

Original Research Article

METHODOLOGY FOR PREDICTING LOCAL IMPACTS OF SEA LEVEL RISE

ABSTRACT

In the future, south Florida will be flush with water due to sea level rise and increased storm intensity, meaning there are three options to deal with this problem – retreat, offshore discharges or finding a use for the water. The first is not an option so the others must be evaluated. To do so, the first task needed to identify solutions to this problem is to define the severity of the problem through a vulnerability analysis so the appropriate decisions can be made.

Aims: The objectives of this research were to develop an accurate methodology for predicting impacts of sea level rise and rainfall patterns at the local level by identifying how existing topographic, groundwater and tidal data sources can be utilized to identify infrastructure vulnerable to sea level rise and flooding.

Study Design: Based on a study of monitoring well water levels on Miami Beach, it was noted that during the year, groundwater levels fluctuate due to tidal levels and rainfall, with the Fall king tides creating the highest vulnerability to infrastructure and property. Once vulnerability is defined a toolbox of options can be developed to deal with local issues.

Results: The research found that the tides create a much larger vulnerability than current sea level rise analyses suggest and that the king tides drive the level of service for the community, while altering the dynamics of future stormwater planning efforts. To mitigate the impacts of

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26 flooding will require new ideas for dealing with excess waters. A toolbox of options was
27 developed.

28 Conclusion: One item that arose was that there is potential to use stormwater adaptation
29 strategies to create future water supplies.

30

31 Key Words: Sea Level Rise, ~~vulnerability~~, Flooding, Risk, Alternative Water Supplies,
32 infiltration galleries, horizontal wells

33

34 **Introduction**

35

36 Climate change is expected to cause more intense rainfall events, such as thunderstorms
37 and tropical cyclones [1-3], warmer temperatures [2,4] and increased sea levels due to increased
38 rates of thermal expansion and ice melt from glaciers [1, 5-18]). Gregory et al. [18] noted that in
39 the last two decades, the global rate of sea level rise (SLR) has been greater than the 20th-
40 century mean, and that there may be increasing contributions to global SLR from the effects of
41 landmass snowmelt, groundwater depletion and loss of storage capacity in surface waters due to
42 siltation. Every part of the world may be affected, although each community needs to evaluate
43 which issues are of greatest concern to them. For example, in southeast Florida, climate change
44 has manifested itself primarily as an increase in sea level [15, 16], which is expected to have
45 significant consequences for coastal areas where the combination of sea level rise (SLR) and
46 population growth makes it essential to continue developing flood management strategies [19-
47 24]. Various researchers have already noted impacts on coastal and island environments [19-21,
48 25-33].

49 The combination of rising seas and intense storms has the potential to overwhelm the
50 highly engineered storm water drainage system of canals and control structures that have
51 effectively enabled management of water tables, reduced the potential for flooding of the low
52 terrain, permitted development and controlled saltwater intrusion in south Florida [34]. The
53 advent of sea level rise will present new challenges because the water table is currently
54 maintained at the highest possible levels to ~~counter-offset~~ saltwater intrusion ~~and while~~
55 maximizinge water supplies [34-36]. As the sea level rises, it will disrupt the policy balance
56 ~~struck~~ between flood risk and water supply availability [34].

57 South Florida has distinct wet and dry seasons [36]. 70 percent of the annual
58 precipitation typically falls from June to September, just before the king tides. Despite receiving
59 60 inches of rainfall each year, ongoing flood protection efforts create a situation where south
60 Florida is often water supply limited during the dry season as topography limits the ability to
61 store excess wet season precipitation in surface reservoirs [36]. Soil storage is limited because
62 the aquifer levels are often just below the surface in the wet season. It is this limited soil storage
63 that leads to flooding, necessitating the extensive drainage works facilitate that discharge large
64 volumes of water during the wet season, reducing availability in the dry, tourist season. These
65 historical water management conflicts create periodic water restrictions, and led to a 2007 rule
66 developed by the South Florida Water Management District that restricts further development of
67 Biscayne aquifer wellfields [36].

68 Despite these historical water management conflicts and periodic disruptions, south
69 Florida will remain a desirable place to live, so the interconnectedness of water will require the
70 traditional barriers between water and storm water to be replaced with a more integrated solution
71 that addresses the immediate concern about the sustainability of the Biscayne aquifer as a viable

72 and efficient water supply source that will satisfy the public demands for future development in
73 south Florida [34, 36], while protecting infrastructure and property from flood damage. New
74 ideas will play a role. Storm water utility managers will need solutions to dispose of excess
75 storm water that causes increased flooding frequency during routine rainfall as a result of soil
76 storage capacity declines, while water supply utility managers are looking for reliable water
77 supply solutions [36]. At present, there is a lack of good data to make decisions on what to do,
78 when and with what priority. The vulnerability of infrastructure is of particular concern on
79 coastal or island communities like those in southeast Florida.

80 A number of data sources are available to local officials to help initial screening of
81 vulnerability. Topography is a key parameter that influences many of the processes involved in
82 coastal change, and thus, up-to-date, high-resolution, high-accuracy elevation data are required
83 to model the coastal environment. Previous approaches to modeling inundation from simulated
84 sea-level rise have been limited by coarse-resolution elevation datasets (surveys), field spot
85 elevations, and United States Geological Survey (USGS) maps) as opposed to high resolution
86 electronic imagery [31, 37-41]. However communicating the importance of sea level rise to low
87 lying local entities requires higher resolution data because inches matter in many low-lying
88 coastal areas [28, 42-43]. An improvement to topographic maps is low resolution Light
89 Detection and Ranging (LiDAR), which is available in many areas, but the coarse vertical
90 definition (+/- 2 feet) is not useful for coastal areas that are within 3 to 5 feet of average sea level
91 ([34]. High-resolution elevation data are needed for investigating the influence of topographic
92 complexity on landscape processes, including drainage canals and levees [41]. The increasing
93 availability of high resolution LiDAR in coastal areas allows for improved assessments to be
94 done over more areas and integrated into national datasets [44], and has led to an increased trust

95 in using electronic measurements as a means for assessing vulnerable infrastructure and property
96 [34, 45-48]. The highest resolution LiDAR available is +/- 3 inches (0.1 m). Recent high
97 resolution LIDAR data is often available in many vulnerable coastal areas of Florida [34, 48-
98 51].

99 The use of LiDAR has the benefit of translating easily to geographic information systems
100 (GIS). The LiDAR data format used for this project was the American Standard Code for
101 Information Interchange (ASCII) ~~which is easily handled~~ an uploaded to by ArcGIS ~~software~~.
102 The ASCII format is comprised of the raw LiDAR data type format, translated into a X, Y, Z
103 global coordinate plane system (49, 52). ~~Of While there are a number of the different~~
104 topographical data repository sources, only the National Oceanographic and Atmospheric
105 Administration (NOAA) offered the native data in ASCII format using the NAVD 1988 vertical
106 datum [34, 49 - 50].

107 Topography identifies vulnerable land, but soil storage capacity is what really identifies
108 flooding potential. Where the soil can drain water, it will (although imperviousness can delay
109 soil drainage). To identify areas with soil storage capacity issues, the groundwater levels need to
110 be determined [49]. Bloetscher et al. [16, 34] noted that prior efforts used a variety of elevations
111 for high tide results, but found that the groundwater elevation would seek high tide as opposed to
112 average tides. Where king tides and rainfall coincide the flooding potential was greatest.

113

114 **Aims of the Study**

115

116 This paper outlines an initial approach to assess sea level rise and flood vulnerability, as
117 applied to Miami Beach, a coastal island community of nearly 100,000 people. The objectives of

118 the research were to develop an accurate methodology for predicting impacts of sea level rise at
119 the local level by identifying how existing topographic, groundwater and tidal data sources can
120 be utilized to identify infrastructure vulnerable to sea level rise. A toolbox of options was
121 developed to determine appropriate means to mitigate flood impacts.

122

123 **Methodology**

124

125

126 There may be a significant difference between mean high tide and the seasonal high tides,
127 which produce the most flooding. To generate the groundwater layer, six existing well locations
128 were selected in Miami Beach. Each was outfitted with data loggers that collect salinity and water
129 depth were placed in each of the monitoring stations in October 2012 to conduct continuous
130 groundwater elevation monitoring (see Figure 1) [34]. An attempt was made to select ~~appropriate~~
131 locations at different distances from the ocean to characterize the tidal responses and based upon
132 the proximity of wells to the coast, to each other, spatially and the hydrogeologic/hydrologic
133 characteristics of their locations [34]. ~~Data loggers that collect salinity and water depth were~~
134 ~~placed in each of the monitoring stations in October 2012 [34].~~ Two rain gauges with an auto-
135 tipping bucket system were also installed at two of the monitoring well locations. This data was
136 collected for a period of thirteen months (October through October 2013), and continues to be
137 collected. The data was downloaded monthly. Figure 2 shows the results for one month. The
138 monitoring wells indicated that the groundwater levels at five of the six sites varied with the tides.
139 Figure 3 is typical results from the 6 wells over the 13 month period. Figure 3 shows that the
140 groundwater table floats 0.2 to 0.5 ft above the high tide elevations.

141 The monitoring well data was used to develop the ground water surface elevation layer.
142 Various interpolation methods were considered to determine the surface. The resulting
143 interpolation that produced the best performance was ordinary krigging. ~~The high tides and the~~
144 ~~groundwater levels in the wells were krigged to create a groundwater surface elevation layer, and~~
145 ~~inserted into the GIS model. Two groundwater maps were developed: mean high tide as the~~
146 ~~current baseline, and peak seasonal water table (October after the wet season and corresponding~~
147 ~~to the seasonal high water table). It should be noted that hydraulic head values may need to be~~
148 ~~converted from NGVD 1929 to NAVD 1988, to match the terrestrial elevation dataset.~~

149 Next tide data was gathered. It was determined that the 95-100 percentile tides occurred
150 primarily in the October timeframe (by listing all tides in order of smallest to largest). Tallying
151 the tides for the 6 years in order, determined that the highest tides were nearly 2.3 feet NAVD88.
152 The frequency of flooding is a level-of-service issue and goes to the acceptability of flood
153 frequency regardless of the source. While each community can define acceptable flooding
154 frequency differently, the expectations of the public must be kept in mind. For example, Miami
155 Beach, the one can assess the acceptability of flooding 50%, 10%, 5% or 1% of the days of the
156 year. The mean condition results in a value of 0.795 ft [34] it should be noted that the initial
157 planning level by the City's consultant used was 0.45 ft, and the prior City Engineer noted that
158 asked the consultants to raise the level to 0.67 ft). However this means that flooding would
159 occur somewhere in the City every other day, which is not acceptable. However if flooding was
160 permitted in certain low lying areas only 10% of the time, the planning level should be 1.2 ft
161 [34]. For 5% of 1% the levels should be 1.39 and 1.72 ft respectively [34]. A level of service for
162 vulnerability was defined as the 99th percentile - 4 flooding events per year (based on discussion

163 with local officials) [34]. Since the tides occur coincidentally with the high water table (1.72 ft,
164 with 0.3 ft of free float, a 2 foot October groundwater level/high, high tide data was krigged.

165 Overlaying the two maps identified the areas lacking capacity to drain the surface – low
166 elevation and high water tables. Drilldown efforts using 10 x 10 ft ArcGIS tiles were used to
167 identify “potentially vulnerable,” and thereafter “vulnerable” infrastructure which comports with
168 directives from the United States Army Corps of Engineers that any coast or near-coast projects
169 must include consideration of sea level rise [34]. This assessment was compared to the “bathtub”
170 models used by other consultants and planners, which assumes that the groundwater is flat.
171 Figure 4 shows a substantial difference in the area that is vulnerable. Table 1 shows that the
172 strategy used in this assessment obtains significantly more vulnerable property than the bathtub
173 model today. The results are exacerbated with time.

174

175 Findings

176

177 [The high tides and the groundwater levels in the wells were krigged to create a](#)
178 [groundwater surface elevation layer, and inserted into the GIS model. Two groundwater maps](#)
179 [were developed: mean high tide as the current baseline, and peak seasonal water table \(October](#)
180 [after the wet season and corresponding to the seasonal high water table\). It should be noted that](#)
181 [hydraulic head values may need to be converted from NGVD 1929 to NAVD 1988, to match the](#)
182 [terrestrial elevation dataset.](#) Mapping the City with LiDAR and topographic maps verified that
183 the mapping could identify flooding areas (red areas in Figure 5a). The yellow areas are caution
184 areas (within 2 feet of the high tide). The areas indicated in green represent land with elevations
185 two feet above the referenced tidal datum, which would be considered low risk under current

186 tidal conditions. Assuming the current high tide for planning purposes, where there is a 1%
187 likelihood for there to be flooding somewhere in the City on any given day

188 Figure 5b shows the vulnerable areas in red. These are the areas that are vulnerable with
189 a 1 ft increase in SLR. The yellow areas are caution areas (within 2 feet of the future high tide).
190 There is a 36% likelihood for there to be flooding somewhere in the City on any given day with
191 one foot of sea level rise. Figure 5c shows the areas that are red are the vulnerable areas with a 2
192 ft increase in SLR. There is a 97% likelihood for there to be flooding somewhere in the City on
193 any given day with two foot of sea level rise. There is a 100% likelihood for there to be flooding
194 somewhere in the City on any given day with three foot of sea level rise (see Figure 5d).

195

196 ***Meeting the Stormwater Challenge***

197

198 Having identified the vulnerable areas of the City, the next step was to investigate
199 potential options to remedy the situation. Pumping is an obvious answer but carries with it water
200 quality impacts in nearshore water [34]s. [Since offshore nutrient concentrations are of concern,](#)
201 [direct discharge could pose a problem.](#) Table 1 is a list of potential stormwater solutions and the
202 benefits and barriers. Transportation agencies and most municipalities rely heavily on
203 exfiltration trenches or French drains. ~~S in southeast Florida is no exception.~~ These systems
204 work because the perforated piping is located above the water table. They cease to function if
205 they are ~~located below the water table~~submerged [34]. ~~However, e~~Exfiltration trenches could be
206 replaced by stormwater gravity wells, Class V injection wells or infiltration galleries[34].
207 Stormwater gravity wells are a useful option where saltwater underlies the surface[34].

~~Drainage~~ Class V drainage wells have been used to dispose of stormwater for years along the southeast Florida coast. Under the right conditions – head, salinity, depth, these wells can dispose of ~~can drain~~ 1 MGD ~~[34]~~ under certain conditions. ~~Drainage wells require splitter boxes and filters to remove~~ Because of the ~~–solids, turbidity and detrital matter from the surface,~~ drainage wells require splitter boxes and filters and ~~regular inspections to insure the wells are not plugged or backflowing saltwater to the surface, maintenance to clean them, and ongoing permit compliance [34].~~ However as sea level rises, the potential differential may be altered

since the saltwater wedge may migrate inland as a result of surficial drainage efforts. Also, increased head due to a water table rise will alter pump characteristics. ~~Drainage wells require splitter boxes and filters to remove solids, turbidity and detrital matter from the surface, regular inspections to insure the wells are not plugged or backflowing saltwater to the surface, maintenance to clean them, and ongoing permit compliance.~~

~~Class V injection wells may be useful as sea level rise progresses. A 24 inch Class V injection well may have to be hundreds of feet deep and requires consideration of the Underground Injection Control program under the Safe Drinking Water Act, something that is not currently considered in most jurisdictions. Permitting and consistent monitoring of Class V wells is required. As a result, the local entities will have to include ongoing stormwater treatment efforts for Class V well compliance.~~

For low lying areas, elevating roads may be an option. However, this option comes with two significant issues: the cost of raising roadway elevations and impacts on adjacent properties from same. Local roadway elevations will be limited by the adjacent buildings [34]. All adjacent properties would need pumps to remove their stormwater and prevent road runoff from entering their property. In addition, sanitary sewers, water mains and other utilities underlie these

231 pavements and would need to be replaced. Right-of-way abandonment is also an option but has
232 | severe consequences to adjacent properties [\[34\]](#).

233 Wellpoint systems are a series of small diameter wells spaced regularly along excavations
234 into the water table for dewatering construction sites. Wellpoint water is usually turbid,
235 containing sand, silt and contaminants from runoff. This form of dewatering requires a discharge
236 zone, which will require offsite property and a means to control turbidity. Wellpoint pump
237 stations would need to be regularly spaced along the affected roadway to be successful in
238 | keeping low-lying roads dry [\[34\]](#). As a result a series of pump stations might be needed for
239 every mile of roadway since typical dewatering systems. Since wellpoints do not function in
240 flood conditions, additional drainage measures must be taken to address wellpoint failure during
241 heavy rainfall events. Infiltration trenches is a similar solution, but with larger capacity and
242 | better performance during rainfall events since they operate more like sanitary sewer lift stations
243 [\[34\]](#).

244 There is commonality among most of these solutions – they can be implemented at the
245 local level, they all have a cost of implementation, and they all require ongoing efforts to control
246 and monitor water quality to discharge points – wells, private property or water bodies. All of
247 these apply to Miami Beach, which is similar in characteristics to many coastal communities. As
248 a result, finding unique solutions to mitigate the water quality impacts might lead to other
249 beneficial solutions.

250

251 ***Meeting the Stormwater and Water Supply Challenge Concurrently?***

252

253 The production and delivery of drinking water, protection from flood waters and the
254 treatment of wastewater are recognized as vital functions of society and the local public works
255 entity. The traditional utility operations have separated “clean” drinking water from “dirty”
256 waste and stormwater for public health simplicity. In most utilities, the crews and equipment are
257 separate even if managed by the same entity. In most cases, little linkage has been established
258 despite efforts by various organizations to look at the total water. Some progress has been made
259 in replacing irrigation with potable water with treated wastewater effluent, but stormwater is
260 generally outside the utility “silo.”

261 The challenge in low lying areas with increase rainfall intensity and sea level rise will be
262 too much water, not too little as has been noted. Where water supplies are restricted, water
263 supplies can ~~become~~ be made more reliable ~~and, in the long-term~~ sustainable through a
264 comprehensive approach to water planning ~~which includes that using~~ combines alternative water
265 sources and planning future infrastructure needs ~~with long term goals in mind~~ [34]. In keeping
266 with these categories of protection and adaptation as defined by Deyle [53], the question is how
267 to make whether infrastructure can serve multiple purposes and be able to be constructed
268 incrementally over time and needs demand, without the need to abandon any of these
269 investments. From a storm water/water supply perspective, the authors believe the answer is yes.

270 ~~Because~~ As noted in Bloetscher, et al [34], the uncertainty associated with of the sea level
271 rise and the ongoing risk from potential for saltwater intrusion as a result of managemd aquifer
272 levels, and the uncertainty of sea level rise, coastal wells will continue to likely be threatened as
273 they have already been limited in south Floridaas history has shown. Alternatives for new water
274 supplies are limited (mostly saltwater sources) which can only be overcome with significant
275 costs to build new water treatment facilities. Stormwater is rarely mentioned as a supply, but all

276 | rivers are stormwater runoff [\[34\]](#). Coastal areas will not be able to store this runoff for
277 | topographical reasons, but, infiltration trenches will work continuously, and require a continuous
278 | point of discharge. A water treatment plant is a solution to the water quality and water supply
279 | conundrum.

280 | The use of infiltration ~~technology to reduce groundwater levels galleries~~ along streets and
281 | ~~in neighborhoods would operate under the same scenario as would accomplish the same thing as~~
282 | ~~wellpoints. The concept is not new as it is used throughout the west as a means to obtain higher~~
283 | ~~quality water from surface rivers and streams. In those places it is termed~~ riverbank filtration. ~~In~~
284 | ~~island communities the technology is used to skim and or for skimming~~ freshwater ~~lenses that~~
285 | ~~reside atop saltwater in island communities where water is limited.~~ Infiltration galleries, ~~which~~
286 | ~~are basically or~~ horizontal wells, have not been used in Florida because vertical wells have
287 | always been so productive. ~~However the benefits is that if~~ infiltration galleries could spread the
288 | cone of depression and minimize drawdowns, ~~which would facilitate the to permit additional the~~
289 | ~~skimming of additional~~ fresh water ~~supplies from above the saltwater intrusion front, while~~
290 | ~~concurrently just below the surface where it can increase~~ soil capacity ~~the most~~. Since these
291 | systems will run continuously, they mimic water supplies.

292 |

293 | **Conclusions and Recommendations**

294 |

295 | The hydrologic cycle is currently changing in many locales. ~~There is strong evidence~~
296 | ~~that global climate change is having an impact upon the world's water resources which may~~
297 | ~~exacerbate current trends. As a result, experts expect more~~ flooding from intense rains ~~will~~
298 | ~~increase~~ with time, especially in urban areas with altered surface conditions. ~~Storm~~ ~~At the same~~

299 | time, storm water utility managers are looking for a solution to identify vulnerable areas and to
300 | identify solutions to deal with increased flooding frequency that residents recognize. ~~At the~~
301 | ~~same time, , and~~ water supply utility managers are looking ~~for~~ for additional, and more reliable
302 | water supply solutions.

303 | In this investigation, GIS mapping, high resolution LiDAR and groundwater mapping
304 | from well data was used to identify the vulnerable areas in Miami Beach ~~from 0, 1,2 and 3. The~~
305 | ~~protocol was extended to 3~~ feet of sea level rise. ~~A series of solutions was found. The City has~~
306 | significant vulnerability which is not surprising. What was noted was that flooding occurs
307 | concurrently with king tides and the end of the wet season, which create the worst conditions on
308 | the island. The same can be applied to other south Florida island communities. The solutions
309 | indicated that ~~One thing that because obvious was that~~ the traditional barriers between utilities
310 | may ~~prevent the potential frustrate efforts to derive for a~~ unique solutions to address both
311 | stormwater excess and water supply needs. ~~One tool identified as having potential to address~~
312 | ~~both was infiltration galleries. Infiltration galleries will were identified as a tool that has the~~
313 | potential to reduce groundwater levels, which make soil capacity to absorb rainfall increase,
314 | while creating a constant water supply. Flooding ~~will frequency should~~ decrease ~~as a result,~~
315 | while water supply sources increase. his The infiltration gallery solution has the potential to
316 | help many low lying areas and island communities extend the life of their communities from
317 | flooding damage by reduce flood risks. ~~At the same time they may while capture capturing~~
318 | water to treat for water supplies.

319 | However the parameters that define infiltration galleries is site specific. The production
320 | from a horizontal well is related to screen length, grain size of the sand, transmissivity of the
321 | sand, head, open space in the screen and other factors, all of which are site specific. Hence ~~a~~ any

322 | proposed infiltration gallery program will require a local testing program ~~would need to be~~
323 | ~~pursued to define~~answer the productivity per foot of well screen. Once ~~these~~this value ~~is~~are
324 | known, the length of horizontal well is easily calculated and long-term development of additional
325 | horizontal wells is easily accomplished.

326 | A bigger challenge will be permitting of the horizontal well. This may take time to
327 | demonstrate that the water used is direct rainfall capture. Once demonstrated, the final task will
328 | be to address the “groundwater under direct influence of surface” water issue in the Safe
329 | Drinking Water Act. This requirement places more frequent monitoring on the utility as
330 | compared with traditional groundwater sources. A program must be designed for ongoing
331 | testing to comply with the groundwater under the direct influence of surface water rules, and
332 | identify appropriate treatment methods. But the use of infiltration trenches would seem to
333 | provide an opportunity to address soil storage capacity and water supply needs while being
334 | protective of both public health and property.

335

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Table 1 Tools to Protect Infrastructure from Sea Level Rise Impacts

Solution	Benefits	Barriers
Increase stormwater drainage system capacity through more pumping	reduce flooding faster	nearshore water quality impacts if discharged to waterways; installation and operations cost, need to constantly increase capacity
Increase the number of pumping stations specifically installed to drain roadway right-of-ways	reduce flooding faster	nearshore water quality impacts if discharged to waterways; installation and operations cost, need to constantly increase capacity
Install gravity wells	Provide place for water to go	Only works where saltwater underlies freshwater, cost, need to constantly increase capacity
Install Class V injection wells	Provide place for water to go; high capacity	Permits, operations and installation cost, need to constantly increase capacity
Identify offsite stormwater retention areas to divert excess stormwater	Water quality and quantity benefit	will become inundated as sea level rises
Exfiltration trenches as a drainage	reduce flooding faster	will cease to work as groundwater

solution		levels rise
Raise roadway elevations	reduce flooding	offsite impacts, right-of-way acquisition
Abandon roadways too low and with neighboring areas too low to elevate without private property impacts	eliminates public sector cost	offsite impacts, lost infrastructure investment, loss of access to property, potentially catastrophic
Reengineering canal systems, control structures and pumping stations	reduce flooding faster	cost, nearshore impacts
Install wellpoint dewatering technology for permanent use	creates soil capacity for drainage, reduces flooding	nearshore water quality impacts if discharged to waterways; installation and operations cost, need to constantly increase capacity
Install infiltration dewatering technology for permanent use	creates soil capacity for drainage, reduces flooding	nearshore water quality impacts if discharged to waterways; installation and operations cost, need to constantly increase capacity

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Figure 1 Location of Monitoring wells.

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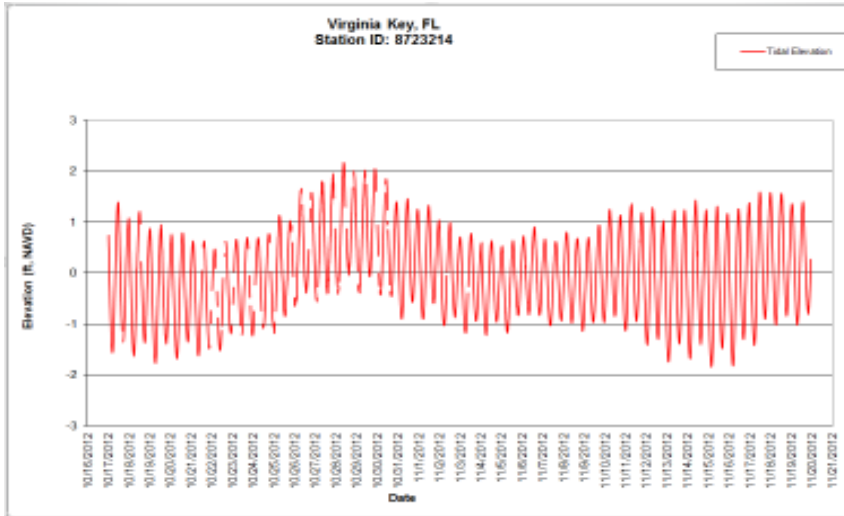
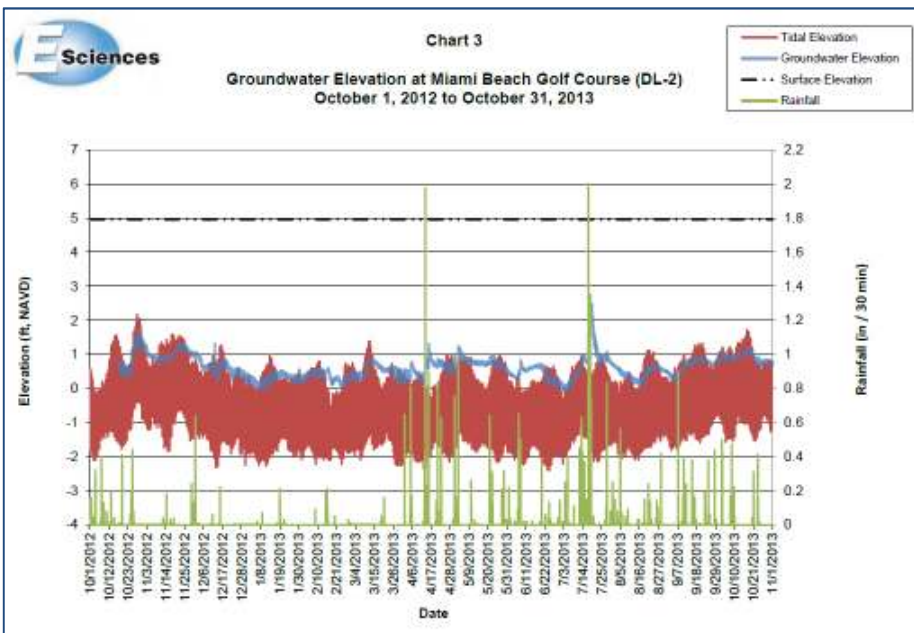
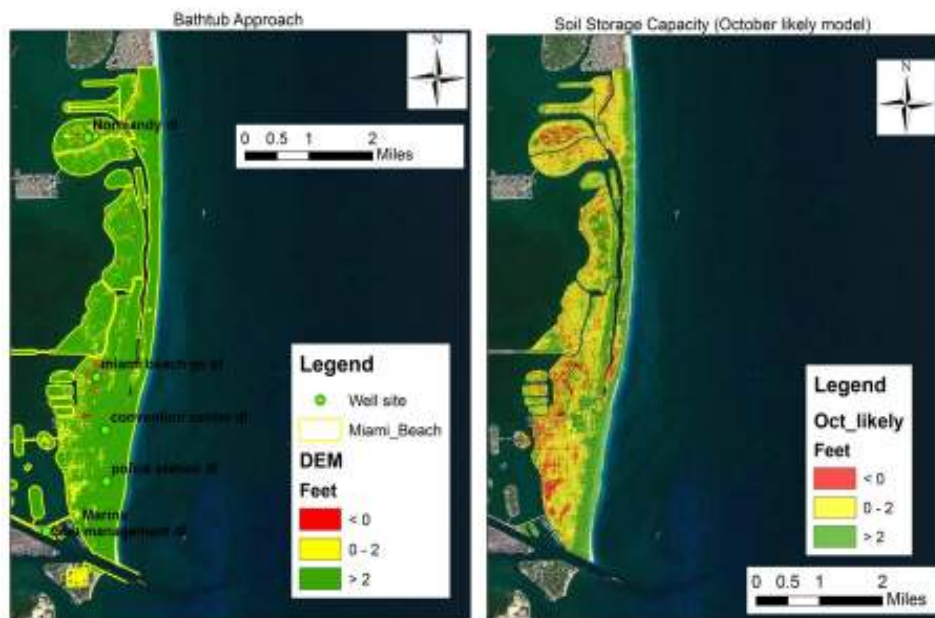


Figure 2 Tides from October 1, 2012 to November 30, 2013. Note the highest 3 day total is 2.0 ft. Normal low water table tide 3 day events are above 1 ft.



523 Figure 3 Miami Beach golf course station. The Miami Beach golf course site shows that the
 524 groundwater level basically matched the high tide, but fluctuated 0.5 ft downward as tides went
 525 out.



526
 527 Figure 4 Comparison of Bathtub model vs. Groundwater adjusted soil storage model
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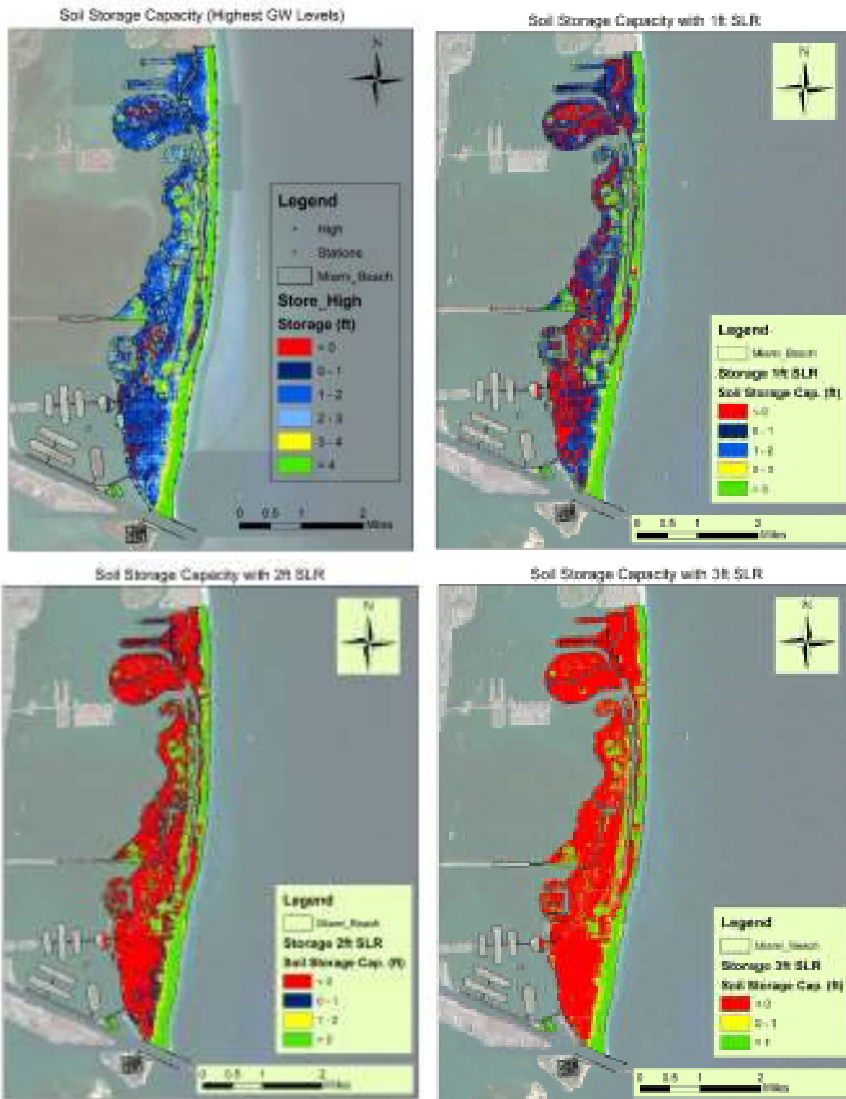


Figure 5a - d – Vulnerable and potentially vulnerable areas in the City of Miami Beach at present and assuming 1, 2 and 3 ft Sea level rise scenarios using soil storage model at 99 percentile tides