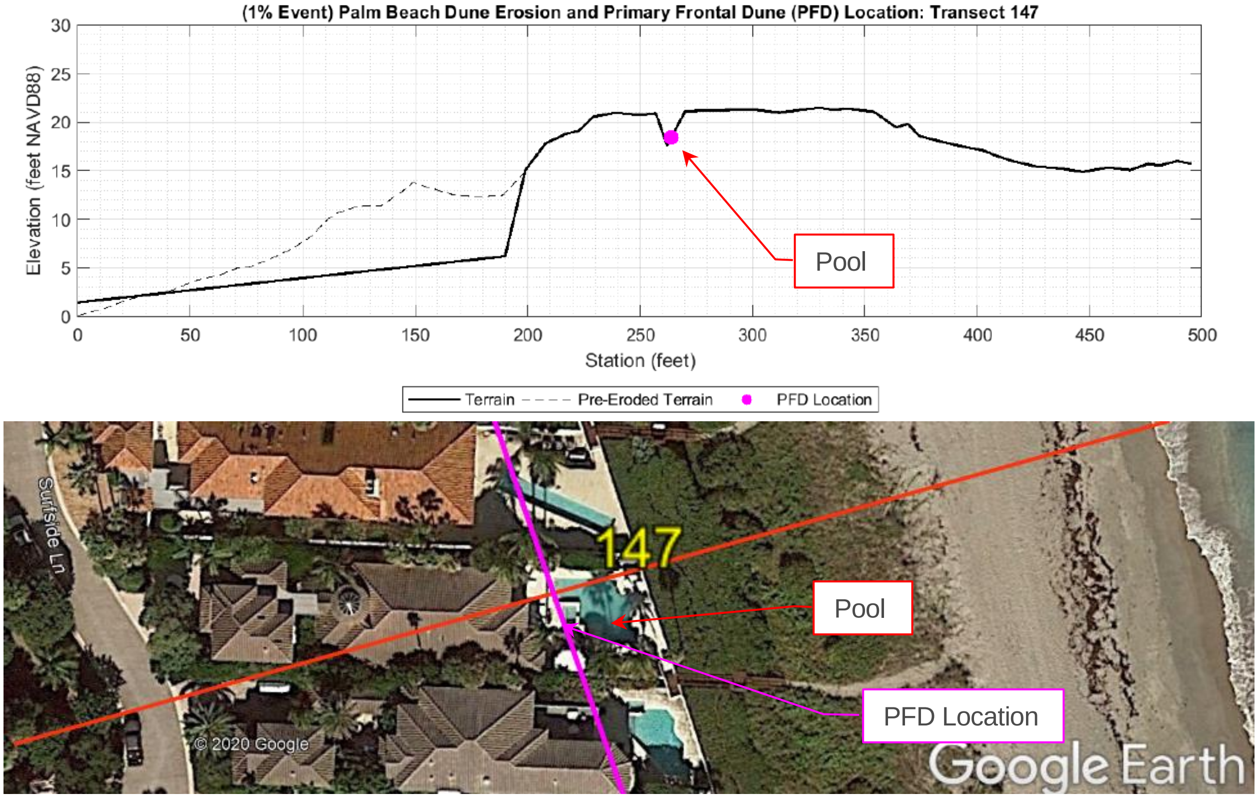


Figure 5.6: PFD – Transect 147 (FEMA, 2019; [15]).

5.2 Sheltered Waters

FEMA's analysis within sheltered waters evaluated overland wave propagation during coastal flooding events (e.g. 1% SWEL) along 30 transects. The transects were located within the Lake Worth Lagoon north of the East Ocean Avenue bridge in Lantana and within the Loxahatchee River. The transects within the Lake Worth Lagoon informed the mapping along the eastern shoreline. FEMA reported that sheltered water (inland) transects within the lagoon south of Lantana were "investigated for overland wave modeling, however, the inland wave conditions in these areas appeared to be influenced by nearby inlets, causing inconsistent mapping between the western and eastern shorelines" [14]. FEMA excluded sheltered water transects within the Lake Worth Lagoon south of the East Ocean Avenue and opted to rely on sheltered water transects to the north in mapping base flood elevations (BFE) along the eastern shoreline of the southern Lake Worth Lagoon.

Exclusion of the sheltered water transects in the southern Lake Worth Lagoon to avoid inconsistent mapping was noted by the FEMA's steering committee in its QC Review Documents. FEMA reported that larger starting wave conditions at the excluded transects, which appeared to be localized outliers as compared elsewhere in the lagoon, would have resulted in the mapping inconsistencies; higher BFE would have been defined along the eastern shoreline as compared to the western shoreline. The larger starting wave conditions, which were extracted from the SWAN+ADICR model results, were not resolved. In disagreement with the steering committee, the SFL study and mapping of the FIRM panels progressed by excluding the sheltered water transects in question. Additional review of FEMA's SWAN+ADCIRC modeling may be warranted to determine if the outlying starting wave conditions in the southern lagoon were related to the model mesh, wind and pressure fields, or other model parameters defined by FEMA (see Section 4.2).

6. Conclusions

FEMA's SFL study leveraged numerical modeling and analyses in an attempt to better define the coastal flood risks associated with storm surge. The document review presented above was intended to identify specific elements of the study that may have misrepresented the water levels and mapping of coastal flood risks with respect to Palm Beach County. The major elements are summarized below.

Validation Storm Selection

- Validation of the SWAN+ADCIRC model was based on five historical hurricanes; Betsy (1965), David (1979), Andrew (1992), Georges (1998), and Wilma (2005). Inclusion of these storms within the model validation may not have been appropriate given the magnitude of storm surge generated, the regional extents of the surge, the locations of gage measurements, and limited measured data. FEMA's statements within the documents also cast doubt as to the appropriateness of the selected storms.
- Inclusion of other validation storms in addition to (or in substitution of) those selected should be considered. For example, Hurricane Frances and Jeanne (2004) are potential storms for consideration.
  - The storms provide a basis for representing storm surges along the Atlantic coastline of the study area, specifically within Palm Beach County.
  - The storms were of historical significance to the study area as reported by FEMA.
  - The storms were used to validate the SWAN+ADCIRC model for FEMA's East Coast Central Florida (ECCFL) coastal study (2014). Inclusion within the SFL study may help improve agreement at the study area boundaries (Martin and Palm Beach county line).
  - The storms provide a basis for performing a wave validation, which was not performed for the study.

SWAN+ADCIRC Model Validation

- Model validation did not account for the location of measured data with respect to the distances from storm tracks, the type of measured data (e.g. hydrographs and HWM), or the timing between measured and modeled peak water levels. Failure to do so may have negatively affected model validation and uncertainties and resulted in water levels that are not representative.
- Hurricane Wilma was the only common validation storm presented between the SFL and ECCFL studies. The same water level gages were not used in both studies, which FEMA did not provide justification. The modeled water levels were on average greater than the measured data for both studies within the 60-mile segment of coastline common between the studies; but the average modeled differences for the SFL study were 64% greater than the ECCFL study. The ECCFL study ultimately eliminated Hurricane Wilma to improve the model's capability to reproduce non-exiting storm conditions and because of increased uncertainty in the wind and pressure fields for exiting storms. Despite this, Hurricane Wilma was included in the SFL study.
- The model uncertainty within Palm Beach County was the lowest of the four counties and 60% less than the uncertainty applied for the study. The greatest uncertainties were realized within Miami-Dade and Monroe Counties, which were attributed to Hurricanes Andrew and Wilma, respectively. Model bias was assessed by FEMA to determine whether the model validation tended to over or under predict water levels. The average of the overall study area reported by FEMA was estimated at -0.25 feet, which FEMA explained as a slight model bias in under predicting water levels. Within Miami-Dade County, the average was -0.52 feet which can be largely attributed to the landfall of Hurricane Andrew in Miami. Within Palm Beach County, the average was +0.25 feet suggesting an over prediction of modeled water levels. No adjustments were made by FEMA to account for spatial variability of model bias within the study area or the influence of the apparent outlier (Miami-Dade County).

Statistical SWEL

- The JPM-OS method was applied to the SFL study and is cited as FEMA's preferred method based on the agency's 1988 publication on Coastal Flooding Hurricane Storm Surge Model [10]. The JPM-OS method requires numerous steps and statistical parameterizations, which makes it difficult to identify the elements that the greatest effect on the model, but several were noted. These elements included storm forward speed and wind field asymmetry, statistical stationarity across the study area, dynamic modeling of tides in generating synthetic storm events, separate JPM-OS analysis for "east" and "west" coast storms, and meteorological and tidal optimizations. New advances in methodology for describing long duration hurricane climatology and joint probability for estimation of low probability inundation have been applied and approved by FEMA elsewhere within a single approach. For example, FEMA applied a Monte Carlo approach for a coastal study in North Carolina (2008) and approved use of this method in FEMA Guidance No. 8-12 (2012). Justification was not provided for not applying more advanced and newer approved FEMA approaches.
- Based on initial review of 1% SWEL as reported by FEMA, several locations within Palm Beach County were identified as areas that may warrant further consideration with respect to the developed model mesh.
- Model uncertainty was evaluated and used to statistically estimate the 1% SWEL within the study area. In developing inputs for the coastal hazard analysis, FEMA concluded that the 1% SWEL were high in some areas because of the model "uncertainty term and the combined storm frequency curves" for east and west coast storms used to define the 1% SWEL [14]. Review of FEMA's reports for the ECCFL study revealed that FEMA excluded west coast (exiting) storms citing that "exiting storms have a minimal effect on the low-frequency water levels" and "the presence of other uncertainties which influence the modeling results to a larger degree." FEMA reported that the influence of west coast (exiting) storms on the SFL study was 0.25 feet (3 times greater than the ECCFL study) but opted to include them regardless.
- At the study area Atlantic boundary between the SFL and ECCFL studies, discrepancies in the 1% SWEL were identified by FEMA. The 1% SWEL for the SFL study were higher by "1.7 feet along the open coast, 2.0 feet in the Intracoastal Waterway, and 2.0 to 4.2 feet up the Loxahatchee and North Fork Loxahatchee Rivers" [12]. FEMA identified a transition area and applied adjustments lowering the 1% SWEL within the northern 5 miles of the County to join the studies. Refinement to FEMA's approach to define adjustments to the 1% SWEL and to consider the entirety of the County in assigning those adjustments appears justified. The alternate approach presented herein, if adopted by FEMA, would result in lower 1% SWELs within the County.

Coastal Hazard Analysis

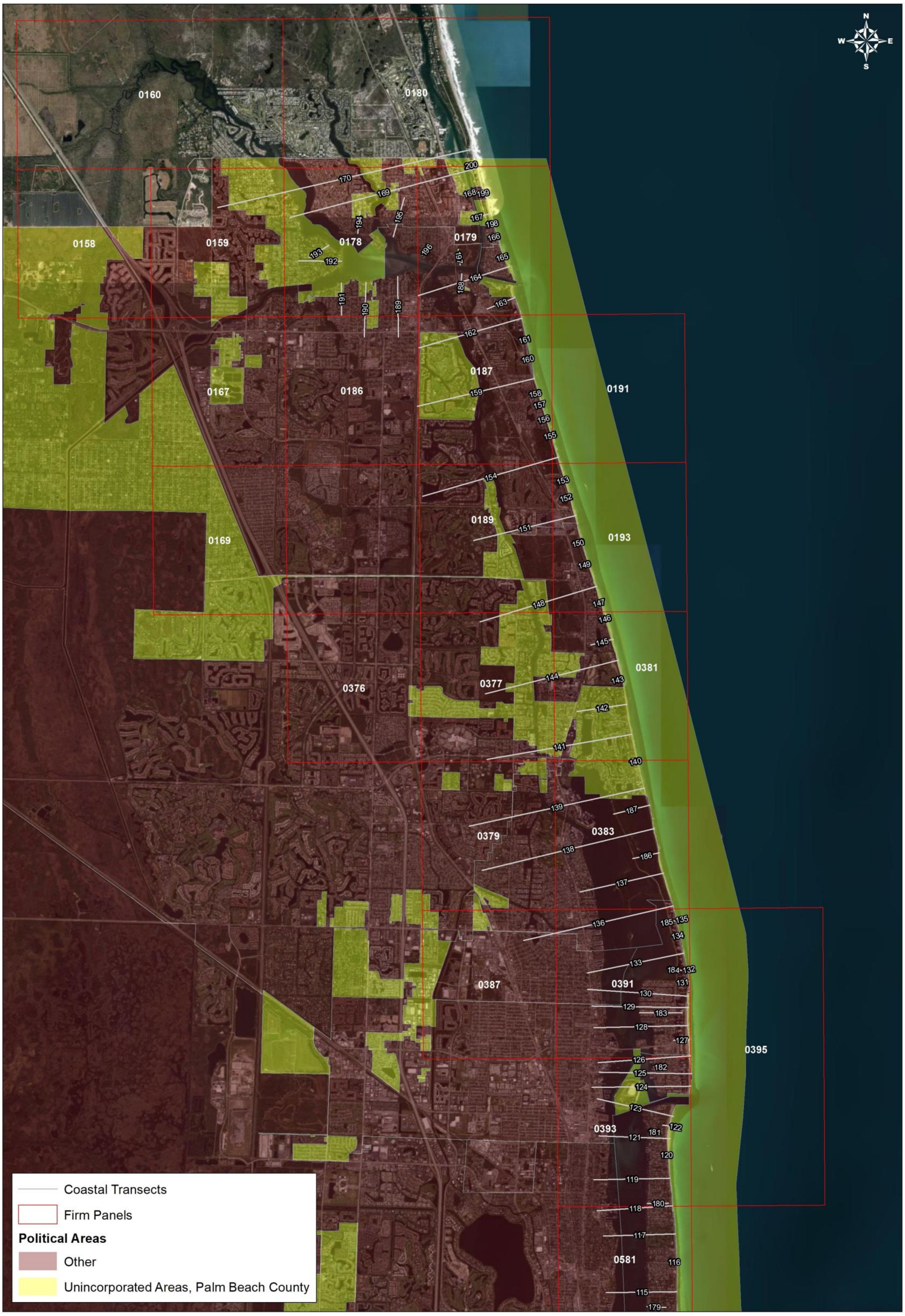
- Revisions to the 1% SWEL may affect FEMA's evaluation of dune response.
- FEMA's WHAFIS modeling assumed that the direction of wave propagation was shore normal (perpendicular to shore) and that the peak wave height coincided with the peak water surface elevation. While not necessarily an incorrect assumption, FEMA did not provide justification for these assumptions and if inappropriate can result in an overestimation of the wave conditions (e.g. wave heights) at the shoreline.
- Review of FEMA's analysis and inspection of open coast transects along the Atlantic coastline suggested there may be opportunities to improve the consistency of the mapping of the VE Zone throughout Palm Beach County and reflect the potential for wave overtopping and the landward limit of moderate wave action. These opportunities include the following.
  - The dune toe, landward limit of the dune crest, eroded profile, and the presence of seawalls could be defined to more consistently align with FEMA guidelines and represent coastal features. Inconsistencies at Transects 134, 136-138, 147, and 158 were noted specifically. Further review of FEMA's modeling is needed to determine if similar inconsistencies exist elsewhere.

    - The PFD defined by FEMA is more often the most landward parameter used by FEMA to map the VE zone along the open coast. The PFD was located further seaward relative to the beach profile in the southern portions of the County as compared to the northern portions. Lake Worth Inlet was identified as the demarcation where the mapping inconsistencies began.
- FEMA's analysis of sheltered water (inland) transects excluded transects within the Lake Worth Lagoon south of the East Ocean Avenue bridge in Lantana to avoid inconsistencies in mapping BFE along the eastern shoreline. The inconsistencies were attributed to the larger starting wave conditions extracted from the SWAN+ADCIRC model results which appeared to be localized outliers as compared the other areas of the lagoon. FEMA opted to rely on sheltered water transects within the lagoon to the north for mapping purposes as opposed to reviewing the SWAN+ADCIRC modeling to resolve the outlying starting wave conditions.

Task 5 will complement Task 4 of our review. Task 5 will review the model setups, inputs, outputs, and other data provide by FEMA to delve beyond the level of detail of contained in FEMA's documents; this will provide the County additional information and details.

Appendix A

Coastal Hazard Analysis Transects



0 1 2 3 km

0 0.5 1 1.5 mi

Political Areas - Map 01

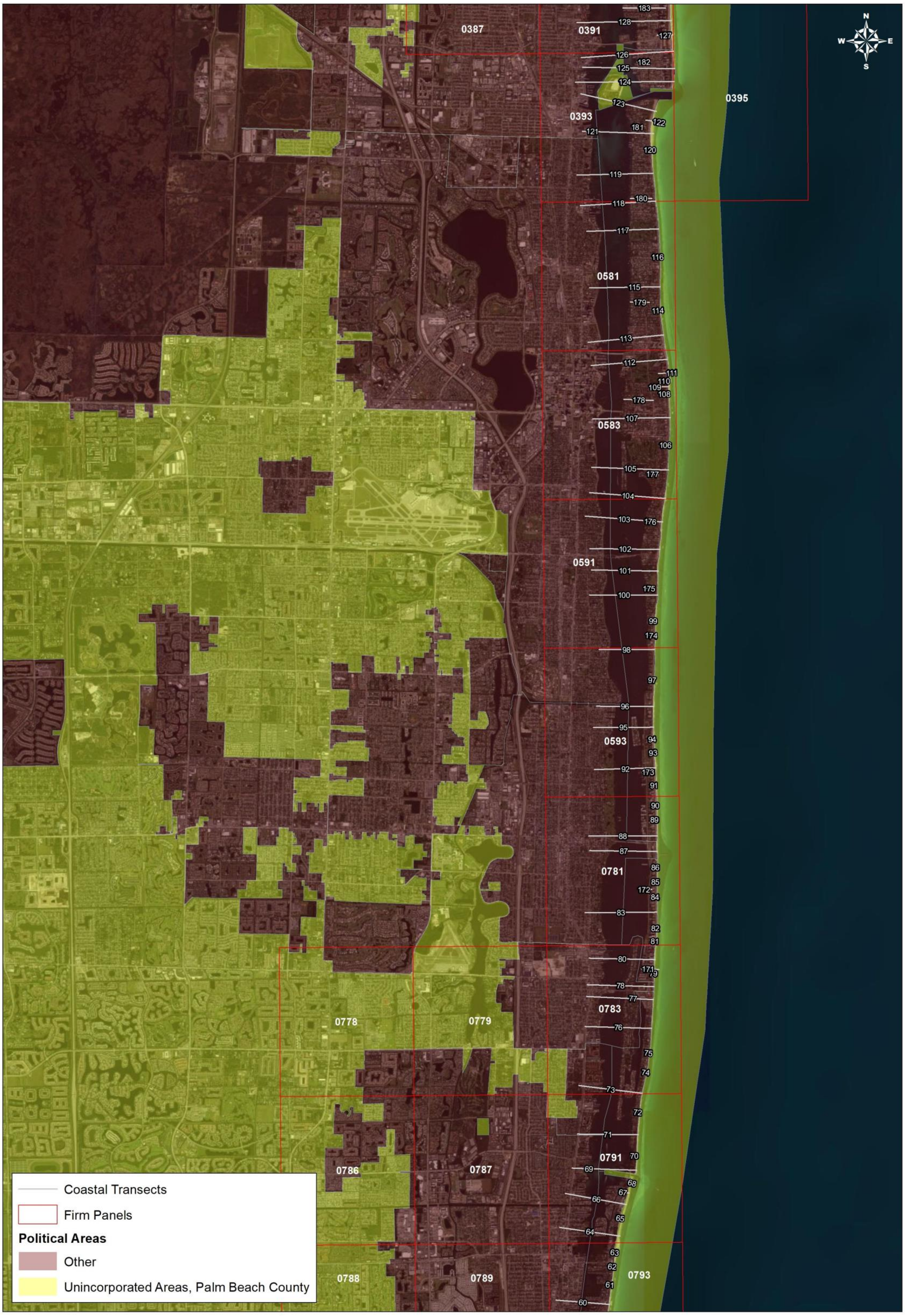
PALM BEACH COUNTY, FLORIDA

Imagery: ESRI World Basemap
Spatial Reference:
NAD 1983 StatePlane Florida East FIPS 0901 Feet

Baird.

13134PalmBeach - Political Boundary Rev02.mxd

Map Published: 2020-05-01



0 1 2 3 km

0 0.5 1 1.5 mi

Political Areas - Map 02

PALM BEACH COUNTY, FLORIDA

Imagery: ESRI World Basemap
Spatial Reference:
NAD 1983 StatePlane Florida East FIPS 0901 Feet

Baird.

Map Published: 2020-05-01

13134PalmBeach - Political Boundary Rev02.mxd

Political Areas - Map 03

PALM BEACH COUNTY, FLORIDA

Appendix B

Primary Frontal Dune Analysis

Open Coast Transect	Erosion Method	Runup Method	1% SWEL (ft, NAVD88)	Runup[1] (ft, NAVD88)	Eroded Profile Crest (ft, NAVD88)	Primary Frontal Dune (PFD)	VE Zone Defined By
1	Structure	Runup2.0	6.99	12.34	13.80	Delineated	PFD
2	Dune Retreat	Runup2.0	6.87	12.42	12.90	Delineated	PFD
3	Structure	Runup2.0	6.90	12.06	10.60	Delineated	Runup
4	Dune Retreat	Runup2.0	6.91	11.35	12.80	Delineated	PFD
5	Dune Retreat	Runup2.0	7.00	10.96	12.30	Delineated	PFD
6	Dune Retreat	Runup2.0	6.75	12.67	17.60	Delineated	PFD
7	Dune Retreat	Runup2.0	7.01	12.79	13.70	Delineated	PFD
8	Dune Retreat	Runup2.0	6.87	12.44	16.60	Delineated	Runup
9	Dune Retreat	Runup2.0	6.76	12.41	15.00	Delineated	Runup
10	Structure	Runup2.0	6.88	12.61	12.80	Delineated	PFD
11	Dune Retreat	Runup2.0	6.54	12.41	25.90	Delineated	PFD
12	Dune Retreat	Runup2.0	6.65	12.30	22.80	Delineated	PFD
13	Dune Retreat	Runup2.0	6.60	11.94	24.00	Delineated	PFD
14	Dune Retreat	Runup2.0	7.04	13.16	20.30	Delineated	PFD
15	Dune Retreat	Runup2.0	6.81	11.73	28.00	Delineated	PFD
16	Dune Retreat	Runup2.0	6.74	12.27	22.94	Delineated	Runup
17	Dune Retreat	Runup2.0	6.84	12.16	19.23	Delineated	Runup
18	Dune Retreat	Runup2.0	6.82	12.05	20.00	Delineated	Runup
19	Dune Retreat	Runup2.0	6.86	11.84	16.67	Delineated	Runup
20	Dune Retreat	Runup2.0	6.82	11.38	17.03	Delineated	Runup
21	Dune Retreat	Runup2.0	6.83	11.27	16.73	Delineated	Runup
22	Dune Retreat	Runup2.0	6.79	12.61	26.84	Delineated	PFD
23	Structure	SPM	6.79	12.46	14.00		Runup
24	Dune Retreat	Runup2.0	6.80	11.65	15.83	Delineated	PFD
25	Dune Retreat	Runup2.0	6.70	12.01	19.36	Delineated	PFD
26	Dune Retreat	Runup2.0	6.90	11.90	16.07	Delineated	PFD
27	Dune Retreat	Runup2.0	6.77	11.62	18.47	Delineated	PFD
28	Dune Retreat	Runup2.0	6.82	11.80	17.45	Delineated	PFD
29	Dune Retreat	Runup2.0	6.75	11.79	14.26	Delineated	Runup
30	Structure	Runup2.0	6.80	11.56	15.10	Delineated	Runup
31	Structure	Runup2.0	6.80	11.51	14.40	Delineated	Runup
32	Structure	Runup2.0	6.77	11.55	13.60	Delineated	Runup
33	Structure	Runup2.0	6.89	11.64	13.70	Delineated	Runup
34	Dune Retreat	Runup2.0	6.99	11.65	18.54	Delineated	Runup
35	Structure	Runup2.0	6.60	11.45	14.90	Delineated	Runup
36	Dune Retreat	Runup2.0	6.88	11.70	15.02	Delineated	PFD
37	Dune Removal	Runup2.0	7.02	12.41	19.95	Delineated	Runup
38	Dune Removal	Runup2.0	6.87	11.89	14.71	Delineated	PFD
39	Dune Removal	Runup2.0	6.84	12.05	15.26	Delineated	PFD
40	Dune Removal	Runup2.0	6.94	11.74	13.58	Delineated	PFD
41	Dune Removal	Runup2.0	7.00	11.84	14.30	Delineated	PFD
42	Dune Retreat	Runup2.0	6.98	11.74	16.30	Delineated	PFD
43	Dune Retreat	Runup2.0	6.67	11.88	16.36	Delineated	PFD
44	Dune Retreat	Runup2.0	6.66	11.97	14.05	Delineated	PFD
45	Dune Retreat	Runup2.0	6.60	11.58	13.62	Delineated	PFD
46	Dune Retreat	Runup2.0	6.60	11.60	15.39	Delineated	PFD
47	Dune Retreat	Runup2.0	6.80	11.41	13.99	Delineated	Runup
48	Structure	Runup2.0	6.72	11.27	10.60	Delineated	Runup
49	Structure	SPM	6.77	11.21	10.76	Delineated	Runup
50	Structure	SPM	6.77	12.40	10.53	Delineated	PFD
51	Structure	SPM	6.77	13.05	10.30	Delineated	PFD
52	Dune Retreat	Runup2.0	6.74	10.92	14.49	Delineated	Runup
53	Structure	SPM	6.79	11.84	11.65	Delineated	PFD
54	Dune Retreat	Runup2.0	6.57	10.78	17.94	Delineated	PFD
55	Dune Retreat	Runup2.0	6.49	10.97	18.24	Delineated	PFD
56	Dune Retreat	Runup2.0	6.54	11.33	17.39	Delineated	PFD
57	Dune Removal	Runup2.0	6.47	11.32	10.79	Delineated	Runup
58	Dune Removal	Runup2.0	6.51	11.14	9.35	Delineated	Runup
59	Dune Removal	Runup2.0	6.47	11.32	9.33	Delineated	Runup
60	Dune Removal	Runup2.0	6.52	11.30	11.89	Delineated	Runup
61	Dune Retreat	Runup2.0	6.71	11.68	19.01	Delineated	PFD
62	Dune Retreat	Runup2.0	6.82	12.42	19.62	Delineated	PFD
63	Dune Retreat	Runup2.0	6.84	12.37	18.85	Delineated	Runup
64	Dune Retreat	Runup2.0	6.73	10.21	19.01	Delineated	Runup
65	Dune Retreat	Runup2.0	6.54	9.45	16.03	Delineated	Runup
66	Dune Retreat	Runup2.0	6.81	9.47	13.44	Delineated	Runup
67	Dune Retreat	Runup2.0	6.78	9.48	13.68	Delineated	Runup
68	Dune Removal	Runup2.0	6.83	9.15	12.97	Delineated	PFD
69	Dune Removal	Runup2.0	6.75	10.53	15.72	Delineated	Runup
70	Dune Removal	Runup2.0	6.62	10.92	11.64	Delineated	PFD
71	Dune Removal	Runup2.0	6.74	11.03	19.71	Delineated	Runup
72	Dune Removal	Runup2.0	6.80	11.12	18.33	Delineated	Runup
73	Structure	SPM	6.70	13.13	12.55		Runup
74	Structure	SPM	6.67	13.71	12.48		Runup
75	Structure	SPM	6.56	13.03	13.37		Runup
76	Structure	SPM	6.60	13.13	14.79		Runup
77	Structure	SPM	6.48	12.28	12.40		Runup
78	Structure	SPM	7.30	14.57	12.34		Runup
79	Structure	SPM	7.29	13.69	16.04		Runup
80	Structure	SPM	6.98	14.32	16.02		Runup
81	Structure	SPM	6.36	11.10	18.80		Runup
82	Dune Retreat	Runup2.0	6.37	10.52	16.90	Delineated	Runup
83	Dune Retreat	Runup2.0	6.36	10.52	17.70	Delineated	PFD
84	Dune Retreat	Runup2.0	6.39	10.52	18.80	Delineated	PFD
85	Structure	SPM	7.10	12.41	16.90		Runup
86	Dune Retreat	Runup2.0	6.46	10.61	15.70	Delineated	PFD
87	Dune Retreat	Runup2.0	6.50	10.53	14.60	Delineated	PFD
88	Dune Retreat	Runup2.0	6.80	10.95	15.00	Delineated	PFD
89	Structure	Runup2.0	6.75	11.27	12.80	Delineated	PFD
90	Dune Retreat	Runup2.0	6.53	10.83	16.50	Delineated	PFD
91	Dune Retreat	Runup2.0	6.48	10.53	10.00	Delineated	Runup
92	Dune Retreat	Runup2.0	6.32	10.49	15.70	Delineated	PFD
93	Dune Retreat	Runup2.0	6.64	10.87	20.40	Delineated	PFD
94	Structure	SPM	6.71	11.55	14.20		Runup
95	Dune Retreat	Runup2.0	6.44	10.97	24.00	Delineated	PFD
96	Dune Retreat	Runup2.0	6.39	10.68	22.70	Delineated	PFD
97	Structure	TAW	6.24	13.51	16.61		Runup
98	Structure	TAW	6.31	14.39	18.97		Runup
99	Structure	TAW	6.37	14.20	17.62		Runup
100	Structure	Runup2.0	6.38	11.17	17.01		Runup

Open Coast Transect	Erosion Method	Runup Method	1% SWEL (ft, NAVD88)	Runup[1] (ft, NAVD88)	Eroded Profile Crest (ft, NAVD88)	Primary Frontal Dune (PFD)	VE Zone Defined By
101	Dune Retreat	Runup2.0	6.28	10.52	16.10	Delineated	PFD
102	Structure	SPM	6.38	11.09	11.60		Runup
103	Structure	SPM	6.43	10.61	11.50		Runup
104	Structure	Runup2.0	6.49	10.56	13.71		Runup
105	Structure	Runup2.0	6.54	10.63	16.70		Runup
106	Structure	Runup2.0	6.47	9.90	15.90		Runup
107	Structure	Runup2.0	6.32	10.33	15.20	Delineated	PFD
108	Dune Retreat	Runup2.0	6.48	9.84	14.40	Delineated	PFD
109	Structure	TAW	6.25	17.11	14.11		Runup
110	Structure	Runup2.0	6.24	10.21	11.69		Runup
111	Structure	SPM	6.20	13.13	16.00		Runup
112	Structure	Runup2.0	6.29	10.70	14.50	Delineated	Runup
113	Structure	Runup2.0	6.40	11.13	12.20		Runup
114	Structure	SPM Curved Runup	6.47	15.86	14.00		Runup
115	Structure	Runup2.0	6.41	11.67	15.60		Runup
116	Structure	Runup2.0	6.33	15.63	17.30		Runup
117	Structure	Runup2.0	6.33	14.31	16.10		Runup
118	Structure	Runup2.0	6.34	12.81	13.90		Runup
119	Structure	Runup2.0	6.59	13.59	14.90		Runup
120	Dune Retreat	Runup2.0	6.67	14.20	12.66	Delineated	Runup
121	Dune Retreat	Runup2.0	6.61	10.59	13.69	Delineated	Runup
122	Dune Removal	Runup2.0	6.62	10.12	11.22	Delineated	PFD
123	Dune Removal	Runup2.0	6.42	10.13	11.06	Delineated	PFD
Lake Worth Inlet							
124	Dune Retreat	Runup2.0	6.07	12.65	14.35	Delineated	PFD
125	Dune Retreat	Runup2.0	6.15	10.24	15.78	Delineated	PFD
126	Dune Retreat	Runup2.0	6.32	9.54	13.00	Delineated	PFD
127	Dune Retreat	Runup2.0	6.36	9.58	10.82	Delineated	PFD
128	Dune Retreat	Runup2.0	6.45	10.48	11.35	Delineated	PFD
129	Dune Removal	Runup2.0	6.46	10.63	9.76	Delineated	PFD
130	Dune Removal	Runup2.0	6.43	10.52	9.12	Delineated	PFD
131	Dune Removal	Runup2.0	6.20	9.62	6.62	Delineated	Runup
132	Structure	Runup2.0	6.15	10.89	22.00	Delineated	PFD
133	Dune Retreat	Runup2.0	6.15	10.54	22.81	Delineated	PFD
134	Dune Removal	Runup2.0	6.18	10.20	13.29	Delineated	PFD
135	Structure	SPM	6.19	10.27	18.70	Delineated	PFD
136	Dune Removal	Runup2.0	6.14	9.88	9.48	Delineated	Runup
137	Dune Removal	Runup2.0	6.36	9.98	7.38	Delineated	Breaking Wave Ht
138	Dune Removal	Runup2.0	6.22	9.77	6.77	Delineated	Breaking Wave Ht
139	Dune Retreat	Runup2.0	6.20	10.62	19.41	Delineated	PFD
140	Dune Retreat	Runup2.0	6.19	10.64	17.33	Delineated	PFD
141	Dune Retreat	Runup2.0	6.22	10.87	18.88	Delineated	PFD
142	Dune Retreat	Runup2.0	6.22	10.07	10.63	Delineated	Runup
143	Dune Retreat	Runup2.0	6.20	9.96	18.12	Delineated	PFD
144	Dune Retreat	Runup2.0	6.19	9.81	21.20	Delineated	PFD
145	Dune Retreat	Runup2.0	6.30	10.02	17.07	Delineated	PFD
146	Dune Retreat	Runup2.0	6.30	9.65	14.07	Delineated	PFD
147	Dune Retreat	Runup2.0	6.20	9.59	20.96	Delineated	PFD
148	Structure	Runup2.0	6.32	9.85	16.40	Delineated	PFD
149	Dune Retreat	Runup2.0	6.30	9.71	15.02	Delineated	PFD
150	Dune Retreat	Runup2.0	6.30	9.49	22.56	Delineated	PFD
151	Dune Retreat	Runup2.0	6.30	9.79	23.37	Delineated	PFD
152	Dune Retreat	Runup2.0	6.20	9.49	22.73	Delineated	PFD
153	Dune Retreat	Runup2.0	6.22	9.69	13.06	Delineated	PFD
154	Dune Retreat	Runup2.0	6.16	9.18	22.30	Delineated	PFD
155	Dune Retreat	Runup2.0	5.97	9.29	15.98	Delineated	PFD
156	Dune Retreat	Runup2.0	6.08	9.18	15.62	Delineated	PFD
157	Dune Retreat	Runup2.0	6.21	9.27	14.69	Delineated	PFD
158	Structure	SPM	5.73	12.27	12.72	Delineated	PFD
159	Dune Retreat	Runup2.0	5.89	8.50	23.26	Delineated	PFD
160	Dune Retreat	Runup2.0	5.98	8.75	13.89	Delineated	PFD
161	Dune Retreat	Runup2.0	5.81	8.50	18.61	Delineated	PFD
162	Dune Retreat	Runup2.0	5.77	7.91	20.61	Delineated	PFD
163	Dune Retreat	Runup2.0	5.79	7.60	13.07	Delineated	PFD
164	Dune Retreat	Runup2.0	5.69	7.83	14.31	Delineated	PFD
165	Dune Retreat	Runup2.0	5.80	8.17	17.23	Delineated	PFD
166	Structure	TAW	5.58	12.12	14.57	Delineated	PFD
167	Dune Retreat	Runup2.0	5.69	9.35	17.07	Delineated	PFD
168	Dune Retreat	Runup2.0	5.59	9.43	17.91	Delineated	PFD
169	Dune Retreat	Runup2.0	5.57	9.27	17.91	Delineated	PFD
170	Dune Removal	Runup2.0	5.45	8.81	6.25	Martin County	N/A

[1]Runup capped at 3 feet above the eroded profile crest elevation for Transects 109, 131, and 138 [14].

Coastline (Open Coast Transects)	# of Transects			% of Transects	
	Open Coast	PFD Delineated	VE Zone Defined by PFD	PFD Delineated	VE Zone Defined by PFD
South of Lake Worth Inlet (1 to 123)	123	92	54	75%	44%
North of Lake Worth Inlet (124 to 170)	47	46	41	98%	87%
Palm Beach County (1 to 170)	170	138	95	81%	56%

Appendix D

Review & Evaluation of FEMA's Coastal Flood Risk Study

Storm Surge, Wave Model & Flood Map Evaluation (Deliverable 5.1)
Task Order #1778-01

September 22, 2020 | 13134.201.R4.Rev0

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Review & Evaluation of FEMA's Coastal Flood Risk Study

Storm Surge, Wave Model & Flood Map Evaluation (Deliverable 5.1)
Task Order #1778-01

Prepared for: **Prepared by:**

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13134.201.R4.Rev0

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Revision	Date	Status	Comments	Prepared	Reviewed	Approved
Rev A	7/17/20	Draft	County review	DS	GT	DS
Rev B	9/4/20	Draft	County comments	DS	GT	DS
Rev 0	9/22/20	Final		DS	GT	DS

Executive Summary

The National Flood Insurance Program (NFIP) is a federal program that provides flood insurance to property owners within participating communities. Palm Beach County and a number of its communities participate in the program. The Federal Emergency Management Agency (FEMA) is responsible for administering the NFIP and, as such, periodically updates information on the flood hazards. The updated information is incorporated into FEMA's Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRM) for a given study area.

FEMA is in the process of updating the FIS for the South Florida study area with the Coastal Flood Risk Study (SFL study), which reevaluated the coastal flood hazard originating from the Atlantic Ocean. Palm Beach County, along with Broward, Miami-Dade, and Monroe Counties, is located within the SFL study area. While FEMA's SFL study leveraged numerical modeling and engineering analyses to better define the coastal flood risks associated with storm surge, a technical review of FEMA's model setups, inputs, outputs, and other provided data identified specific elements to improve the accuracy, consistency, reliability, and repeatability of the study with respect to Palm Beach County. The major elements presented herein are summarized below.

- SWAN+ADCIRC Model Validation [Section 2]: FEMA's extensive model validation resulted in reasonable agreement with measured astronomical tides. However, there was noticeable differences between measured and modeled water levels of the validation storms that suggest the coastal processes associated with storm surge may not be sufficiently represented by FEMA's SWAN+ADCIRC model. FEMA's model validation was based on 244 measured peak water levels. Only 53% of the measured locations were within a 55-mile offset from the validation storm tracks where storm surges were more likely to be experienced. The model uncertainty within the offset was 2.24 times greater than the uncertainty outside the offset, which suggests that the model was not able to accurately simulate peak water levels within the areas that storm surge were most likely to be experienced.

- Statistical Stillwater Elevations (SWEL) [Section 3]: The wind and pressure fields in Palm Beach County north of Boynton Inlet were not included in FEMA's regional (fine) grid and were modeled at a coarser grid resolution as compared to the rest of the SFL study area. The coarser model grid resolution limits the SWAN+ADCIRC model's ability to represent the storm forcing parameters, and to accurately simulate storm surges for storms making landfall north of and near the boundary of the regional grid. Storm surge was FEMA's basis for the defining the 1% SWEL's of the Atlantic Ocean and within interior water bodies (e.g. Lake Worth Lagoon). The 1% SWEL was used by FEMA to map the inland extent of coastal flooding and in turn define special flood hazard areas (SFHA) shown on their FIRM panels.

  Review of FEMA's SWAN+ADCIRC model mesh and modeling of synthetic storms revealed several locations within Palm Beach County where the resolution of the mesh was insufficient to accurately model hydrodynamic and coastal flooding processes. For example, during the synthetic storm that produced the highest water surface elevation (WSE) within the Lake Worth Lagoon, FEMA's model did not allow water to flow out through Boynton Inlet increasing WSE within the lagoon as evidenced by unrealistic changes in the WSE exhibited in the inlet as the storm passed to the north.

  The cumulative contributions (adjustments) to the 1% SWEL's offshore of Palm Beach County due to FEMA having included west coast (exiting) storms within the statistical SWEL's and having accepted an increased model uncertainty during model validation were estimated to have increased FEMA's 1% SWEL approximately 1.3 feet. Figure ES.1 shows the 1% SWEL as reported by FEMA (left panel) and the 1% SWEL adjusted (right panel) after removing the cumulative contributions estimated herein (middle panel). In the absence of reperforming FEMA's modeling and given the consistent contributions offshore, a uniform downward adjustment to the 1% SWEL throughout Palm Beach County (and potentially throughout the east coast of the study area) appears more reasonable than FEMA's approach to applying adjustments. FEMA's approach defined a transition area extending 5 miles north and 5 miles south of the Palm Beach and Martin county line within which the 1% SWEL was adjusted downward 0.85 feet within Palm Beach County and upward 0.85 feet in Martin County. The 1% SWEL adjustments presented herein are based on modeling, information, and data provided by FEMA. Reperforming the SWAN+ADCIRC model is needed to more accurately assess the adjustments to consider the interdependence and spatial variability of improvements to FEMA's modeling, especially within interior water bodies hydraulically connected to coastal inlets.

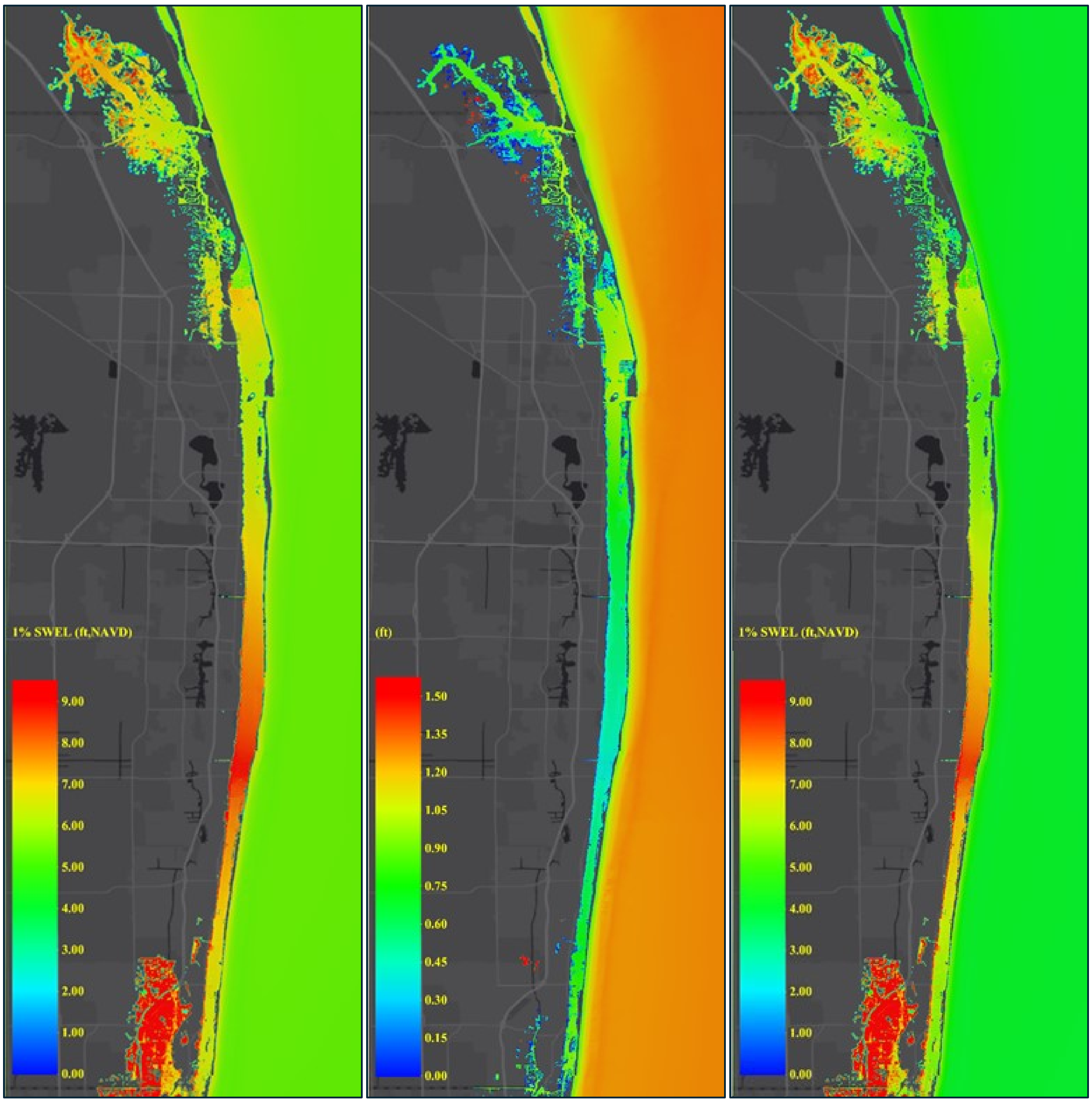

Figure ES.1: 1% SWEL: FEMA (left) – Cumulative Contribution (middle) = Adjusted (right)

- Coastal Hazard Analysis and Mapping [Section 4]: Breaking wave heights were used by FEMA to define the VE zone at only 2 of 170 open coast transects (transects 137 and 138 at MacArthur Beach State Park). A 1.3-foot downward adjustment to the 1% SWEL, as quantified above, would impact the coastal erosion analysis and a dune retreat response would have been identified by FEMA at the transects. A dune retreat response would reduce the northern Lake Worth Lagoon's exposure to Atlantic waves during the 1%-annual-chance event, the inland extent of the VE zone, and in turn may reduce base flood elevations (BFE) of SFHA zones mapped on FEMA's FIRM panels within the lagoon.

  Updates by FEMA to SFHA mapping on several FIRM panels upstream of South Florida Water Management District (SFWMD) water control structures as part of the SFL study do not appear consistent or warranted based on the methodologies applied and justification provided by FEMA elsewhere within Palm Beach County.

The information presented herein for Task 5 as well as Tasks 2, 3, and 4 will be compiled in Task 6 to document the key findings, conclusions, and recommendations regarding future coordination with FEMA.

Table of Contents

Tables

Figures

1. Introduction

The National Flood Insurance Program (NFIP) is a federal program that provides flood insurance to property owners within participating communities. Palm Beach County and a number of its communities participates in the program. The Federal Emergency Management Agency (FEMA) is responsible for administering the NFIP and as such periodically updates information on the flood hazards. The updated information is incorporated into FEMA's Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRM) for a given study area.

FEMA is in the process of updating the FIS for the South Florida study area with the Coastal Flood Risk Study (SFL study), which reevaluated the coastal flood hazard originating from the Atlantic Ocean. Palm Beach County, along with Broward, Miami-Dade, and Monroe Counties, is located within the SFL study area.

Baird was contracted by Palm Beach County to provide a technical review of FEMA's SFL study. Task 4 focused on reviewing the SFL study documents produced by FEMA with respect to their applicability and appropriateness to Palm Beach County. Task 5 delves beyond the level of detail contained in FEMA's documents by reviewing model setups, inputs, outputs, and other pertinent data provided by FEMA. The discussion herein is organized into the following broad categories to provide consistency with Task 4.

- SWAN+ADCIRC Model Validation
- Statistical Stillwater Elevations (SWEL)
- Coastal Hazard Analysis and Mapping

It should be noted that the discussion does not attempt to document all elements that were considered during Baird's review nor does it attempt to provide resolutions to these elements, but rather to provide comments that improve the accuracy, consistency, reliability, and repeatability of the study. Coastal analysis and modeling to evaluate the impact and sensitivity of the elements on FEMA's SFL study and the FIRMs are beyond Baird's scope of work.

Reference to FEMA's documents and other data sources are denoted with "[ ]" and are correlated by the reference numbers assigned in the reference table (Section 6). The table is the same table included in Task 4 to maintain consistency; not all of the listed documents are referenced directly herein.

2. SWAN+ADCIRC Model Validation

The SWAN+ADCIRC model requires validation to “demonstrate satisfactory model performance via comparison of model results with available measured data” [9]. Thus, FEMA’s model validation effort for the SFL study primarily focused on comparing modeled and measured water levels during the following storms:

- Hurricane Betsy (1965)
- Hurricane David (1979)
- Hurricane Andrew (1992)
- Hurricane Georges (1998)
- Hurricane Wilma (2005)

Two types of water level data were considered within the model validation: hydrograph data from gage measurements; and highwater marks (HWM) from post-storm survey measurements. Figure 2.1 was extracted from FEMA’s reports and shows the locations of available water level data for the five selected validation storms used in FEMA’s modeling. The symbols and color scale assigned to the data locations indicate whether the modeled water elevations are above (+) or below (-) the measured water elevations and the magnitudes of the difference between the two. It should be noted that water level data was not available at all locations for each validation storm.

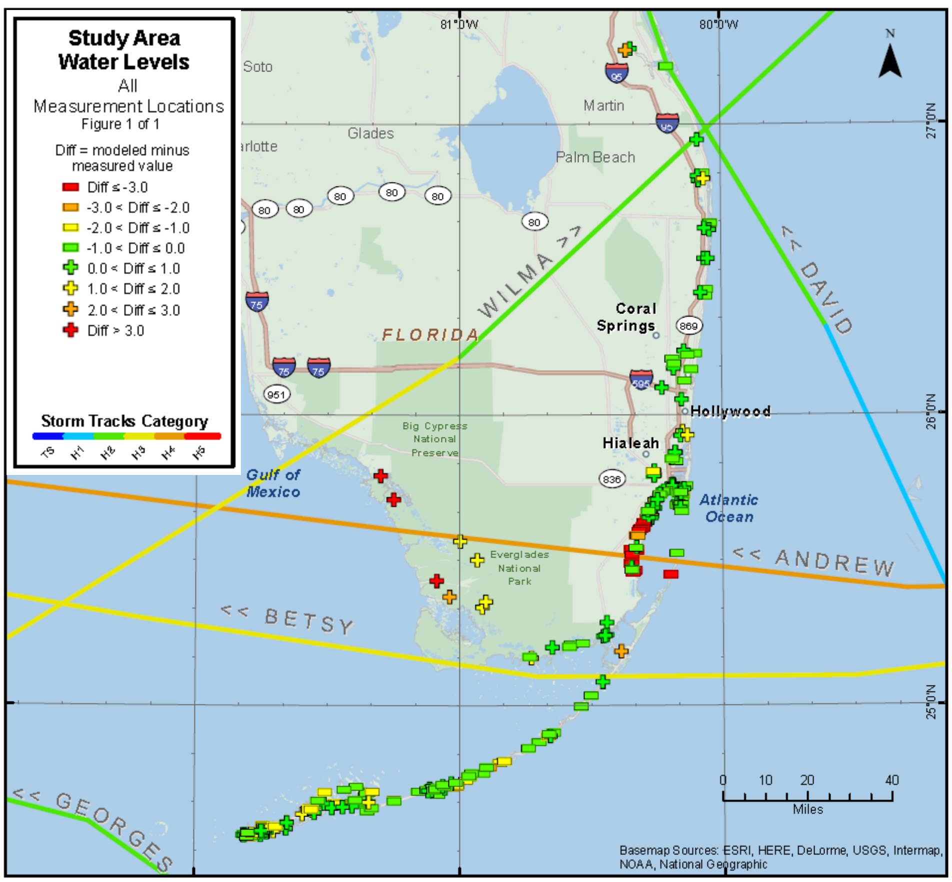

Figure 2.1: Stations with Measured HWM and Hydrograph for All Storms [FEMA, 2019]

Figure 2.2 was extracted from FEMA reports and compares modeled and measured peak water levels. It provides additional detail regarding the validation storm and type of measurement. Solid symbols indicate peak water levels obtained from hydrographs; open symbols indicate HWM.

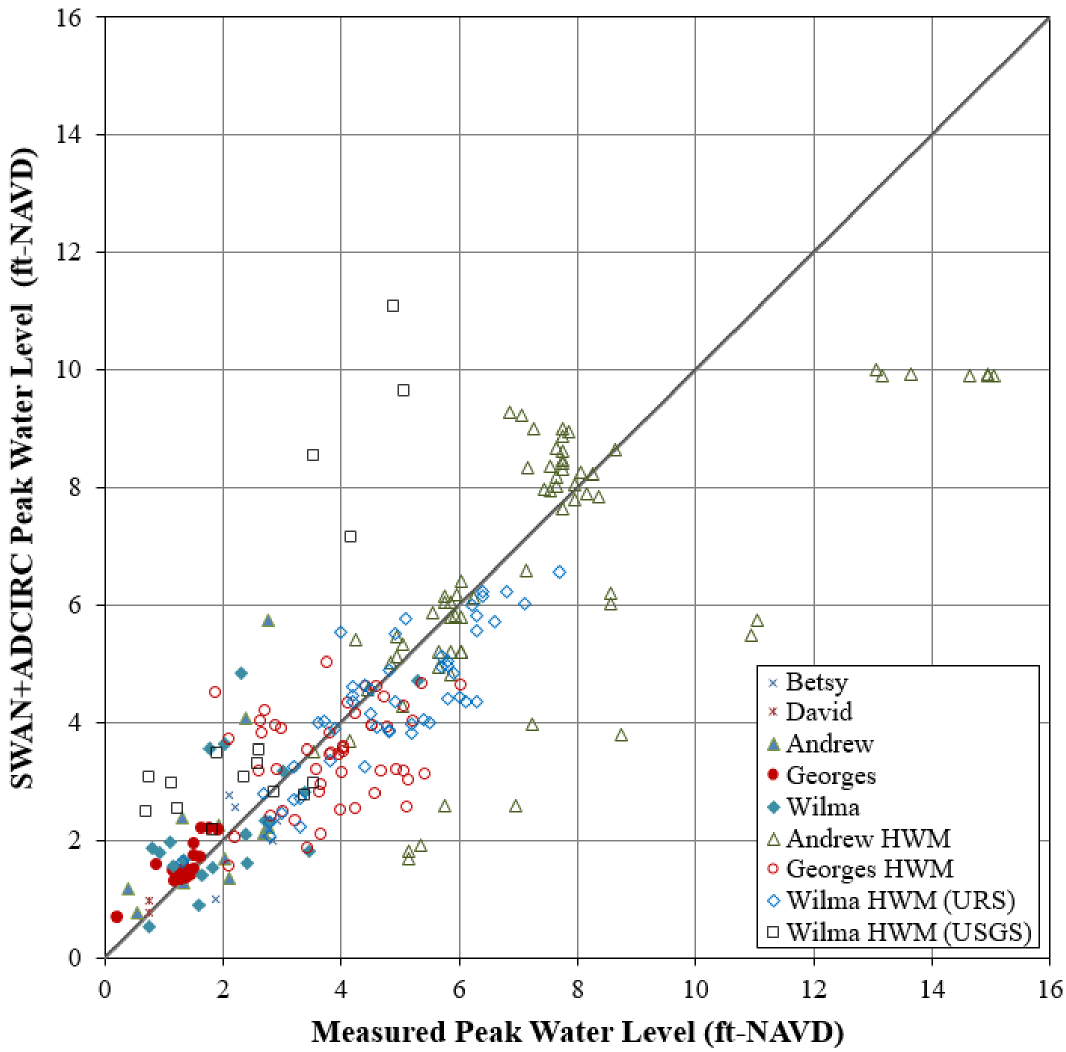

Figure 2.2: Measured-to-Modeled Peak Water Level Comparison for All Storms [FEMA, 2019]

The information presented in FEMA's figures above is discussed in greater detail below with respect to the proximity of measured water levels to storm tracks, model uncertainty, and gage selection.

2.1 Proximity of Measured Water Levels to Storm Tracks

Storm surge is generally greatest along a storm's track. As the distance from a storm's track increases or as the storm tracks away from a particular location, storm surge decreases and changes in water levels become increasingly governed by astronomical tides. **While it is acknowledged that FEMA's extensive model validation resulted in reasonable agreement with measured astronomical tides, less favorable agreement with measured water levels during the modeled validation storms suggests that the coastal processes associated with storm surge may not be sufficiently represented by the SWAN+ADCIRC model developed by FEMA**. This concept was highlighted in Task 4 by comparing hydrographs of measured and modeled water levels for a given location for several validation storms. The concept is further developed herein by comparing the model uncertainty (model skill) within a zone defined by offsetting the original validation storm track to both its sides. Model uncertainty is defined as the difference between the modeled and measured peak water levels.

The National Oceanic and Atmospheric Administration (NOAA) provides an online database of historical hurricane storm tracks along with a variety of information. NOAA's database for the validation storms was reviewed for the distance (radius) from the storm center that hurricane storm force winds extended. Hurricane storm force winds are defined as 64 knots (74 mph). The information available for the validation storms was reviewed, but only Hurricane Wilma contain information regarding the radius of hurricane force winds. On October 23, 2005 immediately prior to landfall on the west coast of Florida, Wilma's hurricane force winds (Figure 2.3, black line "R64") extended approximately 50 nautical miles (nm) or 57 miles from the storm's center. NOAA'S database reported that the radius of maximum sustained winds for the validation storms ranged from 9 to 36 nm with Hurricane Wilma being the greatest. As such, a 55-mile offset to either side of NOAA's published storm tracks was assumed for the analysis presented below to represent the segment of coastline that likely experienced the greatest storm surges during a given validation storm.

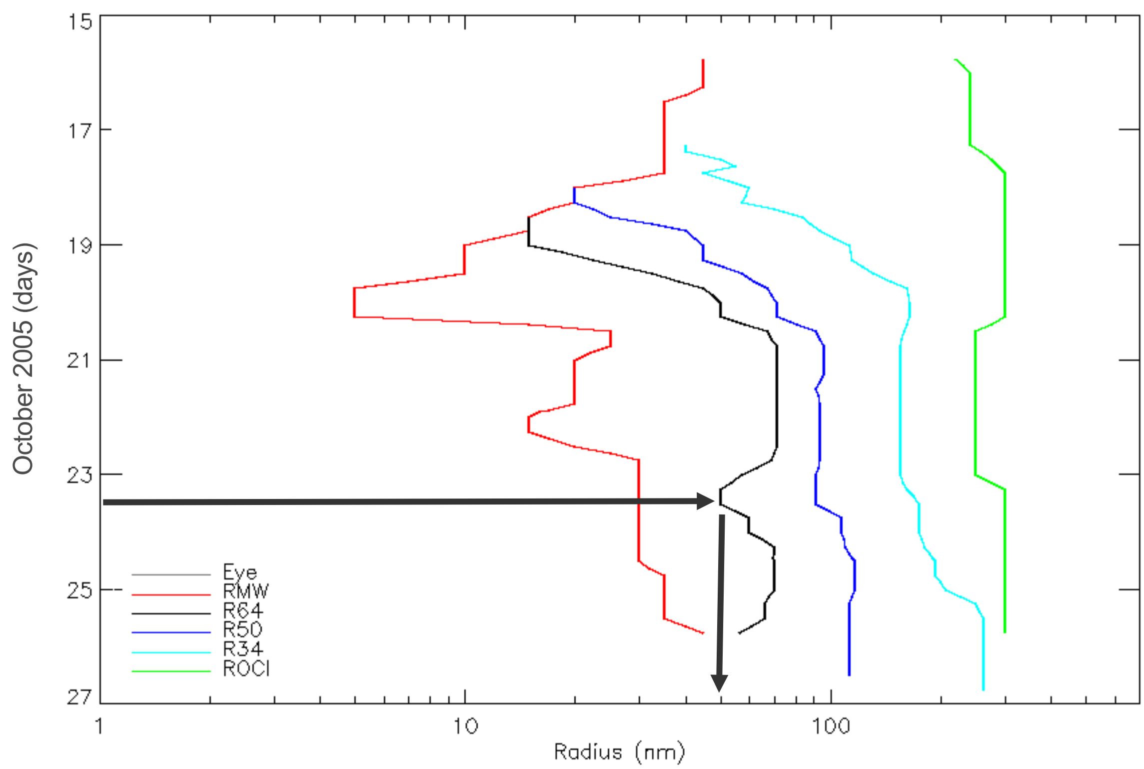

Figure 2.3: Hurricane Wilma – Wind Field Time Series [NOAA, 2020]

FEMA's SWAN+ADCIRC model validation was based on 244 measured peak water levels (58 from hydrographs and 186 from HWM). The locations of the measured water levels used by FEMA were analyzed with respect to the 55-mile offset relative to the tracks of the validation storms. The locations of the measured water levels within the 55-mile offset (green dots) and outside the offset (red dots) for each of the validation storms are shown in Figure 2.4 through Figure 2.8. This analysis is summarized in Table 2.1 and revealed the following regarding the validation storms and measured water level locations.

- Hurricanes Betsy and David validations were based on comparisons with 5 and 4 measured water level locations, respectively. 80% (Betsy) and 50% (David) of the measurements for these storms were outside the 55-mile offset.
- Hurricanes Andrew and Wilma validations were based on 80+ comparisons of measured water level locations. 75 (94%) of the locations were within the offset for Hurricane Andrew, while 18 (21%) were within the offset for Hurricane Wilma.
- **53% (130 out of 244) of the measured water level locations used by FEMA to validate the model were within the 55-mile offset from the validation storm tracks where storm surges were more likely to be experienced**; 47% were outside the offset.

Table 2.1: Measured Water Levels Locations relative to Storm Track Offset

Validation Storm	Measured Water Level Locations		
	Within Offset[1]	Outside Offset[1]	Total
Betsy (1965)	1 (1 Hydrograph + 0 HWM)	4 (4 Hydrograph + 0 HWM)	5 (5 Hydrographs + 0 HWM)
David (1979)	2 (2 Hydrograph + 0 HWM)	2 (2 Hydrograph + 0 HWM)	4 (4 Hydrographs + 0 HWM)
Andrew (1992)	75 (6 Hydrograph + 69 HWM)	5 (5 Hydrograph + 0 HWM)	80 (11 Hydrographs + 69 HWM)
Georges (1998)	34 (2 Hydrograph + 32 HWM)	35 (16 Hydrograph + 19 HWM)	69 (18 Hydrographs + 51 HWM)
Wilma (2005)	18 (12 Hydrograph + 6 HWM)	68 (8 Hydrograph + 60 HWM)	86 (20 Hydrographs + 66 HWM)
Total:	130	114	244
Percentage:	53%	47%	100%

[1]Offset = 55 miles on either side of NOAA's published storm tracks.

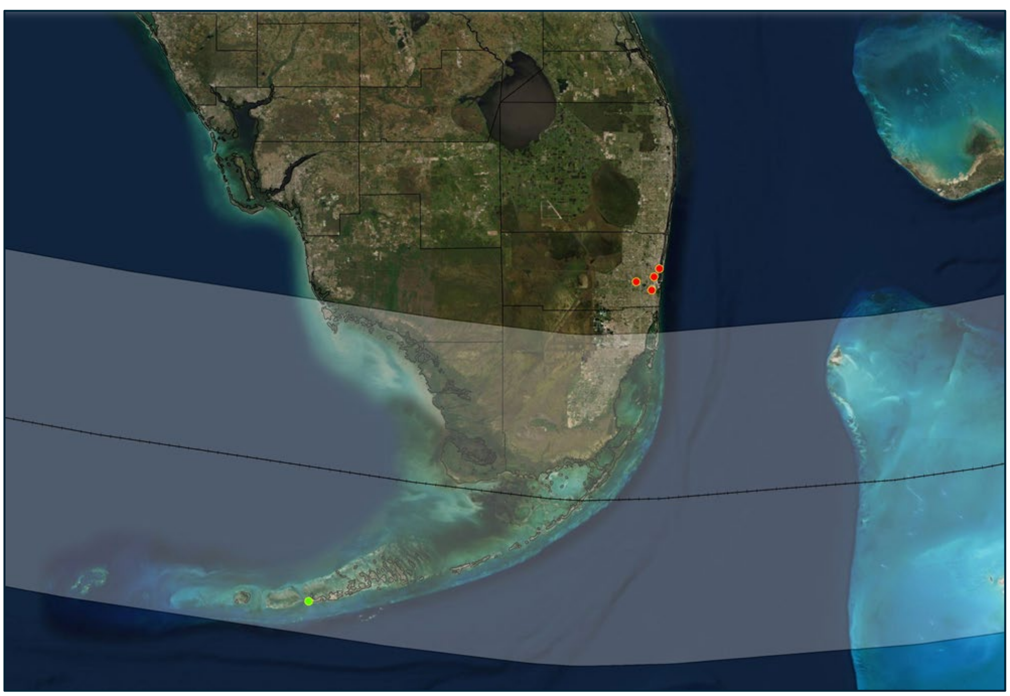

Figure 2.4: Measured Water Level Locations relative to Storm Track Offset – Hurricane Betsy

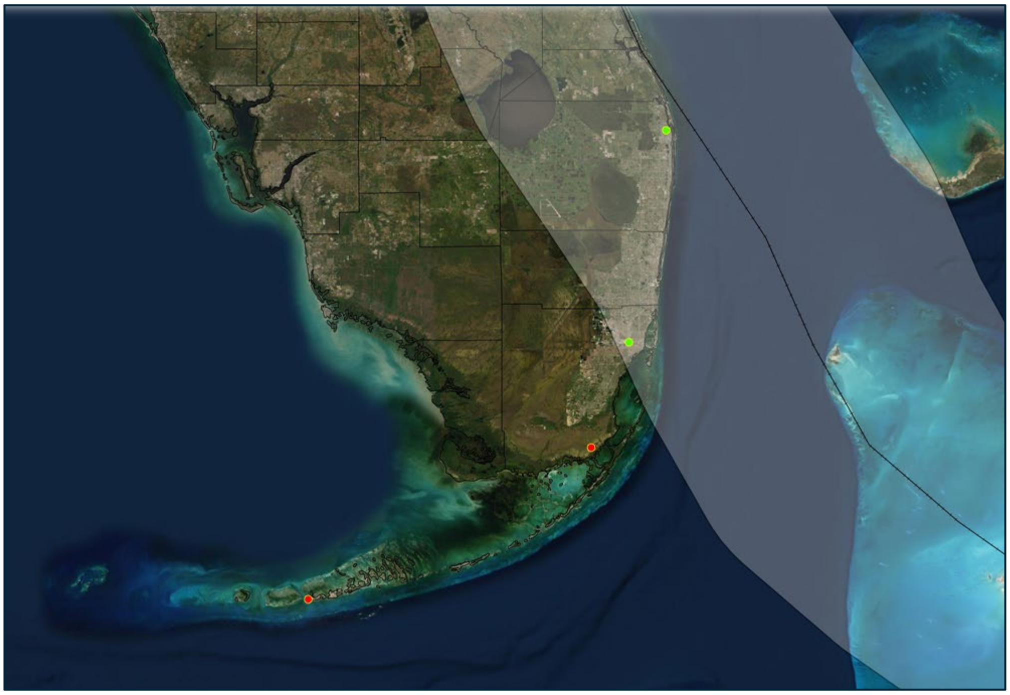

Figure 2.5: Measured Water Level Locations relative to Storm Track Offset – Hurricane David

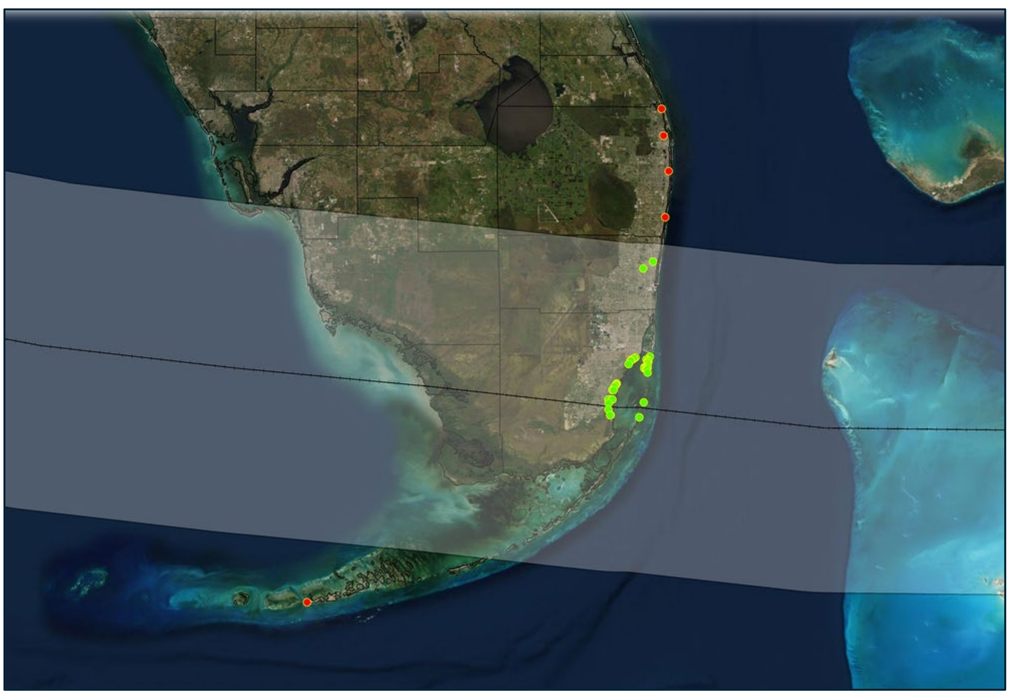

Figure 2.6: Measured Water Level Locations relative to Storm Track Offset – Hurricane Andrew

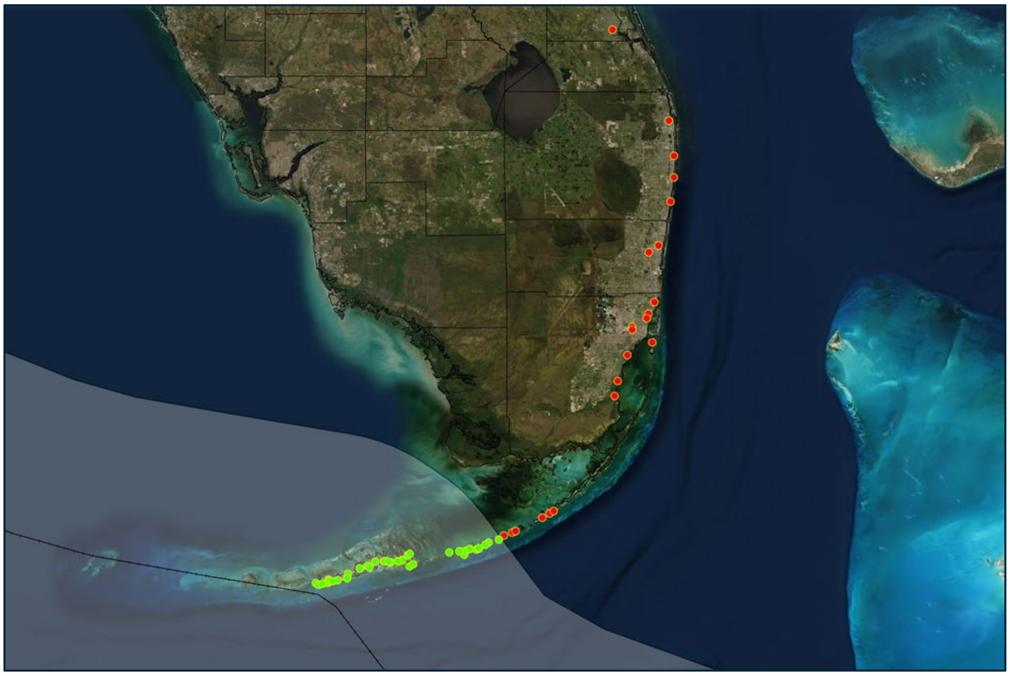

Figure 2.7: Measured Water Level Locations relative to Storm Track Offset – Hurricane Georges

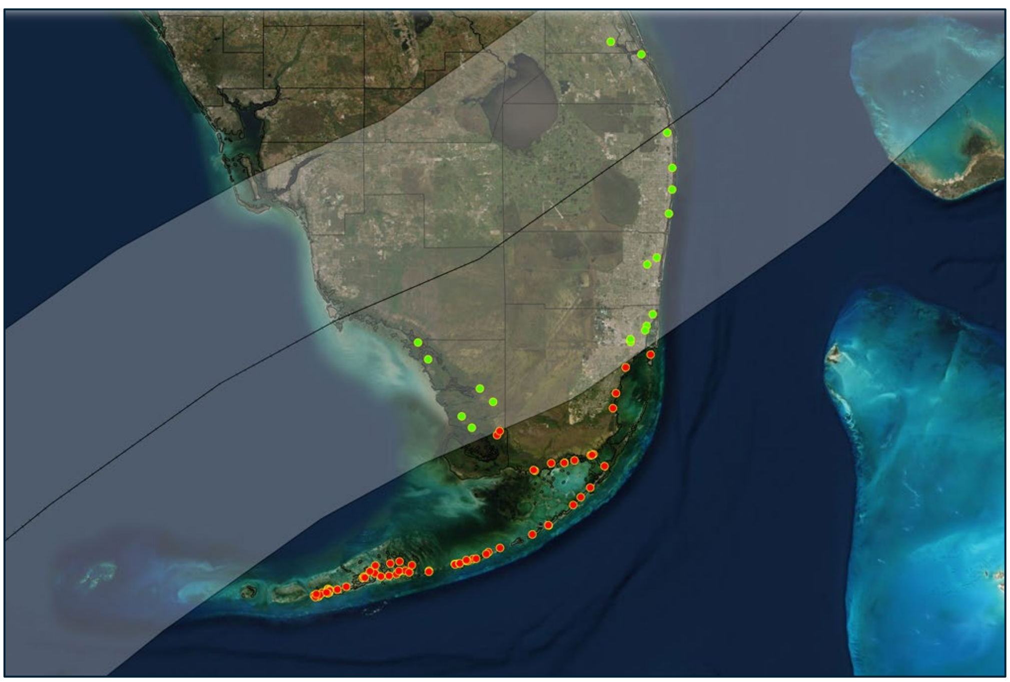

Figure 2.8: Measured Water Level Locations relative to Storm Track Offset – Hurricane Wilma

2.2 Model Uncertainty

The model uncertainty defined by FEMA is comprised of two terms: model skill; and the planetary boundary layer terms. The model skill term "represents the variations in water surface elevations due to lack of modeling accuracy as a result of approximations in physical processes" [12]. The planetary boundary layer term "represents the variations in water surface elevations due to a range of departures from the real behavior of hurricane wind and pressure fields that are not well represented by the planetary boundary layer" [12]. Model uncertainty discussed in this section pertains to the model skill term.

FEMA compared 244 measured peak water levels to modeled peak water levels to assess the SWAN+ADCIRC model's ability to simulate the peak of the storm stage during the validation storms. The model's ability was measured as uncertainty (skill), which was defined by FEMA as the standard deviations of the differences between model and measured water levels. FEMA identified an overall model uncertainty of 1.54 feet as shown in Table 2.2, but FEMA did not consider the proximity of measured water levels with respect to the storm tracks as part of the model validation.

Further analysis of the model uncertainty was performed with respect to the measured water level locations within and outside the 55-mile offset. (Table 2.2). The following was revealed.

- Hurricane Betsy: Model uncertainty could not be mathematically quantified within the offset, because only one location was available.
- Hurricanes Andrew and Wilma: The storms contained the greatest number of measured water level locations as compared to the other validation storms, but the storms had the greatest model uncertainties within the offset as well as for FEMA's approach in considering all of the locations. FEMA spent considerable efforts to improve the model validation for these storms. Hurricane Wilma was considered in both the SFL and East Coast Central Florida (ECCFL) studies, but ultimately eliminated from the ECCFL model validation citing "improvement of the capability of the [model]…to reproduce non-existing storm conditions within the project area," as well as "increased uncertainty in the wind and pressure fields for existing storms" [12]. Significant disagreement between modeled and measured water levels for Hurricane Andrew was noted by FEMA during the SFL study model validation, which necessitated an extensive sensitivity analysis of various parameters including bottom friction, nearshore reef elevations, wind sheltering and canopy settings, water depths in Biscayne Bay, initial water levels, wind drag coefficients, wind speed factors, storm landfall location, and storm forcing time intervals. The sensitivity analysis for Hurricane Andrew accounted for 75 out of the 142 model setup iterations performed by FEMA to validate the model. Ultimately, FEMA concluded that the model during Hurricane Andrew "produced a limited validation of the storm surge" [9] for the SFL study.
- **The overall model uncertainty within the offset was 1.95 feet as compared to 0.87 feet outside the offset. The model uncertainty within the offset was 2.24 times greater that the uncertainty outside the offset, which suggests that the model was not able to accurately simulate peak water levels within the areas that storm surges were most likely to be experienced**.
- The ECCFL study reported a model validation with an uncertainty of 0.75 feet for a study area with a 130 mile north-south coastline length. The model uncertainty for the SFL study within the 55-mile offset (= 110 miles of coastline for each storm) was 1.95 feet or 2.6 times greater than the ECCFL study.

Table 2.2: Model Uncertainty relative to Storm Track

Validation Storm	Model Uncertainty (feet)		
	Within Offset	Outside Offset	FEMA
Betsy (1965)	-	0.72	0.72
David (1979)	0.11	0.15	0.13
Andrew (1992)	2.05	0.58	2.00
Georges (1998)	0.99	0.94	0.99
Wilma (2005)	2.11	0.87	1.41
Overall:	1.95	0.87	1.54

The modeled versus measured peak water levels within the 55-mile offset, outside the offset, and for all points as reported by FEMA are presented as scatter plots in Figure 2.9. Clustering of points along the diagonal line in the figure indicates agreement between the modeled and measured data; greater spread indicates less agreement.

- According to NOAA's tide gage (Station #8722670) at the Lake Worth Pier in Palm Beach County, the highest astronomical tide for the tidal epoch between 1983 and 2001 was approximately +1.8 feet, NAVD88. Measured water levels below this elevation (grey boxes) were assumed to be largely influenced by astronomical tides and below the magnitude of the 1% still water elevations (SWEL) that the SFL study targeted.
- FEMA's modeling resulted in 1% SWEL's ranging from 5 to 9 feet, NAVD88 within Palm Beach County (orange boxes).
- Within the 55-mile offset (left panel), there was noticeably greater spread (less agreement) between the measured and modeled data above, below, and within the range of FEMA's 1% SWEL. Outside the 55-mile offset (middle panel), there was noticeably less spread (better agreement) but below the range of FEMA's 1% SWEL. All of the data as presented by FEMA (right panel) was provided for reference.

The analysis presented herein demonstrates that FEMA's ADCIRC+SWAN model had limited accuracy in simulating storm surge. This limitation contributed to greater model uncertainty and ultimately increased statistical SWEL (see Section 3).

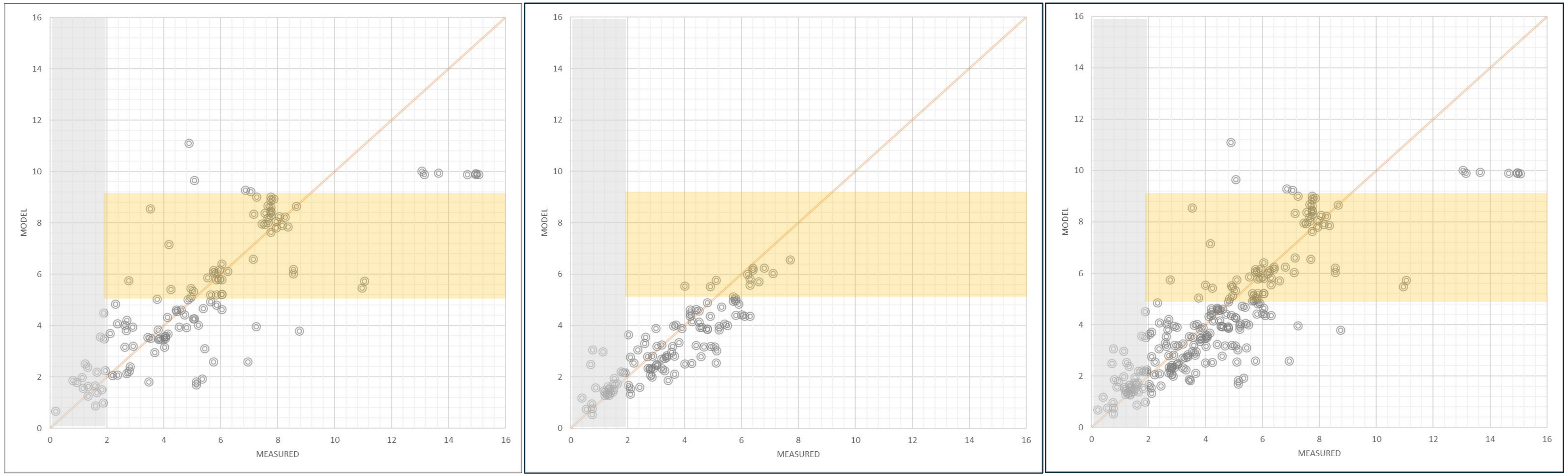

Figure 2.9: Measured-to-Modeled Peak Water Level (Left panel: Within Offset; Middle panel: Outside Offset; Right panel: FEMA/all)

2.3 Gage Selection

FEMA selected five storms for validation of the SWAN+ADCIRC model; one of which was Hurricane Wilma. Hurricane Wilma occurred in 2005 and tracked from southwest to northeast across the study area. The hurricane made landfall on the west coast within Collier County near Naples and exited on the east coast within Palm Beach County near Juno Beach. The model validation associated with Hurricane Wilma was reviewed further for the following reasons.

- It "did not produce significant surge in southern Palm Beach County or Broward Counties" [9] according to FEMA.
- It was the only "west" coast storm (i.e. making landfall on the west coast of Florida) and thus represented the only exiting storm for the SFL study.
- It had the second highest model uncertainty of the SFL study validation storms following Hurricane Andrew.
- It was the only common validation storm between FEMA's ECCFL study and the SFL study. The ECCFL study area extended north of the SFL study area to include Martin, St. Lucie, Indian River, and Brevard Counties.
- It was ultimately eliminated from the model validation of the ECCFL study citing "improvement of the capability of the [model]…to reproduce non-existing conditions" as well as "increased uncertainty in the wind and pressure fields for existing storms."

FEMA's model validation was based on the difference between measured and modeled peak water levels. Two hydrograph gages presented for the ECCFL within Palm Beach County included the South Florida Water Management District's (SFWMD) gages S46_T and S40_T positioned downstream (ocean side) of the SWFMD's water control structures for the C-18 and C-15 canals, respectively. The modeled water levels from the SFL study and ECCFL study overlain on the measured water levels at the S46_T and S40_T gages are discussed below.

- <u>SFWMD Gage S46_T</u> (Figure 2.11): **The gage is located within the Loxahatchee River system where the greatest discrepancies in 1% SWEL between the ECCFL and SFL studies were identified by FEMA. The gage was located approximately 2 miles north of Wilma's track according to NOAA, but the gage was not included in FEMA's model validation for the SFL study despite it being considered in the ECCFL study. FEMA did not provide an explanation for excluding the gage**. The maximum WSE modeled during the ECCFL study was 1.21 feet higher than the measured water level on October 24, 2005 (black circle). **The modeled WSE from the SFL study was extracted from FEMA's model data at the gage location and was found to resemble a sinusoidal shape associated with astronomical tides with little evidence of storm surge being simulated by the model**.
- <u>SFWMD Gage S40_T</u> (Figure 2.12): The gage is located on the west side of the intracoastal waterway at the border of Delray Beach and Boca Raton. The WSE modeled during the ECCFL study was constant before and after the storm, which indicates an error in the model setup as it did not account for tidally induced water level changes. The maximum WSE modeled during the SFL study exhibited better agreement before and after the storm and simulating storm surge (black circle).

The comparison revealed that the SFL study exhibited better agreement with measured peak WSE in southern Palm Beach County during model validation with Hurricane Wilma as compared to northern Palm Beach County. **This suggests that the SWAN+ADCIRC model's ability to accurately simulate storm surge in northern Palm Beach County may not be reliable and further raises doubt about FEMA excluding the northern SFWMD gage (S46_T) from the SFL model validation**. This may be related to the regional grid developed by FEMA for the storm forcing parameters not covering northern Palm Beach County and the resolution of the model mesh for simulating hydrodynamics through Jupiter Inlet (see Section 3).

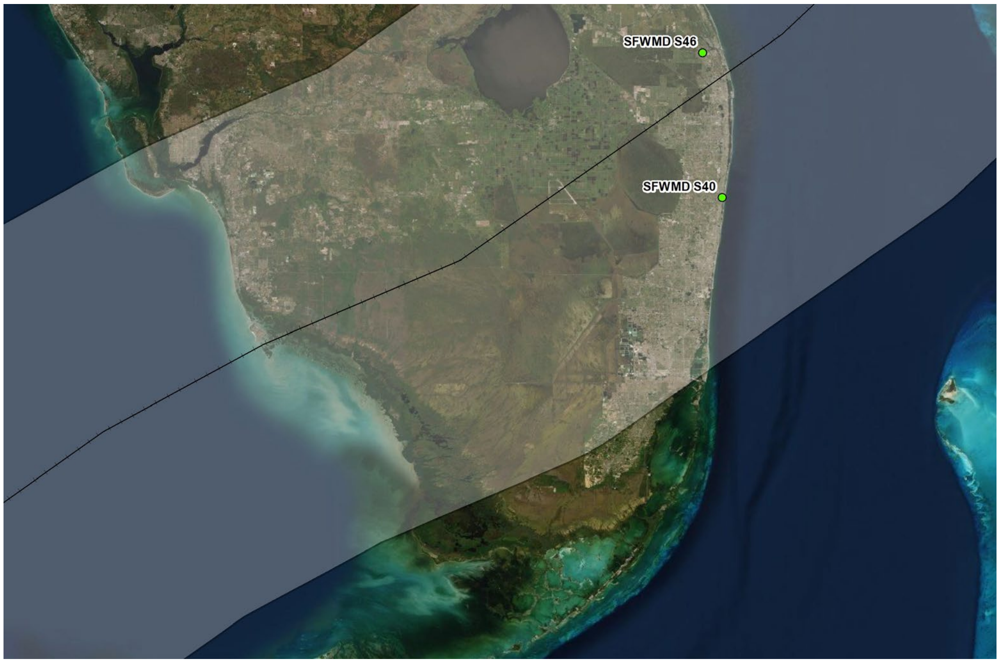

Figure 2.10: Hurricane Wilma Storm Track and SFWMD Gages

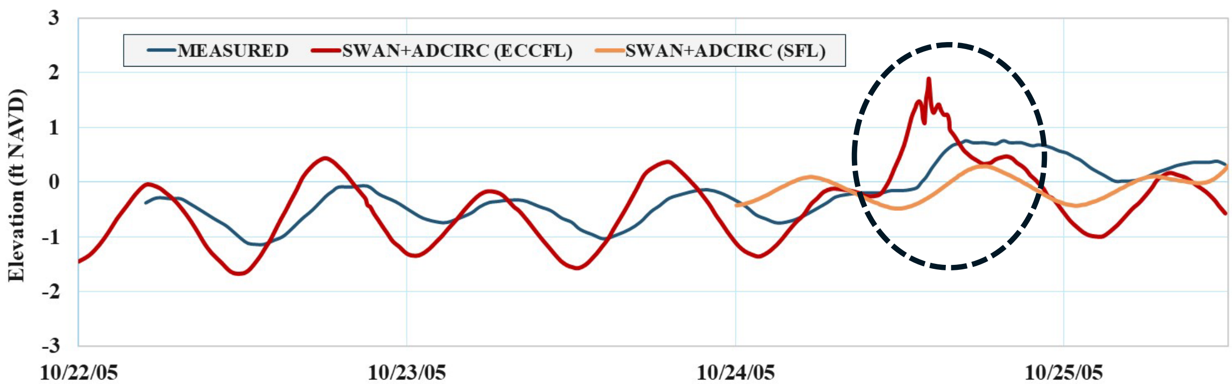

Figure 2.11: Hydrograph SFWMD Gage S46_T – Hurricane Wilma

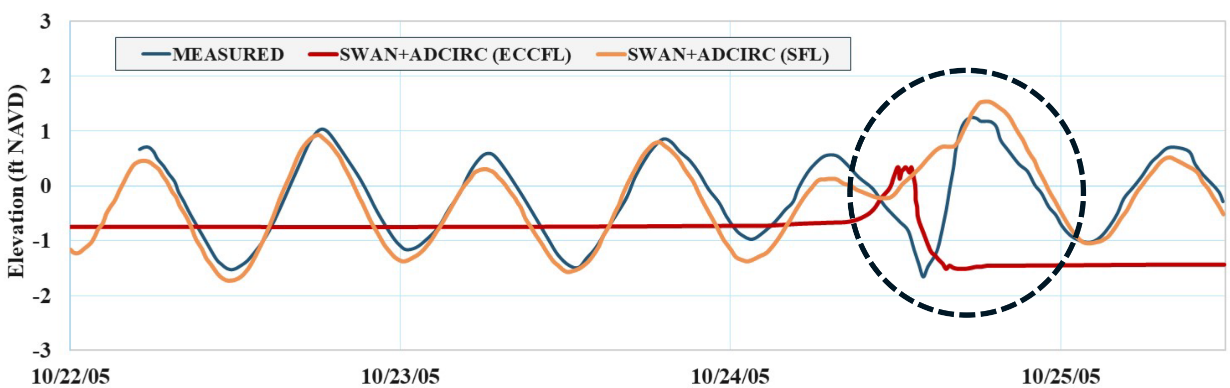

Figure 2.12: Hydrograph SFWMD Gage S40_T – Hurricane Wilma

3. Statistical SWEL

The SWAN+ADCIRC model was used by FEMA to simulate water surface elevations (WSE) throughout the study area during 392 synthetic storms. At each model node for each storm, the maximum WSE was recorded along with recurrence interval of the storm. This information along with the model uncertainty estimated by FEMA during model validation (see Section 2) were used as inputs to the SURGE_STAT program, which generated the statistical still water elevations (SWEL) for each node within the SWAN+ADCIRC model domain. A major contribution in identifying FEMA's special flood hazard areas (SFHA) is the 1% SWEL. Thus, considerations with respect to the development of the 1% SWEL are presented below.

3.1 Wind and Pressure Field Grids

In order to achieve satisfactory model performance, the SWAN+ADCIRC model requires a mesh that sufficiently represents bathymetric, topographic and land cover features of the study area as well as spatially varying storm forcing parameters (e.g. winds and pressure fields) defined on grids covering the entirety of the model domain to drive the hydrodynamic processes. FEMA states "for each new SWAN+ADCIRC model mesh, validation must demonstrate satisfactory model performance" [9]. Model performance for the SFL study focused on WSE.

The SWAN+ADCIRC model requires model mesh and grids resolution that can accurately define storm forcing parameters, resolve the hydrodynamic processes, and locally resolve numerical instabilities at land-water interfaces, around complex topographies/ bathymetries, and within inland water bodies, channels, and canals. However, running the model with finer resolutions is computationally more expensive. Computational time is balanced by creating a mesh that has coarser resolution (greater distances between nodes) outside the study area and that has finer resolution (reduced distances between nodes) within the study area, especially around features that is expected to experience high water level and current speed changes.

FEMA's coarse (basin) grid was approximately 5 times coarser than its finer (regional) grid that were used to simulate storm wind and pressure fields. FEMA's basin grid for simulating storm wind and pressure fields covers the whole model domain (Figure 3.1) at a resolution of 0.25 degrees (approximately 15 nm x 15 nm). Within the SFL study area, FEMA used a fine (regional) grid to resolve the distributions of the wind and pressure fields at a resolution of 0.05 degrees (approximately 3 nm x 3 nm) (Figure 3.2). The northern boundary of FEMA's regional grid was located approximately 12 miles north of the Palm Beach and Broward county lines, thus, **the northern 32 miles of Palm Beach County was not included in the finer regional grid and was modeled with the coarser basin grid**. **Therefore, the wind and pressure fields in Palm Beach County north of Boynton Inlet were modeled at a coarser resolution as compared to the rest of the SFL study area.**

The highest 1% SWEL reported by FEMA in Palm Beach County were found to occur within the southern portion of the Lake Worth Lagoon near Boynton Inlet. Review of FEMA's modeling data for the synthetic storms indicated that storm #21 produced the highest modeled WSE within this portion of the lagoon. Storm #21 was an "east" coast storm making landfall to the north near Palm Beach Inlet with a storm track from southeast to northwest as shown by the blue lines in Figure 3.1 and Figure 3.2. The track was located north, outside the regional grid. The modeled wind field at landfall for storm #21, extracted from FEMA's modeling data, is shown in Figure 3.3 to highlight the difference in model resolution between the basin (blue arrows) and regional (red arrows) grids. **The insufficient wind and pressure fields grid resolution over most of Palm Beach County limits the SWAN+ADCIRC model's ability to accurately simulate storm surges for storms making landfall north of and near the boundary of the regional grid.**

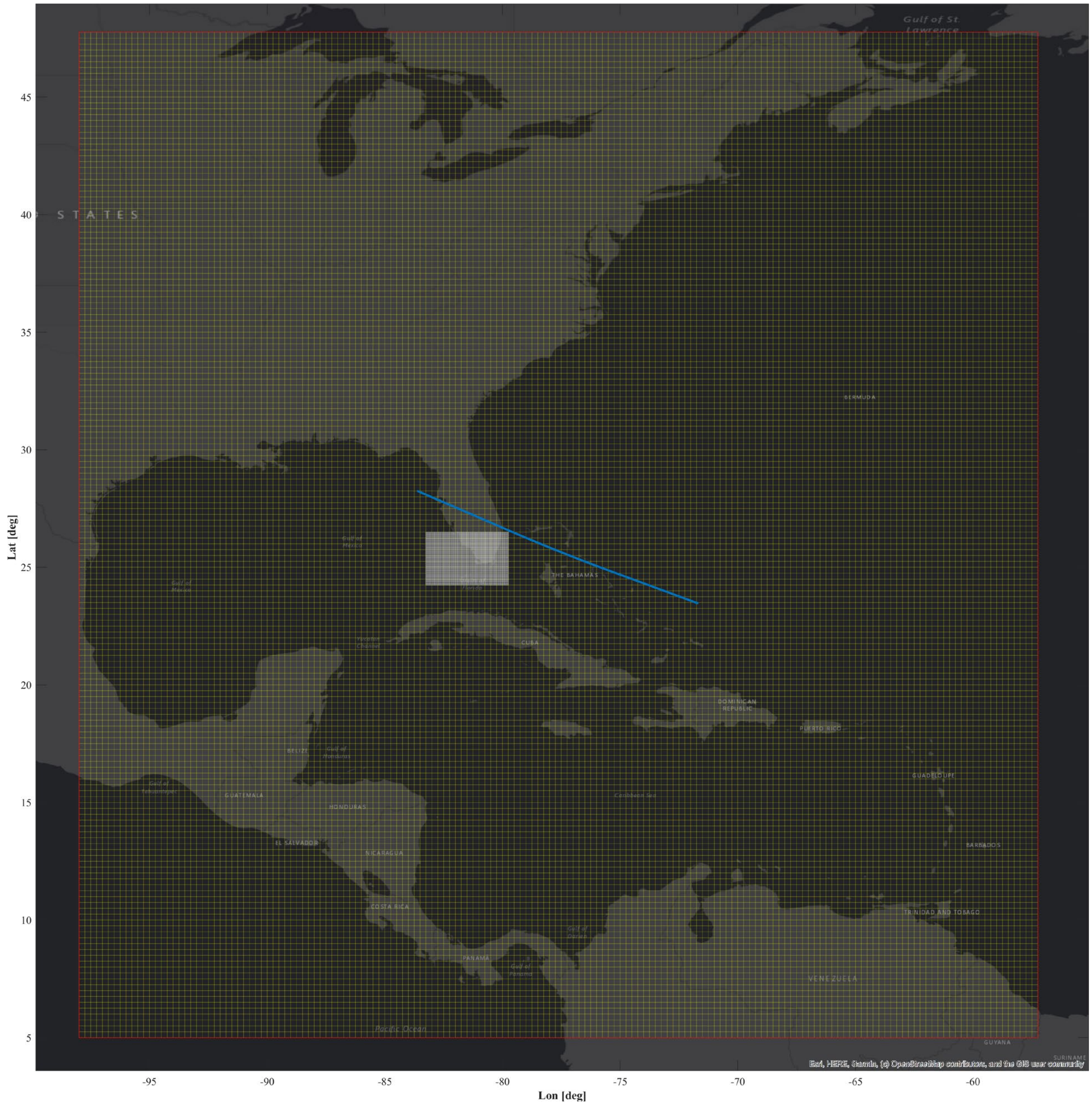

Figure 3.1: Wind and Pressure Field Grids (Basin Grid: yellow; Regional Grid: white)

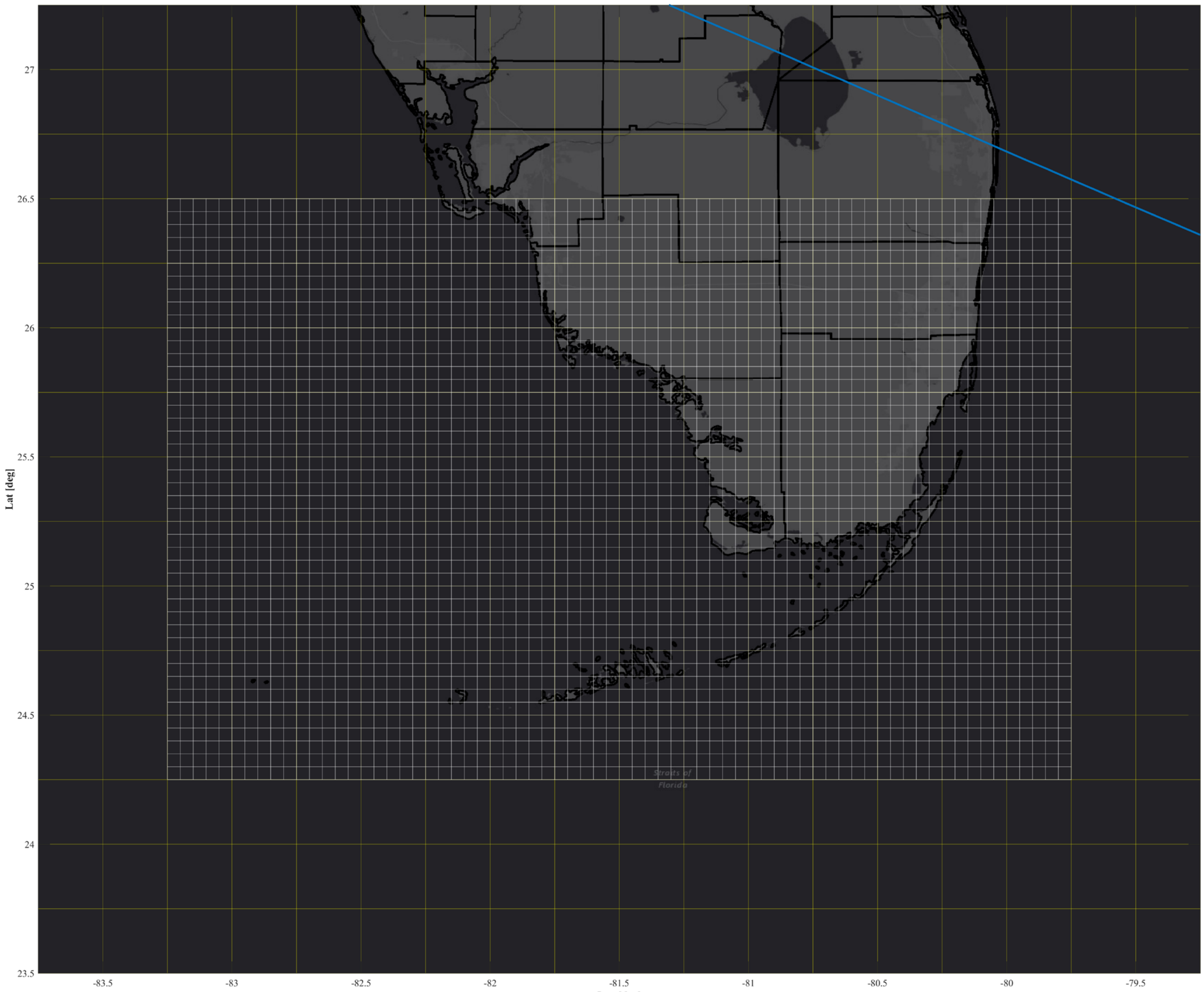

Figure 3.2: Wind and Pressure Field Grids (Basin Grid: yellow; Regional Grid: white)

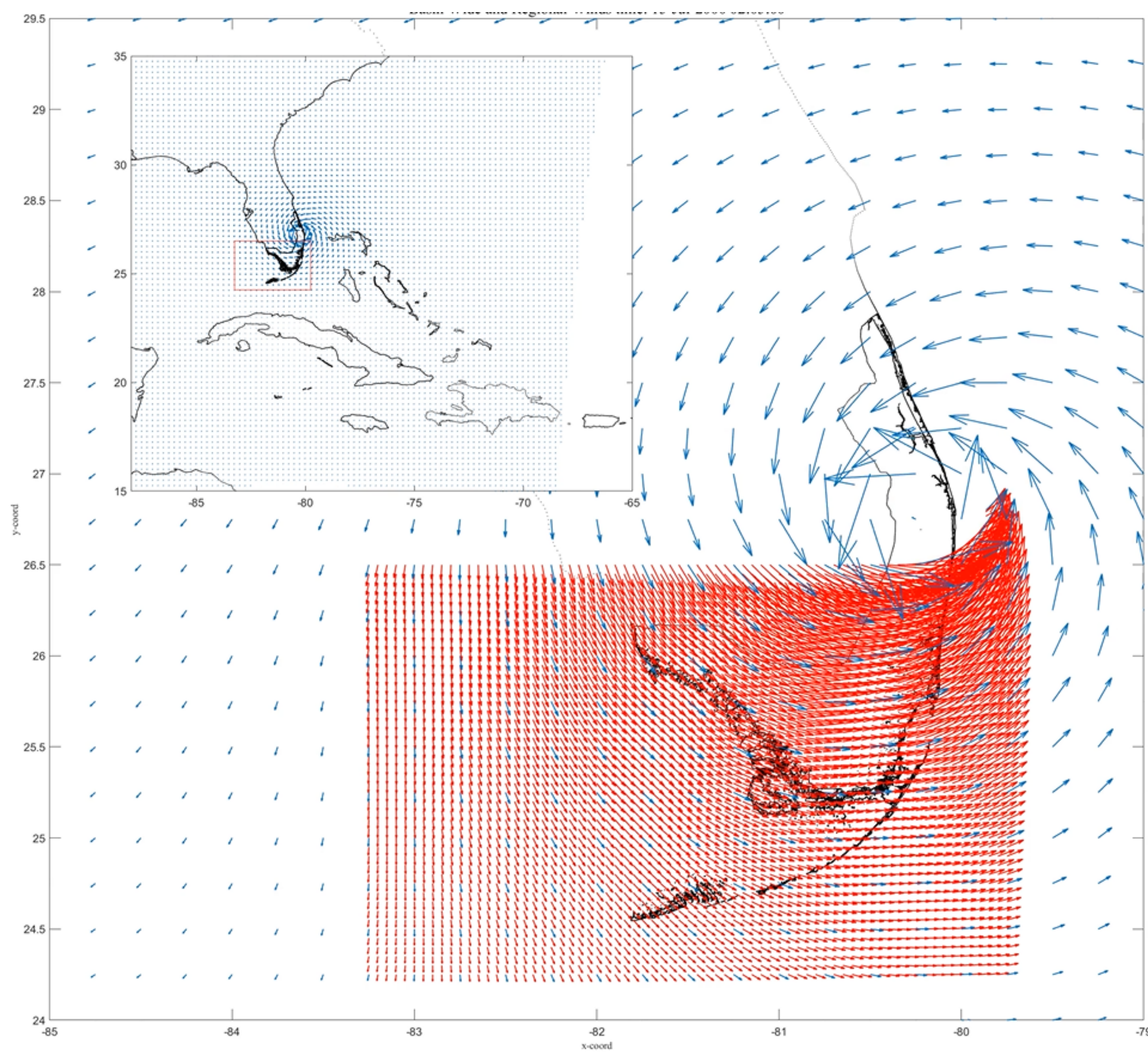

Figure 3.3: Wind Field Grids – Synthetic Storm #21 at Landfall (Basin Grid: blue; Regional Grid: red)

Storm #21, which produced the highest modeled WSE, was among 60 synthetic storms (out of FEMA's 392 total) that made landfall outside the wind and pressure fields regional grid. Figure 3.4 show landfall locations for each of the FEMA's 392 synthetic storms. Red dots indicate storms with landfall locations outside FEMA's regional grid; yellow dots indicate storms making landfall within the grid. Dots located offshore of land (e.g. northern Palm Beach County, south and west of Key West) indicate the closest point of the storms' tracks to the SFL study area.

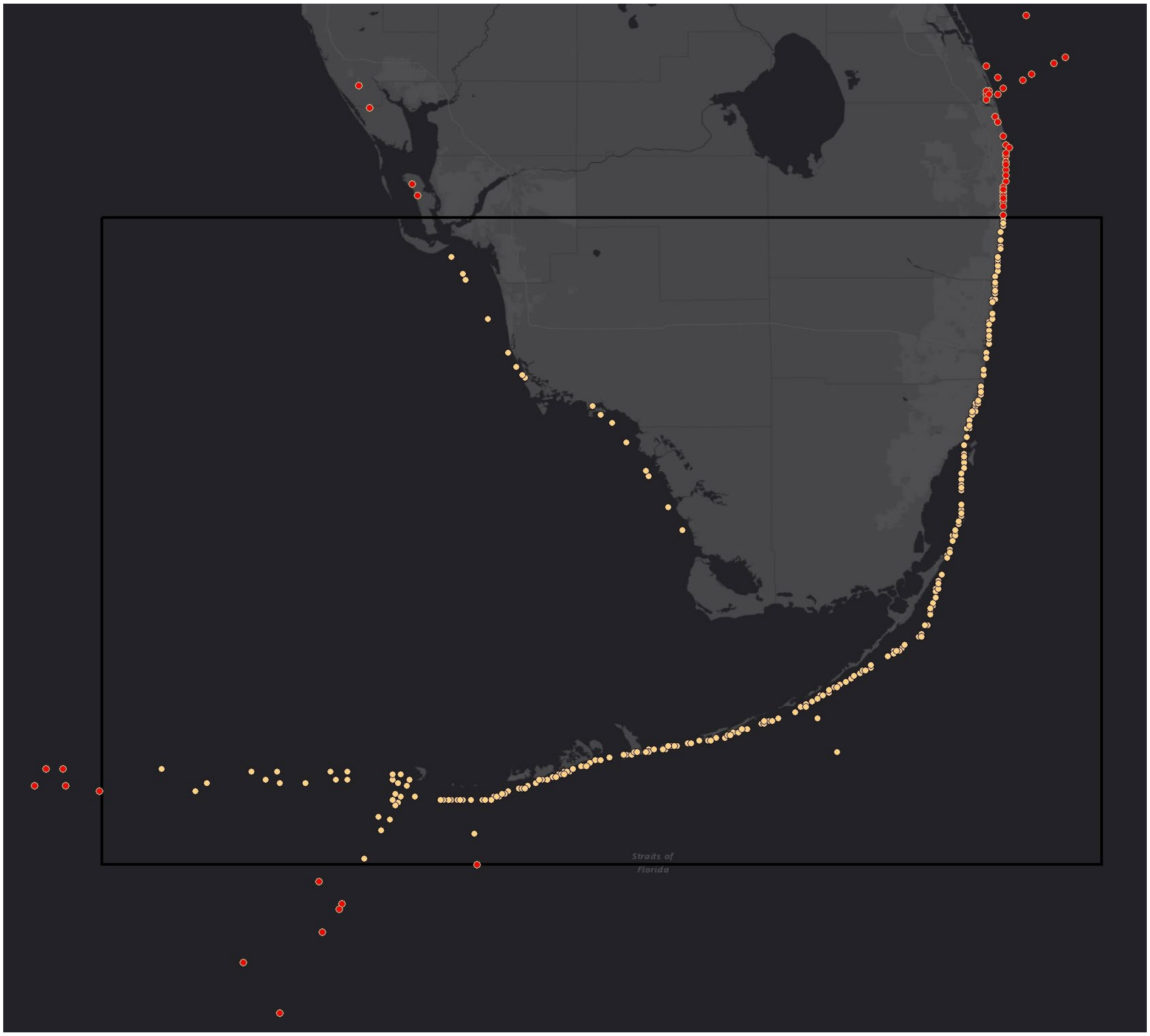

Figure 3.4: Wind and Pressure Field Regional Grid and Synthetic Storm Landfall Locations

3.2 Model Mesh

The SWAN+ADCIRC model requires a model mesh that sufficiently represents bathymetric, topographic, and land cover features within the study area. Finer mesh resolution increases computational time similar to wind and pressure field grids, but also reduces model instabilities.

FEMA encountered several model instabilities while simulating the synthetic storms. **FEMA's approaches to resolving the instabilities were to adjust the model meshes by "filling" canals or hydraulic connections and to restrict localized water level gradients between model nodes. These approaches are routine and customary for numerical models as long as it is demonstrated that they do not alter the hydrodynamic and coastal flooding processes elsewhere within the study area. FEMA's documentation was presented at a countywide scale, but not at a scale that the localized effects could be reviewed.**

FEMA's approaches to resolving model instabilities were applied at the following locations within Palm Beach County:

- <u>"Filling" Canals</u>: Wetting and drying of model nodes during model simulations can cause model instabilities, which "filling" can alleviate. Canals along the Loxahatchee River and ICWW in Jupiter and Tequesta were filled by FEMA as shown in Figure 3.5. The left graphic shows the model mesh based on topographic elevations prior to "filling" canals; the right graphic shows the model mesh after "filling" canals. The red circles identify the areas that the model mesh was manipulated.
- <u>Restricting Localized Water Level Gradients</u>: Sudden and drastic changes in water levels (e.g. gradients) between model nodes can cause model instabilities, which defining localized maximum gradients can alleviate. FEMA defined gradients at two locations within Palm Beach County near the northern and southern ends of the Lake Worth Lagoon as shown in Figure 3.6. The model nodes where localized gradients were specified are indicated as by the blue and purple dots.

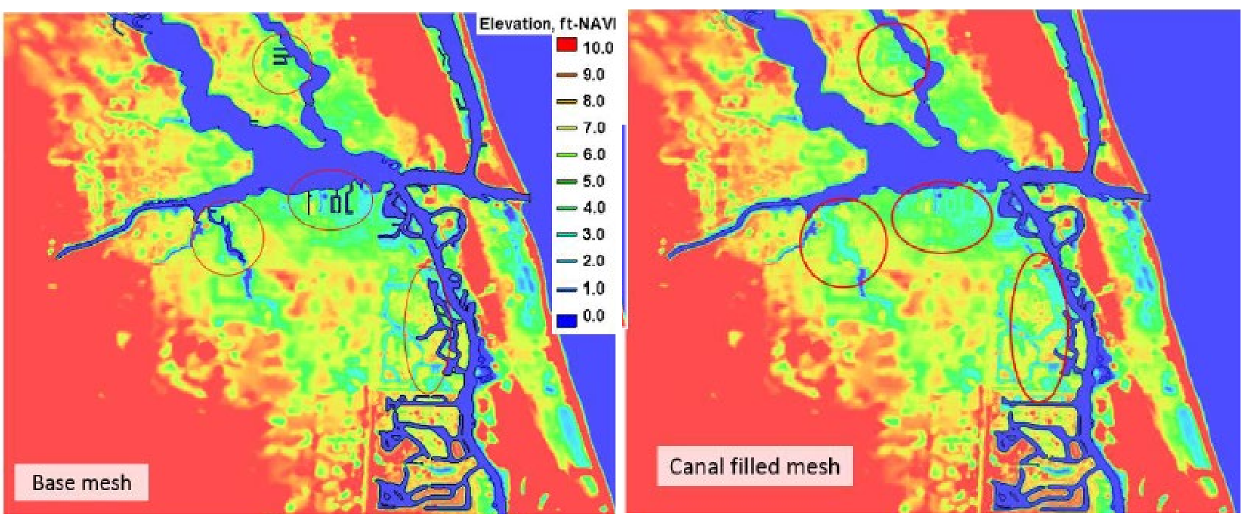

Figure 3.5: Model Instabilities – "Filled" Canals (FEMA, 2019, [9])

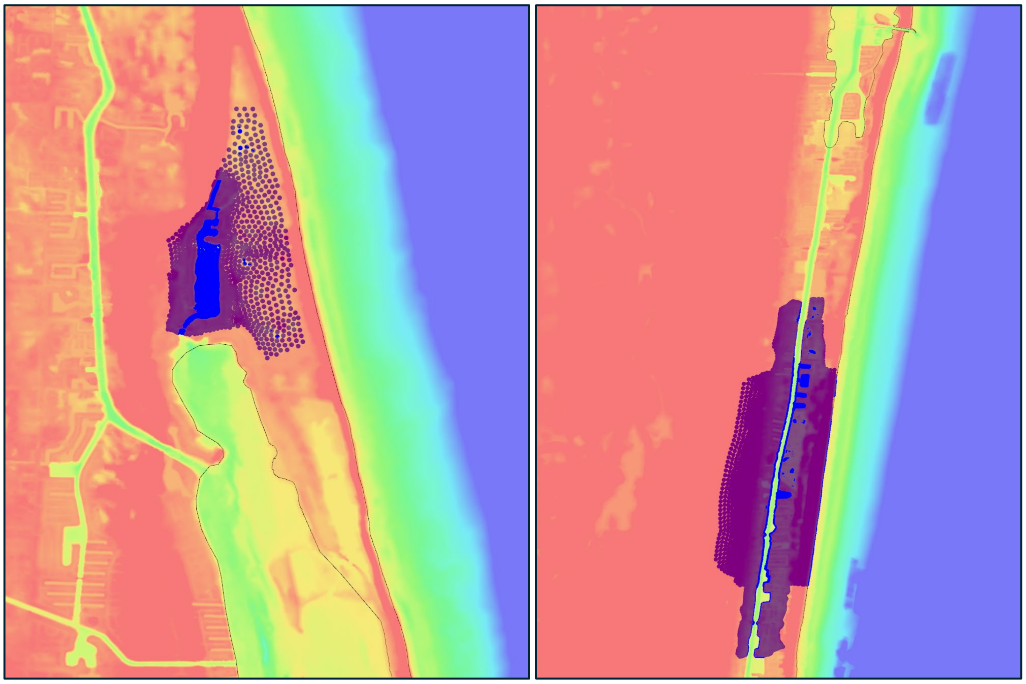

Figure 3.6: Model Instabilities – Restricted Localized Water Level Gradients (FEMA, 2019, [9])

FEMA reported that the model mesh developed for the SFL study provided sufficient resolution to "included channels at least 30-feet wide," while channels narrower than 30 feet were excluded. **Review of FEMA's model mesh and results of synthetic storm revealed several locations within Palm Beach County where the mesh resolution was insufficient to accurately model hydrodynamic and coastal flooding processes within the study area.** The insufficient mesh resolution and/or improper mesh definition was identified in four particular locations and are discussed below.

- Boynton Inlet: The inlet is located at the southern end of the Lake Worth Lagoon where some of the highest modeled WSE that contributes to 1% SWEL's within Palm Beach County were simulated by FEMA. The inlet is narrow (~120 feet wide) as compared to other east coast inlets, but 4 times wider than FEMA's 30-foot minimum criteria. **During the synthetic storm (#21) that produced the highest WSE within the lagoon, FEMA's model did not allow water to flow out through the inlet creating unrealistic WSE changes in the inlet thereby affecting WSE within the lagoon as the storm passed to the north**. This was evident by the elevated WSE within the lagoon (+10 ft, NAVD88), rapid drawdown of the WSE within the inlet (-10 ft, NAVD88), and then the rapid rise to match the WSE within the Atlantic Ocean (+2 ft, NAVD88) as shown by the red dashed circle in Figure 3.7. The WSE changes occurred within a distance of approximately 500 feet. A closer look at the model mesh revealed that within the inlet one node had been included along the inlet centerline with adjacent nodes along the inlet banks. The wetting/drying of nodes within the SWAN+ADCIRC model combined with insufficient mesh resolution appears to have contributed to the unrealistic WSE changes thereby not accurately simulating hydrodynamics through the inlet and in turn affecting WSE within the lagoon.

  In addition, the model mesh at Boynton Inlet was found to include a gap (low section) in the north jetty at the intersection with the coastline creating an additional hydraulic connection, which does not exist.

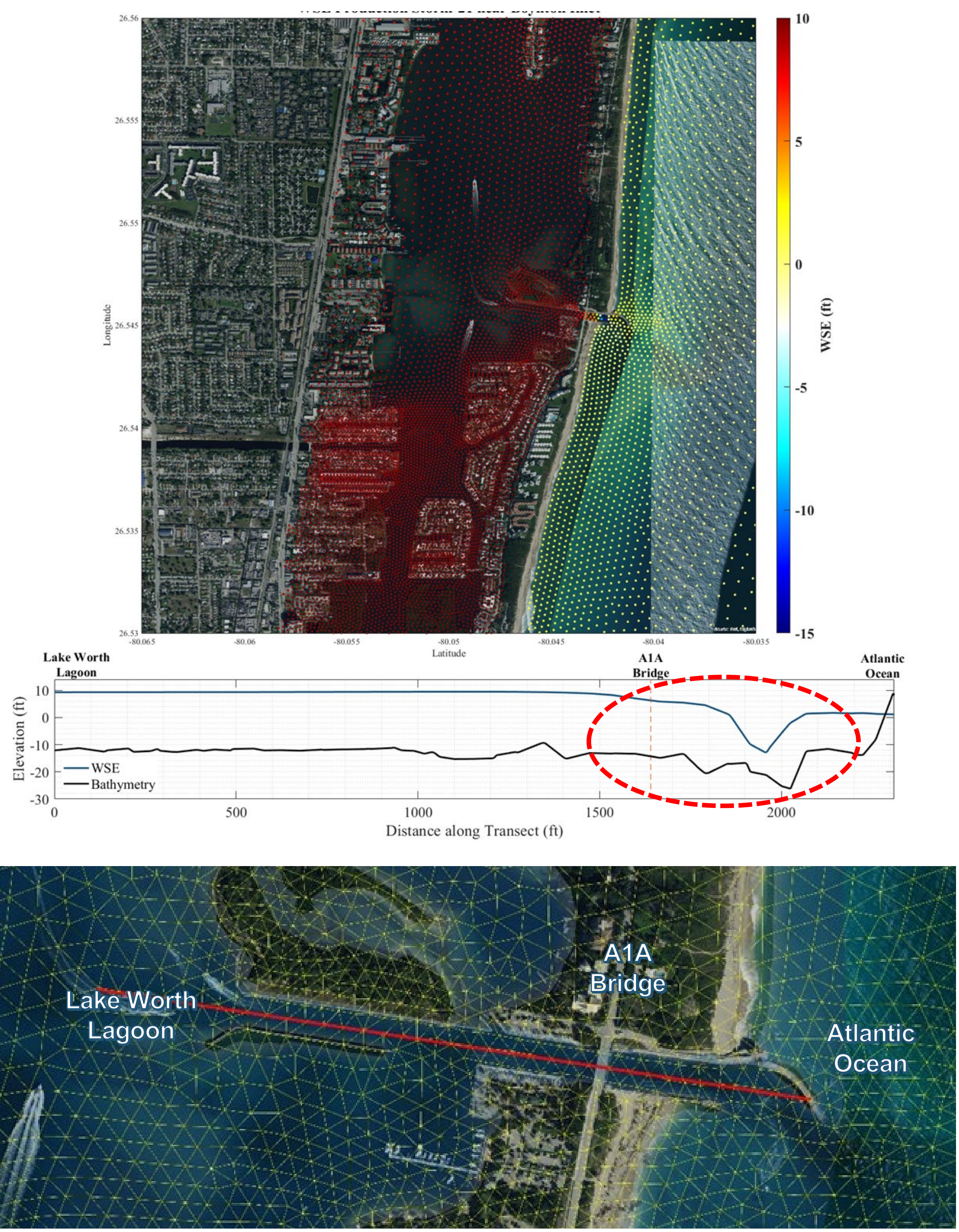

Figure 3.7: Water Surface Elevation – Boynton Inlet – Synthetic Storm #21

- Jupiter Inlet: Similar to Boynton Inlet, discontinuities in the WSE were observed during the synthetic storm (#21) that generated the highest WSE within the inlet. As the storm passed to the south, the model did not allow water to flow into the inlet creating discontinuities in the WSE. This was evident by the elevated WSE within the Atlantic Ocean (+6 ft, NAVD88), drawdown of the WSE within the inlet (+2 ft, NAVD88), and then the rise to match the WSE within the Loxahatchee River (+4 ft, NAVD88) as shown by the red dashed circle in Figure 3.8. The discontinuities occurred within a distance of approximately 1,000 feet.

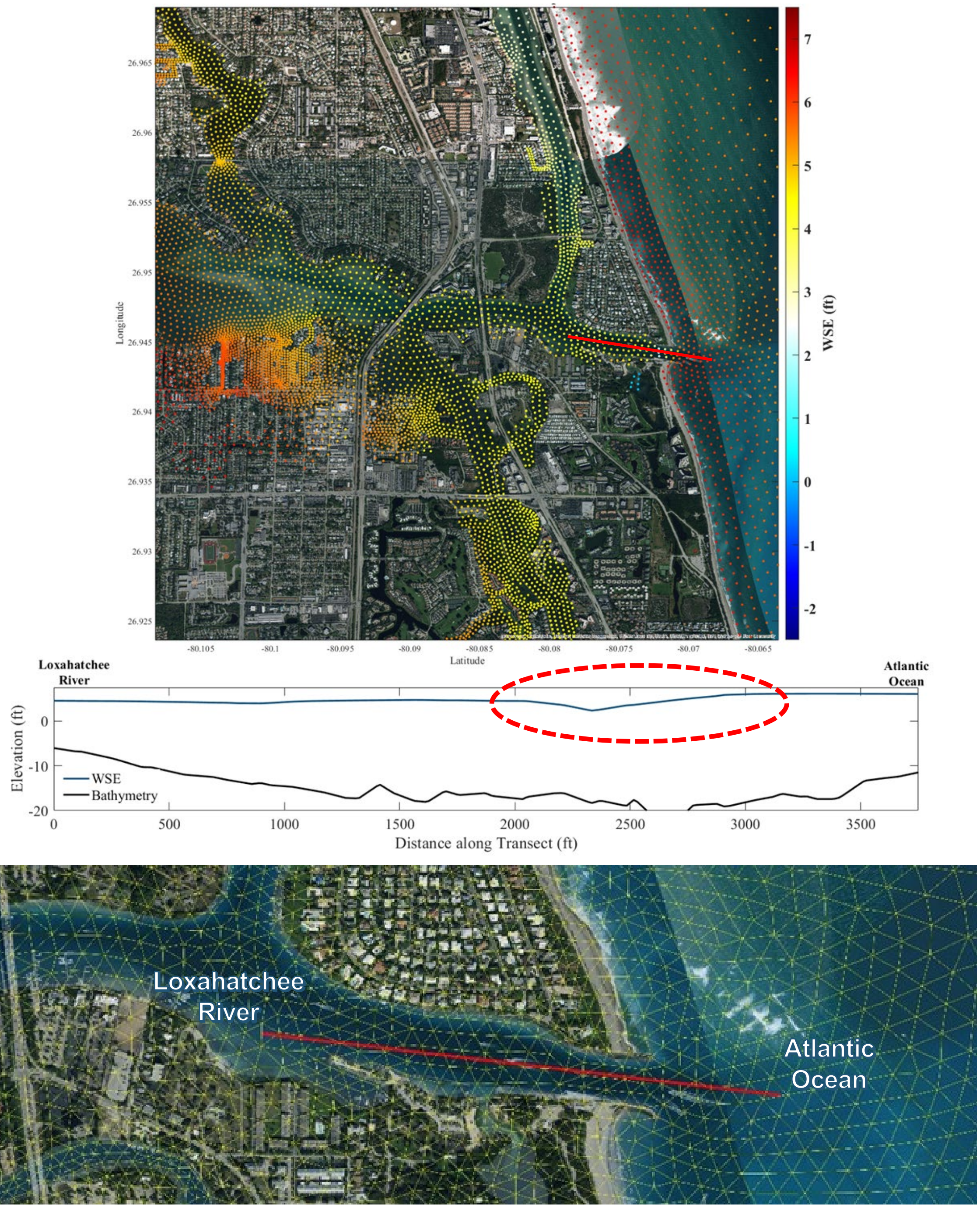

Figure 3.8: Water Surface Elevation – Jupiter Inlet – Synthetic Storm #21

- <u>Lake Little Worth</u>: FEMA's model mesh at Jack Nicklaus Drive Bridge separating Lake Little Worth from the Lake Worth Lagoon was not found to be representative of the conditions at the bridge. The mesh indicated a bottom elevation of approximately +4 feet, NAVD88 beneath the bridge, which would render the 75+ foot wide channel unnavigable to boat traffic. The model mesh created a "dike" representing a closed channel condition eliminating a known hydraulic connection greater than FEMA's 30-foot minimum criteria. Elevated WSE within the lagoon could not flow into or out of the lake until the water overtopped the "dike" as shown by the red dashed circle in Figure 3.9. The closed condition eliminated a hydraulic connection, diverting storm surge, and thereby affecting WSE elsewhere within the localized area.

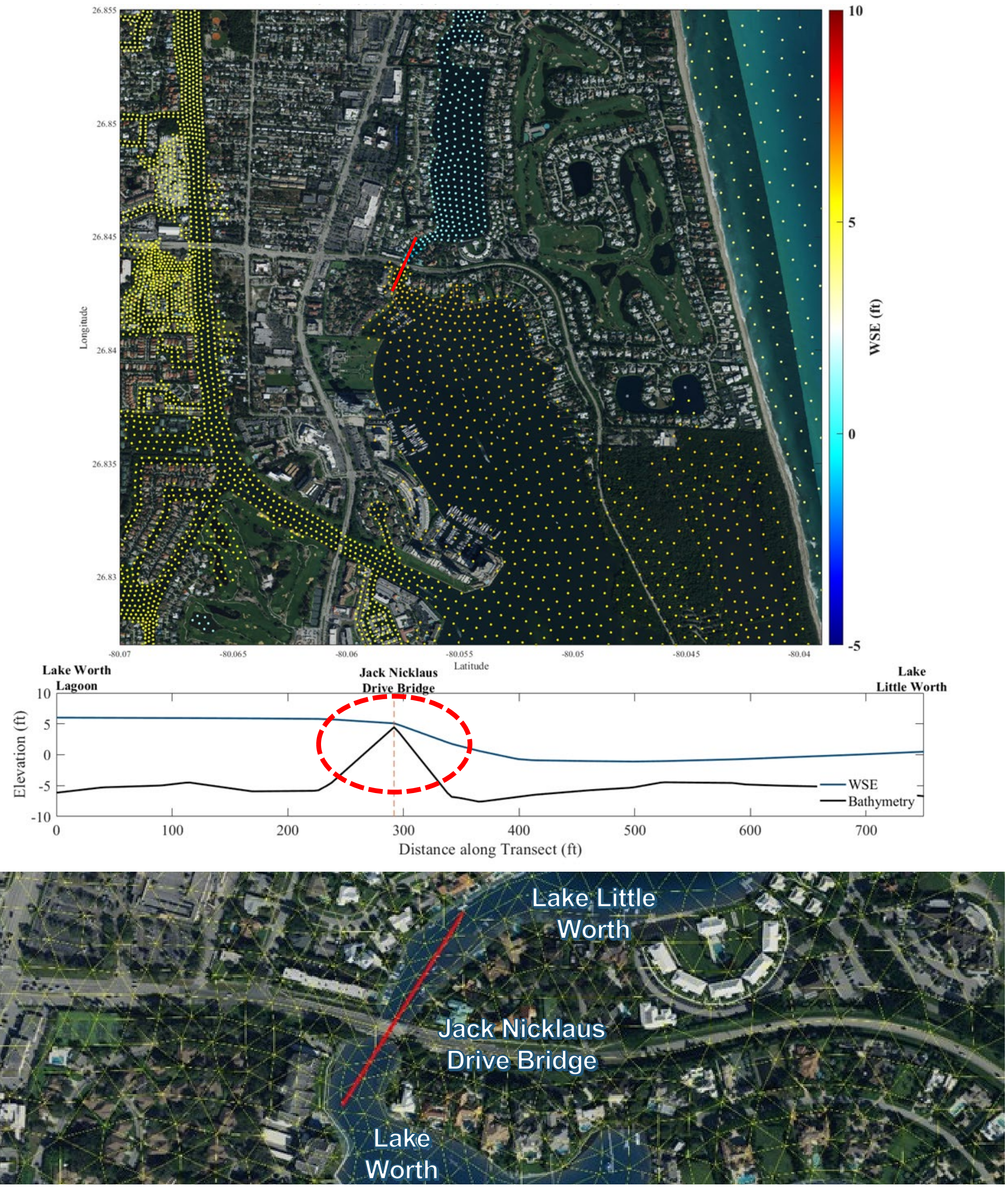

Figure 3.9: Water Surface Elevation – Lake Little Worth – Synthetic Storm #21

- Northern Palm Beach: Similar to Lake Little Worth, the model mesh did not reflect conditions within the north-south canal under the Lighthouse Drive Bridge in Northern Palm Beach. The mesh indicated a bathymetric elevation of approximately +3 feet, NAVD88 beneath the bridge, which would render the 50+ foot wide channel unnavigable to boat traffic. The model mesh reflected closed channel condition eliminating a known hydraulic connection that is greater than FEMA's 30-foot minimum criteria. Elevated WSE north of the bridge could not flow south as shown by the red dashed circle in Figure 3.10. The closed condition eliminated a hydraulic connection thereby affecting WSE within the localized area.

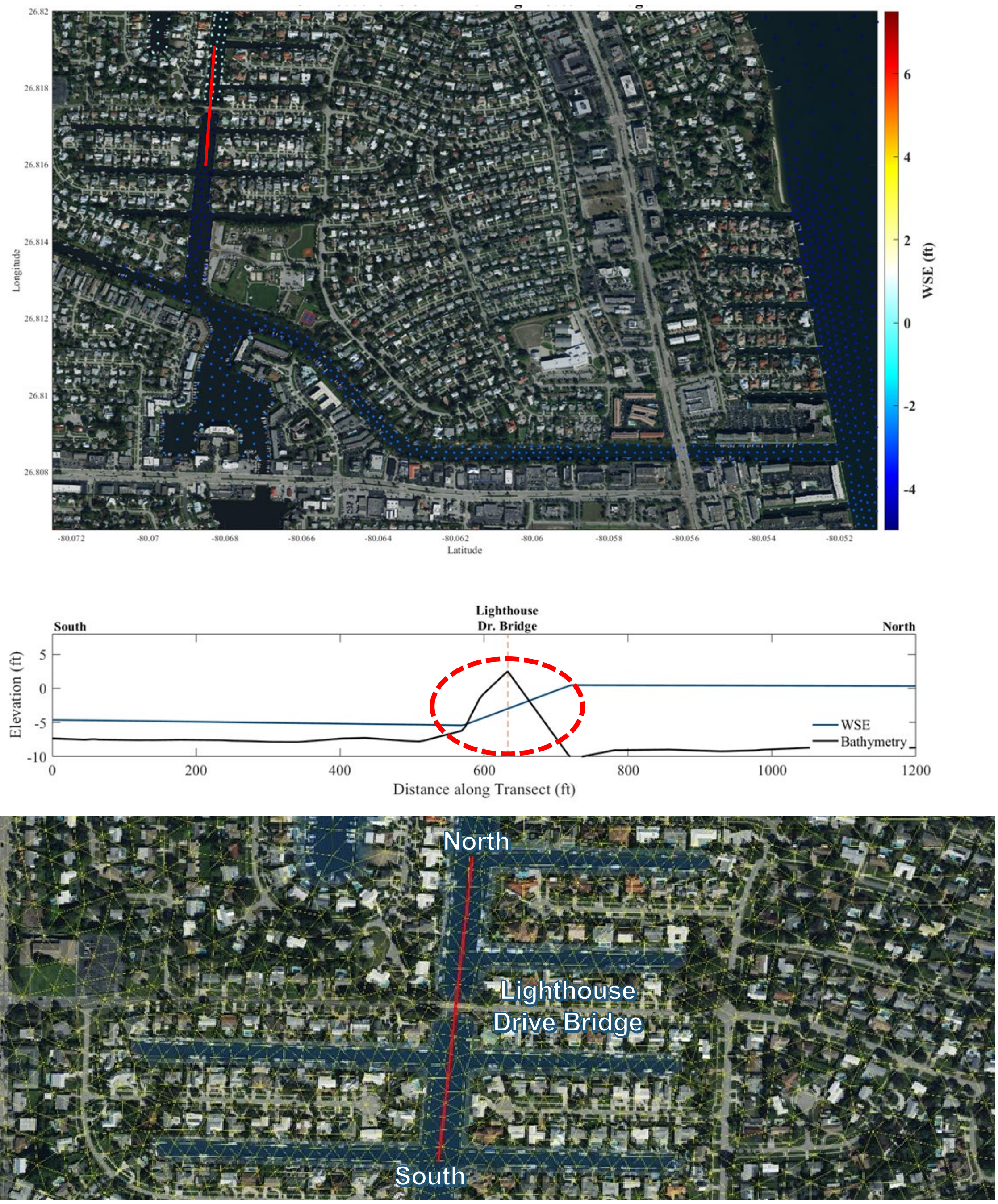

Figure 3.10: Water Surface Elevation – Northern Palm Beach – Synthetic Storm #21

3.3 1% SWEL

The 1% SWEL was considered by FEMA as the major component to define the inland extent of coastal special flood hazard areas (SFHA) when overlaid on digital elevation models (DEM). The maximum water surface elevation (WSE) for each synthetic storm from the SWAN+ADCIRC modeling was recorded by FEMA at each of the nodes within the model mesh. FEMA used the maximum WSE and model uncertainties as inputs to the SURGE_STAT program to generate return frequency curves at each model node. These frequency curves are then used to derive the 1%-annual-chance WSE (1% SWEL) at each node.

FEMA's methodology to define wave input parameters for the coastal hazard analysis requires that the synthetic storm with a maximum WSE closest to the 1% SWEL be identified as well as the nine storms with WSE above and nine storms below the 1% SWEL. The average wave conditions generated by these 19 storms bracketing the 1% SWEL are then used as wave input parameters for the coastal hazard analysis.

FEMA reported that model nodes "in some areas" of the SFL study had 1% SWEL that were not bracketed in accordance with FEMA's standards or that were above the maximum WSE generated by the synthetic storms. FEMA attributed this to the model "uncertainty and the combined storm frequency curves" used define the 1% SWEL. FEMA's methodology to extract the wave parameters for the coastal hazard analysis was modified reducing the number of storms included in the average to allow the wave parameters to be defined. However, FEMA provided limited (if any) information regarding the locations or spatial extents of the nodes where the modified methodology was applied.

Figure 3.11, developed from FEMA's modeling data, conveys the number of synthetic storms that generated WSE greater than the 1% SWEL at each of the SWAN+ADCIRC model nodes. Red nodes indicate model nodes where none of the storms generated WSE above the 1% SWEL; green nodes indicate model nodes where more than nine storms generated WSE above the 1% SWEL.

- West Coast: Offshore of the coast, the model nodes indicated there were 9+ synthetic storms with WSE above the 1% SWEL.
- East Coast: **Offshore of the coast, the model nodes indicated there were no synthetic storms with WSE above the 1% SWEL**. A major contributor to coastal storm surge on the east coast of Florida is water from the Atlantic Ocean being forced up against the coast and into interior water bodies through coastal inlets or overtopping of the barrier islands during storm events. **With no storms bracketing FEMA's 1% SWEL immediately offshore of Palm Beach County (and the east coast of the study area), the more extreme synthetic storms were not statistically represented by FEMA's modeling and/or FEMA's 1% SWEL may have been overestimated. Unreliable offshore water levels translate into potentially unreliable water levels within interior water bodies and unreliable mapping of flood risks.**

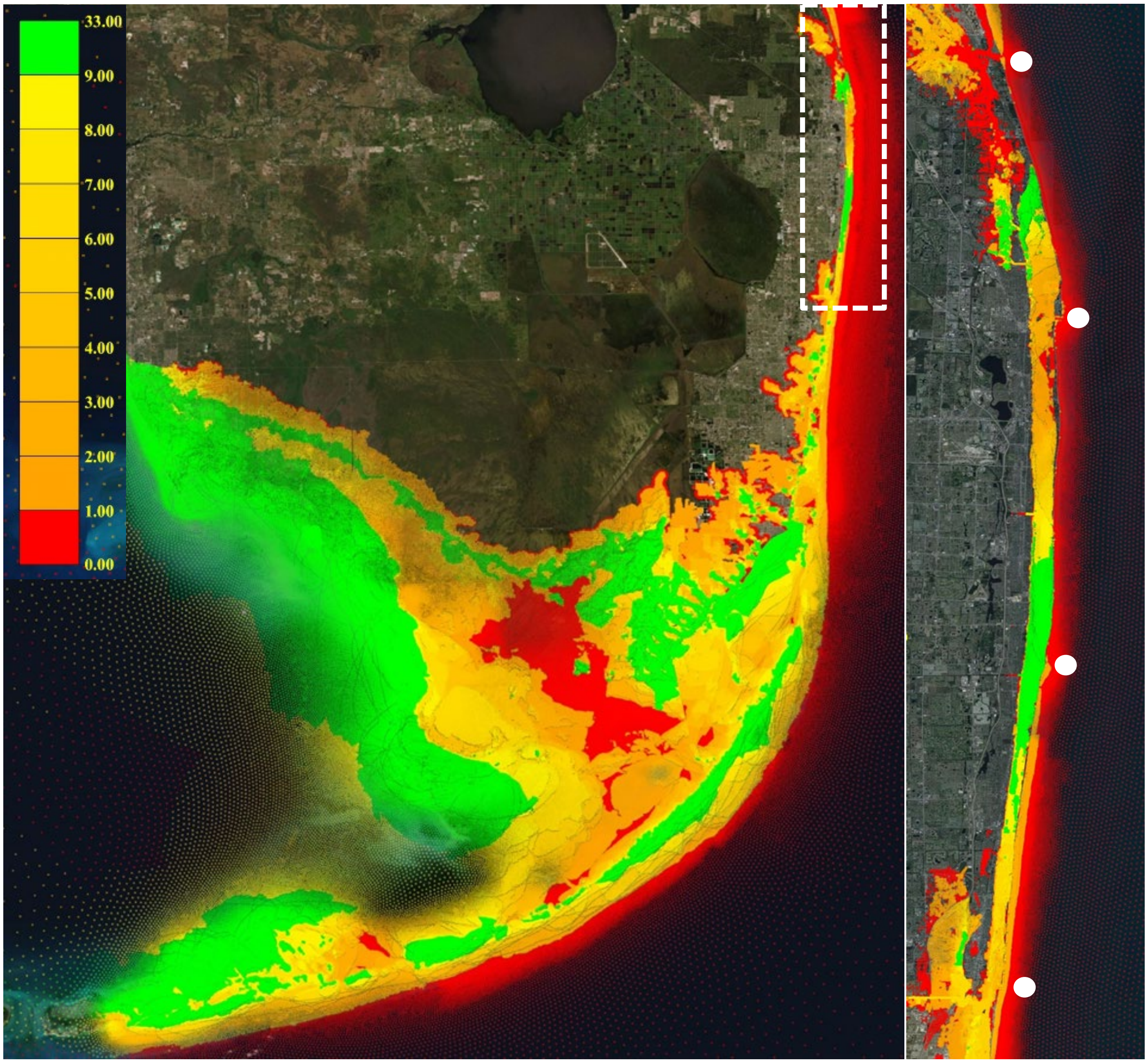

Figure 3.11: SWAN+ADCIRC Model Nodes – # of Synthetic Storms with Maximum WSE > 1% SWEL

FEMA utilized the SURGE_STAT program to generate the WSE return frequency curves at each SWAN+ADCIRC model node. The white symbols in Figure 3.11 are located offshore of the four coastal inlets in Palm Beach County, which from north to south include Jupiter Inlet, Palm Beach (Lake Worth) Inlet, Boynton (South Lake Worth) Inlet, and Boca Inlet. The symbols indicate model nodes within water depths of approximately 40-60 feet that are largely offshore of the wave breaking to be consistent with FEMA's basis for defining the starting wave conditions for its coastal hazard analysis. The WSE return period frequency curves extracted from FEMA's modeling data at each of the nodes are shown in Figure 3.12 and Figure 3.13. The curves for the "west" coast storms (red curve; exiting storms) and "east" coast storms (blue curve; landfalling storms) were shown to highlight their contribution on the "combined" curves (black) developed by FEMA. The dots along each curve represent FEMA's simulated maximum WSE for each of the synthetic storms. The horizontal green dashed line represents the threshold for defining the 1% annual chance level of occurrence (1% SWEL). In reviewing the curves, the following observations were made.

- The WSE of west coast storms were generally clustered above the 5% annual chance level. Note higher percent annual chance levels equate to lower WSE.
- The WSE of the east coast storms were above the 1% annual chance level, thus the WSE did not exceed 1% SWEL.
- The WSE of the combined set of storms (east + west coast storms) indicated even greater WSE for the 1% SWEL compared to the east and west coast storms.

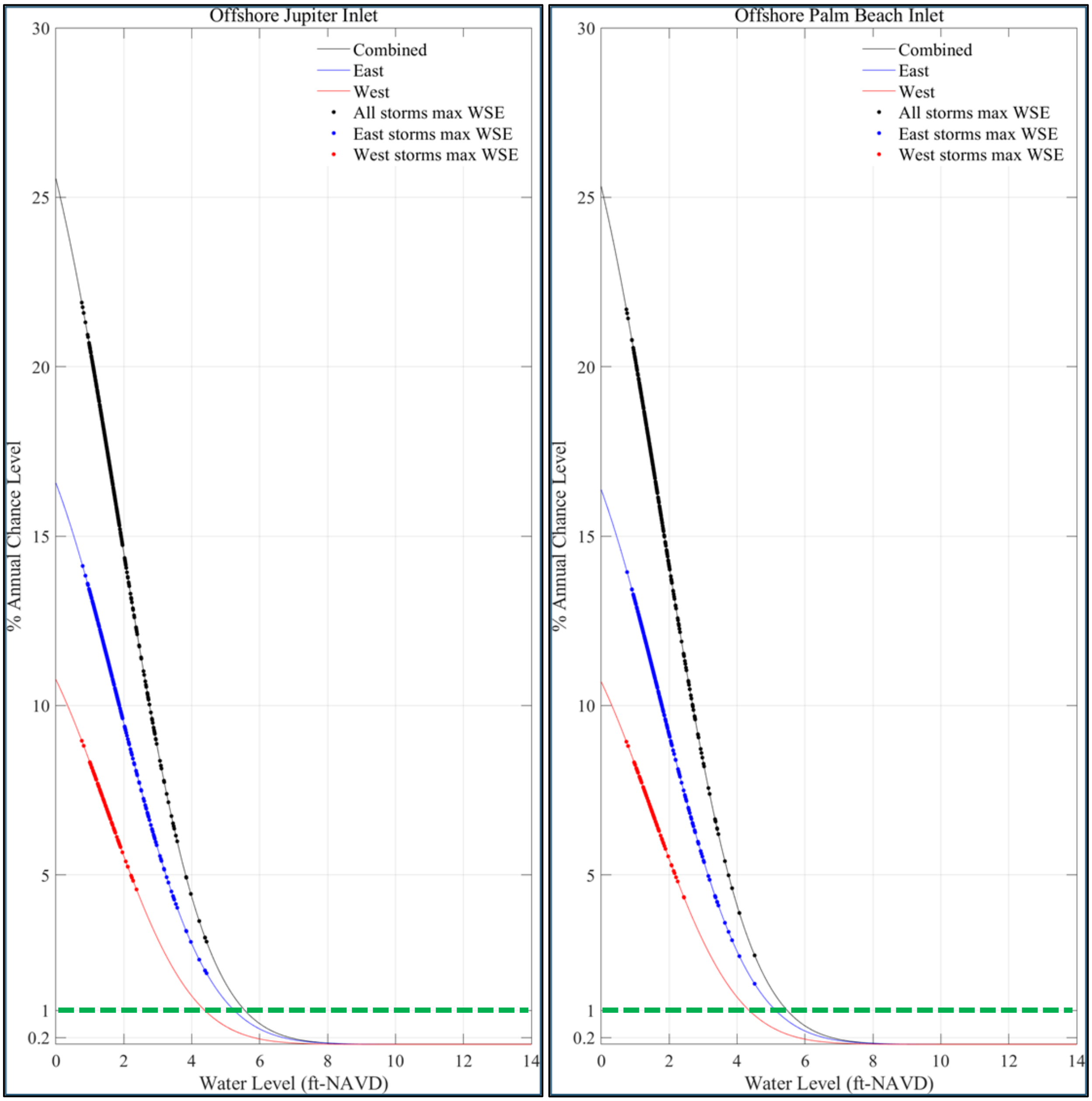

Figure 3.12: FEMA's WSE Frequency Curve – Jupiter Inlet (left); Palm Beach Inlet (right)

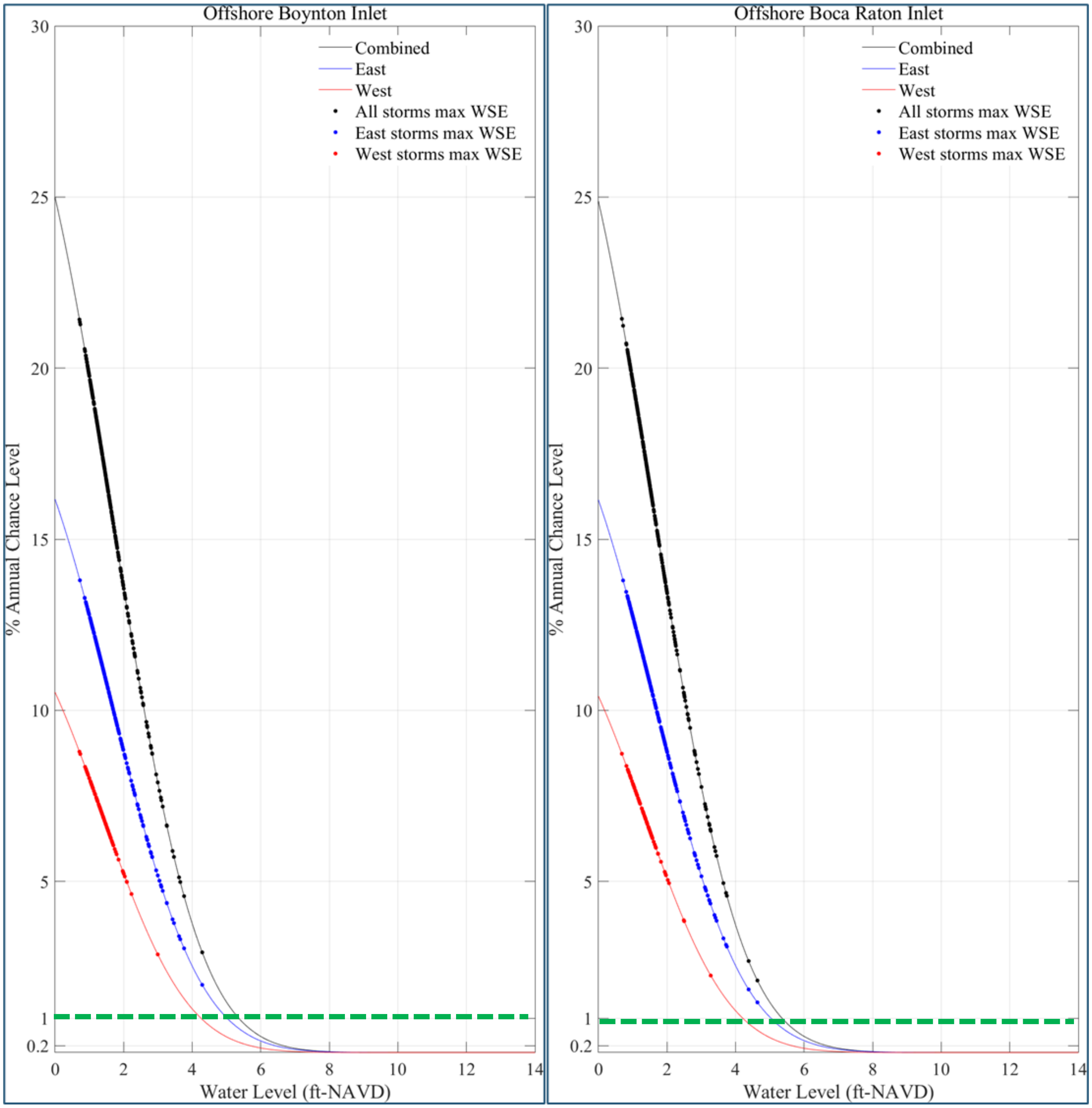

Figure 3.13: FEMA's WSE Frequency Curve – Boynton Inlet (left); Boca Inlet (right)

The observations above highlight that the maximum WSE generated by the synthetic storms offshore of the coastal inlets in Palm Beach County were not adequate to define the "tail" end of the WSE frequency curves. The "tail" of the east and west coast curves below the 1% annual chance are the portions of the curves that when combined affect FEMA's 1% SWEL. Furthermore, the west coast storms may not contribute to the 1% SWEL due to **the physical processes associated with exiting storms limiting the extreme WSE that can be generated within Palm Beach County.** These physical processes include the following:

- Exiting coast storms generally weaken in intensity as they pass over land; wind fields become disorganized and central pressures rise.

- The magnitude of storm surge, which is the major factor in elevated WSE, is related to a storm's time over water and the track of the storm. Exiting storms have limited time once reemerging over water to generate storm surge before moving offshore. Furthermore, the larger storm surge potential associated with a storm is generated ahead of the storm, which are directed offshore for exiting storms.

Assuming that west coast (exiting) storms were removed from the SFL study similar to the ECCFL study, the combined frequency curve would be represented by the east coast curve**.** The contributions of west coast storms on the 1% SWEL **offshore of Palm Beach County were approximately 0.4 feet based on FEMA's modeling data** as shown in the left panel of Figure 3.14.

Model uncertainty during the SWAN+ADCIRC model validation was also noted by FEMA as a contributing factor in the higher 1% SWEL. Model uncertainty included two terms: model skill; and the planetary boundary layer terms. The uncertainty associated with the model skill may have been closer to 1.95 feet for the SFL study as compared to 1.54 feet and 0.75 feet as reported by FEMA for the SFL study and ECCFL study, respectively (see Section 2). When the planetary boundary term (1.17 feet as reported by FEMA) was factored into the model uncertainty, the total uncertainty reported by FEMA was 1.93 feet and 1.39 feet for the SFL study and ECCFL study, respectively. Assuming that improved model validation would result in reduced model uncertainties for the SFL study that would be consistent with the ECCFL study, the contributions of increased model uncertainties on the 1% SWEL within Palm Beach County are shown in the middle panel of Figure 3.14. **The contributions of increased model uncertainty offshore of Palm Beach County were approximately 0.9 feet based on FEMA's modeling**.

The cumulative contributions of the west coast storms and increased model uncertainty offshore of Palm Beach County were estimated to have increased FEMA's 1% SWEL by approximately 1.3 feet as shown in right panel of Figure 3.14. Figure 3.15 shows the 1% SWEL as reported by FEMA (left panel) and the 1% SWEL adjusted (right panel) after removing the cumulative contributions estimated herein (middle panel). **In the absence of reperforming the modeling and given the consistent contributions offshore, a uniform downward adjustment to the 1% SWEL throughout Palm Beach County (and potentially throughout the east coast of the study area) appears most reasonable.** This contrasts with FEMA's approach of defining a transition area extending 5 miles north and 5 miles south of the Palm Beach and Martin county line within which the 1% SWEL was adjusted downward 0.85 feet within Palm Beach County and upward 0.85 feet in Martin County.

The 1% SWEL adjustments presented herein are based on modeling, information, and data provided by FEMA. Reperforming the SWAN+ADCIRC modeling is needed to more accurately assess the adjustments to consider the interdependence and spatial variability of improvements to FEMA's modeling, especially within interior water bodies hydraulically connected to coastal inlets. Improvements to the model should include the following:

- Model validation that improves the model's ability to simulate storm surge.
- Model mesh and grids with improved resolution and accuracies.
- Re-evaluation of the storm surge bias and tidal optimization. The cumulative contributions presented herein do not include the potential contributions of 0.25 feet and 0.1 feet associated with storm surge bias and tidal optimization, respectively, as presented in Task 4.
- Assessment of the cumulative contributions and thus adjustments to the 1% SWEL within interior water bodies. The actual contributions and adjustments within these water bodies may be higher or lower that those shown given the interior water levels are directly dependent on offshore water levels.
- Outputs to FEMA's coastal hazard analysis. FEMA's analysis is dependent on the 1% SWEL and starting wave conditions to define dune response, wave runup and overtopping, and overland wave propagation. Thus, the coastal hazard analysis will be required to be updated if the 1% SWEL is adjusted.

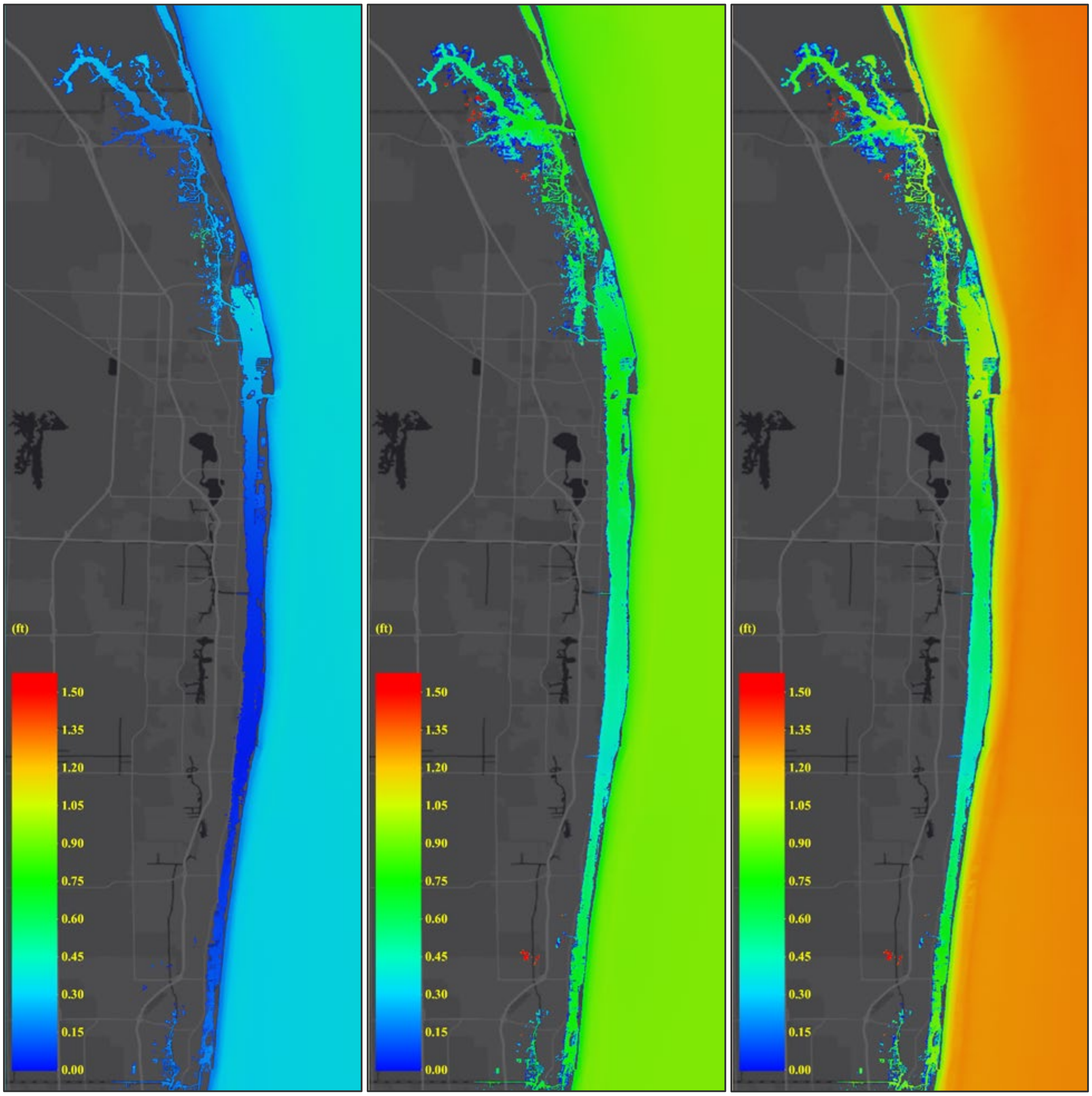

Figure 3.14: 1% SWEL Contributions: West Storms(left) +Model Uncertainty(middle) =Cumulative(right)

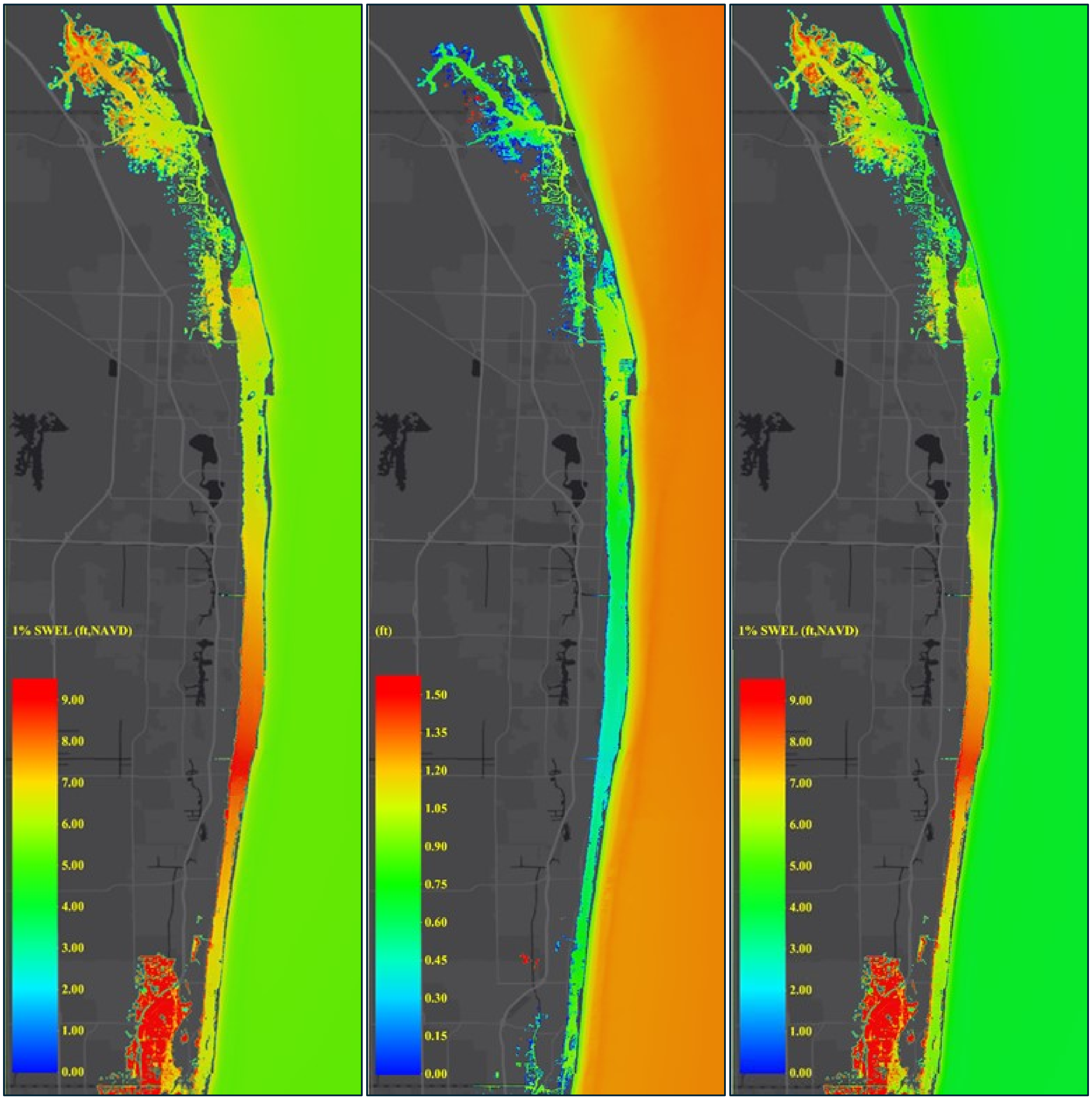

Figure 3.15: 1% SWEL: FEMA(left) – Cumulative Contributions(middle) = Adjusted(right)

4. Coastal Hazard Analysis and Mapping

4.1 Coastal Hazard Analysis

FEMA's coastal hazard analysis along the Atlantic Coast (open coast) evaluated coastal erosion, wave runup, and overtopping during extreme storm events at defined cross-shore transects. The SFL study analyzed 170 transects within Palm Beach County for each of the coastal processes to map the VE zone.

FEMA's VE zone is within the SFHA and is defined as "the flood insurance rate map zone that corresponds to the 1% annual chance coastal floodplains that have additional hazards associated with storm waves" [15]. The wave hazards are defined by breaking waves heights 3-feet or greater.

FEMA's coastal erosion standard methodologies establish a dune's response during storm events based on the volume of sand within the dune [20]. For "ridge" type dunes as shown by Figure 4.1 extracted from FEMA's guidance document, the frontal dune reservoir is defined by the dune's volume seaward of the dune peak and above the total stillwater elevation (1% SWEL). For "mound" type dunes, the reservoir is defined by the dune's rear shoulder. Both types of dunes are present in Palm Beach County. A dune reservoir greater than 540 ft^2 results in dune retreat (erosion of the frontal dune reservoir), while volumes less than or equal to 540 ft^2 results in dune removal (lowering of the peak and loss of the dune feature).

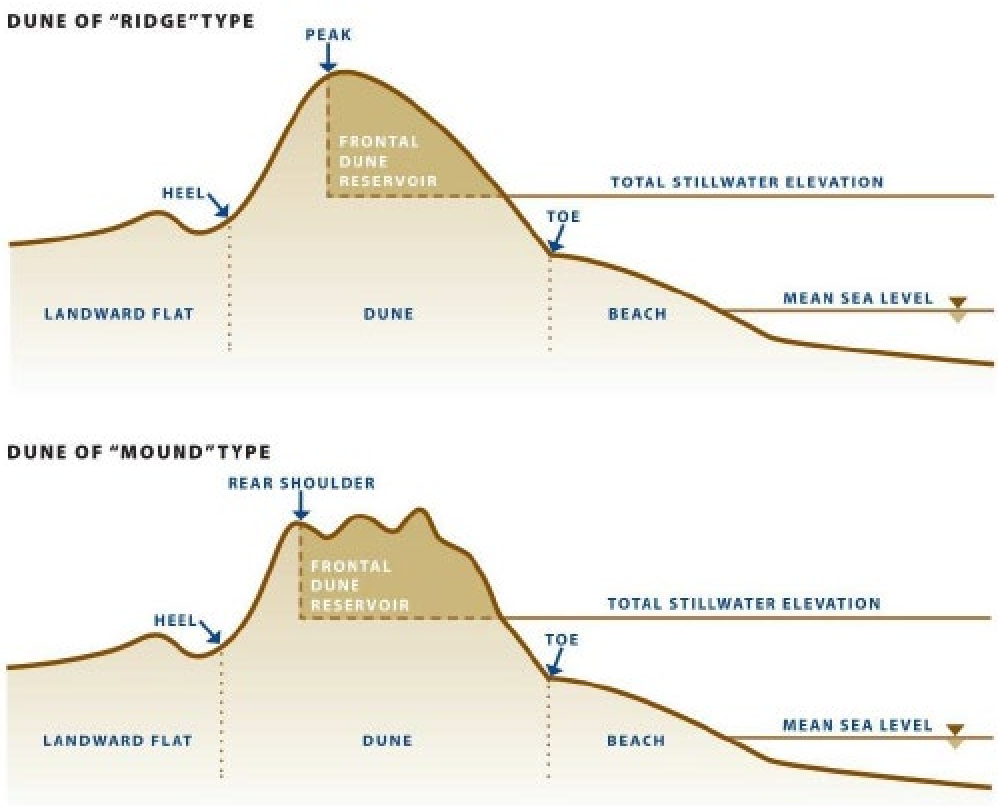

Figure 4.1: FEMA Dune Response (FEMA, 2018, [20])

Of the 170 open coast transects, breaking wave heights were used by FEMA to define the VE zone at two transects (137 and 138 at MacArthur Beach State Park). FEMA's analysis resulted in dune removal being identified at the transects and the eroded dune profiles being specified at elevations below the 1% SWEL (see Task 4). This triggered FEMA to use breaking wave heights to define the VE zone for these transects and resulted in FEMA mapping the VE zone landward of the dune and within the Lake Worth Lagoon. As such, FEMA's model data for the transects were reviewed with respect to the volumes of the dune reservoir and subsequent the dune responses (Table 4.1).

- Transect 137: FEMA's SFL study defined the 1% SWEL at +6.36 ft, NAVD88 and the dune peak at 20.4 ft, NAVD88 which resulted in a reservoir volume of 536 ft^2. This was less than 540 ft^2 and resulted in dune removal being identified by FEMA. Inspection of the data indicated that the dune peak had been incorrectly identified along the seaward slope of the dune and that the dune peak was actually at 20.9 ft, NAVD88. If the correct dune peak had been used by FEMA (red text), the reservoir volume would have been 553 ft^2 and consequently a dune retreat response (not dune removal) identified by FEMA. The analysis was repeated with the 1% SWEL lowered 1.3 feet to highlight the contributions of the west coast storms and increased model uncertainty on FEMA's coastal analysis. The lower SWEL reaffirmed a dune retreat response.
- Transect 138: The coastal erosion analysis was repeated with the 1% SWEL lowered 1.3 feet to highlight the contributions of the west coast storms and increased model uncertainty on FEMA's analysis. The lower SWEL resulted in a dune retreat response as opposed to removal as identified by FEMA.

A dune retreat response at these two profiles would reduce the exposure of the northern Lake Worth Lagoon to Atlantic waves during the 1%-annual-chance event, the inland extent of the VE zone, and in turn may reduce base flood elevations (BFE) of SFHA zones mapped on FEMA's FIRM panels within the lagoon.

Table 4.1: Dune Response

Transect (Open Coast)	FEMA SFL Study				SWEL Adjusted (-1.3 ft)		
	1% SWEL (ft, NAVD88)	Dune Peak (ft, NAVD88)	Reservior[1] (ft^2)	Dune Response	1% SWEL (ft, NAVD88)	Reservior[1] (ft^2)	Dune Response
137	6.36	20.4	536	Removal			
		20.9	553	Retreat	5.06	746	Retreat
138	6.22	22.2	430	Removal	4.92	544	Retreat

[1]Dune reservior defined by FEMA as the volume of sand seaward of the dune peak and above the 1% SWEL. FEMA specifies dune retreat when the volume greater than 540 ft^2 and dune removal when the volume is less.

4.2 Mapping

The SFWMD operates several water control structures in Palm Beach County, which are listed from north to south in Table 4.2.

According to FEMA, the SWAN+ADCIRC model mesh developed for the SFL study…

- "…captures the SFWMD canals from the ocean to the most seaward control structure…Upstream from the first (seaward) control structures, canal water levels can vary depending on operations at upstream and downstream control structures…
- "…actively excludes the upstream canal by placing model nodes along the channel banks…"
- "…often the 2- and 1-percent-annual-chance water levels upstream of the structures were not calculated…"

FIRM panels to be updated for the SFL study were excluded west of the control structures at the S-44 and S-155 structures, while panels west of the S-41 and S-40 structures were included. The SFL study was performed to update flood risks associated with coastal storm surge and did not include precipitation or riverine flooding analyses. Delineations of the AE zones and BFEs upstream of the structures did not change on the preliminary FIRM's issued for the SFL study, but X zones were mapped in greater detail. Furthermore, panels noted by "*" indicate panels where the AE zones were extended west along drainage canals for which no justification was provided by FEMA. **Updates by FEMA to SFHA mapping on the following eight FIRM panels upstream of SFWMD water control structures as part of the SFL study do not appear consistent or warranted based on the methodologies applied and justification provided by FEMA elsewhere within Palm Beach County**.

- 0778G*
- 0779G*
- 0786G*
- 0787G*
- 0788G
- 0789G
- 0976G*
- 0978G*

Table 4.2: SFWMD Water Control Structures – Palm Beach County

Water Control Structure	Canal	Bypass Elevation[1] (ft, NAVD88)	Upstream FIRM Designation	
			Effective 2017	Preliminary[2]
S-46	C-18	18.5	-	-
S-44	C-17	10.5	AE10	AE10
S-155	C-51	8.0	AE10.4	AE10.4
S-41	C-16	10.0	AE9	AE9
S-40	C-15	10.0	AE9	AE9
G-56	Hillsboro	10.4	AE	AE

[1]Elevation reported by FEMA at which flood waters will bypass and flow around the structure [3].
[2]Released with the preliminary documents for SFL study.

FEMA's AE zone is within the SFHA and is defined as "the flood insurance rate map zone that corresponds to the 1% annual chance coastal floodplains" [15]. FEMA's X zone is outside the SFHA and is defined as "areas of 0.2% annual chance flood hazards and areas of 1% annual chance flood hazards with average depths of less than 1 foot or with drainage areas less than 1 square mile" [15].

5. Conclusions

FEMA's SFL study leveraged numerical modeling and analyses to better define the coastal flood risks associated with storm surge. The discussion above was intended to identify specific elements to improve the accuracy, consistency, reliability, and repeatability of the study with respect to Palm Beach County. The major elements are summarized below. Task 5 and the conclusion presented herein are intended to compliment Task 4 of Baird's technical review.

SWAN+ADCIRC Model Validation

- While it is acknowledged that FEMA's extensive model validation resulted in reasonable agreement with measured astronomical tides, less favorable agreement with measured water levels during the modeled validation storms suggests that the coastal processes and WSE associated with storm surge may not be represented by the SWAN+ADCIRC model developed by FEMA.
- FEMA's SWAN+ADCIRC model validation was based on 244 measured peak water levels. Only 53% of the measured water level locations used by FEMA to validate the model were within a 55-mile offset of the validation storm tracks where storm surges were more likely to be experienced.
- The model uncertainty within the 55-mile offset was 1.95 feet as compared to 0.87 feet outside the offset. This equated to a model uncertainty within the offset that was 2.24 times greater that the uncertainty outside the offset, which suggests that the model was not able to accurately simulate peak water levels within the areas that storm surges were most likely to be experienced.
- The SFWMD S46_T gage is located within the Loxahatchee River system where the greatest discrepancies in 1% SWEL between the ECCFL and SFL studies were identified by FEMA. The gage was located approximately 2 miles north of Wilma's track according to NOAA, but the gage was not included in FEMA's model validation for the SFL study despite it being considered in the ECCFL study. FEMA did not provide an explanation for excluding the S46_T gage from the SFL study. The modeled WSE from the SFL study was extracted from FEMA's model data at the gage location and was found to resemble a sinusoidal shape associated with astronomical tides with little evidence of storm surge being simulated by the model. Comparison with SFWMD S40_T gage in southern Palm Beach County indicated that FEMA's SWAN+ADCIRC model better simulated storm surge experienced during the storm. This suggests that the model's ability to accurately simulate storm surges in northern Palm Beach County may not be reliable and further raises doubt about FEMA excluding the northern SFWMD gage (S46_T) from the SFL model validation.

Statistical SWEL

- FEMA's regional grid developed to resolve the distributions of the wind and pressure fields did not include the northern 32 miles of Palm Beach County. Therefore, the wind and pressure fields in Palm Beach County north of Boynton Inlet were modeled at a coarser resolution as compared to the rest of the SFL study area. The insufficient wind and pressure fields grid resolution over most of Palm Beach County limits the SWAN+ADCIRC model's ability to accurately simulate storm surges for storms making landfall north of and near the boundary of the regional grid.
- FEMA's approaches to resolving model instabilities were to adjust the model meshes by "filling" canals or hydraulic connections and to restrict localized water level gradients between model nodes. These approaches are routine and customary for numerical models as long as it is demonstrated that they do not alter the hydrodynamic and coastal flooding processes elsewhere within the study area. FEMA's documentation was presented at a countywide scale, but not at a scale that the localized effects could be reviewed.
- Review of FEMA's model mesh and modeling of synthetic storms revealed several locations within Palm Beach County where the mesh resolution was insufficient to accurately model hydrodynamic and coastal

flooding processes within the study area. For example, during the synthetic storm (#21) that produced the highest WSE within the Lake Worth Lagoon, FEMA's model did not allow water to flow out through Boynton Inlet creating unrealistic WSE changes in the inlet thereby affecting WSE within the lagoon as the storm passed to the north. Other noted locations include Jupiter Inlet, Jack Nicklaus Drive bridge at Lake Little Worth, and the canal under Lighthouse Drive bridge in North Palm Beach.

- Offshore of the study area's east coast, the SWAN+ADCIRC model nodes indicated there were no synthetic storms with WSE above the 1% SWEL. With no storms bracketing FEMA's 1% SWEL immediately offshore of Palm Beach County (and the east coast of the study area), the more extreme synthetic storms were not statistically represented by FEMA's modeling and/or FEMA's 1% SWEL may have been overestimated. Unreliable offshore water levels translate into potentially unreliable water levels within interior water bodies and unreliable mapping of flood risks.
- The physical processes associated with exiting (west coast) storms may limit the extreme WSE that can be generated offshore of Palm Beach County and the contribution of these storms to FEMA's 1% SWEL. The contributions of west coast storms to the 1% SWEL offshore of Palm Beach County were approximately 0.4 feet based on FEMA's modeling data.
- Assuming that improved model validation would result in reduced model uncertainties for the SFL study that would be consistent with the ECCFL study, the contributions of increased model uncertainties to the 1% SWEL offshore of Palm Beach County were approximately 0.9 feet based on FEMA's modeling data.
- The cumulative contributions (adjustments) of the west coast storms and increased model uncertainty offshore of Palm Beach County were estimated to have increased FEMA's 1% SWEL by approximately 1.3 feet. In the absence of reperforming the modeling and given the consistent contributions offshore, a uniform downward adjustment to the 1% SWEL throughout Palm Beach County (and potentially throughout the east coast of the study area) appears most reasonable. This contrasts with FEMA's approach of defining a transition area extending 5 miles north and 5 miles south of the Palm Beach and Martin county line within which the 1% SWEL was adjusted downward 0.85 feet within Palm Beach County and upward 0.85 feet in Martin County.
- The 1% SWEL adjustments presented herein are based on modeling, information, and data provided by FEMA. Reperforming the SWAN+ADCIRC modeling is need to more accurately assess the adjustments to consider the interdependence and spatial variability of improvements to FEMA's modeling, especially within interior water bodies hydraulically connected to coastal inlets.

Coastal Hazard Analysis and Mapping

- Of the 170 open coast transects, breaking wave heights were used by FEMA to define the VE zone at only two transects (137 and 138 at MacArthur Beach State Park). A 1.3-foot downward adjustment to the 1% SWEL, as quantified above, would impact the coastal erosion analysis and would have resulted in a dune retreat response instead of dune removal as identified by FEMA at the two transects for the northern Lake Worth Lagoon. A dune retreat response at these transects would reduce the exposure of the lagoon to Atlantic waves during the 1%-annual-chance event, the inland extent of the VE zone, and in turn may reduce base flood elevations (BFE) of SFHA zones mapped on FEMA's FIRM panels within the lagoon.
- According to FEMA, the SWAN+ADCIRC model mesh developed for the SFL study excludes canals upstream of SFWMD water control structures and 1% SWELs were not calculated. Updates by FEMA to SFHA mapping on several FIRM panels upstream of the SFWMD structures as part of the SFL study do not appear consistent or warranted based on the methodologies applied and justification provided by FEMA elsewhere within Palm Beach County.

The information presented herein for Task 5 as well as Tasks 2, 3, and 4 will be compiled in Task 6 to document the key findings, conclusions, and recommendations regarding future coordination with FEMA.

6. References

National Oceanic & Atmospheric Administration (NOAA), 2020. https://coast.noaa.gov/hurricanes/#map=4/32/-80.

FEMA Document		Date	Description	Reference #
SFL Coastal Study Documents				
Coastal Discovery Report		Apr 2015	Presents available data and information considered by FEMA for inclusion in the updated coastal study.	[1]
Intermediate Data Submittal (IDS) Reports				
#1	Section 1 - Technical Approach	Nov 2014	Introduces the major technical study components contained in IDS Report #1, Sections 2-7.	[2]
	Section 2 - Digital Elevation Model (DEM)	Mar 2016	Discuss topographic and bathymetric data sets, DEM development, and creation of the finite element model mesh utilized in the SWAN+ADCIRC modeling, WHAFIS modeling, and coastal hazard analyses.	[3]
	Section 3 - Validation Storm Selection	Feb 2015	Presents wave and water level data sets and the methodology applied to develop the studys validation storm suite for the SWAN+ADCIRC modeling.	[4]
	Section 4 - Study Area & Site Reconnaissance	May 2015	Details site reconnaissance performed and the procedure followed to identify coastal structures and to delienate the primary frontal dune (PFD).	[5]
	Section 5 - JPM-OS Probablistic Model Development	Jun 2015	Documents the storm climatology and initial probabilistic model development.	[6]
	Section 6 - Tropical Analysis & Forcing Development	Feb 2015	Presents the methodology applied to develop wind and pressure fields as inputs to the SWAN-ADCIRC modeling.	[7]
	Section 7 - Hydrodynamic & Wave Model Development	Jan 2016	Details the wave and hydrodynamic storm surge model and mesh development methods.	[8]
#2	Section 1 - Wave & Hydrodynamic Model Validation	Feb 2017	Describes the methodology and results of the wave and hydrodynamic modeling validation.	[9]
	Section 2 - JPM-OS	Oct 2016	Describes development of the representative stor set and associated annual recurrance rates (return period) of storms.	[10]
#3	Section 1 - Production Runs	Jun 2018	Describes the SWAN+ADCIRC modeling of the synethetic storms developed as part of the JPM-OS analysis. The modeling resulted in total maximum water levels and wave conditions for return period storms.	[11]
	Section 2 - Low-Frequency Analysis	Jul 2018	Documents the methodology used to define still water elevations (SWEL) throughout the SWAN+ADCIRC modeling domain for low-frequency (2-, 1-, and 0.2-percent-annual-chance) storm events.	[12]
	Section 3 - Regional Fequency Analysis of Tide Gage Water Levels	Jul 2019	Documents the methodology used to define still water elevations (SWEL) throughout the SWAN+ADCIRC modeling domain for high-frequency (50-, 20-, 10-, and 4-percent-annual-chance) storm events.	[13]
#4,5	Coastal Hazard Analysis	Oct 2019	Decribes the analyses of overland wave propagation, wave runup, wave overtopping, coastal structures, storm induced erosion used to define special flood hazard araes (SFHA) and delineate flood zones boundaries.	[14]
Preliminary Flood Insurance Study (FIS)		Dec 2019	Summarizes the general framework of the study, engineering methods considered in the study, and mapping methods.	[15]
Preliminary Flood Insurance Rate Map (FIRM) Panels		Dec 2019	Maps depicting SFHA, flood zones, and base flood elevations (BFE) resulting from the study. Maps provide a level of detail that individual building and parcels can be identified.	[16]
FEMA Guidance Documents				
Atlantic Ocean & Gulf of Mexico Coastal Guidelines Update		Feb 2007	Technical guidance governing the breadth of the modeling and analysis for coastal study updates.	[17]
Guidance for Coastal Flood Hazard Analysis & Mapping (CFHAM)				
Sheltered Waters		Feb 2008	Guidance for analyzing flood harzards (primarily 1-percent-annual chance- storm events) within sheltered water areas.	[18]
Overland Wave Propagation		Nov 2015	Guidance on applying the WHAFIS model, defining input parameters, and interpreting model results.	[19]
Erosion		Feb 2018	Guidance on methods available to estimate profile changes for erodible shorelines due to storm events.	[20]
Coastal Floodplain Mapping		Nov 2019	Guidance on delineating coastal flood zones and defining BFE's.	[21]
Coastal Water Levels		May 2016	Guidance on extracting stillwater level (SWL) data from measured water levels and on determining SWL where storm surge processes dominate.	[22]
Coastal Structures		Nov 2019	Guidance on methods available to analyze the stability and effects of coastal structures during the 1-percent-annual-chance storm event.	[23]
Coastal General Study Considerations		Nov 2019	Guidance provides an overview of coastal flooding processes and describes general considerations for FEMA coastal flood hazard studies.	[24]
Determination of Wave Characteristics		Feb 2019	Guidance on determining wave characteristics that are required for a coastal hazard analysis.	[25]
Wave Height Analysis for Flood Insurance Studies (WHAFIS)				
WHAFIS Technical Documentation Version 3.0		Sep 1988	User manual for the WHAFIS model.	[26]
Supplementary WHAFIS Documentation Version 4.0		Aug 2007	Supplemental information for a later version of the WHAFIS model.	[27]

Appendix E

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October 5, 2020

Via Email: mark.vieira@fema.dhs.gov

Mark A. Vieira, PE
Federal Emergency Management Agency, Region 4
Mitigation Division, Risk Analysis Branch
3003 Chamblee Tucker Road
Atlanta, GA 30341

Dear Mr. Vieira,

Subject: Coastal Flood Risk Study Project for South Florida

Being a coastal community dedicated to responsible and modern floodplain management, Palm Beach County (County) considers Federal Emergency Management Agency (FEMA) flood zone designations to be extremely important. While the County understands the need for FEMA to incorporate updated data and information into the Coastal Flood Risk Study Project for South Florida (Coastal Flood Risk Study), it is imperative that FEMA employs accurate data and appropriate methodologies when developing updated coastal flood zones. Storm surge and wave model configurations, assumptions and techniques can result in higher than desirable uncertainty, unreliable water levels and unreliable mapping of flood risks, all of which can have significant implications for County residents and businesses.

In January 2020, the County initiated a comprehensive Review and Evaluation of FEMA's Coastal Flood Risk Study. On September 22, 2020, the Board of County Commissioners was briefed on the review's key findings and directed staff to coordinate with and transmit relevant documents to FEMA. The following documents, available at https://discover.pbcgov.org/pzb/building/Pages/Flood-Information.aspx, are being provided for review by FEMA and its technical team:

1. Topographic Evaluation Data Technical Memorandum (Deliverable 2.1) dated September 3, 2020
2. Data and Documents Review Technical Memorandum (Deliverable 4.1) dated October 1, 2020
3. Storm Surge, Wave Model & Flood Map Evaluation (Deliverable 5.1) dated September 22, 2020

In addition, the County would like to schedule a phone- or web-based meeting with your technical team within the next 3-4 weeks to discuss the County's key findings and related issues documented during the County's Review and Evaluation of FEMA's Coastal Flood Risk Study. Please contact me via phone at 561-355-4600 or via email at jmcbryan@pbcgov.org to schedule this meeting.

The County continues to share FEMA's vision for safer communities and responsible floodplain management and looks forward to receiving additional information from FEMA related to the Coastal Flood Risk Study.

Sincerely,

Jeremy McBryan, PE, CFM
County Water Resources Manager

cc: Verdenia Baker, County Administrator
Jon Van Arnam, Deputy County Administrator
Patrick Rutter, Assistant County Administrator
Doug Wise, Building Division Director, Palm Beach County
Michael Taylor, AECOM
Dave Swigler, W.F. Baird & Associates Ltd.