ORIGINAL ARTICLE

Establishing a framework of a watershed-wide screening tool to support the development of watershed-based flood protection plans for low-lying coastal communities

Frederick Bloetscher[*], *Anthony Abbate, Jeffery Huber, Wiebo Liu, Daniel E. Meeroff, Diana Mitsova, S. Nagarajan, Colin Polsky, Hongbo Su, Ramesh Teegavarapu, Zhixiao Xie, Yan Yong, Caiyun Zhang, Richard Jones, Glen Oglesby, Eva Suarez, Jared Weaver, Mushfiqul Hoque and Tucker Hindle*

Florida Atlantic University, Boca Raton, Florida, USA

ABSTRACT

Flood risk analysis is the instrument by which floodplain and stormwater utility managers create strategic adaptation plans to reduce the likelihood of flood damages in their communities, but there is a need to develop a screening tool to analyze watersheds and identify areas that should be targeted and prioritized for mitigation measures. The authors developed a screening tool that combines readily available data on topography, groundwater, surface water, tidal information for coastal communities, soils, land use, and precipitation data. Using the outputs of the screening tool for various design storms, a means to identify and prioritize improvements to be funded with scarce capital funds was developed, which combines the likelihood of flooding from the screening tool with a consequence of flooding assessment based on land use and parcel size. This framework appears to be viable across cities that may be inundated with water due to sea-level rise, rainfall, runoff upstream, and other natural events. The framework was applied to two communities using the 1-day 100-year storm event: one in southeast Broward County with an existing capital plan and one inland community with no capital plan.

Keywords: flooding; watershed; flood modeling; screening tool; risk; infrastructure prioritization

1. Introduction

Flooding can impact a community's social, cultural, environmental, and economic resources, and so making sound, science-based, long-term decisions to improve resiliency are critical for future prosperity and growth. To meet the longer-term goals to protect life and property, in 1990 the Federal Emergency Management Agency (FEMA) created the National Flood Insurance Program's (NFIP) Community Rating System (CRS), a voluntary program for recognizing and encouraging community floodplain management activities. Nearly 3.6 million policyholders in 1,444 communities participate in the CRS program, but this is only 5% of the over 22,000 communities in the United States participating in the NFIP (FEMA, 2017).

Under the CRS program, flood insurance premium rates are discounted to reward community actions that (1) reduce flood damage to insurable property, (2) strengthen and support the insurance aspects of the NFIP, and (3) encourage a comprehensive approach to floodplain management. The Florida Division of Emergency Management (FDEM) reported that in 2019, there were 1.73 million policies in Florida, which comprised one-third of all policies nationwide. FDEM believes that the development of watershed master plans would improve the safety of the public, reduce property losses, limit economic disruption, and save $60 million in annual flood insurance premiums. The savings were determined based on a table for discounts provided in the CRS Coordinator's Manual (FEMA, 2018).

One of the key aspects of developing a watershed master plan involves defining flood risk due to compounding hydrographic influences. To evaluate risk, a spatial screening tool that addresses flooding is required. The concept of a screening tool relies on geographical information system (GIS) data, Light Detection and Ranging (LiDAR) data, groundwater levels, tidal and surface water levels, available soil storage, land cover, available stormwater infrastructure, and rainfall amounts. The screening software's simulation runs can provide data to create risk contours that are useful for predicting flooded areas after heavy rains.

The screening tool conceptually depicted in Figure 1 was built on prior works by Bloetscher and Wood (2016), Bloetscher and Romah (2015), Wood Jr. (2016), E Sciences (2014), Romah (2011), and Zhang et al. (2020). Romah (2011) and Wood Jr. (2016) defined flood risk using LiDAR and groundwater measurements on a given day, with the requisite high tides on that day. However, in all the references noted, the focus was on sea-level rise. Each demonstrated that low relief coastal areas may see increased flood risk due to increasing sea levels. The screening tool, refined here, would predict how areas with low elevations may be affected by inundation in three ways: 1) from direct surface flooding, 2) from rising groundwater levels, and 3) from the inability of inland areas to drain. This was an improvement over Overpeck and Weiss (2009), who used a bathtub model, which did not account for the fact that groundwater levels generally increase as the distance from the coast increases (Chang et al., 2011; Romah, 2011; Bloetscher et al., 2012). Romah (2011) found a 1:1 relationship between tidal rise and groundwater levels using the methodology described in Chang et al. (2011). This was confirmed for barrier islands in the E Sciences (2014) report, which also predicted flood risk profiles for Miami Beach, Florida, and identified the 99th percentile as the critical time, corresponding to four flooding events per year.

Catastrophic flooding should be expected during heavy rain events if there is nowhere for the runoff to go. The vulnerability of infrastructure will require the design of more resistant and adaptive infrastructure and network systems. This will, in turn, involve the development of new performance measures to assess the ability of infrastructure systems to withstand flood events, and to enhance resilience standards and guidelines for the design and construction of facilities. Specifically, considerations include retrofitting, material protective measures, rehabilitation and, in some cases, the relocation of facilities to accommodate sea-level rise impacts. As groundwater and sea-level rise are related, groundwater is, similarly, expected to have a significant impact on flooding in low-lying areas as a result of the loss of soil storage capacity. Evapotranspiration in low-lying areas with high groundwater will become more important, which is why ecologically-based stormwater management that employs natural native vegetation will become more important over time in certain communities.

Ultimately, the goal of identifying areas that are vulnerable to flooding is to develop tools for increasing community resistance to flood and climate risk (resilience). However, there are a series of challenges that impact the implementation of solutions that involve economics, political influence, and critical structures. As a result, communities may pursue localized solutions across the service areas, as opposed to targeted solutions with broader community benefits. These solutions are often unequally distributed across sectors and communities (Makondo and Thomas, 2018; Matin et al., 2018), leading to outcomes where only certain sectors benefit (Anguelovski et al., 2016). Global trends in urbanization suggest challenges arise in communities with higher levels of poverty, unemployment or lack of job prospects, or income disparity (Williams et al., 2019), whereby the distribution of equitable solutions is particularly skewed toward the politically powerful and wealthy when adaptation plans and actions are primarily assessed through the prism of economic and/or financial viability (Shi et al., 2016; Anguelovski et al., 2016; Rice et al., 2020; Shokry et al., 2020). For example, in Miami-Dade County, researchers found that adaptation had a positive effect on property values (Keenan et al., 2018), which increased the value of properties (and rents) and in turn displaced large numbers of vulnerable populations. In Australia, wealthy residents who prefer waterfront living pressured local governments to protect coastal zones first, as opposed to the protection of essential services and at-risk communities with few options to relocate (Torabi et al., 2018). The focus of adapting only economically important assets can also divert policy attention away from general social equity and urban sustainability priorities (Chu, 2016; Blok, 2020).

Scoville-Simonds, Jamali, and Hufty (2020) found that requiring only minor modifications of current infrastructure to meet adaptation goals perpetuates development-as-usual, since new developments do not incorporate resilience in their design, requiring the public sector to address these omissions at a later date (Granberg and Glover, 2014). Municipal adaptation plans do not always deliver effective outcomes, and implemented actions often diverge from adaptation plans as a result of the insistence to identify cost-benefits, which can work against solutions in at-risk communities where the community is undervalued. As a result, adaptation plans, policies, or actions can erode the current resiliency of at-risk communities, thereby increasing community vulnerability (Juhola et al., 2016; Neset et al., 2019). Instead, more targeted protection can support better long-term transformations toward more sustainable, adaptive, and resilient societies (Adger et al., 2014; Hallegatte et al., 2016; Béné et al., 2018; Carter and Janzen, 2018; Shi et al., 2018).

The goal of this paper is to take advantage of the flood risk modeling efforts undertaken by

Bloetscher and Wood (2016), Bloetscher and Romah (2015), Wood Jr. (2016), E Sciences (2014), Romah (2011), and Zhang et al. (2020) to identify 1) the potential options for improvements to reduce flooding, and 2) the prioritization of where these improvements should be undertaken, while addressing the potential for inequities caused by the political process.

2. Methodology

For the purpose of identifying potential areas where flood risk is present concurrently with critical facilities, two areas were selected. The first was Broward County, Florida, which is a relatively flat, densely developed coastal community of nearly two million people that includes the City of Fort Lauderdale. The area experiences king tides, coastal flooding, tropical weather, and rainfall-driven flooding. The incidence of flooding events appears to be increasing with time. The second community was the City of Clewiston, which is an inland municipality of 7,000 people located on the south side of the Herbert Hoover Dike that surrounds Lake Okeechobee in Hendry County, a sparsely populated area of mainly agricultural enterprises. Like Broward County, the area is relatively flat but is over 70 miles from either coast. Both communities provide critical services to residents, rely on state roadways for commerce, and contain commercial development, as well as vulnerable communities. Data for screening the communities for flood risk were also available from a variety of databases (refer to Zhang et al. (2020) for more details).

To inform an effective framework for creating or updating watershed master plans, pertinent information and technical data were gathered from appropriate sources. For example, groundwater table elevations and surface water gages were obtained from the regional water management districts, tidal information for coastal areas was obtained from the National Oceanic and Atmospheric Administration (NOAA), soil maps were obtained from the USDA, and topographic LiDAR data was obtained from various sources. The design storms for calculation purposes were the 3-day 25-year storm, which is the standard used by the South Florida Water Management District (SFWMD), and the 1-day 100-year storm used by FEMA and other water management districts. **Figure 1** outlines the data used in the screening tool and how they were combined to analyze risk and vulnerability, which is needed for Community Rating System (CRS) crediting.

Note that scaling is relevant. Localized infrastructure improvements in small subwatersheds will have more impact on the results than in larger watersheds. Hence, there is some degree of economy of scale—larger infrastructures will exert more influence on the screening model's result compared with a single catch basin when analyzed at watershed scale. At the same time, at the neighborhood level, under-designed piping, which will not impact regional flood models, will be identified as failing to meet the level of service standard for the subwatershed and causing major flood concerns.

After careful consideration, the researchers chose to use CASCADE 2001, which is a macroscale, multi-basin, spatial hydrologic/hydraulic routing model developed by SFWMD but is more widely applicable. For the model to work accurately, the basin boundaries must be chosen carefully. The model computes stormwater runoff from user-provided rainfall amounts, durations, and land use information and then routes the runoff through basins connected in series or parallel to outfalls. The program can compute simultaneous flows through more than one discharge control structures in a basin. The screening tool described here began with CASCADE 2001 as the flood response model to develop flood risk/hazard maps at 10m resolution, utilizing pertinent information and technical
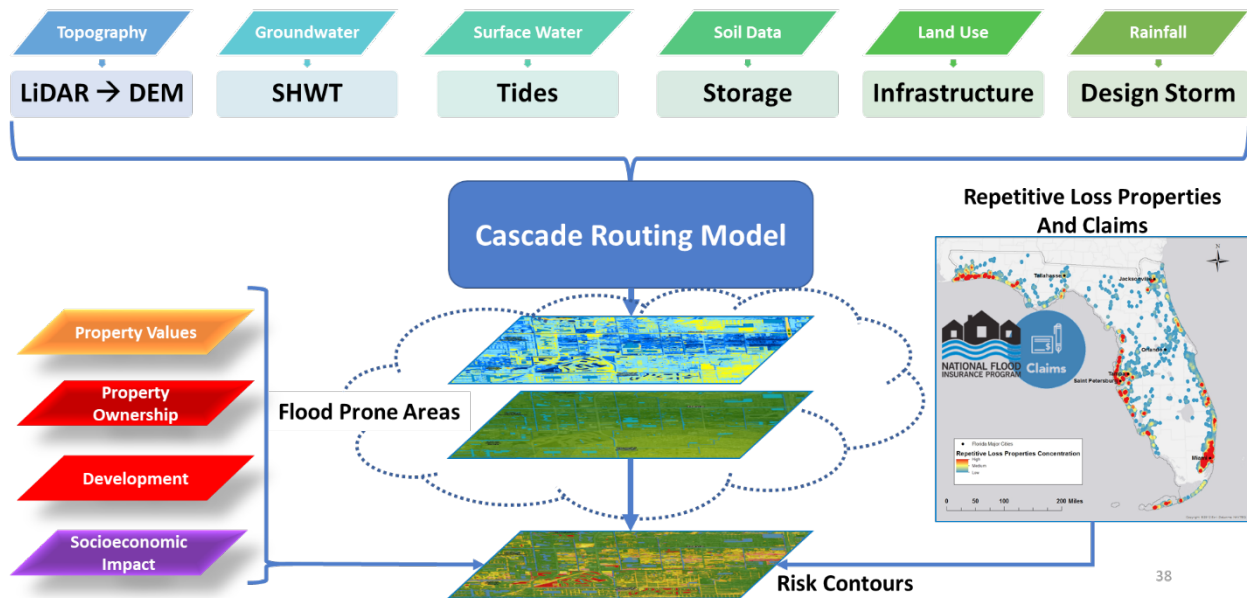
Figure 1. Databases that contributed information layers in GIS and were integrated through modeling software to create the flood risk screening tool used in this paper.

data to create the input file. Specifically, groundwater table elevations and surface water levels were downloaded from the applicable water management district databases for the time period of 2000 to 2018; tidal information for coastal areas was obtained from the NOAA Tides & Currents website (https://tidesandcurrents.noaa.gov); soil maps were obtained from the USDA database (FY2019 USDA Soil SSURGO gSSURGO, https://sdmdataaccess.nrcs.usda.gov); topographic data was obtained from the USGS (2016 South Florida flight); land cover was obtained from the 2009 FLUCCS Level 1 land use (SFWMD - Florida Land Use Cover Classification System (FLUCCS), which is digitized by photo-interpretation on county-based aerial photography with varying resolution in the range of 0.3–2ft pixel; and stormwater infrastructure locations (gravity, pump, and gated spillways) were inputs (note that only regional infrastructures, such as dams and structures, were included in the watershed level modeling). The software required identifying the offsite receiving body and creates a glass box control volume where water rises to a certain level and then discharges. The simulation required defining the basin boundaries (HUC or sub-HUC), elevation data, initial groundwater table elevations taken as the 99th percentile (Zhang et al., 2020), longest travel time for runoff to reach the most distant point of discharge, and available water storage for a soil layer 0–150cm thick. The output dataset defined the flood level elevation for the basin in the GIS. In areas that flooded in the simulation, the same procedure was undertaken to re-run the model at a smaller scale to better resolve vulnerable areas.

The headwater height output surface from the model was used to predict flood risk, defined as the probability of inundation based on ground elevation. Root mean square error (RMSE) computation was used as a means to assess the probability of flooding, which took into consideration the vertical accuracy error in the elevation datasets, which may vary depending on the available data spatial resolution (the 3m horizontal tiles provided +/- 4 inches of vertical accuracy) (Romah, 2011). The uncertainties associated with the digital elevation model's (DEM) vertical accuracy, the estimated depths to the groundwater table, and the modeling approach itself were used to determine Z-scores

per the NOAA method (NOAA, 2010) as follows:

Probability of Inundation = Standard_Normal_CDF(Z-Score)

$$Z-Score = \frac{High\ headwater\ height - Ground\ elevation\ from\ LiDAR\ DEM}{\sqrt{RMSE\_LidarDEM^2 + RMSE\_CRT2001Model^2}}$$

= (Headwater Height – LiDAR DEM Elevation) / 0.46

The value suggested by NOAA for coastal vulnerability assessments is 0.46 (NOAA, 2010). The Z-score for each location was then mapped directly in the GIS. For example, the value of Z for the 75th percentile was 0.675. Thus, the value must be 0.675 standard deviations above the mean to be in the 75th percentile. The GIS layers were then classified into one of six bins with the cutoff Z-scores, as shown in **Table 1**.

Once the probability of flooding was depicted on a map, the next step was to establish the consequence of risk factors associated with the potential loss of properties or assets. To help with defining areas that represented higher exposure, the following were suggested to represent the risk factors that relate to the consequence of flooding:

1. **Critical facilities (water stations, sewers, public safety facilities, hospitals, schools, power plants):** These essential service facilities are required to respond to emergencies and protect public health, safety, and welfare. Areas that include these facilities should be rated the highest.

2. **Tier 2 critical facilities (groceries, pharmacies, roadways):** These facilities are needed to sustain people by providing food, medications, and mobility access. These received the second-highest priority. Most are located along major roadways that act as access routes to a given community. Most roads are state-owned or county-owned.

3. **Economic centers:** These facilities were rated high in order to protect jobs, so that the community can keep the local economy flowing, while minimizing disruption to daily life.

4. **At-risk communities:** The highest-rated residential communities involved at-risk people who have limited ability, financially or otherwise, to escape the impacts of flooding. These may include high-density developments, and so flooding will impact a larger number of people that may have health, food, age, and other limitations to adapt to flood conditions.

5. **Other urban/suburban properties:** Note that for residential properties, identifying at-risk communities (income, age, disability, health) required a further drilldown to the neighborhood level (i.e., wealthy neighborhoods with few older, poor-health individuals

Table 1. Z-score for GIS layers

Risk of Flooding	Description	Range of Corresponding Z-Scores
Below 10%	Unlikely to be flooded	< –1.282
10% ~ 25%	Low risk	From –1.282 to –0.675
25% ~ 50%	Low-moderate risk	From –0.675 to 0
50% ~ 75%	Moderate-high risk	From 0 to 0.675
75% ~ 90%	High risk	From 0.675 to 1.282
Above 90%	Highest risk	> 1.282

would have a lower priority than at-risk communities, which generally have lower-value and denser housing developments).

6. **Agriculture/public and vacant/undeveloped properties:** These properties do not affect people.

Most states have a standardized system for coding land uses, which is used for property appraisal and taxing purposes. These same codes can easily be used to assign properties to the priority tiers. However, identifying at-risk communities (income, age, disability, health) required a further drilldown to the neighborhood level, i.e., wealthy neighborhoods with few older individuals in poor health would have a lower priority than at-risk communities, which generally have lower-value and denser housing developments. In the latter case, more people are impacted, and those people have less ability to mitigate risks. The same is true for public properties (parks would be a lower priority than water treatment plants, etc.).

Based on these priorities, the relative risk priority of the land use codes was evaluated based on a scale of 1 to 6, where 1 is most vulnerable and 6 is the least vulnerable. After assigning the land use priority tier to a property, it was converted to its inverse scale to obtain the *consequence of risk* factor by the following equation:

Consequence of risk factor = 7 – Department of Revenue Land Use Code Priority Tier

To evaluate flood vulnerability at the subwatershed scale or at the parcel (or local) level, the analysis started by converting the flood risk map to a binary flooding surface (0 = below 50% chance of flooding; 1 = 50% or higher chance of flooding on any part of a given parcel) based on the output from the screening tool for a specified design storm. All parcels in Tiers 1–4 that have greater than 50% chance of flooding during a particular design storm would have the percent of the parcel that would flood during that event, calculated to develop a priority risk score (see **Table 2**). Once all field data were included, the table was exported as a CSV file, which was converted into an Excel format. Then the percent of the parcel that is flooded during the specified design storm was calculated, and the rows were sorted to show the higher-priority tiers and higher percent-flooded values first. To reduce the number of critical facilities that might be on the priority list, a filter was created to show only critical facilities with 10% or more flooded areas in the parcel during the specified storm event (e.g., 3-day 25-year, 1-day 100-year storm, or 1-day 10-year events).

The next step was to establish a scoring system, which consisted of *Consequence of risk factor* and *Flood Risk factor* for each project. *Flood Risk factor* relates to how frequently or likely the event that would put the community at risk will occur. For *flood risk factor*, we chose the percent

Table 2. Flood percentages and risk factors used for determining capital project priority

Percent of Parcel Flooded	Flood Risk Factor
90%–100%	6
80%–89%	5
70%–79%	4
60%–69%	3
50%–59%	2
<50%	1

chance of flooding as derived from the Z-score described earlier, and for *consequence of risk factor* we chose the percent of the area flooded (Table 2). Although weighting is not necessary, decision-makers may place a higher priority on one of the selection criteria. Thus, a weighting factor related to the level of importance assigned to each criterion can be applied: 75% of the importance is assigned to the consequence of flooding and 25% importance to flood risk to yield a composite score as follows:

Composite Score = Flood Risk Factor × 25% + Consequence of Risk Factor × 75%

For example, for a property in Tier 1 (consequence of risk = 6) with 15% of the parcel flooded during the design storm (flood risk factor = 1), the composite score would be:

$1 \times 25\% + 6 \times 75\% = 4.75$

The goal is to have the highest composite risk score. After this analysis, if the conclusion of the stakeholder group is that none of the identified vulnerable areas met the minimum threshold score, then none of the parcels will be added to the prioritized project list. If, however, some of them do meet the requirements established by the stakeholder group, then each parcel that does should qualify to be placed on the prioritized project list for capital improvements. The exact decision of the various implementation projects will vary from watershed to watershed, but this process should help to narrow down or identify those projects that should be prioritized for maximum effect with limited funds. This process is systematic and objective rather than subjective. However, it is ultimately up to the stakeholder group to assign the weights of the flood's probability factor and the
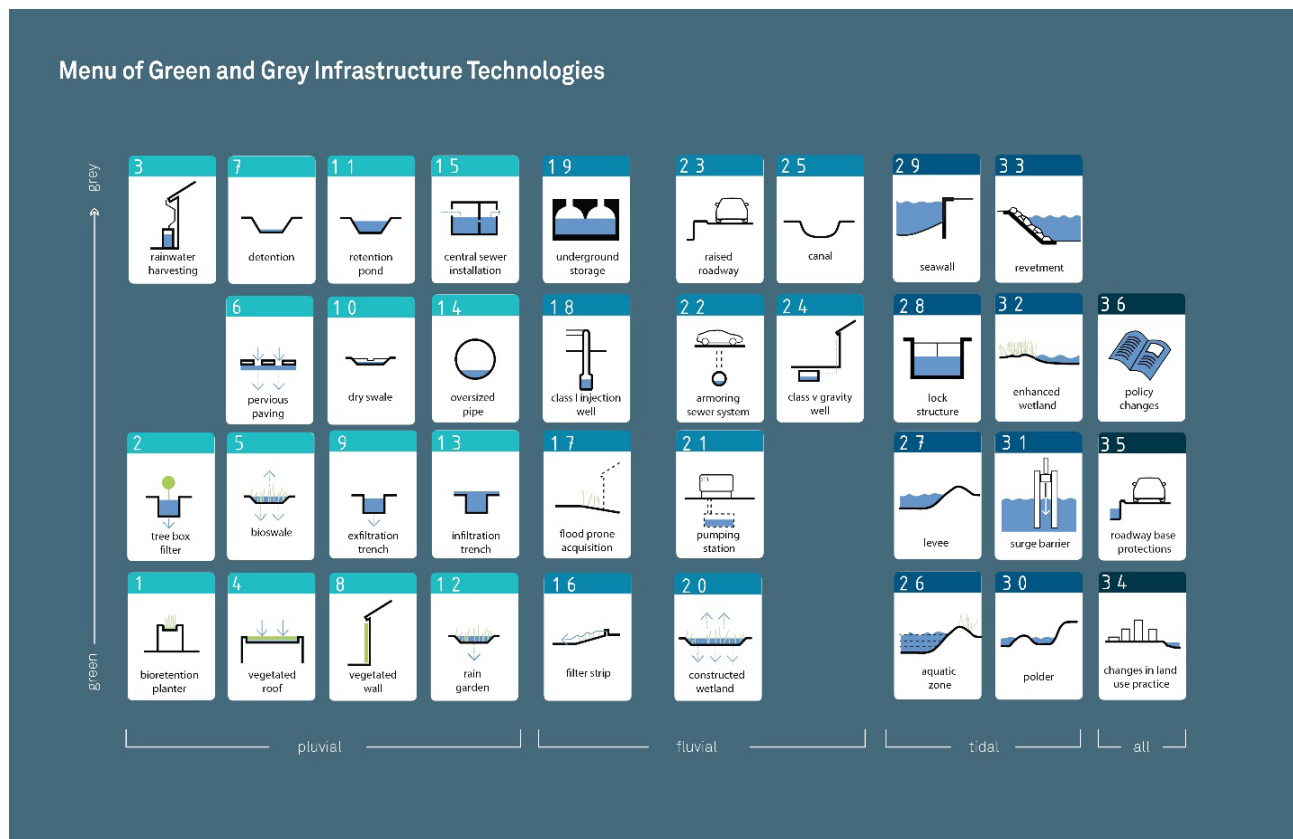

Figure 2. Menu of green and grey infrastructure technology options.

consequence of risk factor, as well as the tie-breaker procedure and regional priorities, so that the process best meets the needs of the community and both upstream and downstream partners.

To help develop solutions for the identified priority areas, a toolbox was developed that described a variety of strategies (*n* = 36) to improve potential flood management conditions. These include natural and nature-based features (NNBF) (Bridges et al., 2015). This menu of green and grey infrastructure technologies is shown in **Figure 2** and was organized to address various flooding types, from *pluvial* (rainfall and runoff mitigation in upland areas), *fluvial* (runoff, high groundwater, and surface water management in low-lying flood-prone areas), *tidal* (flooding associated with storm surge and high groundwater and is tidally influenced), and *all* (applies across the spectrum). Each is site-specific, and most require significant engineering and planning to determine the most efficient configuration to achieve the community's goals. Details for these elements, including their benefits and limitations, can be used by local officials to develop solutions to the areas identified as being at risk. Note that the elements in Figure 2 include whether the strategy is green (natural-system-based) infrastructures, gray (concrete/piping/urban) infrastructures, or policy-oriented. Policy decisions on implementation rest with cost-benefit analyses.

3. Results

The method used to prioritize infrastructure solutions was applied to a subwatershed basin in southeastern Broward County, Florida. **Figure 3** shows the flood risk assessment, utilizing the data and methods outlined in Figure 1. The right side of Figure 3 shows the critical-facility tiers superimposed on the flood risk map where critical infrastructure might be vulnerable, and therefore where the solutions from Figure 2 might be applied.

The challenge at this scale was that so many needs and solutions were required. A drilldown is preferable, as more information would become visible and Tier 1 facilities can be readily identified (e.g., schools, water and wastewater plants, fire stations, hospitals, EMS facilities, police departments). However, if a series of projects that were proposed in the area were evaluated using the protocol to prioritize projects, **Table 3** results.

A similar strategy was applied to the community of Clewiston, Florida, which is located in
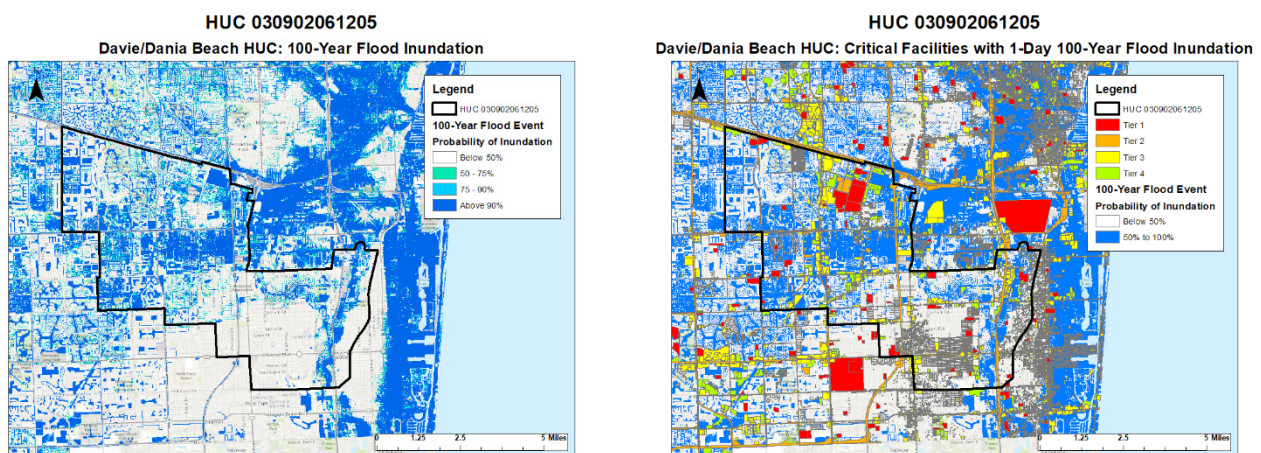

Figure 3. Beach subwatershed flood risk map for 1-day 100-year storm event and critical infrastructure map.

eastern Hendry County. The eastern and northern portions of the city were identified by the screening tool as flood-prone (**Figure 4**). The darker shaded areas correspond to those properties that are flooded during the design storm evaluated, which in this case was a 1-day 100-year storm event (note that the large flooded areas on the northwest are farm fields that are not developed). **Figure 5** highlights the locations of the Department of Revenue land use code Tier 1–4 facilities. Note that many of the commercial areas and portions of multi-family housing developments are located in the flood risk areas along US 27, a federal roadway connecting the Miami area to Orlando. Figure 5 suggests that certain critical infrastructures along this route (including the roadway itself) are vulnerable during the 1-day 100-year storm event. A closer look identifies Tier 2 and 3 areas as areas with major commercial activities (groceries, Walmart, etc.) and Tier 1 areas as areas that include City Hall and the utility, police, and fire departments. Tier 4 areas at the east end of US27 comprised primarily restaurants and automotive repair businesses.
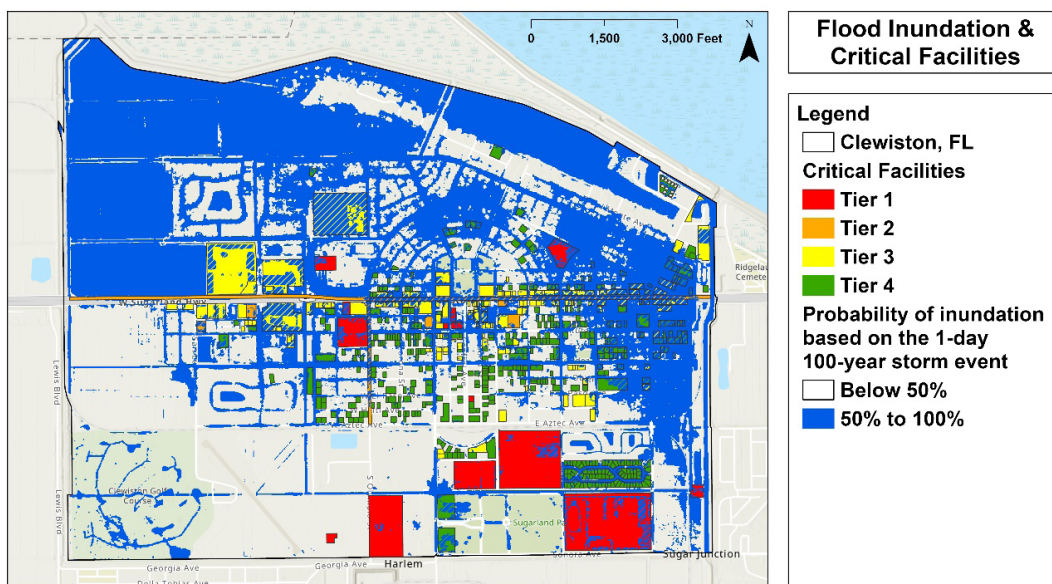

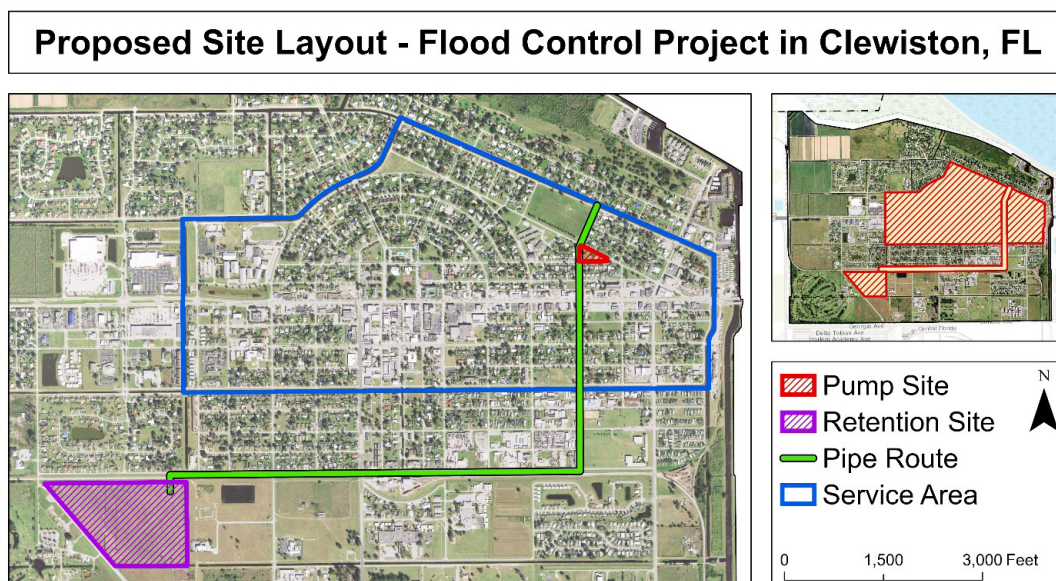**Figure 4.** City of Clewiston's flood risk and critical infrastructure for 1-day 100-year storm event.

Figure 5. Proposed layout of flood control pump station for eastern Clewiston, Florida.

Table 3. Priority of projects based on scoring

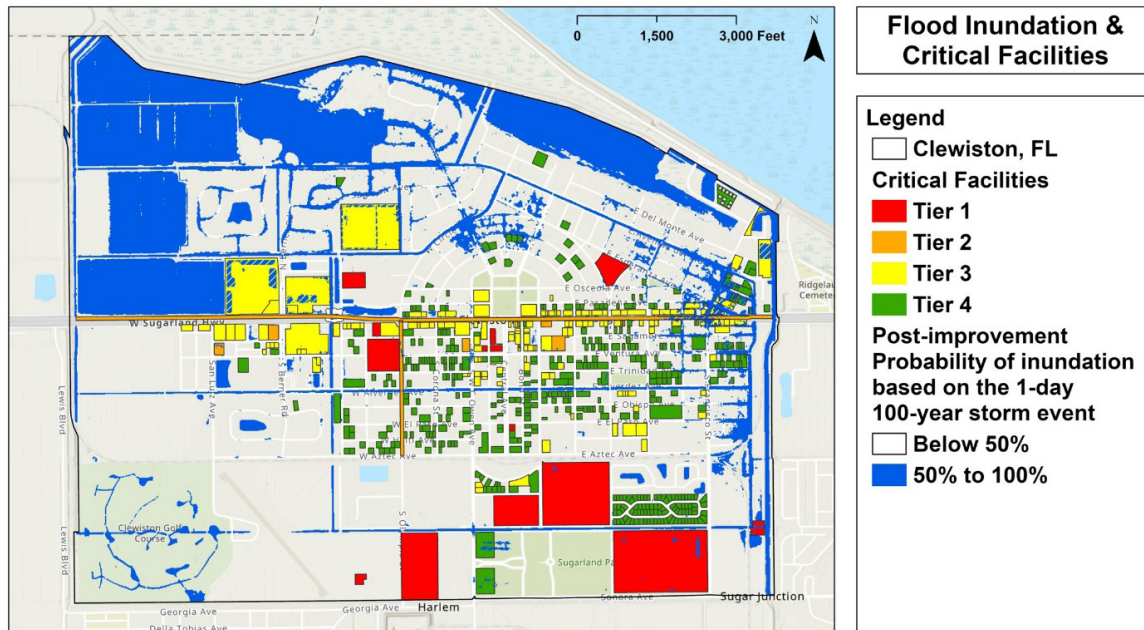| Priority Score	Priority	Name of Project	Project Location	Resp. Agency	Benefiting Jurisdiction	Hazard Mitigated	Fund Source	Match (if Applicable)	Opinion of Cost ($ '000)	Type of Constr. (New, Deferred Completed, Delete)	Timeframe for Completion
5.25	1	DCOTA- NW Dania	Dania Beach	Dania Beach	Dania Beach	Flooding	SE utility	n/a	2500	New	2025
5.00	2	Davie - College area	Davie	Davie	Davie	Flooding	Gen Fund	n/a	5000	New	2025
5.00	3	W Hollywood Taft	Hollywood	Hollywood	Hollywood	Flooding	SW Utility	n/a	2500	New	2028
4.75	4	W Hollywood/ Driftwood	Hollywood	Hollywood	Hollywood	Flooding	SW Utility	n/a	1500	New	2026
4.75	5	Hollywood/ Attucks	Hollywood	Hollywood	Hollywood	Flooding	SW Utility	n/a	2500	New	2029
4.75	6	Cooper City School/City Hall	Cooper City	Cooper City	Cooper City	Flooding	SW Utility	n/a	2500	New	2030
4.75	7	Davie Fox Trail	Davie	Davie	Davie	Flooding	Gen Fund	n/a	2500	New	2025

11

Figure 6. City of Clewiston's flood risk and critical infrastructure for 1-day 100-year storm event with infrastructures installed.

The city has few structures and no planned capital projects. Therefore, determining where projects should be focused would involve a series of test projects to see what works. One idea is that the data from Figure 4 suggests that the solution of a pump station might reduce flooding in the eastern portion of the City. This solution is depicted in Figure 5, showing the pump station and the piping associated with conveying the stormwater away from critical areas in the northeastern section to an open area in the southwest corner of the city.

A simulation of the impact of installing the pumping station shows a substantial difference in the expected flooding (see **Figure 6**), and that the Tier 1 facilities are less impacted than shown in Figure 4. The darker shaded areas correspond to those properties that are flooded during the 1-day 100-year storm event with the proposed infrastructure improvements.

Comparing Figures 4 and 6, the improvement made by the proposed piping shows that flooding is reduced by 80 percent in the eastern portion of the city. Because of the lesser percent of areas that are flooded, and the fewer critical infrastructures affected, this project would likely score highly against other projects in the community.

4. Conclusion

A scalable screening tool methodology was developed to model flooding throughout the state of Florida. As part of the process, a protocol to prioritize land uses to compare with flooding was also developed. At the larger watershed scale, the implementation of solutions has many variables. However, drilling down to the subwatershed scale permitted more specific results to be determined that are more applicable to local solutions to mitigate flooding, such as those outlined in Figure 2.

In communities where there are already projects that have been proposed, the prioritization process using flooded areas and critical infrastructures can help identify which projects will lessen

the risk to the community, as was done in the Davie/Dania Beach subwatershed. As projects are added, the same process can be undertaken (there were another 20–30 projects that scored lower for this watershed, which were not included in Table 2) because priority against one another is not the means to create the scores—impact and flooded areas are.

In communities with few infrastructures and less funding and needs, projects can be developed to target specifically those areas where flooding and critical infrastructure overlaps, as was done for Clewiston. In both cases, the ability to prioritize infrastructure spending permits the coordination between financial, budget, and administrative units to allow managers to properly allocate costs to those benefiting most from the service and provide policies that can be clearly explained to the public. As projects are identified, they can be prioritized for inclusion in operating and capital programs that create the most benefits and can be maintained.

References

Adger WN, Pulhin JN, Barnett J, et al. (2014) "Human security". In: Field CB, Varros VR, Dokken DJ, et al. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 755–791. Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9781107415379.017

Anguelovski I, Shi L, Chu E, et al. (2016). "Equity impacts of urban land use planning for climate adaptation: Critical perspectives from the global North and South". *Journal of Planning Education and Research*, 36(3): 333–348. https://doi.org/10.1177/0739456X16645166

Béné C, Cornelius A and Howland F (2018). "Bridging humanitarian responses and long-term development through transformative changes—Some initial reflections from the World Bank's adaptive social protection program in the Sahel". *Sustainability*, 10(6): Article 1697. https://doi.org/10.3390/su10061697

Bloetscher F and Romah T (2015). "Tools for assessing sea level rise vulnerability". *Journal of Water and Climate Change*, 6(2): 181–190. https://doi.org/10.2166/wcc.2014.045

Bloetscher F and Wood M (2016). "Assessing the impacts of sea level rise using existing data". *Journal of Geoscience and Environment Protection*, 4(9): Article 71043. https://doi.org/10.4236/gep.2016.49012

Bloetscher F, Romah T, Berry L, et al. (2012). "Identification of physical transportation infrastructure vulnerable to sea level rise". *Journal of Sustainable Development*, 5(12): 40–51. https://doi.org/10.5539/jsd.v5n12p40

Blok A (2020). "Urban green gentrification in an unequal world of climate change". *Urban Studies*, 57(14): Article 0042098019891050. https://doi.org/10.1177/0042098019891050

Bridges TS, Burks-Copes KA, Bates ME, et al. (2015). *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Vicksburg, MS, USA: Environmental Laboratory and Coastal and Hydraulics Laboratory, US Army Engineer Research and Development Center.

Carter MR and Janzen SA (2018). "Social protection in the face of climate change: Targeting principles and financing mechanisms". *Environment and Development Economics*, 23(Special issue 3): 369–389. https://doi.org/10.1017/s1355770x17000407

Chang SW, Clement TP, Simpson MJ and Lee K-K (2011). "Does sea-level rise have an impact on saltwater intrusion?" *Advances in Water Resources*, 34(10): 1283–1291. http://doi.org/10.1016/j.advwatres.2011.06.006

Chu E (2016) "The political economy of urban climate adaptation and development planning in Surat, India". *Environment and Planning C: Government and Policy*, 34(2): 281–298. https://doi.org/10.1177/0263774x15614174

E Sciences (2014). "Groundwater elevation monitoring and mapping six monitoring stations throughout Miami

Beach, Miami Beach, Miami-Dade County, Florida". E Sciences Project Number 7-0002-005. Fort Lauderdale, FL, USA: E Sciences.

Federal Emergency Management Agency (FEMA) (2017) *Community Rating System*. Washington, DC, USA: FEMA. https://www.fbfl.us/DocumentCenter/View/17848/NFIP_CRS_Fact_Sheet_2017_508OK?bidId=

_____ (2018). *National Flood Insurance Program Community Rating System Coordinator's Manual*. Washington, DC, USA: FEMA. https://www.fema.gov/sites/default/files/documents/fema_community-rating-system_local-guide-flood-insurance-2018.pdf

Granberg M and Glover L (2014) "Adaptation and maladaptation in Australian national climate change policy". *Journal of Environmental Policy & Planning*, 16(2): 147–159, https://doi.org/10.1080/1523908X.2013.823857

Hallegatte S, Bangalore M, Bonzanigo L et al. (2016). Shock Waves: Managing the Impacts of Climate Change on Poverty. *Climate Change and Development*. Washington, DC, USA: World Bank.

Juhola S, Glaas E, Linnér B-O and Neset T-S (2016). "Redefining maladaptation". *Environmental Science & Policy*, 55: 135–140. https://doi.org/10.1016/j.envsci.2015.09.014

Keenan JM, Hill T and Gumber A (2018). "Climate gentrification: From theory to empiricism in Miami-Dade County, Florida". *Environmental Research Letters*, 13(5): 054001–054001. https://doi.org/10.1088/1748-9326/aabb32

Makondo CC and Thomas DSG (2018). "Climate change adaptation: Linking indigenous knowledge with Western science for effective adaptation". *Environmental Science & Policy*, 88: 83–91. https://doi.org/10.1016/j.envsci.2018.06.014

Matin N, Forrester J and Ensor J (2018). "What is equitable resilience?" *World Development*, 109: 197–205. https://doi.org/10.1016/j.worlddev.2018.04.020

Neset T-S, Wiréhn L, Klein N, et al. (2019). "Maladaptation in Nordic agriculture". *Climate Risk Management*, 23: 78–87. https://doi.org/10.1016/j.crm.2018.12.003

National Oceanic and Atmospheric Administration (NOAA) (2010). *Mapping Inundation Uncertainty*. Charleston, SC, USA: NOAA Coastal Services Center.

Overpeck JT and Weiss JL (2009). "Projections of future sea level becoming more dire". *Proceedings of the National Academy of Sciences of the United States of America*, 106: 21461–21462. https://doi.org/10.1073/pnas.0912878107

Rice JL, Cohen DA, Long J and Jurjevich JR (2020). "Contradictions of the climate-friendly city: New perspectives on eco-gentrification and housing justice". *International Journal of Urban and Regional Research*, 44(1): 145–165. https://doi.org/10.1111/1468-2427.12740

Romah T (2011). *Advanced Methods in Sea Level Rise Vulnerability Assessment*. Master's thesis. Florida Atlantic University, Boca Raton, Florida, USA.

Scoville-Simonds M, Jamali H and Hufty M (2020). "The hazards of mainstreaming: Climate change adaptation politics in three dimensions". *World Development*, 125: Article 104683. https://doi.org/10.1016/j.worlddev.2019.104683

Shi L, Chu E, Anguelovski I, et al. (2016). "Roadmap towards justice in urban climate adaptation research". *Nature Climate Change*, 6(2): 131–137. https://doi.org/10.1038/nclimate2841

Shi Z, Watanabe S, Ogawa K and Kubo H (2018). *Structural Resilience in Sewer Reconstruction: From Theory to Practice*. Oxford, UK: Elsevier.

Shokry G, Connolly JJT and Anguelovski I (2020). "Understanding climate gentrification and shifting landscapes of protection and vulnerability in green resilient Philadelphia". *Urban Climate*, 31: Article 100539. https://doi.org/10.1016/j.uclim.2019.100539

Torabi E, Dedekorkut-Howes A and Howes M (2018). "Adapting or maladapting: Building resilience to climate-related disasters in coastal cities". *Cities*, 72 Part B: 295–309. https://doi.org/10.1016/j.cities.2017.09.008

Williams DS, Costa MM, Sutherland C, et al. (2019). "Vulnerability of informal settlements in the context of rapid urbanization and climate change". *Environment and Urbanization*, 3(1): Article 0956247818819694.

https://doi.org/10.1177/0956247818819694

Wood Jr. MB (2016). *Using a Groundwater Influenced Sea Level Rise Model to Assess the Costs Due to Sea-Level Rise on a Coastal Community's Stormwater Infrastructure Using Limited Groundwater Data*. Master's thesis. Florida Atlantic University, Boca Raton, Florida, USA.

Zhang C, Su H, Li T, et al. (2020). "Modeling and mapping high water table for a coastal region in Florida using Lidar DEM data". *Groundwater*, 5(2): 190–198. https://doi.org/10.1111/gwat.13041