Results & Discussion

Overview & Exposure Breakdown

The following section describes the overall results of the exposure analysis by grouping the units into three classes based on percent of assets listed as high exposure (Table 5). Unit specific analysis and results can be found in Appendices C-F.

Low Exposure Group:
< 25 % of assets high exposure
Intermediate Exposure Group:
26-75 % of assets high exposure
High Exposure Group:
> 75% of assets high exposure

Low Exposure Group

Sixteen of the 40 coastal units fell into the Low Exposure Group, three of which had no assets (0%) listed as high exposure (Table 5). SAMO is a national recreation area encompassing many state and county beaches and parks, but no NPS owned assets are situated on the coast. Instead, the NPS assets are located in the northern mountainous region of the park. CABR is situated on the rocky, high elevation (several hundred feet) Point Loma shoreline in southern California and has few assets near sea level. PAAL is a national battlefield in southern Texas that is situated several miles inland,

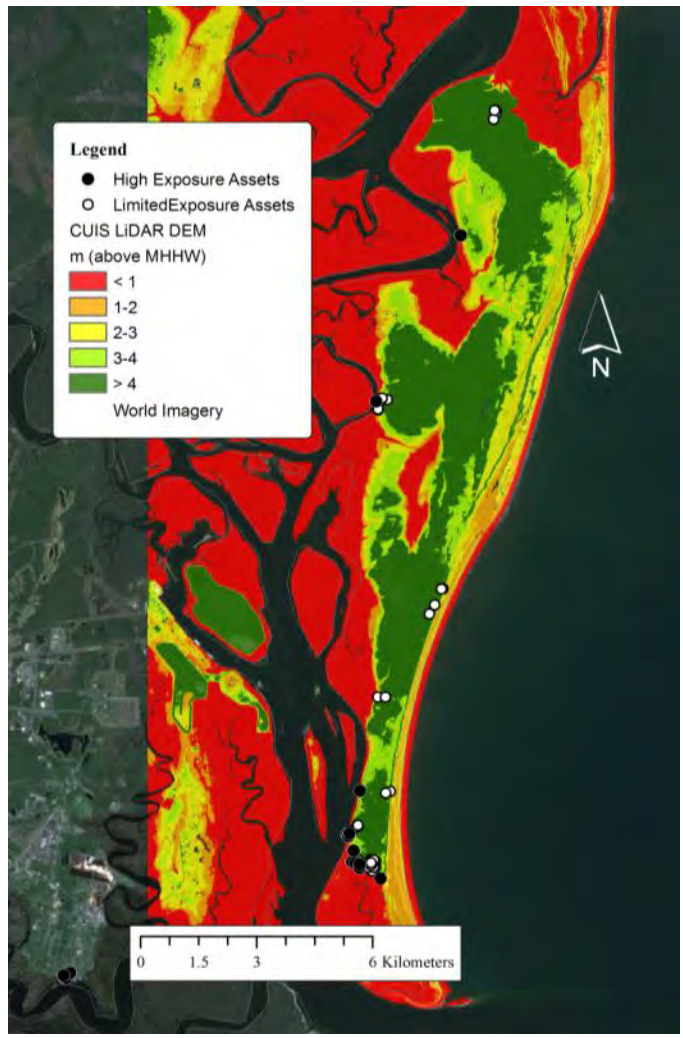

Figure 4. CUIS map with LiDAR DEM and asset locations. Notice the relatively high elevations (green shades) and the overall width of the island.

with elevations above 1 m. These geomorphologic factors led to the conclusion that all assets within these three units (SAMO, CABR and PAAL) should have all assets designated as having a limited exposure to long-term SLR.

The thirteen remaining units in the Low Exposure Group are primarily high elevation NER and PWR units. The exceptions are CUIS and PAIS, two barrier island parks which are geomorphologically different from the other island units in this study. Both have higher elevations (> 3 m) and overall widths (> 4 km) than most barrier islands, and most of the NPS assets are located within these wider, higher elevation zones (Figures 3 and 4). Also important to note is that unlike most coastal parks, a large portion of these islands are accreting (information via personal communications with park staff).

Intermediate Exposure Group

The Intermediate Exposure Group contains four units from the NER, three from the PWR and one from the SER (Table 5). FIIS and LEWI fall within the higher end of this percentage range, with 58% and 70%, respectively. A number of units within this exposure group, such as FIIS and GATE, were severely affected by Hurricane Sandy in October 2012. It is important to note that this storm occurred after the initial visits and analyses were completed for this project. Therefore, it is likely that a number of NER units would have different results if completed post-storm. Many assets within GATE that were well over the 1 m elevation threshold for this project were severely affected, some even destroyed, during Hurricane Sandy. Therefore, the percentage of high exposure assets within many units may have dramatically different results if analyzed today. Because of this recognition, the results from GATE were reviewed in detail with park staff and compared to new post-Sandy flood data. The results of this case study will be discussed in a later section of this document.

High Exposure Group

A total of 16 units fell into the High Exposure Group; 11 of these had all NPS assets (100%) designated as high exposure. These 100% exposed units include most of the SER, as well as the NER units of CACL and STLI (Table 5). The SER units that have 100% of assets designated as high exposure were included in the broad categorization of low-lying units that was established during discussions with NPS staff (Table 3). The majority of the assets within these units are already threatened by coastal hazards (i.e., tropical storms) and have extremely low elevations and, therefore, an additional 1 m of SLR would likely affect all assets within these units. The NER units with 100% of assets designated as high exposure are relatively small units with low elevations, situated directly on or within New York Harbor. The combination of these units being exposed to storms and having extremely low elevations yielded the result of all assets being designated as high exposure to long-term SLR (Table 4).

The five remaining units in the High Exposure Group include three units from the NER (ASIS, BOST, and SAMA) and two units from the SER (BICY and GUIS). Two of these units, ASIS and GUIS, are low-lying barrier islands with a few assets on the mainland. BICY is a unit on the west coast of Florida with large sections of NPS property situated far inland from the coast. The other two, SAMA and BOST, are historic units situated directly on the water within low elevation, highly developed coastal cities (Salem and Boston, MA).

Table 5. Exposure results for all 40 coastal NPS units.

Region	Unit	All Analyzed Assets		High Exposure Results				
		# Assets	CRV	# Assets	% Assets	CRV	% CRV	Exposure Range
NER	ACAD	584	$741,643,375	69	12%	$49,065,405	7%	Low
	ASIS	188	$141,894,898	179	95%	$135,180,045	95%	High
	BOHA	143	$121,763,441	54	38%	$55,498,822	46%	Intermediate
	BOST	77	$608,380,029	65	84%	$408,185,040	67%	High
	CACL	5	$23,606,659	5	100%	$23,606,659	100%	High
	CACO	414	$248,946,088	70	17%	$51,385,721	21%	Low
	FIIS	228	$98,806,696	132	58%	$56,036,479	57%	Intermediate
	FOMC	44	$183,243,495	4	9%	$77,494,234	42%	Low
	GATE	1089	$6,594,927,986	302	28%	$2,672,440,355	41%	Intermediate
	GEWA	56	$37,708,870	2	4%	$4,984,022.67	13%	Low
	GOIS	32	$153,484,095	11	34%	$71,223,382	46%	Intermediate
	NEBE	20	n/a	5	25%	n/a	n/a	Low
	SAHI	43	$41,787,745	1	2%	$1,122,038	3%	Low
	SAMA	32	$41,641,700	27	84%	$30,948,717	74%	High
	STLI	104	$1,512,459,244	104	100%	$1,512,459,244	100%	High
SER	BICY	254	$1,030,477,750	210	83%	$414,159,499	40%	High
	BISC	68	$67,913,211	68	100%	$67,913,211	100%	High
	CAHA	559	$1,173,309,846	559	100%	$1,173,309,846	100%	High
	CALO	289	$878,717,414	289	100%	$878,717,414	100%	High
	CANA	167	$88,404,508	167	100%	$88,404,508	100%	High
	CASA	54	$26,571,807,938	54	100%	$26,571,807,938	100%	High
	CUIS	204	$112,431,019	33	16%	$19,361,490	17%	Low
	DESO	10	$3,366,160	10	100%	$3,366,160	100%	High
	EVER	493	$657,087,096	493	100%	$657,087,096	100%	High
	FOPU	52	$286,318,757	52	100%	$286,318,757	100%	High
	FOSU	38	$1,230,735,376	38	100%	$1,230,735,376	100%	High
	GUIS	436	$4,938,540,247	355	81%	$3,930,189,186	80%	High
	TIMU	111	$28,262,535	42	38%	$9,941,883	35%	Intermediate
PWR	CABR	55	$41,741,304	0	0%	$0	0%	Low
	CHIS	166	$160,239,240	23	14%	$46,691,845	29%	Low
	FOPO	17	$208,178,640	5	29%	$191,161,089	92%	Intermediate
	GOGA	1049	$4,934,700,016	114	11%	$617,570,959	13%	Low
	LEWI	50	$33,397,041	35	70%	$18,047,865	54%	Intermediate
	OLYM	873	$973,129,278	72	8%	$37,500,350	4%	Low
	PORE	639	$739,325,357	25	4%	$34,929,157	5%	Low
	REDW	490	$367,895,176	20	4%	$7,871,075	2%	Low
	SAFR	49	$901,209,688	21	43%	$262,743,226	29%	Intermediate
	SAMO	270	$163,605,010	0	0%	$0	0%	Low
IMR	PAAL	26	$9,366,512	0	0%	$0	0%	Low
	PAIS	78	$77,165,636	14	18%	$40,920,359	53%	Low

Service-Wide Exposure & Risk

Within the 40 coastal NPS units in this study, almost 10,000 assets with over $56 billion in current replacement value (CRV; from FMSS) were analyzed for exposure to long-term SLR (Table 6). Approximately 39% of NPS assets were designated as high exposure; these assets combined have a CRV of over $41 billion. The SER has the highest percentage of assets at risk (87%) and these assets make up over 85% ($35 billion) of the total value (CRV) at risk in all 40 units. The PWR and IMR have the lowest percentage of high exposure assets, with 9% and 13%, respectively. This sharp divide between the regions is primarily a function of elevation differences between the Atlantic and Pacific coasts. The NER has the highest percentage of assets at risk that are considered historic (in FMSS; Table 6).

Table 6. National and regional SLR exposure data results.

Region	Total Assets Analyzed		High Exposure Results				
	# Assets	CRV	# Assets	% Assets	CRV	% of CRV	% Historic
NER	3059	$10,550,294,321	1030	34%	$5,149,630,164	49%	21%
SER	2735	$37,067,371,857	2370	87%	$35,331,312,364	95%	13%
PWR	3658	$8,523,420,750	315	9%	$1,216,515,566	14%	12%
IMR	104	$86,532,148	14	13%	$40,920,359	47%	0%
All Units	9556	$56,227,619,076	3729	39%	$41,738,378,453	74%	15%

In terms of Asset Type (as coded by FMSS), buildings and parking make up the majority of the high exposure assets, with 42% and 11%, respectively (Table 7). However, fortifications make up most (over 80 %) of the total value (CRV) of the threatened assets (Table 7). This is a function of the extremely high CRV of these historic features in FMSS; the fortification at CASA alone has a CRV of over $25 billion. The CRVs assigned for these fortifications are exceptionally high compared to other asset types and make it difficult to evaluate the relative exposure of the other asset categories.

Removing the fortifications from the analysis gives a clearer picture of how the other asset types compare. Table 8 shows the top five high exposure asset types based on percentage of CRV, with fortifications removed from the analysis. In this revised analysis, buildings make up over 37% of the CRV of the high exposure asset types. While this type of analysis is useful, it is important to note that removing fortifications from the analysis should only be used as a way to compare the other asset types. The fortifications have a high CRV because they represent unique and irreplaceable resources and, therefore, must be included to get a complete representation of the scale and value of assets at risk.

Table 7. High exposure results listed by asset type. Historic is defined in FMSS as any asset greater than 50 years old.

Asset Code	Asset Description	# Assets	% Assets	CRV	% CRV	% Historic
1100	Road	371	10.04%	$809,950,504.27	1.94%	7%
1300	Parking	403	10.90%	$225,691,765.10	0.54%	4%
1700	Road Bridge	53	1.43%	$122,342,193.83	0.29%	9%
2100	Trail	313	8.47%	$452,381,156.18	1.08%	5%
2200	Trail Bridge	12	0.32%	$3,371,097.00	0.01%	17%
2300	Trail Tunnel	1	0.03%	$2,531,243.95	0.01%	100%
3100	Maintained Landscape	210	5.68%	$1,668,010,936.21	4.00%	6%
3800	Boundary	4	0.11%	$3,966,740.00	0.01%	75%
4100	Building	1576	42.64%	$2,816,396,622.25	6.75%	18%
4300	Quarters	48	1.30%	$17,443,425.00	0.04%	21%
5100	Water System	21	0.57%	$34,551,477.97	0.08%	24%
5200	Waste Water System	54	1.46%	$839,129.00	0.00%	0%
5300	Heating & Cooling	1	0.03%	$500,159.81	0.00%	0%
5400	Electrical System	3	0.08%	$2,711,957.01	0.01%	0%
5700	Fuel System	14	0.38%	$3,440,619.98	0.01%	7%
6100	Dam/Levee/Dike	10	0.27%	$39,266,722.33	0.09%	30%
6200	Constructed Waterway	23	0.62%	$142,133,363.00	0.34%	13%
6300	Marina/Waterfront System	166	4.49%	$1,041,180,713.61	2.49%	12%
6400	Aviation	4	0.11%	$18,773,580.96	0.04%	25%
7100	Monuments	35	0.95%	$33,921,706.46	0.08%	26%
7200	Maintained Archaeological	136	3.68%	$63,690,858.24	0.15%	71%
7300	Fortification	56	1.52%	$34,161,004,760.69	81.85%	88%
7400	Towers/Missile Silos	7	0.19%	$1,502,070.99	0.00%	57%
7500	Interpretive Media	167	4.52%	$57,713,570.14	0.14%	0%
7900	Amphitheaters	8	0.22%	$14,688,398.90	0.04%	0%

Table 8. Top five high exposure asset types based on % of total CRV, with fortifications removed from analysis.

Asset Code	Asset Description	CRV	% CRV	% Historic
4100	Building	$2,816,396,622.25	37.17%	18%
3100	Maintained Landscape	$1,668,010,936.21	22.01%	6%
6300	Marina/Waterfront System	$1,041,180,713.61	13.74%	12%
1100	Road	$809,950,504.27	10.69%	7%
2100	Trail	$452,381,156.18	5.97%	5%

FMSS, NPS Resources and Adaptation

Cultural resource conservation and history and heritage education are primary functions of NPS. One way that NPS fulfills these functions is by maintaining, protecting and exhibiting historic and cultural resources, such as buildings, landscapes, fortifications and archaeological sites. These resources are often the back-bone of public education regarding national, regional and local heritage. Therefore, when an asset is at risk to SLR, it may be important to consider if it is listed as historic within FMSS (greater than 50 years old, as defined in FMSS). For example, a historic building vulnerable to SLR will be evaluated differently in terms of potential restoration, protection, relocation or demolition than a non-historic building, as preservation of these assets are a tenant of the NPS mission statement.

Within these 40 coastal units, there are 1,576 buildings designated as high exposure to SLR (Table 7). This is an average of 39 buildings per unit that will likely need a plan for adaptation in the next 100+ years. However, only 280 of the high exposure buildings are listed as historic in FMSS. Although these historic buildings make up a smaller percent (18%) of the total buildings at risk, it is important to note that these structures have the highest CRVs (over two-thirds of the total value for buildings). During the review process, the accuracy of FMSS was mentioned numerous times. For example, it was noted that many assets are erroneously listed as non-historic within FMSS (at the time the data was obtained). This is especially true for assets types such as maintained archaeological sites, of which only 71% are listed as historic (this number should likely be 100%). Also, many cultural resources, including most archaeological sites, are not currently part of the FMSS database. Therefore, the total risk to these types of resources is not encompassed within this particular study.

The age and the value of an asset are just a few pieces of information that can be used as tools when considering climate change adaptation strategies. Assets within FMSS have additional properties that may be helpful for evaluating adaptation options, including the priority of an asset to the park's mission (Asset Priority Index, API) and the relative condition of the asset (Facilities Condition Index, FCI). For example, a historic building in poor condition with a low priority to the unit would not likely need the same adaptation strategy as a historic building in good condition and of high priority. The relationship between the condition and priority of an asset has recently been a focus for decision making within NPS facilities management. For example, NPS is currently in the process of updating FMSS with more accurate Optimizer Band (OB) scores. OB scores are a banding of assets found in FMSS that is based on the API and FCI. The scores are meant to help guide the priority of funding and investment for a particular asset and will be another important piece of data to review when considering adaptation options.

NPS is also committed to natural resource preservation. One major hurdle that NPS faces in the future as SLR threatens an increasing number of assets is the balance between protecting cultural resources and infrastructure, and preserving natural resources. In many cases, protection of assets in place (e.g., by adding a seawall) can damage or remove the surrounding natural environment. Therefore, not only should the FMSS properties (i.e., API, FCI, and CRV) be considered when discussing adaptation strategies, but also the possible risk of damage to other NPS resources.

Each unit also has its own unique enabling legislation and general management plan to follow when developing adaptation options. For example, ASIS, which is a national seashore containing wilderness area, is required to preserve natural resources and provide compatible recreation, whereas FOSU, which is almost entirely composed of cultural resources (a fortification), faces different management challenges to protect non-renewable cultural resources along an eroding shore. Complex decisions about how best to protect assets from SLR and other impacts of climate change will increase as climate change continues to affect our coastlines, requiring significant financial commitment and staffing. It is important that NPS begin to put together national and regional plans for climate change adaptation.

Case Study: Hurricane Sandy and GATE

Hurricane Sandy made landfall in October 2012 and had significant impacts within several NER units, including GATE. The SLR exposure analysis for this project was completed prior to Sandy, which brought unprecedented storm surge and flooding to many portions of these units. After the storm, it was clear that many areas of GATE were at a higher risk from coastal hazards (i.e., storm surge and erosion) than previously acknowledged.

Many states affected by Sandy have since collected new pertinent coastal data, such as LiDAR-derived elevation maps, and have also updated out-of-date coastal hazard maps, such as flood hazard and flood zone maps. This new wealth of data is an important tool for understanding the exposure of NPS assets to storms and flooding. Therefore, the assets at GATE were analyzed as a case study to illustrate how units will not only be affected by SLR over the long term, but are also severely at risk to storm hazards.

As part of this case study, we compared the georeferenced assets at GATE with the new Federal Emergency Management Agency (FEMA) Flood Hazard Maps. Using ArcGIS, we determined which assets within the unit were located within one of two FEMA flood hazard zones, the Special Flood Hazard Risk Areas (AE zone) and the Coastal High Hazard Areas (VE zone). Table 9 shows the results of this analysis and Table 10 shows the results of our initial SLR exposure analysis for GATE.

Table 9. Results from FEMA flood zone analysis within GATE. The total number of assets analyzed differs from the total number of assets analyzed in the SLR exposure analysis due to availability of geographic data. Only assets with known specific location data were included in this analysis.

Location	# Assets	% Assets	Total CRV	% CRV
Total Analyzed	986	n/a	$6,054,494,902.78	n/a
VE Zone	49	5%	$127,545,541	2%
AE Zone	515	52%	$2,268,983,336.46	37%
AE + VE Combined	564	57%	$2,396,528,877	40%

Table 10. Summarized results from the SLR exposure analysis within this study.

	# Assets	% Assets	Total CRV	% CRV
Total Analyzed	1089	n/a	$6,594,852,975	n/a
High Exposure	302	28%	$2,672,440,355	41%

Hurricane Sandy Lessons

The results from our exposure designation for GATE yielded 28% of the assets having a high exposure to SLR over the next 100 years (Table 10). However, the post-Sandy FEMA flood zones analysis shows that 57% of the assets within GATE are within the high flood risk and coastal high hazard areas (the AE and VE zones, Table 9). These results confirm our initial speculation that the results from the SLR exposure designation were likely conservative, especially for units with narrow barrier island sections such as GATE. The case study analysis of GATE and the FEMA flood zones shows that almost two-thirds of the assets are within high coastal risk areas; however, this percentage is considerably higher for some areas of the park. For example, 82% of the assets located on Sandy Hook were in one of the FEMA high risk flood zones (Table 11), compared to 30% that were considered high exposure to long-term SLR (Figure 5).

The different results yielded by these two methods of risk analysis are primarily due to the nature of the data and the hazard in question. The new post-Sandy FEMA flood zones (Figure 5A) are meant to include the land area that is at risk to a 1-percent-annual-chance flood and comprises a very large area of the coastal zone. Therefore, the assets in these zones are those vulnerable to flood hazards, such as storm surge. Our SLR exposure analysis, however, categorized assets as high exposure that were at or near 1 m elevation above mean higher high water (red shades in Figure 5B). This analysis determined the asset risk related to long-term rise in sea level, and not flooding risk associated with storms. Therefore, a much greater number of assets were determined to be at risk according to the FEMA flood zone analysis. Many assets within the high risk FEMA flood zones may be at elevations much higher than 1 meter; in fact, storms (such as Sandy) produced surge flooding above 3 meters in this region.

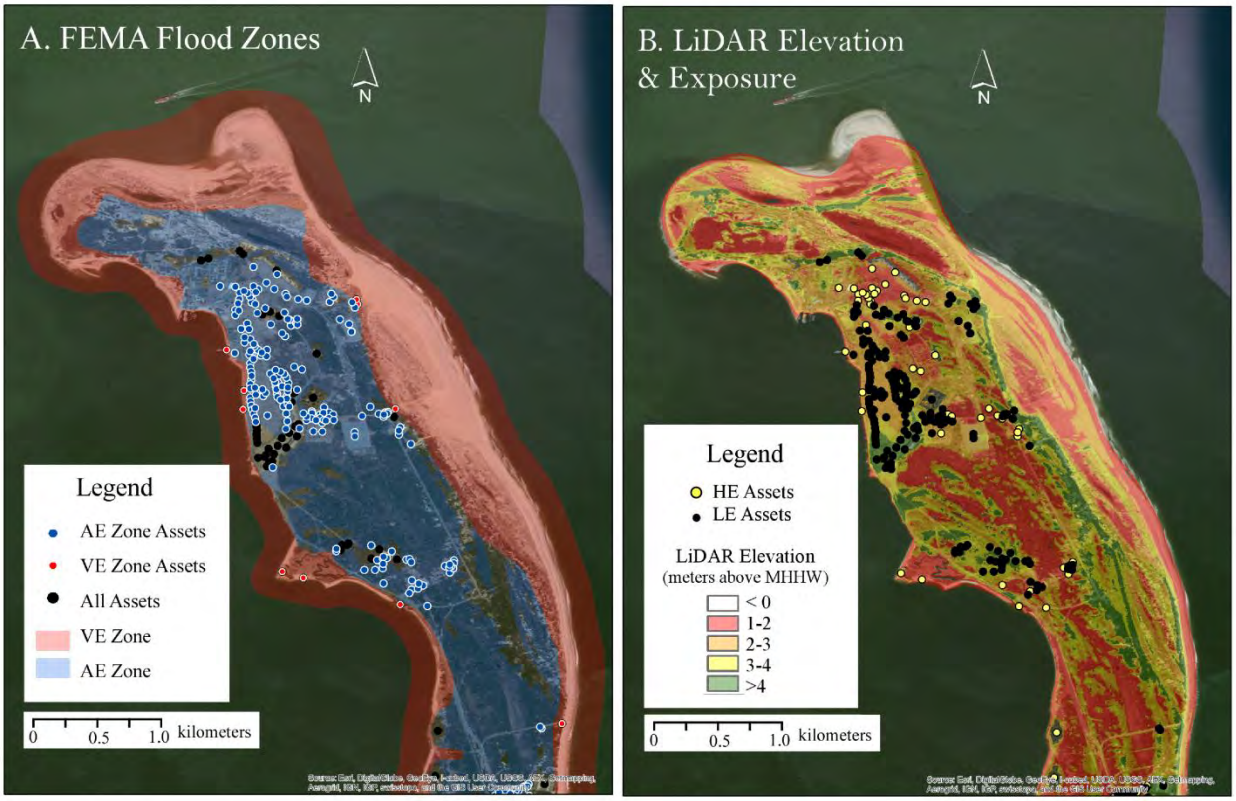

Figure 5. Comparison map of the results from the Sandy Hook portion of GATE, including the FEMA flood zone analysis (A) and the SLR exposure analysis (B) for assets within the area (HE = high exposure, LE = limited exposure).

The findings from this case study at GATE have proven that while it is essential to determine NPS assets at risk to long-term SLR, it is also extremely vital to understand and consider other hazards that may impact these assets in the short term. **Additionally, the SLR exposure analysis is likely a fairly conservative estimate of the number of assets at risk over the next 100 years, as storm impacts (especially within the units along the east coast) may be a more imminent threat to NPS property**. As more parks continue to georeference their assets and define the relation of their assets to available flood hazard zones, the overall exposure of NPS assets to rising sea level can be better characterized. Hopefully, this type of data will eventually be incorporated into FMSS.