A SunCam online continuing education course

Resiliency Strategies for Smaller Scale Sites

by

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Course #366

Introduction

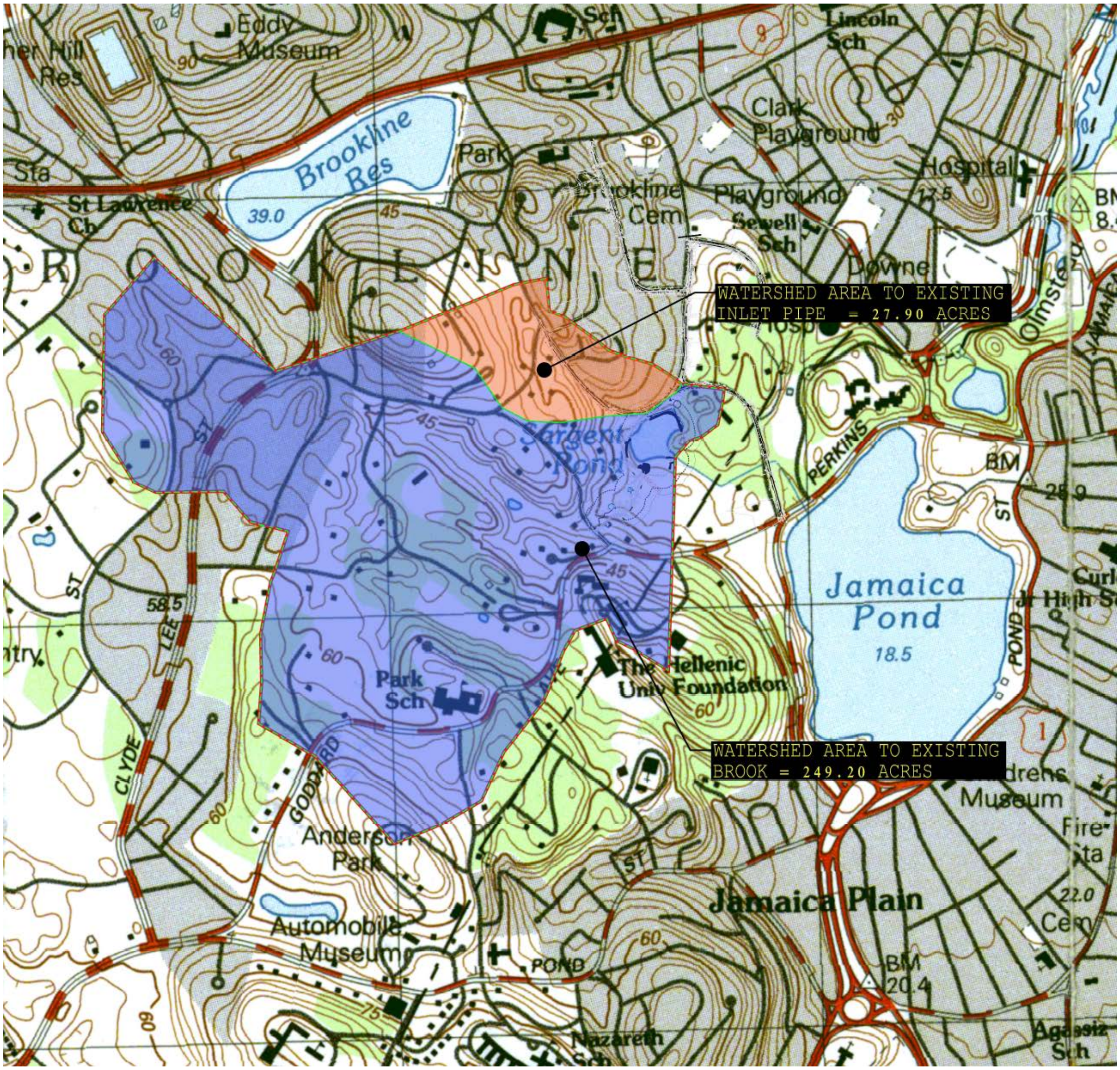
The purpose of this course is to explore different options that are available for helping to make smaller scale sites more resilient and adapted to better handle the larger, more frequent storm events. Resiliency is usually thought of being done at a much larger scale; municipalities and states implementing large scale strategies that are focused at making their target areas more resilient and less susceptible to large storm events or rising sea levels. Those large-scale resiliency projects are often complicated and very expensive; therefore, it doesn't seem like there is much that can be done on a smaller site. In the course, however we will exam some of the ideas and strategies that are implemented on a large scale and see how they can be scaled down to be viable on a smaller site. We will also review other strategies that can be implemented to make a site better situated to withstand or minimize the impact of a large storm event. It may not be feasible to completely protect a site and its infrastructure by itself, however we will review design strategies and actions that can mitigate or reduce impacts from large storm events, flooding, and sea level rise.

Review Existing Condition Data

The first step in coming up with some resiliency options is to review the site in its existing condition and see what information is readily available for review. Your client, the local floodplain manager or the local municipality may have copies of plans, reports, studies, and permits for work previously done at or near a Site. A good Site Plan with accurate information regarding structures, roadways, infrastructure, topography and impervious cover is infinitely valuable as a base map to start your evaluation. If your client doesn't have a good Site Plan that they can provide to you, the first action you should have them take is to get a properly surveyed existing condition drawing.

Another fruitful action is checking publicly available information as GIS programs and databases can provide a wealth of data and information on a project Site. Some valuable information you may be able to gain from GIS analysis can include:

- Property lines and parcel sizes
- Surrounding topography (a USGS topographic map is a great tool for looking at the tributary watershed for the site)
- Physical infrastructure near the site (roadways, rail, etc.)
- Land use within the surrounding watershed
- Wetlands and natural resources in the area
- Mapped Floodplains

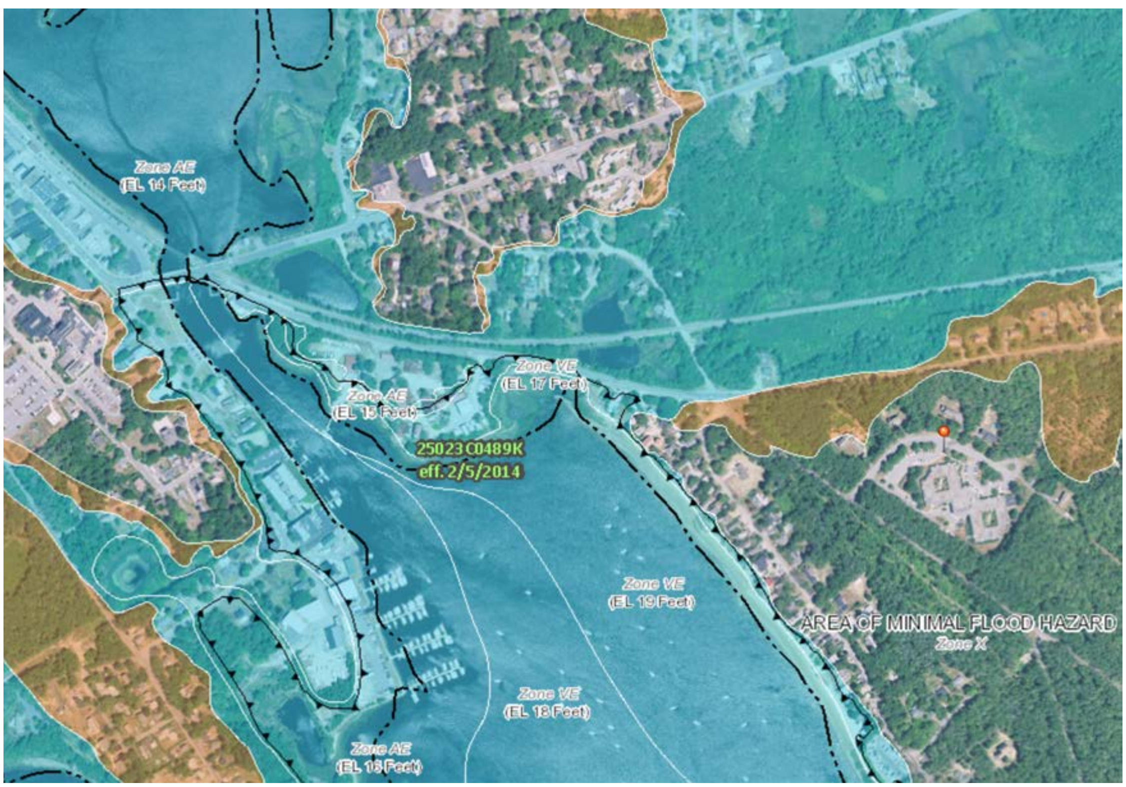


Source: USGS - The above image shows a USGS topographic and the estimated tributary watershed areas to a subject site This is helpful to gauge how much area is draining to a site being evaluated and what lies down-gradient of the site.

Combing the information gathered from GIS sources and the existing condition Site Plan from your client will provide a strong base to begin evaluations on how to make the site more resilient.

Floodplains

Understanding how a property is situated with respect to the floodplain is a crucial element in determining what the risks and exposures are for the site, as well as what can be permitted to be done. The presence of a mapped floodplain on a site will influence where key infrastructure should and should not be placed, whether changes in grade will be possible, and most importantly a mapped floodplain will convey the amount of risk posed to the site from flooding. The Federal Emergency Management Agency (FEMA) produces Flood Insurance Rate Maps (FIRMs) through its National Flood Insurance Program that makes its quick and easy to determine if your Site lies within a mapped floodplain and what the annual chance of flooding is associated with that floodplain. The Map Service Center, https://msc.fema.gov/portal/home , should be the first stop to make a "FIRMette" for the Site showing it with relationship to the floodplain. These maps typically show the base flood elevation (BFE) for the floodplain, which is in the NAVD88 datum. So, its important when comparing a base flood elevation to the site elevations of any plans you may have that you understand how the datums correlate. Furthermore, the state or municipality may have more floodplain information and data layers that can be incorporated into your review and assessment.



Source: FEMA

The above image shows several mapped floodplains for the area and even provides the base flood elevation (called out as Elevation 14-19 depending on the location). The plan also shows areas mapped as 0.2 percent chance of annual flood (the orange shade) and the Zone X, areas of Minimal Flood Hazards.

Climate Change and Rising Sea Levels

Rising sea levels can pose many different risks to a Site and can exacerbate existing flooding issues or create new ones as the rising seas may cause backups down-gradient of your site that may cause more water to be retained upgradient for longer. Rising sea levels, when combined with storm surge and high tides, may pose a risk of greater flooding, as the Boston Seaport District and much of the New England coastline experienced in early January 2018. Utility infrastructure could be put at risk with rising sea levels, as stormwater outfalls may be submerged more often or permanently; water and electrical subsurface infrastructure may be more susceptible to infiltration and inflow as well due to higher resting water levels.

Most coastal communities have conducted some form of assessment and projected water level increases. If that data is accessible, it would be beneficial to review it and see how those projections would influence the Site you are reviewing and whether that will exacerbate an existing problem, or potentially create new problems. NOAA does have a Sea Level Rise viewer that can provide useful information for your assessment: https://coast.noaa.gov/slr/

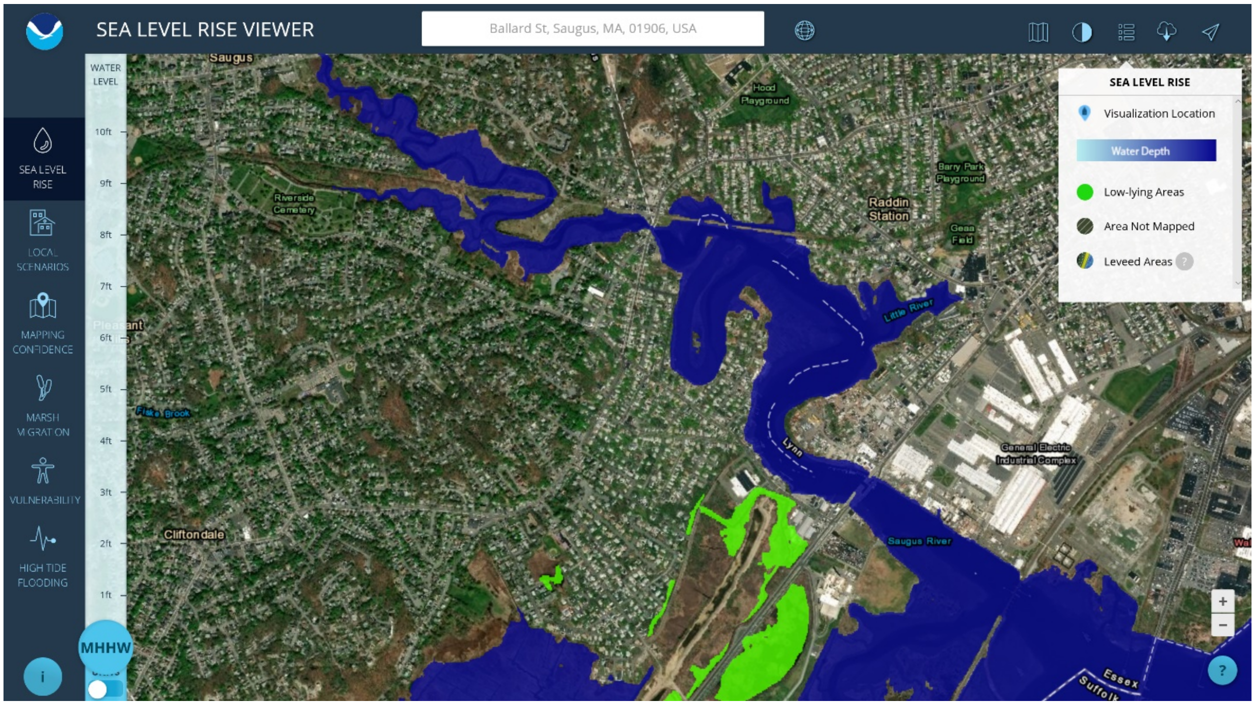


Image 1: Site conditions at current Mean Higher High-Water levels (Source: https://coast.noaa.gov/slr/)

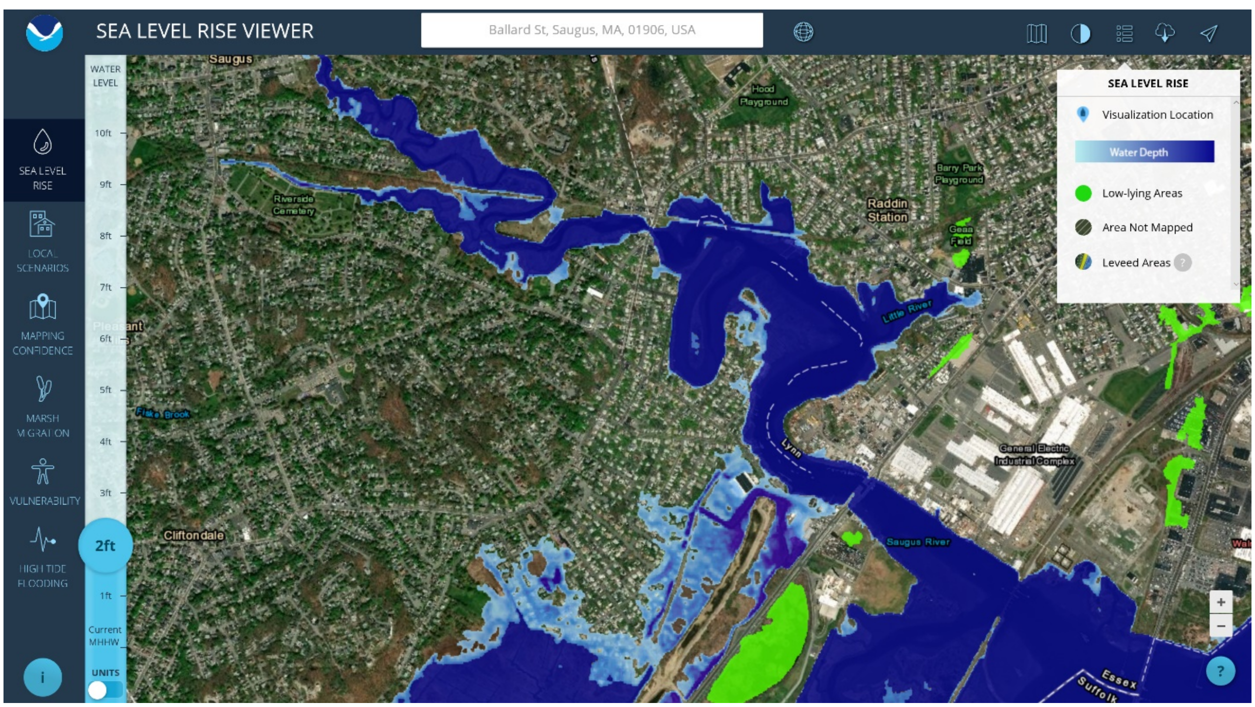


Image 2: Site conditions with a 2-foot increase over current Mean Higher High-Water levels (Source: https://coast.noaa.gov/slr/)

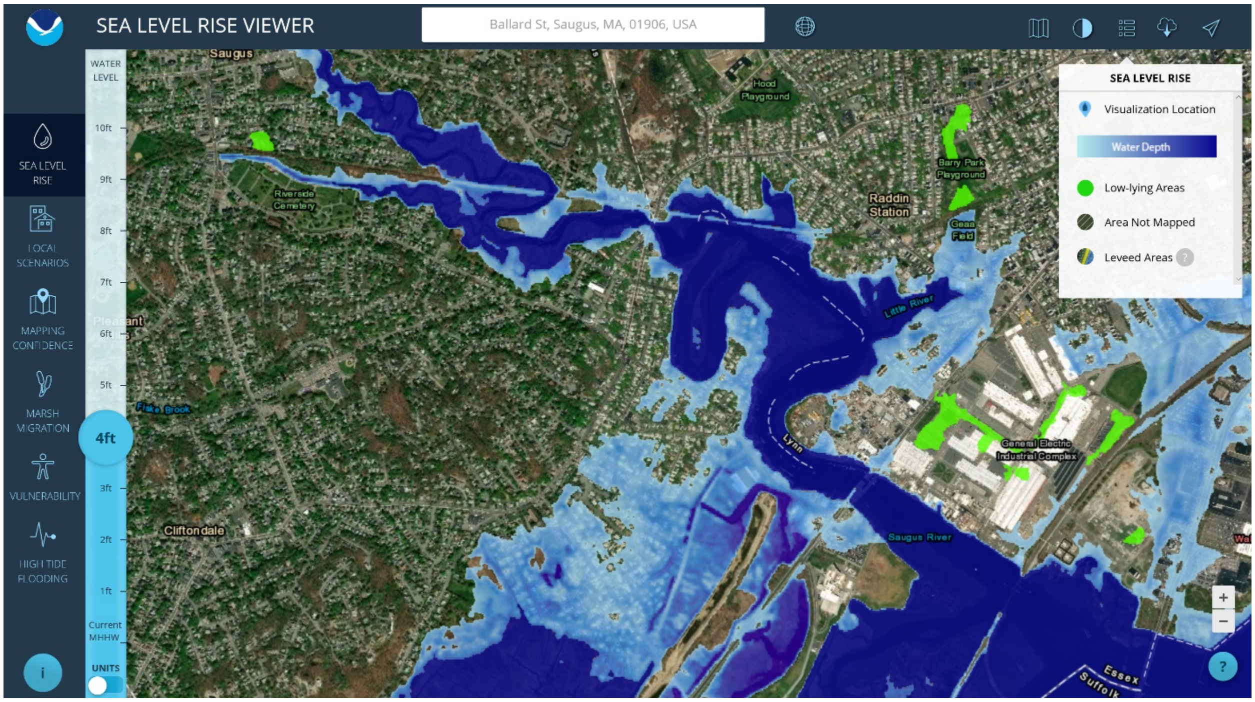


Image 3: Site conditions with a 4-foot increase over current Mean Higher High-Water levels (Source: https://coast.noaa.gov/slr/)

The three images above show how vulnerable these coastal sites are to the influence of sea level rise over current conditions. As you can see when comparing Image 2 to Image 1, a two-foot rise in sea level increases the areas of increased flooding, particularly in the low-lying areas adjacent to the river. An even bigger area of impact comes with a 4-foot rise in sea levels, as shown in Image 3. Image 3 shows increased flooding going much further inland and affecting a significantly higher amount of properties in this densely developed area.

Climate change isn't only influencing rising sea levels. We are seeing more frequent, higher intensity rainfall events. That's why it is important to review the on-site stormwater management system, as well as gain an understanding of the stormwater management system of the area. If an onsite system is undersized or marginal, it is unlikely to perform well in the future, and therefore would require significant upgrades as part of any redevelopment scenario. If the stormwater outfalls for the site are tidal, then high intensity storm events (several inches per hour) that occur when the tide cycle is on the higher end will cause backups in the stormwater management system as there is less capacity to discharge and more hydraulic head is required to activate tide gates on discharge pipes. This could cause localized flooding on site and upstream in the area.

Site Visit and Documentation

The next step in the process is to go visit the Site and document the conditions you see. Oftentimes you learn something or gain a better understanding of an aspect of a site that wasn't readily conveyed on a site plan or aerial image. I like to walk around a site, starting at an outer perimeter or lowest part of the site and work my way inward and upgradient. Essentially, I'm walking the path of what the flood water would take. This will allow you to see or confirm which aspects of the site will be impacted first and are most vulnerable. Next, I look at the buildings and infrastructure so I can document them and note any relevant observations I see. Are there signs of recent flooding? Is the critical infrastructure bunched together or spread out over the site? Also look at operational practices that could have an impact. For example, has the stockpile of spring mulch been placed close to a storm drain where it risks clogging it up and exacerbating flooding? Note where things are stored on the exterior of a property and what, if any, impact that may have.

Conducting an interview with Site personnel, such as managers and maintenance workers can provide very useful information to help in your planning and assessment. They will be able to tell you where the historical concerns have been, how the Site has fared in various storm events, and what they do in preparation for large storm events. This primary source information can help you pick up on vulnerabilities or issues that might not have been apparent from the Site plan or even the Site visit.

Operational Changes and Actions

Once you have a good understanding of the site and its susceptibility to flooding or storm damage, you can begin to approach and develop changes at the site, and the first, and least expensive, is to come up with operational changes and actions on site. These are actions that can be taken in advance of a coming storm that have minimal costs but make significant impacts on storm resistance.

The first step will be to work with the Site or Building Manager and the maintenance crew to devise a plan and Standard Operating Procedure for storm events. The plan should identify how to track weather and storm events, actions to be taken within certain time periods before, during, and after the storm, and include contact and notification procedures for the relevant parties. For instance, it might be good to have a designated staff member check the 10-day forecast every Monday and Thursday to look for storm events on the horizon. If something is forecast in the future, then that staff member can make note to track it and if it appears to be an imminent threat to the area within the next three days, notify the rest of the team to start making storm preparation actions. Looking at the 10-day forecast twice per week allows for overlap in the forecast, so it's more likely that the projections will accurately capture the impending events. Doing it twice per week also allows preparation and planning for the week ahead to arrange staffing, and if something is forecast to hit over the weekend when the Site might be closed down operationally, allow for planning and adjustments on Friday to implement the storm action plan.

In addition to having a methodology for how to track an upcoming storm, the plan should identify operational procedures to be carried out in advance of a coming storm, such as:

- Clean up and remove items that could become debris or wash away. This could include landscaping materials, wood pallets, cardboard and other items that are stored outside, but could get blown about in a storm.
- Ensure storm drain inlets and receptors are clean and operational. Leaves and debris tend to collect in these areas and prevent proper drainage, greatly exacerbating flooding issues.
- Any hazardous materials should be moved to a designated safer location.

The plan should also account for long term plans and be updated based on experiences, including:

- A method to identify capital improvement projects such as moving generators and critical infrastructure to higher areas (rooftops), repairing or redesigning areas susceptible to storm damage, etc.
- A section to review each storm events and damages resulting. Note what worked well and what needs improvement.
- A way to develop probability scenarios for weighing which changes should be made and when. This will be valuable in budgeting and performing cost benefit analyses for the improvements.
- A list of useful items to have for storm events like gas powered portable pumps that can be used and deployed in different places in the case of localized flooding.

Physical Interventions

Physical interventions used to minimize and mitigate flood damage can come in both temporary and permanent measures and span a wide range of budgetary figures. Typically, these interventions require planning, study, design and construction, so they have a longer lead time and a higher price tag than the operational changes.

Determining Design Flood Elevation

In order to provide effective and useful intervention, you really need to know what you are up against in terms of storm events so you can plan effectively. The FEMA maps provide a Base Flood Elevation (BFE) that has been studied and modeled and therefore represents an accurate flood elevation that can be used for design purposes. These BFE's represent the elevation with a 1% annual probability of being exceeded. For some sites and site operators, they are willing to live with that relatively small risk, but for others, perhaps with critical and expensive infrastructure, they may want more protection. For instance, in October 2015, there was a storm event in South Carolina that deposited over 2 feet of rainfall, what was referred to as a 1 in 1,000-year storm event, so interventions designed to protect up to the BFE would have been exceeded and damage would have occurred to properties in that area. Also, FEMA BFE's are based on historical data and do not account for sea level rise or climate change conditions (unless they have been very recently updated with that specific intention). Oftentimes, when you are making the investment to protect a property up to the BFE, there may be marginally extra cost to make the changes up to a higher elevation and add significantly greater protection. This cost-benefit analysis should be conducted and discussed with your client.

So what other methods can be used for creating a design flood elevation? There are several options, and the one you will choose will really depend on your client's appetite for modelling. Most clients that run a relatively small site don't have the desire or budget to pay for a localized floodplain model, so that option quickly comes off the table. Knowing the BFE however will allow you to make a relatively crude hydrologic model of the site. If you know the tributary watershed area (which you can take off a USGS topographic map, the 100-year storm event (you can check TP-40 or an updated regional model, such as the Northeast Regional Climate Center's Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada) and the BFE, you can reverse engineer a quick model for the site in HEC-RAS, HydroCAD or some other hydrological modeling software. Then, using that quick model, you can plug in other rainfall events, such as a 500-year return event or a 1000-year return event, or if you have a background in dam safety and inspections, you could use the Probable Maximum Precipitation

(PMP) Amounts. The National Weather Service has a series of studies that can be used to get PMP figures (www.nws.noaa.gov/oh/hdsc/studies/pmp.html). The problem with using a PMP is that you are probably going to be oversizing your interventions for an extremely rare event and it may become cost prohibitive to implement. PMPs are used for dam safety analysis because a breach or failure in a dam could lead to loss of life or severe destruction of property and environmental damage. That being said an intervention designed to withstand a PMP probably would have been one of the few interventions that was effective against the October 2015 flooding in South Carolina.

Lastly, there is always the rule of thumb method, which doesn't require any modeling or analysis. The rule of thumb for simple planning purposes to is to provide protection for water up to a level of 4 feet. The four-foot rule is useful because in most cases adding 4 foot of additional flood protection is more than sufficient for most storms and going over 4 feet typically requires significant structural upgrades due to the increased hydrostatic forces being exerted by the floodwaters. So, if your client is unwilling to pay for a hydrologic study or modeling and wants to maximize how much of the budget goes into the interventions, then this may be the best approach. That being said, the client needs to be very aware of the limitations in the design and protection levels with using this rule of thumb approach.

Building upgrades

Once you have your design flood elevation, you can begin looking at physical interventions. The first line of defense is to address the existing buildings' vulnerabilities and optimize their level of resiliency. There are several strategies for achieving this with some more effective than others and some most effective when combined with others. Some of the actions that can be performed include:

- Installing Flood seals and reinforcement for doors. Flood seals are typically rubberized gaskets that are placed at door sills and along its frame to provide a watertight seal when the door is closed. These flood seals are intended to seal the gaps where the door meets the frame, which is often the path of least resistance for flood waters.
- Adding Waterproofing and elastomeric barriers on the building foundation. This will keep water away from the building and prevent seepage into the building. Most concrete foundations are coated with the waterproofing up to the ground surface but extending it upwards can add a layer of protection, the problem is that they aren't typically very aesthetically pleasing. These barriers also need a footing drain or some way to convey the

water away from the foundation as they aren't completely impermeable and will work best if water does not remain in contact for an extended period of time.

- Install interior subfloor underdrains if possible, based on the building structure. These will need to be sized based on diameter and slope to ensure there is adequate flow capacity in the underdrains. The subfloor drains will be a redundancy in your resiliency strategy to collect and convey water that gets through your first (or second) line of defense on the outside.
- Install Sump pumping systems. Just like the interior flood drains, these are a redundancy in case other interventions fail or are overwhelmed. It is unrealistic to expect a sump pump to catch up and discharge flood waters to keep them from building up within the building, but they can slow the progress and help get the flood waters down faster once the flood has started to recede. These systems should have separate or backup electrical power connections in case the permanent power connection goes down in a storm.
- Add Backflow preventers on sewerage lines, typically swing style check valves. I prefer to use a double swing type check valve to have the redundancy in the system and it's a marginal cost to put in 2 versus 1. The check valves will protect against sewage backups and surge through the building. When backups do occur and the check valves are functioning, it will not allow the discharge of sewerage from the building, so to maintain operations during a backup event, some people also install an offline storage tank so water can be used during backflow conditions. These offline tanks can be sized to handle 12-, 24- or 48 hours' worth of water and have pumps to allow it to pump back into the sewer lines (or hauled off by a septic waste hauler) once the backup event has dissipated.
- Sealing conduits and penetrations into building, these prevent water from seeping in through open pipe penetrations. This is an easy intervention to implement and very low cost compared to the others. Most times the solution is as simple as plugging the gaps and penetrations with a waterproof acrylic polymer caulk.
- Upgrading doors to be resistant to certain flood levels and handle the associated hydrostatic pressures. These heavier duty doors and frames will also provide better security since they are heavier duty.
- Depending upon the type of construction of the building and the need for structural reinforcements, the building can be retrofitted from stud frame construction to 4 ft high concrete walls. Concrete walls, along with proper coatings and protection, can be made more resistant to water intrusion than a typical wood frame construction. This is generally a costly and intrusive upgrade, but it can be phased in over time. As part of that retrofit, all windows should be raised above the level of the concrete to maximize the strength of the retro-fitted building.

- Moving infrastructure to less vulnerable areas. This could mean placing electrical transformers, generators, and other critical infrastructure on the roof, on an upper level floor, or creating an elevated platform for them off the side of the building.

Temporary Flood prevention barriers

Temporary barriers can be stored on site and deployed in advance of a storm. Deployment can be simple, requiring only a single person, or more involved, requiring the use of a team of people, a forklift, or a 4-wheel drive vehicle with a tow hitch. One major advantage of these options is that they require no permanent changes to the building or infrastructure. Temporary deployable systems are flexible and customizable, so the deployment can be scaled up or down depending on the desired protection areas. One of the biggest risks with these systems is user error in deployment (improper connections, lack of seal, etc.) or lack of maintenance, including improper storage that can weaken and nullify any affects and advantages these systems provide. There are several different options and types.

The above image shows solid panel flood doors stored on a wall in a warehouse area. Along the bottom there is also a steel beam that was added to provide structural reinforcement to better resist hydrostatic pressures.

- Solid panels are the most common type, usually laminated with a reinforced frame. These panels interlock, can be installed by a team of 10 at a rate of 300 ft per hour. The solid panels are typically stored together flat and when implemented, they are rotated up, usually with a hinge and piston system and locked in place. Some of the panels are anchored to the ground, others rely on the hydrostatic force of the water to keep them in place.
- Geotextile and welded frame barriers are options that can be filled with sand or water for reinforcement and stability of the system. The barriers themselves can be rapidly deployed, however the longest duration effort is taken in filling the products with the sand or water for its stability. Also, after the storm and/or deployment, there is the need to remove the fill material that was placed into it for the protection against the storm.
- Hard plastic barriers are typically interlocking but need to be filled with water for stability. They are typically quickly deployed when empty, and then filled with water.
- Softer plastic membranes and seals, which are rolled up and easily deployed by a single person. There are both perimeter protection systems and “socks” that can be used to seal off doors and entranceways. The advantage of these options is that they are cheaper, easy to deploy and don’t take up much storage space.

Property changes and upgrades

The final step that can have the biggest impact, along with the biggest expense, is to make physical changes to the infrastructure and layout of the property. Physical changes to the property typically require site specific engineering and permitting to ensure compliance with the governing regulations in the area and not transferring flood risk to a neighboring property. Some potential ideas to be explored:

- Fine grading work to create more area at a lower elevation where there is less critical infrastructure. This is essentially creating a sacrificial part of the site that would receive flood waters first and create more of a buffer of volume from the critical infrastructure than what currently exists. An example of location like this might be a rear or overflow parking area that could be lowered or bermed to receive floodwaters first.

- Reduce the impervious cover and add fine grading work (landscape sculpting). This option requires a detailed investigation to identify the ideal locations. The principle behind this option is that in reducing impervious cover, you are reducing the amount of runoff from your site, which in the case of a small site in a large floodplain, may not make a very significant impact on the volume. If there is extraneous parking on the property or concrete pads that aren't consistently used, they could be converted to a green space that surrounds the property. This adds a softer feel to a site while adding a natural flood buffer.
- Install large subsurface storage chambers to capture and store water below parking areas. The storage capacity would need to be sized appropriately, factoring in soils, and target flood storage and protection. Chambers can be used to capture and retain flood water as it rises and keep it away from the building and critical infrastructure. During a storm event, a pump system could also be installed to pump out flood waters from the chambers as subsurface recharge/ infiltration is unlikely given that during flood events soils are typically saturated. These chambers can be installed under existing parking areas but are typically an expensive upgrade to add.
- Create earthen or landscaped berms around the property or around critical infrastructure. The berms would need to tie into a part of the site at a higher elevation to create the best protection. The size will really depend on the topography on site, however a berm of between 6 inches and 2 feet could provide significant flood protection. There is obviously less protection with shallower berms, but there is also less visual impact and less cost associated with that. This item would require further exploration of the stormwater management system to make sure the on-site controls can handle the new catchment areas created by the berms and wouldn't cause ponding from inside the bermed area.
- Flood walls and berms could be built around critical infrastructure, such as an electrical transformer, a backup generator, or utility areas. These flood walls would likely be a minimum of 4 ft high and have sealed, flood rated access doors for operation and maintenance purposes.

The photo above shows a good location for a flood wall, as there is critical infrastructure exposed behind the building in the parking area.

Summary

Several options have been presented herein which, when combined with the operational and process modifications presented, can significantly increase the subject property's resiliency. Resiliency concepts have been presented very broadly and each provide a targeted level of protection. Interventions such as the installation of flood seals, flood doors and sealing of all penetrations are effective building and appurtenance protections. Installation of subsurface recharge chambers and reducing impervious cover have a broader protective effect beyond the building and equipment envelopes. Creating sacrificial flood areas, implementing new berms and sculpting of the landscape for simultaneous rising water protection and water storage/ infiltration having the highest level of subject site protection. All of the options presented above become more effective when used in combination.

The most important thing when approaching a sustainability plan for a site is to discuss with your client what their tolerance for risk is, what their appetite for spending is on a project like this and then discussing the different options and strategies that are available along with the trade-offs and limitations for each one. With working in a regional or floodplain-wide plan, it is nearly impossible or at least cost prohibitive to completely protect a site. However, there are both physical and operational changes for almost every budgetary range that can be made to make a site more resilient and better protected from rising sea levels, flooding and larger, more frequent storm events.

