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Monroe County, FL: GIS Vulnerability Assessment for Sea Level Rise Planning

Appended Responses to Peer Review and Staff Comments from Draft Document

Nick Aumen's comments

Comment 1: *I worry that SLR scenarios used in this analysis are too conservative, based on more recent scientific literature. Even if higher levels are more uncertain, would it not be prudent at least to consider the impacts of more severe changes than considered here?*

As a scientist, I completely understand this concern. However, this planning effort was undertaken under the funding and approval of the Monroe County Board of County Commissioners, who are signatories to the Southeast Florida Regional Climate Change Compact. The 2011 Unified Sea Level Rise projections were adopted for the explicit purpose of providing analytic clarity and uniformity to vulnerability assessments. Through this project there was a remarkable lack of argument, at least from public officials, about use of the accelerated sea level rise curves. Introduction of higher curves into the planning effort at the end of the project, frankly, would not only be a source of new modeling effort, but could also undermine the consensus and trust earned throughout the consistent use of scenarios throughout the project. There is therefore little support among Monroe County staff, or the planning team to use a higher curve than those already seen and agreed by the BOCC.

From an applied sense, the analyses already show that 24 inches by 2060 scenario would have extremely severe impacts on Monroe County by 2060. In fact, it is likely that this rate of sea level rise would exceed resilience and adaptation thresholds for most areas of Monroe County. Such a future scenario would also be accompanied by clear knowledge that seas would continue to rise at a high rate for decades and centuries to come, not to mention disruptions of global agriculture and other difficulties associated with runaway global warming and climate change. Because the 24 inches by 2060 scenario already presents such an extreme and dire case (even if not the most extreme that is technically possible), it is my sincere professional opinion there is very little to gain from a general vulnerability assessment of this type using a higher sea level rise curve, at least within Monroe County.

I do know that the draft guidance for the updated SEFRCCC suggests using the higher SLR curve (6.6 feet by 2100, which translates to about 31 inches by 2060 using the 2011 SEFRCCC methodology) from the National Climate Assessment for "low risk tolerance" infrastructure. My understanding is that "low risk tolerance" infrastructure refers to new construction of facilities like nuclear power plants that cannot be moved and would be continue to be extremely dangerous once inundated. One could perhaps make the argument that Monroe County should consider developing and implementing design standards for its wastewater treatment infrastructure to be resilient through 2060 under the most extreme sea level rise scenarios, and for there to be specific decommissioning protocols in the case that the infrastructure must be abandoned before 2060 due to catastrophic sea level rise. As noted in more detail below, such engineering assessments and design criteria ultimately exceed the level of technical detail we currently have available for this vulnerability assessment.

All that said, I have amended the text to note that higher rates of sea level rise are possible and noted in the scientific literature (pg. 2). Because we also received some public demands to consider lower sea level

rise (i.e., simple continuation of the linear trend) scenarios, I've also included language to that effect as well.

Comment 2: *Another climate change possibility that could have dramatic effects in Monroe County is the possibility of lower amounts of precipitation, coupled with increasing temperature (and associated increases in evapotranspiration). A recent analysis suggested that a 10% decrease in rainfall accompanied by a 1.5-degree C increase in temperature could result in major impacts on Lake Okeechobee and Everglades water levels, which could affect water supply for the Keys (see Aumen et al. 2015 for an overview). The document recognizes the potential impacts from sea level rise on water supply (p. 50), but gives little attention to potential impacts from the coupling of decreased rainfall and increased evapotranspiration.*

I have modified a paragraph on pg. 53 to read as follows:

"It is also widely documented that severe droughts can quickly lower the freshwater lens and in some cases result in both landward and upward movement of the saltwater interface within the Biscayne Aquifer (Peters and Reynolds 2008). This saltwater movement is associated with drops in interconnected regional surface water resources that occur due to evaporation and lack of rainfall replenishment, as well as increased human demand for freshwater supply from surface and groundwater surfaces (Bloetscher et al. 2010). Some climate change models suggest that increasingly severe drought conditions and higher dry season temperatures are more likely to occur within southeast Florida over the next several decades, further stressing regional freshwater resources and providing conditions that further promote the landward encroachment of saltwater lenses (Bloetscher et al. 2011). Thus, there is great regional concern that the interacting stressors of sea level rise, increased water demand, malfunctioning drainage canals, and anomalously severe droughts could together precipitate significant regional saltwater contamination of freshwater wells within the Biscayne Aquifer over the next several decades (Aumen et al. 2015)."

Comment 3: *As an ecologist by training, and not a geospatial expert, I have no specific comments on the methods and approaches used in this document other than they seem very appropriate and relevant. However, I have an overarching concern about how we project impacts from sea level rise. This document focuses on footprints of critical buildings and roadways, which is understandable. However, how likely is it that there would be a functioning infrastructure and inhabitants in an area where only the buildings and the roads are above water? Is there a way to extend the analysis to examine some sort of threshold at which rises in sea level overcome our ability to adapt, resulting in migration? I also could imagine a scenario in which critical buildings and roadways are preserved, but one or more critical functions are lost that make the buildings and roadways irrelevant. Examples include the loss of water supply, flood control, and sewage treatment capabilities. The only text that I could find related to this concern is on p. 37, which mentions the possibility of altered patterns of population settlement.*

These are important questions, and ones I think about A LOT. The technical answer is that we don't really know what the thresholds for migration are, although – as an aside – I am currently collaborating with a demographer at University of Georgia, Mathew Hauer, on case study research to maybe get at this. I very

much agree that the abandonment thresholds are very likely to be below the point at which buildings get regularly inundated by tidewaters.

However, the only (and wholly unsatisfying) answer I can give here is that trying to model those system dynamics thresholds is well beyond the scope of what Monroe County contracted us to do for this particular project. What we are trying to do here is at least begin getting a more direct handle on their infrastructure vulnerabilities, and perhaps laying the groundwork for a decision framework for determining thresholds at which infrastructure should either be improved – or abandoned. But these are complex, value-laden decisions that we are not yet equipped to even model (to my knowledge), much less make firm recommendations from a policy or technical perspective.

Comment 4: *With respect to roadways, sea level rise will compromise roads at sea levels well below the actual road surface. Wetter soils and more frequent inundation can compromise the road bed long before the road is actually submerged. This possibility is mentioned in the document for structures and access roads, but not for the main roadways. The potential compromise of the roadbed for Tamiami Trail is one of the major impediments to raising canal stages in the adjacent L-29 Canal for Everglades restoration purposes. Hundreds of millions of dollars have been spent and will be spent in the future to construct bridges and to raise the roadbed along the most vulnerable stretches of Tamiami Trail.*

Good point. I've added this text to introduce the roads section:

"Increased tidal inundation of road beds and road surfaces is generally one of the earliest impacts of sea level rise observed in low lying coastal communities. Although saltwater infiltration into road surfaces may begin as an infrequent and temporary nuisance, repeated and severe inundation of road beds and road surfaces can cause a wide range of significant problems and expensive damages. The most readily apparent of these issues is blockage or restriction of traffic lanes due to flooding conditions and increased corrosion of metals on vehicles that may frequently pass through shallow saltwater puddles. Because roads often serve as conduits for stormwater, tidal flooding of roadways during heavy rains may in some cases result in loss of drainage potential that causes more widespread local flooding. Repeated tidal saturation of road bed soils and flowing tidewater action across road surfaces may also in some cases result in wash out or partial collapse of road surfaces (Titus 2002)."

Comment 5: *Also, a hard-to-define loss in quality of life, perhaps through loss of nearby natural areas, could end up being more important than loss of some infrastructure. Another hard-to-quantify example might be the loss of the characteristic vegetation in the Keys from more frequent salt water inundation, which, while only a temporary nuisance for drainage and traffic, can cause irreversible changes in soil characteristics. A colleague of mine spent a lot of money and time planting native vegetation on his property on Cudjoe Key. The Hurricane Wilma storm surge in October 2005 inundated his property, and killed the new vegetation. The increased salinity of the soil prevented the restoration of this vegetation for years, and that was only from one storm surge event. If the Keys landscape becomes less aesthetically pleasing because of these vegetation changes, it is possible that this impact could be far more serious from an economic standpoint than drainage or traffic nuisances?*

I do agree with these sentiments, but they get into issues of aesthetic preference and human values that are simply beyond the specific scope of this project.

Comment 6: *Justification should be included for omission of the Key West, Key Colony Beach, Marathon, and Islamorada WWT facilities (p. 35). It seems like these facilities should be part of the evaluation.*

The rationale for omitting these is that the County staff was pretty adamant about not doing any extra work/analysis of infrastructure belonging to municipalities. Where locations for municipal infrastructure were provided by the County, we included the analysis. If not provided, we did not develop the data necessary to do the analysis. I've included this amended text on pg. 38:

"Because this study was conducted for unincorporated Monroe County, additional wastewater treatment facilities operated by the municipalities of Key West, Key Colony Beach, Marathon, and Islamorada were not included in the vulnerability assessment."

Comment 7: *It appears that the evaluation of the WWTPs was limited to inundation of structures within the facilities. Is it possible that the WWTPs would lose function before sea levels rise to the point of more frequent inundation? For example, could higher sea levels decrease the ability to gravity drain wastewater, or even to pump wastewater? An assessment of WWTP function seems necessary under these various scenarios. Additionally, do any WWTPs in Monroe county presently utilize, or plan to utilize in the future, constructed wetlands for tertiary treatment? If so, WWTP function would be interrupted by sea level rises far below those that would impact actual structures.*

Yes, failure of WWTP systems could occur due to many factors independent of the central facilities. However, the failure points of these systems require very detailed engineering assessments and site-specific data far beyond what we were provided or, frankly, could be expected to evaluate wholly for this sort of planning project. I have added some language into the report to recommend the need for follow-up engineering assessments of the type suggested here:

"The EPA (2014) has recently released a guidance document for auditing site-level flood resilience of wastewater infrastructure. Following this guide, we specifically recommend that the Monroe County's Floodplain Coordinators be supplied with site-level assessments that characterize resistance of above-ground structures and associated electrical components to damages from extreme event flooding. Development of maintenance recording protocols and, as necessary, engineering assessment to assess resistance and resilience of below-grade wastewater pipes and pump infrastructure to increased saltwater incursion associated with sea-level rise is also recommended."

Comment 8: *On page 95, the following statement is made: "There is wide agreement that the most generally predictable of these projected impacts is long-term disappearance of upland ecosystems and associated species that become inundated by rising seas." I am concerned about this statement for two reasons. One, if there is wide agreement, references should be provided to support the assertion. Two, the statement leaves the impression that much less is known about the other components of climate change, which I do not think is true. Although I am not a marine ecologist, I think that coral reef changes from increased ocean temperature already have been documented scientifically. I think the same is true from*

ocean acidification, but I do not know for sure. The document does address these issues more completely in subsequent sections (beginning on p. 97). In any event, these issues should be explored more carefully or the wording might be revised. The same general comments might apply to the discussion about mangrove communities. Again, I have the sense that some work has been done and published. I would suggest that you ask one or two experts in these areas to review this section.

Points very well-taken re: the references and strength of the language here. I've adjusted this paragraph in this way:

"Perhaps the most generally predictable of these projected impacts is long-term disappearance of upland ecosystems and associated species that become inundated by rising seas (Ross et al. 2008; Menon et al. 2010; Saha et al. 2011). However, there is also significant potential for large-scale changes in the composition and productivity of marine ecosystems due to the combined stressors of ocean acidification (as associated with increased atmospheric carbon dioxide), increased ocean temperatures, and rapid sea level rise (Duarte 2002; Orth et al. 2006; Hoegh-Guldberg et al. 2007; De'ath et al. 2012; Cunning and Baker 2013). Impacts of climate change on intertidal mangrove wetland communities are perhaps among the least predictable, as such communities could potentially decline or expand depending on multiple factors that include rate of sea level rise, changes in regional sedimentation patterns, and the future extent of human engineering interventions within the intertidal zone (Krauss et al. 2014)."

I do think it is appropriate and defensible to state that disappearance of terrestrial ecosystems is the most generally predictable impact of sea level rise. We can be pretty certain that once a terrestrial ecosystem becomes affected by tidewater, it will convert into something else. By contrast, the thresholds for marine ecosystems are not as straightforward and the relationships are trickier. In coral reefs, for example, there is interaction between nutrients, food chain structure, and other factors that prevent a straightforward inference of X climate change = Y ecosystem change. Same thing goes for mangroves and sea grass communities. We know there are thresholds, but the uncertainty bounds are relatively high due to confounding multivariate factors. However, we can say with very high confidence that X sea level rise = Y loss of upland communities. Basically, if they are under MHHW or even annual higher water, we can be assured that they will have turned into something else.

Comment 9: *The Keller and Causey 2005 reference on p. 96 is very dated with respect to characterizing restoration efforts in the Everglades. Perhaps a reference to information contained in www.evergladesrestoration.gov would be better. Also, it is a bit of overstatement to say in this paragraph that improvement of the Keys coral reef ecosystem was the express reason for efforts to restore Everglades flows. The Keys were certainly one important reason, but one of many.*

I've reworded this a bit here. The point is intended to be the narrow one that the Keys were one of many reasons for Everglades restoration. There is no intention to imply that the Keys were the only reason.

"For all these reasons, there has been longstanding effort to implement management interventions and governmental policies that support the improvement of water quality and ecosystem health within the Florida Keys coral reef ecosystem. Such efforts have included large-

scale replacement of septic tanks with centralized sewerage throughout Monroe County, local load reduction of nutrients and sediments into the near-shore environment (Rehr et al. 2012), and reduced fishing pressures on apex predators and other slowly reproducing species (Bohnsack et al. 1994; Suman et al. 1999)." Improvement of the coral reef system is one of the broader ecosystem restoration goals for long-term plans to restore regional hydrologic flows from the Everglades (Keller and Causey 2005; Caraco and Drescher 2011)."

As for the Keller and Causey (2005) reference, I've left that here because it does provide the explicit linkage from Everglades restoration to coral reef restoration. I've also added the Caraco and Drescher (2011) reference, which is more recent and goes into much more detail on linkages between CERP and coral reef protection.

Comment 10: *In the second paragraph on p. 98, the implication is that local efforts to reduce carbon dioxide are of little use. Although "leading by example" is mentioned subsequently, I think it is important to call attention to the need for carbon dioxide reductions globally. Such global reduction efforts will fail if local areas such as Monroe County do not do their part.*

I have given this a lot of thought and ultimately decided to just delete this paragraph as falling outside the scope of a habitat vulnerability assessment.

Comment 11: *On p. 98, last paragraph, the first major alteration/stress to Florida Bay was the completion of the Flagler railroad, which via its causeways, cut off tidal flushing from the Atlantic. The signal of this impact can be seen in cores of corals in Florida Bay, showing decreased growth rates beginning in the 1920s.*

This paragraph has been amended as follows:

"The other major water quality issue in Florida Bay is a long-term increase in the bay's salinity. These salinity increases have been largely caused by losses of regional freshwater inputs from the Everglades (Hall et al. 2007). However, blockages of tidal exchange between Florida Bay and the Atlantic Ocean, particularly as associated with construction of the Flagler Railway causeway in the early 20th century, have also resulted in increased residence times and onset of hypersaline conditions in low flush areas (Rudnick et al. 2005). These long-term salinity increases are thought to be another major contributing factor in the decline of many seagrass patches and associated aquatic organisms observed in the Florida Keys region over the past several decades (Boyer et al. 2009)."

Comment 12: *On p. 102, I do not understand the explanation provided at the end of the next-to-last paragraph. I understand how LIDAR can overestimate land elevation under vegetation cover, but it is not clear to me how this issue led to the stated result. I am not an expert in this area, but I am assuming this document is geared toward technically literature folks who are not expert in every area.*

I've tried to make this explanation more clear.

"However, an idiosyncratic result is that undeveloped dry land ecosystems show an increase in area by 2030 under the low sea level rise scenario (i.e., three inches total sea level rise), while

developed dry land ecosystems show a decrease in area. A likely explanation for this discrepancy is that LIDAR elevations are often biased upward in areas of high coastal vegetation cover (Wang et al. 2009; Hladik and Alber 2012). This upward elevation bias may result in ground elevation data points within intertidal ecosystems being (erroneously) recorded as higher than MHHW or, in some cases, even higher than annual high water. Such an upward bias could, in turn, lead SLAMM to convert some extant coastal wetland areas into undeveloped dry land under a low sea level rise scenario. This is because tidal vegetation communities that erroneously show underlying elevations in exceedance of annual high water would be assumed to undergo successional growth into non-tidal, upland vegetation communities."

The basic idea is that if SLAMM encounters a mangrove community with an underlying elevation that is higher than annual high water at the given scenario year, it will convert that mangrove community into an upland forest. For example, a given area of mangroves may have a "true" elevation of 0 (i.e., at MHHW), but have an erroneous LIDAR value of 1.4 feet above MHHW. At three inches of sea level rise, the mangrove community with an (erroneous) elevation of 1.4 feet above MHHW could transition into an upland forest.

In reality, it is absurd to think that there would be any increase of upland forest at the expense of mangrove under even minimal sea level rise in the FL Keys (or elsewhere, for that matter). However, at small increments of sea level rise (e.g., 3 inches), it's very likely that the upward elevation bias will lead to some predicted conversion of mangroves into upland forest in SLAMM, as the (mistaken) input elevation is shown as higher than MHHW.

There are emerging techniques for reducing this kind of bias, particularly in saltmarshes (Hladik and Alber 2012, reference below and also added to the report), but these are pretty field data intensive and beyond the scope of the GreenKeys project. Therefore, we need to caveat the results appropriately and, perhaps, make recommendations for developed of enhanced ground elevation data and/or local field corrections.

Comment 13*: At the beginning of the third paragraph on p. 99, I would be cautious about saying there is general consensus among scientists on these points (in general, this document should be reviewed for possible overuse of phrases like "general consensus", "high consensus", and "widespread agreement", unless the author is abundantly sure that these are true and can back the statements up with references). In fact, I think there remains somewhat of a scientific debate about whether nutrient reduction or restoration of freshwater inputs are more important to stabilize seagrass communities and other ecosystem components of the Bay. In fact, one of the main foundations of the Comprehensive Everglades Restoration Project is to get more freshwater to Florida Bay.*

Point well-taken re: the use of the term "consensus" and its ilk. I've gone through and either removed those phrases, or made sure to follow them up with a chain of supporting references. As for this specific comment, I've changed the paragraph as follows:

"Under conditions of rapidly warming and rising seas, conservation of seagrass communities will clearly require a multi-pronged strategy. The fundamental piece of this strategy is reduction of

phosphorus, nitrogen, and other anthropogenic pollutant loads into shallow marine waters that have historically supported seagrass communities. Algal blooms fueled by nutrient loading remain as the primary global stressor to seagrass communities, and there is high consensus among scientists that seagrass areas with low anthropogenic nutrient burdens are likely to show the highest resilience to both sea-level rise and warming of marine waters (Orth et al. 2006; Bricker et al. 2008; Paerl and Paul 2012). Continued nutrient mitigation in Florida Bay through advanced wastewater treatment, stormwater management, and other water quality improvement practices can therefore be expected to increase the resilience of the sea grass community to climate change stressors. Efforts to improve water quality through restoration of regional freshwater inputs and increased tidal flushing are also considered critical to the long-term recovery and future resilience of sea grass communities within the Florida Bay ecosystem (Rudnick et al. 2005)."

Hladik, C. and M. Alber. 2012. Accuracy assessment and correction of a LIDAR-derived salt marsh digital elevation model. Remote Sensing of Environment 121:224-235.

Jayantha Obeysekera's comments

Comment 1: *Please be aware that these numbers (sea level rise scenarios) have changed in the latest projections of the Compact.*

Please see the response to Nick Aumen's first comment, which also notes the revised Compact projections. I have added language in the report to acknowledge that higher sea level rise scenarios are within the range of possibility, while also being clear about the rationale for using the 2011 projections.

Comment 2: *How did you compute the 2010 elevation in terms of the Geodetic Datum? See paper by Flick et al. (2013) Matching Mean Sea Level Rise Projections to Local Elevation Datums, J. of Waterway, Port, Coastal and Ocean Engineering, March 2013*

Thank you for the Flick et al. (2013) reference. Without realizing it, I followed their exact methodology to make the adjustments between the fixed geodetic datum (NAVD88), the 1992 tidal datum, and the differential values for 2010 MHHW used for each of the different sea level rise curves. I've spelled these calculations out in full detail now on pages 2-4.

In practice, I actually modeled everything relative to a DEM based on the 1992 tidal datum, rather than make different adjustments for the two sea level rise curves. So, for example, I modeled vulnerability for the 2030 low sea level rise at 5 inches above 1992 MHHW and the 2030 high sea level rise at 27 inches above 1992 MHHW. This gives the same result as the Compact scenarios, while removing the messiness of creating separate DEMs with a different elevation "datum" for each scenario. However, I realize that I had previously communicated this very poorly in both Table 2 and Table 3. For the sake of clarity, what I've done now is change the reference in these tables to the 1992 national tidal datum epoch for Tables 2 and 3.

As an aside, I did notice that the new Compact projections apparently use the 1992 tidal epoch datum, rather than adjusted 2010 baselines. My assumption is that the Compact did this because the 2010 adjustments end up being pretty confusing to explain, particularly if one starts doing analyses based upon several different sea level rise projections that each end up having slightly different 2010 "baselines."

Comment 3: *It is not clear why this particular dataset (UF GeoPlan DEM at 5 m cell size) was used. I thought there is a point cloud and/or a 5 ft data set.*

There are a few reasons why we chose to use this UF GeoPlan dataset, as opposed to the other sources noted. First, assembling a new DEM from the raw LIDAR point cloud is a very intensive operation to perform across the entirety of the Keys, and the project was tasked and budgeted under the assumption that a new DEM would not be created. There are algorithms available from NOAA Digital Coast to create a DEM from raw LIDAR clouds, but it requires a lot of secondary processing and filtering to remove "false" ground return data from the NOAA output. These also arrive in multiple tiles, which then have to be mosaicked together in batches after the filtering and quality check processes are completed. I say all this just to reiterate that creation of a new DEM from raw LIDAR at the scale of Monroe County is not an endeavor to be taken lightly.

I did obtain and evaluate a 10 ft resolution DEM developed by SFWMD. However, I decided against using that dataset, primarily due to concerns about the point cloud filtering. For example, there are some cells in Key West that show ground elevations over 90 feet above NAVD in the SFWMD DEM, and there are numerous cells that register above 20 ft NAVD throughout Monroe County. Virtually all of these values can be assumed to be an artifact of misclassified building rooftops and/or vegetation canopy as ground returns. The UF GeoPlan apparently used a more aggressive point removal algorithm to construct its DEM, and the highest ground elevation anywhere in the Keys in the UF DEM is just over 19 feet above NAVD. This difference alone in the apparent quality of point filtering provided a straightforward justification for choosing the UF DEM over the SFWMD DEM, at least for the type of analyses we performed here.

Even though I agree that it's marginally desirable to improve upon the 5 meter resolution of the UF DEM, it's also important to note that virtually all the building infrastructure of concern that we analyzed for this project is much larger than the 25 m^2 cell size associated with the UF DEM. This implies that the raster resolution is generally sufficient to capture potential vulnerabilities within these structures.

The UF DEM also provides the basis for the FDOT Sea Level Rise Sketch Tool analyses and the SLAMM runs. Use of the same base DEM dataset as the basis for other analyses is arguably desirable simply for the sake of analytic consistency.

All that said, I haven't added anything in the report to dwell on the technical decisions behind use of the UF DEM dataset in the report. I've instead left the matter at documenting the source

and associated limitations of the dataset we did use, rather than discuss issues or limitations with other available datasets.

Comment 4: *Just curious how this (Inverse Distance Weighting) compares with, say Kriging.*

Inverse Distance Weighting (IDW) is a deterministic interpolation technique, whereas kriging utilizes more complex stochastic geostatistical metrics, particularly spatial autocorrelation, to derive an interpolation surface. Most LIDAR DEMs use an IDW technique because of the high density of points available to create the surface. The high density of points generally makes it unnecessary to undertake a much more computationally intense kriging operation.

The basic answer as to why IDW is more appropriate for this application is really twofold: 1) we have a very large number of sample points from which to make the interpolation; and 2) the Keys do not have a complex or steep terrain that might otherwise favor the use of a kriging technique. Kriging would generally be more appropriate if we were basing the interpolation off a relatively few number of points and/or if we were trying to get at high topographical nuance underneath buildings. Since neither of these conditions applied to our case, the potential benefits of a kriging approach can be assumed as marginal, at best.

See, for example, Liu, X, Z. Zhang, and J. Peterson. 2009. Evaluation of the performance of DEM interpolation algorithms for LiDAR data. In: Ostendorf, B., B. Baldock, D. Bruce, M. Burdett, and P. Corcoran (eds.) Proceedings of the Surveying and Spatial Sciences Institute Biennial International Conference, Adelaide 2009, Surveying & Spatial Sciences Institute, pp. 771-780.

Comment 5: *This description of (VDatum) transformations is not very clear. A sketch explaining what was done may help. Also more details on the VDATUM application will be helpful.*

I very much appreciate and, after re-reading this section, agree very much with the first part of this comment. I have added much more detail as to the VDatum interface, and also provided important clarification to the method that was used. The previous description was indeed somewhat incomplete, and as written likely could not have been replicated readily by others. For what it's worth, I have had one of my (best) GIS students go through the procedure as now described, and she was able to replicate it successfully within VDatum and ArcGIS.

I've also added some text and a reference (Yang et al. 2012) to the NOAA technical document that describes the VDatum modeling for the Keys. However, I'm admittedly hesitant to get into a lot of technical detail about the VDatum transformation methods, as it's frankly a very complicated methodology that's a bit ancillary to our purposes here. I think the big key point to emphasize, which hopefully I've done, is that it is absolutely critical to do this transformation when working with LIDAR in SE Florida (and, frankly, most anywhere else if working on a large geographic area with tidal variability).

Comment 6: *How was SLR from the tidal datum to 2010 handled?*

Please see the answer to comment 2 above.

Comment 7: *Does this (nuisance flooding threshold of 1.08 feet above MHHW) apply to the entire county?*

This is the defined NOAA threshold for the Key West tide gauge, and the typical practice is to indeed assign these thresholds by County – or, in cases where there is not a tide gauge in a County, to the nearest tide gauge.

Comment 8: *How the values (in Table 2) were derived is not very clear. Please elaborate since the text is not detailed enough. How was this computed using station tidal epoch? (1981-2001?)*

As noted above in response to Comment 2, I've updated the values in Table 2 and 3 to correspond to the 1992 National Tidal Datum Epoch. The shifting datums between the low and high sea level rise scenarios (i.e., as referenced to 2010) is exceptionally difficult to explain for each table.

Comment 9: *Was this (extreme storm value of 6 feet above MHHW) from statistical modeling of extremes?*

This value was based upon agreement among Monroe County officials and stakeholders that the Wilma surge, which is the highest on record for both Monroe County tide gauges, should serve as the basis of an "extreme event." I've clarified the text to make this history more clear.

Comment 10: *Actually this (VDatum methodology) was based on NOAA.*

I've changed "developed" to "presented" in this sentence. This, I think, now only denotes that the methodology can be found in the SEFRCCC (2012) document, but removes the implication that SEFRCCC "developed" it.

<u>Jennifer Jurado's comments</u>

Comment 1: *I suggest rewording as "current" is relative. Maybe clarify that used the adopted projections approve at the time of project. You might note that projection in process of being updated to include planning scenario for low risk tolerance projections. Agree with Nick that important to note that while there are other scenarios, (although) this set of curves deemed most relevant for the type of planning decisions and planning horizons for local and regional planning. Might also be worth noting some of the assumptions or recognized limitations, eg. Doesn't adequately reflect contributions of sea level rise due to ice melt, such that rate and amount of rise could both be underestimated.*

As noted above in response to Comment 1 from Nick Aumen, I have rewritten and expanded the sea level rise scenarios section to account for these types of concerns. The high 2060 sea level

rise scenario (24 inches from 2010, but about 5 feet by 2100) does imply onset of significant polar ice melt, although it is indeed true that higher melt rate scenarios are found within the literature. The National Climate Assessment's "High Curve" (6.6 feet by 2100) implies the onset of somewhat more catastrophic melt, and that is the highest scenario that, to my knowledge, is in use by any national or international agency. By comparison, the most recent IPCC "high" scenario sea level rise for 2100 is at approximately 1 meter (3.3 feet).

I do know that James Hansen and others have recently published a paper that suggests the possibility of much more rapid near-term sea level rise (one ice sheet meltwater scenario suggests upward of 15 feet of sea level rise by about 2050). However, this paper is being pretty hotly debated currently within the scientific community, and I'm quite frankly a bit reluctant to delve onto the margins of such arguments about sea level rise rates within this planning effort.

Comment 2: *This could be correct, but I thought it (Confidence Interval for LIDAR) was 6 inches or 0.5 feet. I could be wrong.*

I have rechecked the LIDAR specifications from FDEM, and the Root Means Square Error is 0.3 feet, which does correspond to a 95% confidence interval of 0.6 feet as noted in the text.

Comment 3: Consider alternative language "to provide that" or "in a manner that"

Language changed to "to provide that."

Comment 4: *Word choice. "throughout" or "in"*

Changed to throughout.

Comment 5: *Missing a number or something? Sentence isn't clear.*

On page 33 of the revised document, this sentence now reads (with addition in red): "Notably, all but two building with potential exposure of finished first floors of structures to regular tidal flooding (i.e., not considering storm surge), and most facilities that show potential future access issues due to low adjacent grade elevation, for any sea level rise scenario are located within the Pigeon Key historic district.

Comment 6: *Is there a reference? Maybe I missed it?*

This comment highlights the text "GreenKeys!" While the GreenKeys! moniker is introduced at the beginning of the technical document, I've gone ahead and changed the text to say "this project."

Comment 7: *LaPointe as correct spelling?*

Corrected.

Comment 8: *Agree with Nick, that if this is a county-wide assessment, that these facilities should be included.*

As noted in response to Comment 6 for Nick Aumen, the project scope was limited to facilities for unincorporated Monroe County. Development of additional data and analyses for facilities owned and operated by municipalities was deemed outside the scope of this project.

Comment 9: *In this series of graphics, it is hard to tell what the arrow is pointing to. Is it the outline of the inundated structure, or something you could identify with a star? Maybe the arrow can be shifted to better show it is the outline of the shape, if appropriate? Sometimes the arrow is directly on top of the outline, so its not entirely clear.*

This comment is referring to wastewater treatment plant visualizations, Figures 7-12. I have removed the arrows and replaced with yellow stars located within structures identified as having 2060 flood risk under the high sea level rise scenario.

Comment 10: *In this section, suggest inclusion of figure that shows saltwater line relative to wellfields and predictions of movement with time if available. What about statement about extent to which SLR influences intrusion? How much of historical?*

A figure from Prinos et al. (2014) has been added as Figure 14 within the document. We do have predictions of movement with time from Hearn et al. (2013), but discussions with SFWMD staff have indicated that the findings from Prinos et al. (2014) raise questions about the validity of the Hearn et al. (2013) results. For example, the Hearn et al. (2013) results showed no risk of saltwater intrusion to FKAA even with 24 inches of sea level rise at 2060. Given the complexity and sensitivity of saltwater intrusion modeling, we have chosen to be conservative with both the visualizations and language that we put into the planning document.

Comment 11: *Contributed to (suggested word change from "caused")*

Changed as suggested.

Comment 12: *and development? Affects recharge. (Referring to saltwater intrusion in Biscayne Bay)*

Sentence changed to: "These include construction of drainage canals that directly connect inland freshwater surface waters to coastal water bodies, lowered surface headwater pressures in the Everglades due to regional flood control and agricultural drainage, large-scale groundwater pumping for municipal and agricultural supply, and development of impervious urban surfaces that reduce local recharge (Andersen et al. 1988; Dausman et al. 2005; Prinos et al. 2014)."

Comment 13: *Westward relocation of wellfields, well abandonment.(Referring to well fields)*

Sentence changed to: "Increased monitoring of saltwater movement in the Biscayne Aquifer, decreases of groundwater withdrawals from high-risk well-fields, abandonment and westward

relocation of highly affected well-fields, and large-scale regional hydrologic interventions associated with the multi-decade Comprehensive Everglades Restoration Plan (CERP) have all been implemented for the purpose of mitigating regional saltwater intrusion issues throughout southeast Florida (Prinos et al 2014)."

Comment 14: *Consider word choice. Drops in resources or reductions in resources, or in water levels? Reduced regional storage and recharge rates?*

Changed to "water levels" (pg. 57)

Comment 15: *I would clarify to note reduced recharge associated with each of these.*

Sentence (pg. 57) changed to: "This saltwater movement is associated with drops in interconnected regional surface water levels that occur due to evaporation and lack of groundwater recharge through rainfall replenishment, as well as increased human demand for freshwater supply from surface and groundwater surfaces for agricultural and urban landscape uses during drought periods (Bloetscher et al. 2010)."

Comment 16: *What are malfunctioning canals?*

Sentence (pg. 57) changed to: "Thus, there is great regional concern that the interacting stressors of sea level rise, increased water demand, drainage canals that promote landward movement of sea water, and anomalously severe droughts could together precipitate significant regional saltwater contamination of freshwater wells within the Biscayne Aquifer over the next decades (Aumen et al. 2015)."

Comment 17: *Marginally? Likely slightly less vulnerable? I might clarify.*

This sentence (pg. 57) changed by removing "marginally." "This location, along with the relatively low water demands of Monroe County as compared to much larger Miami-Dade and Broward counties, has generally made the FKAA well-field show less near-term vulnerability to sea level rise and associated saltwater intrusion than larger Biscayne Aquifer well-fields located to the north and east (Hearn et al. 2013)."

Comment 18: *From current wellfield (clarifier for Biscayne Aquifer)*

Sentence (pg. 57-58) changed as follows: "Although Prinos et al. (2014) note that recently installed saltwater control structures in the Card Sound Road Canal systems are expected to provide important mitigation of this saltwater intrusion, water managers and planners at FKAA (2011) have recognized that the cumulative impacts of sea-level rise, drought stress, and regional population growth will limit Monroe County's future capacity for freshwater withdrawals from the current Biscayne Aquifer wellfield."

Comment 19 & 20: *References. I would expand further, like cisterns, or reservoirs, or ASR. Not sure what is being suggested.*

This sentence (pg. 58) amended as: "Over the longer term, it is widely recognized that development of greater desalination capacity, increased reuse of wastewater resources, deployment of local rainfall capture devices (e.g., cisterns), local and regional conservation, and other regional alternative supply mechanisms (e.g., surface water reservoirs and aquifer storage and recovery) will be required to ensure sustainable water supply for future residents and visitors to Monroe County (FKAA 2011; Borisova et al. 2013; SFWMD 2013)."

Comment 21 & 22: *Unreasonable if you can't get home. Want to mention as an economic disrupter as well? (In regards to nuisance flooding of roads)*

This paragraph has been edited for clarity: "Tolerance for nuisance road flooding impacts is dependent on the amount of traffic served by the road being impacted. For less-traveled neighborhood roads, onset of shallow nuisance road flooding that occurs several times each year may not necessarily impose severe traffic constraints, although access to individual homes may be temporarily restricted. However, even infrequent nuisance tidal flooding conditions on major highway thoroughfares pose clear concerns for public safety, health, and welfare, while also impacting the local economy through the temporary loss of primary transportation routes. Such consequences justify near-term and preventive action to mitigate existing or potential flood risks on primary highway transportation routes."

Comment 23: *Maybe reference a recent economic assessment, valuing coastal resources?*

References added: For these reasons, there has been a long-term recognition that the health and sustainability of natural ecosystems is central to the economy, lifestyle, and overall heritage of Monroe County (Park et al. 2002; Bhat 2003; Mozumder et al. 2011).

Comment 24 & 25 & 26: *Agreement among the referenced studies? Again reference. I suggest modified language as it seems this type of verbiage is frequently used throughout text. I might suggest reviewing for repetitive use. Alternatives "has been identified as" or strike "widely" or "has been characterized or deemed"*

As noted above in response to Comment 13 from Nick Aumen, the document has been revised to remove terms such as "general consensus" and numerous supporting references have been added.

Comment 27: *By who? Scientific community? Or across broad geographic areas?*

Text (pg. 108) modified as: "Because seagrass die-offs in Florida Bay and other areas of the world have been associated with elevated water temperatures (Boesch et al. 1993), there is concern among scientists that the local and worldwide frequency and extent of such events may increase as marine waters continue to warm over the next several decades (Orth et al. 2006; Paerl and Paul 2012)."

Comment 28: *And the question would be can the new colonization (of sea grass) keep pace with rate of rise?*

This comment is associated with the following sentence: "While all seagrass species have the evolutionary capacity to colonize areas that become newly submerged due to rising sea levels, most seagrass researchers believe that rapid sea level rise in conjunction with other human disturbances (e.g., eutrophication and coastal development) will most likely result in significant net losses of seagrass area for the foreseeable future (Duarte 2002; Orth et al. 2006)."

This is an open question as to what rate of sea level rise that would allow for sustained migration of sea grasses. However, the consensus is indeed that combined human impacts are very likely to result in loss of sea grass habitat.

Comment 29: *Alternative language as "strong" also used later in same paragraph.*

Deleted "strongly" later in the paragraph to avoid the repetition.

Comment 30: *Suggest restating as currently reads that under these conditions the community will come to this realization, rather than noting that the community provides this recommendation under this condition. Maybe suggest alternative verbiage to "general consensus" as it used above.*

Reworded (pg. 109) as: "Under conditions of rapidly warming and rising seas, conservation of seagrass communities will clearly require a multi-pronged strategy."

Comment 31 & 32: *Suggest different verbiage. Suggest different verbiage.*

Sentences have been reworded to avoid use of terms "consensus" and "clear evidence."

Comment 33: *Maybe its in here. But will living shorelines be presented as a general conservation and adaptation strategy?*

Sentence has been added (pg. 109): "It is also recommended that Monroe County promote living shorelines and mangrove restoration as an alternative to traditional bulkheads for near-term stabilization of eroding coastal areas, while also allowing for long-term marine ecosystem migration (Bulleri and Chapman 2010; Spalding et al. 2014)."

Comment 34: *Suggest rewording.*

The previous "More long-term" (pg. 110) has been reworded as "Over a longer time horizon, Monroe County may wish to pursue "blue carbon" payments for conserved and restored seagrass areas through international carbon mitigation markets that may begin emerging over the next decade (see, e.g., Ullman et al. 2013)."

Comment 35: *Physical mechanism for what? Suggest expanding statement.*

This has been expanded (pg. 112): "For mangrove ecosystems, the primary physical mechanism behind different transition scenarios is the ability of mangroves roots to capture sediment flux. In

low sea level rise scenarios or areas with high sediment loads, mangrove ecosystems may capture sufficient sediment flux to outpace the effects of sea level rise (Parkinson et al. 1994). By contrast, higher rates of sea level rise and/or low sediment fluxes may outpace the sediment capture ability, thus leading to mangrove mortality and subsequent transition to a subtidal or open water ecosystem."

Comment 36: *Or builds upon?*

I believe comment is whether it is appropriate to say in the following paragraph (pg. 112) that the current project "updates this prior FWC work" (noted in yellow below), or if this should be changed to "builds upon."

"Our SLAMM analysis builds upon a previous iteration of SLAMM runs (see Glazer 2013) performed by the Florida Fish and Wildlife Conservation Commission (FWC). The previous FWC analysis utilized a previous version of SLAMM (version 6.01) and sea level rise curves developed by the 2001 Intergovernmental Panel on Climate Change (IPCC). Our analysis updates this prior FWC work by using a later version of SLAMM (version 6.2) and revised sea level rise curves that conform precisely to the lower and upper bounds of the Southeast Florida Regional Climate Change Compact (2011)."

In the full context of the paragraph, I believe it is appropriate to say that we both build upon (i.e., use the datasets and inputs provided by FWC) and update (i.e., use a new version of SLAMM and new sea level rise curves) the FWC work.

Michael Roberts Comments (in email dated August 5, 2015)

Comment: *I think the report looks fine. I'm a little surprised to see that the SLAMM model indicates reductions in ALL of the habitats analyzed. I would have thought that some habitats would increase in area with rising seas. I'm particularly surprised at the loss of salt marsh and scrub shrub marsh – habitats that I would have thought would increase in extent, particularly in the "low" scenario. This should lead to some interesting adaptation discussions.*

These are valid concerns regarding the potential limitations of the SLAMM predictions. A caveat in the report regarding the current limitations of SLAMM and the need for further research is noted on pages 113-114: "Although SLAMM is an advanced ecosystem and land cover change model, we do note that caution is warranted in terms of how the results of SLAMM should be interpreted within the Florida Keys. Underlying elevation errors within the LIDAR DEM, classification errors within the land cover file, and geographic transformations necessary for the model to function all introduce uncertainty about the results, particularly at lower levels of sea level rise. In addition, careful calibration of the model with historic land cover change and field observations (Gilman et al. 2007) would provide helpful guidance for further updates and revisions of the modeling input parameters to better fit the specific ecological nuances of the Florida Keys."

Comment: *As for the approach with the "new" SLR curves – I concur. Particularly being our Board has not seen this data and may be reluctant to incorporate it into the planning process. Thanks for the advance look and good job.*

This comment from staff, I think, bolsters the response to other peer reviewers about why we are not introducing higher sea level curves into this modeling or planning effort.

Judith Clarke Comments (in email dated September 11, 2015)

Comment: *I don't have any comments on the document, but I have some questions about using the data for planning with regard to county roads. The first thing I'm wondering is whether I can get copies of or a version of the data showing the road inundation/nuisance flooding or access to a GIS layer, whatever, because the ones in the report are too small for me to use when we are evaluating road projects.*

Yes – all GIS data for this project will be provided in full to the Monroe County GIS Department upon project completion.

Comment: *Second, and I'm not sure there are answers to all of these but if not they are questions that we should start discussing:*

Has the county accepted or adopted a specific scenario for design purposes (I may have asked this before)? Design life of a paving project is 20 years, so I am mainly looking at the 2030 data right now but have we decided on low or high scenario?

This is a very good policy question. It is one that we can help the County pursue with the Regional Sea Grant project.

Have there been any discussions or decisions about tolerable levels of nuisance flooding/king tide flooding? I'm guessing not based on the report but historically in the Keys there is a certain amount of water on the road that people have to accept (large rainstorms, etc) but some sort of criteria may need to be developed to decide when we mitigate it with a construction project. Most of our roads are local and only serve the residential population but some are through streets.

This is one of those "holy grail" questions that people everywhere are asking, but, so far as I know, there is not any sort of definitive answer. I have been having discussions with behavioral economists, migration demographers, and population geographers about we might try to get at this question. Again, this is an excellent question that, I hope, we can help answer in follow-on work.

Due to the fact that our water table is so high in most places, much of our stormwater control system is tidally dependent; as we experience sea level rise we will have flooding not just from

inundation and king tides but from rain storms (possibly getting larger as weather changes) that now drain away more slowly. I have no idea how to quantify this in any way, and I don't know if that's been looked at for the Keys but I know from living in Key West that when we have hurricanes (Wilma) the areas around the shore get inundated but when we have large rainstorms we have a lot of flooding in old town in the higher elevation areas so it is clearly a different flooding mechanism.

Another big part of the Regional Sea Grant is to help get at least some of the Keys (particularly US 1 corridor) stormwater systems into a GIS database. Understanding those pipe chokepoints and interactions with rainfall is clearly critical for effective adaptation. Having a GIS dataset with all of that information readily available for hydrologic evaluations will be a major asset for ongoing adaptation efforts, in my view.