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Technical Track Abstracts

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Table of Contents

Track 1: Coastal Resiliency

Moderated by Liv Haselbach, P.E., Ph.D., F.ASCE

A Resilient Texas Coastline – Aligning Our Natural and Built Infrastructure for the Future

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Keywords: Coastal Resilience, Collaboration, Hazard Mitigation, Master Planning, Nature-Based Solutions, Sea Level Rise

ABSTRACT

Texas is taking steps to proactively plan for climate-related challenges along its coast, both in the immediate future and the long-term. The Texas General Land Office (GLO) has led the charge to assemble the Texas Coastal Resiliency Master Plan to confront the challenge our coast is facing. Taking a collaborative approach to planning, the GLO has embraced the perspectives of local coastal communities, scientists, planners, industry, and academia to enhance resiliency, mitigate risks, and protect coastal environments and communities along the coast. Understanding the latest science and continued dynamism of the coastal zone, including impending changes to weather patterns and sea levels, is paramount to the planning effort. Another critical development in the planning process has been to build consensus among stakeholders with dramatically different priorities by promoting collaborative solutions and helping Texans rally support behind key proposed projects. Growing collective understanding in what community infrastructure looks like in an evolving landscape is critical to identifying actionable and resilient projects that integrate both nature-based and traditional infrastructure working together. Ultimately, the Master Plan is one step in an effort to stand together along the Texas coast, championing a healthy coast for generations to come.

This presentation will provide perspectives of community resilience through the lenses of coastal managers representing multiple entities along the Texas coast, including agencies, consulting, and academia. Under this lens, we will discuss the ability to develop resilient communities while also preserving the coast's natural systems.

Coastal Resilience and Sustainable Infrastructure Management System

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Keywords: Climate, Coastal, Infrastructure, Management, Resilience, Sustainability

ABSTRACT

Over 90% of urban centres worldwide are in coastal areas, and cities face increasing risks from destructive hurricanes, floods, and other natural hazards that are becoming more frequent, intense, and severe due to climate change and its effects.

A critical issue confronting the coastal cities and island states in the Americas is the vulnerability of its population and economy to the effects of climate change and natural disasters, which has seriously impacted the environment, communities, and the productive sectors. Development pressures and systemic deficiencies have resulted in substantial damage to critical infrastructure, housing, and livelihoods during disasters.

The goal of this project is to develop a Coastal Resilience and Sustainable Infrastructure Management System to optimize the resilience and sustainability of infrastructure in coastal regions in North America, South America and the Caribbean by 2030, in tandem with the United Nations Sustainable Development Goals (SDGs).

The project activities are to (1) Identify existing work on actual and potential future climate change-related effects and sustainable development, ongoing activities, and good practice examples; and (2) Develop a coastal resilience and sustainability digital road map towards the year 2030, based on stakeholder engagement, the SDGs, the Sendai framework and applicable international sustainability rating systems such as Envision.

The Coastal Resilience and Sustainable Infrastructure Management System has the potential to positively impact the infrastructure, environment, economy and livelihoods of coastal nations in the Americas and would serve as a foundation for the development of similar projects to help shape the future of digital sustainable development engineering.

Galveston Bay Park Plan SSPEED Center (Severe Storm Prediction, Education, & Evacuation from Disasters)

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Keywords: Economic Imperative, Environmental Protection, Habitat, Multipurpose Solution, Resiliency, Storm Surge

ABSTRACT

In 2008 Hurricane Ike made a direct hit on Galveston Bay with a flood surge not experienced in the area since the early 1900's. This event spurred the concept of the Ike Dike, a coastal barrier along Galveston Island and Bolivar Peninsula to protect the bay and Galveston from future storms, and a companion project, Galveston Bay Park.

The risk of a major storm surge hitting Galveston Bay is a national and international concern. The Port of Houston is currently the largest port in terms of tonnage in the United States. The widening of the Panama Canal and the increase in goods coming into and going out of the US has played a large role in the growth of the Port of Houston. Over 25% of all petrochemical activity in the US takes place within this area, including over 30% of the nation's aviation fuel and 13% of the national refining capacity. Impact to this area would have a significant impact to the national and global economy.

The area has an overall population of over 5,000,000 people with more than 800,000 people located in areas of direct impact risk from storm surge in Galveston Bay. Galveston Bay is one of the most productive estuaries in the nation providing oysters, shrimp, sport fishing, birding, boating and many other recreational activities. The bay is part of the migratory route for a number of bird species and is a favorite spot for birders during the migratory season. Even a relatively small spill as a result of storm surge could have an immeasurable impact on the bay, potentially creating impacts that would last decades.

The threat is real. While every storm has its unique characteristics, the fact is that gulf storms are getting larger, stronger, and less predictable. Category 3 to 5 storms are more prevalent. The chance of a storm hitting the southeast coast in a location that would send a huge surge up the Houston Ship Channel into Galveston Bay has increased. To not prepare for such an event is unthinkable.

Hurricane Ike did get attention. Bill Merrill at Texas A&M Galveston started looking at the possibility of developing a coastal barrier, taking a page out of the book from The Netherlands to envision a barrier that would run from High Island to Freeport. His effort led to a state-funded effort that was eventually turned into a project for the US Army Corps of Engineers in Galveston. The project became known as the Ike Dike due to its similarities to the Dutch system.

The Ike Dike was studied by the US Army Corps of Engineers (USACE) and is being presented as the locally preferred plan. However, during Dr. Merrill's TAMU Study and the USACE study, the Severe Storm Prediction, Education, & Evacuation from Disasters (SSPEED) Center, funded by the Houston Endowment, was studying similar protection alternatives that would protect against in-bay surge that the Ike Dike would not completely address. The SSPEED Center project was announced to be a compatible project to the Ike Dike to add the additional protection that would replace a portion of the USACE solution for the west side of Galveston Bay.

The solution was Galveston Bay Park, a resilient project proposed to provide year round recreational and commercial benefits, aid in widening and maintaining the Houston Ship Channel, provide environmental measures to help clean the waters within Galveston Bay, and provide greater protection to the area from Texas City to Baytown, including the Port of Houston and the surrounding industrial complex as well as the homes of many of the residents that provide the labor needed to operate those facilities. The project is a more inclusive and more complete solution to the trending large magnitude storms.

The Galveston Bay Park is a continuation of the legacy of those that came before. After the 1900 storm that wiped out Galveston, Jesse Jones, a leader in the region at the time, started to develop the idea to move the port from Galveston to Houston. The result was a 40-mile channel starting 20 miles out into the Gulf of Mexico and running up the swampy river known as Buffalo Bayou. The timing was everything. At the time the Houston Ship Channel was being constructed, another major shipping marvel was underway, the Panama Canal. Shortly thereafter, Spindletop, the start of the Texas Oil Boom, was drilled. The result is the major port that Houston and Galveston Bay has become. The leadership and vision of Jesse Jones is the legacy that Galveston Bay Park is taking to take another bold step to create a world class multipurpose facility that will help protect the region from the growing threat of coastal surge while providing everyday use for recreation, as a long term cost effective use of ship channel maintenance dredging spoils, as a way to help fund and optimize widening the Houston Ship Channel to make it safer and capable of larger vessels, all while providing some environmental enhancements and protecting the west side of Galveston Bay from CAT 5 storms.

It is important to note that the Coastal Spine, while a major portion of the coastal protection, is limited in what can be done due to the limitations on the barrier and the size of the bay behind it. The large size of Galveston Bay makes it susceptible to residual surge, which occurs when surge caused by the wind and pressure from a storm causes surge of water just within the Bay. And due to the limited height of the coastal spine, a CAT 4 or 5 storm would overtop it and add to the water contributing to the in-bay surge damages along the shores and up the tributaries draining into Galveston Bay. The current plan in the USACE Coastal Spine solution puts gates in Clear Creek at Clear Lake and in Dickenson Bayou, but leaves the homes and industries along the shoreline and the Houston Ship Channel exposed to the residual surge. This is where the Galveston Bay Park plan comes in, providing that additional protection to the most vulnerable and critical areas. This second line of defense is the same approach used in The Netherlands to protect the Zuider Zee and Amsterdam.

Galveston Bay Park provides a 25' high surge barrier island in the middle of Galveston Bay. The barrier is to be constructed with dredged material from widening the Houston Ship Channel beyond the currently approved plan to expand the width from 530' to 700' by an additional 200'. The 900' width was one of the options included in the Environmental Impact Statement for the currently approved plan. The current channel is unsafe and typically has to be used as a one-way system. The additional 200' beyond the currently approved plan will add to the safety of the channel and allow larger vessels to enter Galveston Bay and access the Port of Houston and other port facilities within the Bay. Using the dredged material for the barrier puts the material to beneficial use and reduces the cost of the dredging operations since the deposits will be immediately adjacent to the channel. It is also this adjacency that provides ongoing benefit for the continuous maintenance dredging that is ongoing to keep the channel from silting in.

Galveston Bay is typically a shallow estuary with normal depths ranging from 4' to 12'. There are channels cut throughout the bay for deeper-keeled craft. The Galveston Bay Park barrier will cross three of these channels plus the Houston Ship Channel where gates are planned to serve navigation in the bay. In addition, there are two additional locations where small craft gates are planned to improve access within the bay and to improve water circulation. The small gates are planned to roughly match the current channel width or as needed to improve navigation and water circulation. The large Houston Ship Channel gate will be in the same class as the large navigation storm gates across the world such as the Maeslant Barrier outside of Rotterdam in the Netherlands, the Thames River Barrier in London, and the St. Petersburg Dam in Russia. The smaller gates will include bridges that will provide access to the barrier for recreation and maintenance.

The Galveston Bay Park barrier is unique in that the barrier has a beneficial use even when not providing protection from storms. Galveston Bay currently has a very limited public beach access. Private ownership extends to the bay with only a few parks providing direct public access. The barrier, when fully built out, will create over 22 miles of beach and marsh lands for public access, providing fishing, birding, camping, and other outdoor recreation opportunities. It is anticipated that the barrier will allow franchise development of public amenities such as marinas, fish camps, horseback rentals, performance venues, etc. which will provide ongoing income to help pay for the maintenance of the barrier.

The project is currently in a study phase to firm up cost, determine the best sources of financing, address potential environmental concerns, and advance the design of the barrier. The intent is to move forward with the environmental permits once the study is completed. Depending on the permitting process and the success in finding a funding mechanism, the project could move forward into final design in a couple of years, pushing for approvals and moving into construction before the end of the decade.

Findings from Two Flood Disaster Response Exercises for Southeast Texas

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ABSTRACT

Disaster preparedness needs regular updates to identify strengths and weaknesses of available resources and increase resilience. This study overview activities to increase collaboration between infrastructure professionals, emergency personnel and decision makers. Two virtual Homeland Security Exercise and Evaluation Program tabletop exercises were held. They focused on Southeast Texas but are applicable to other disaster-prone areas. The SETx Flood Exercise identified major strengths for disaster resilience of the various parties and recommended some areas for enhancement. The Sabine River Authority Exercise focused on a river gauge website which was found to be very useful, but for added ease of use, upgrades might include enhanced map symbology and comparative and predictive data. Obtaining familiarity with running virtual tabletop exercises can aid in preparation for, response to and recovery from disasters that affect our infrastructure especially under multi-disaster conditions and virtual exercises may be more accessible and inclusive for the varied parties involved.

Track 2: Green Infrastructure

Moderated by Cliff Davidson

Engaging Owners in Low Impact Development (LID): Lessons Learned from Implementing Sustainable Design with Public and Private Institutions

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Keywords: Bioswale, Client, Green Infrastructure, LID, Low Impact Development, Owner

ABSTRACT

The environmental benefits of LID are well understood, so why can it be difficult to generate buy-in from owners and see green infrastructure designs come to fruition?

Private developments generally focus on the Return on Investment (ROI) of a property/project, which can make adoption of sustainability practices that don't have short or measurable ROI less appealing. For the designers and engineers who work for these clients, the general rule has been: if it doesn't pay back, they are not interested. So how do you describe the ROI in a way that continues the conversation and better represents the benefits of sustainable practices such as LID?

Institutions have different drivers and, while ROI is still a big part of the equation, their decision-making tends to have more variables including educational benefits and long-term ownership. How is green infrastructure both facilitated and hindered by municipal regulations through the lens of these client types?

This study focuses on lessons learned from engaging different types of owners in sustainable design, featuring cases studies from both institutional and private clients that found ROI in implementing LID.

Use of Green Stormwater Infrastructure to Sustainably Address Changing Storms

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Keywords: Bioretention, Climate Change, Green Infrastructure, GSI, Stormwater, Sustainability

ABSTRACT

Changing storm characteristics present challenges for developed areas, where criteria used to size existing stormwater infrastructure may no longer be reflective of the current climate. Conventional approaches to overburdened stormwater infrastructure often involve adding or replacing pipe infrastructure; however, these efforts can be disruptive and expensive with limitations on scalability. Additionally, with substantial removal, disposal, and new material installation, these efforts can lack many characteristics of a sustainable infrastructure project.

Green stormwater infrastructure (GSI) can provide multiple benefits and support sustainability efforts; however, these controls are often intended to manage small, frequent storm events. An analysis of observed recent storm characteristics in relation to NOAA Atlas 14 demonstrates that many locations in the United States are realizing an above average frequency of storm events associated with nuisance flooding issues and an incremental increase in storm depths and intensities. A hydrologic analysis of multiple bioretention design configurations reveals that while basic GSI controls have limited impact on the storms used to design stormwater conveyance infrastructure, basic design modifications can mitigate the incremental increases in storm size associated with climate change and provide broader peak flow reduction benefits. Results suggest GSI can play a valuable role in conjunction with existing grey infrastructure to mitigate the incremental increases in storm depths and intensities associated with climate change while supporting other sustainability objectives. This presentation will discuss the analyses described herein and provide examples of where green stormwater infrastructure is and is not a reasonable option to assist in providing climate resiliency.

Green Infrastructure for the Anthropocene: An Early Career Perspective

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ABSTRACT

Climate-related disruptions expose the obduracy of existing urban systems built to deal with conditions of the past without the needed flexibility to address the challenges of the Anthropocene. Green infrastructure (GI) is a promising tool of resilience with the potential to address these disruptions. While GI's benefits span social, ecological, and technological dimensions, the commonly accepted definition—the direct use or mimicry of ecological systems (e.g. vegetated land) to perform infrastructural services (e.g. stormwater management)—oftentimes reduces GI to the technological dimension, which is maladaptive toward coordinated social and ecological transformations (Matsler et al. 2021). To better position GI for resiliency, we examine GI through robust interdisciplinarity and propose the social-ecological-technological systems (SETS) lens as a guiding framework. We present perspectives from a group of early career researchers and practitioners with diverse disciplinary backgrounds who participated in a 4-day symposia series. Throughout the symposia, participants led a collaborative autoethnographic study to generate holistic principles for GI design, implementation, and maintenance. The emergent principles emphasize process transparency, stakeholder and community engagement, simultaneous consideration of SETS objectives, and adaptive management to 1) address previously dismissed needs and emergent issues and 2) clarify responsibilities for increased accountability. These principles challenge existing procedures surrounding GI and present a research agenda to move toward more holistic implementation.

Reference:

Matsler, A.M., Meerow, S., Mell, I.C., Pavao-Zuckerman, M.A. (2021). "A 'green' chameleon: Exploring the many disciplinary definitions, goals, and forms of 'green infrastructure'". *Landscape and Urban Planning* 214, 104145. doi:10.1016/j.landurbplan.2021.104145.

Measurement and Modeling of Hydrologic Flows and Energy Flows on a Large, Extensive Green Roof in Syracuse, New York

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Keywords: CHAMPS-BES, Energy Flow, Green Roof, HYDRUS, Stormwater, SWMM

ABSTRACT

Increasing numbers of cities in recent years have turned to green infrastructure for stormwater management, and this trend is likely to continue as decision makers study the benefits of green over traditional gray infrastructure (Flynn and Davidson, 2016). For example, the Save the Rain program in Onondaga County, New York has implemented more than 200 green infrastructure projects through public-private partnerships in the past decade. One of the largest of these projects is the 5,550 m^2 green roof planted with sedum on the Onondaga County Convention Center (OnCenter) constructed in 2011 in downtown Syracuse. To study the performance of the roof, temperature sensors have been installed to obtain a multi-point profile through the roof layers at five locations on the roof, an electromagnetic flow meter is positioned to measure the stormwater runoff flowing down the roof drains, several soil moisture sensors have been buried in the engineered soil to determine volumetric water content in the growth medium, and a weather station has been set up on the roof. In addition, samples of rain and leaf washoff are collected for chemical species analysis to determine atmospheric wet and dry deposition.

In this extended abstract, we discuss research findings in three categories. First, we address the hydrology of the roof, examining retention of stormwater to reduce combined sewer overflows (CSOs) and flooding. Second, we report on modeling the hydrology of the roof using two well-known computer models, SWMM and HYDRUS. Third, we consider energy flow through the roof, monitoring the temperatures in the various roof layers as well as modeling heat flow through the roof. Although not discussed in this extended abstract, studies on the green roof and the SU campus are examining the transfer of chemical pollutants from the atmosphere to the surface by wet and dry deposition.

Measured Retention of Stormwater. The roof contains a 3-inch depth of engineered soil and is planted with six species of sedum, designed to effectively capture a 1-inch storm. There have been several measurement campaigns; the first campaign ran from October 2014 to July 2016, a total of 21 months (Squier-Babcock and Davidson, 2020). The overall retention rate was 56% for this time period, and the reduction of peak runoff relative to peak rainfall averaged 65% for all events with runoff.

The amount of stormwater retained by the roof was a function of several factors, especially the moisture content of the engineered soil at the start of the rain and the total depth of rainfall in a particular storm. The storms fell into one of four categories: very small (< 2 mm), small (2-10 mm), medium (10-20 mm), and large (> 20 mm). Removing data when snow was present and when there was instrument malfunction, a total of 165 rainstorms could be analyzed with a total depth of 1062 mm. Roughly half of these were very small, having a total of only 5% of the measured rainfall throughout the 21 months. Only one of these very small events had runoff, indicating that the roof captured essentially all the rain in very small events. In contrast, there were only 11 large events, which accounted for 38% of the total rainfall. Just 24% of the total measured retention occurred during these large events, suggesting the roof is more effective at capturing small and medium events.

The effectiveness of the roof in capturing stormwater has not been constant over time, according to Yang and Davidson (2021). Comparing retention data for the year 2015 with retention data for the year 2017 suggests that the roof has gotten slightly more effective with age in capturing rainwater. The maximum water holding capacity of the engineered soil increased from 39% in 2011 to 46% in 2018; consistent with this measurement, the fraction of soil particles with diameter smaller than 0.05 micrometers increased from 5.9% in 2011 to 8.4% in 2018.

Modeling hydrologic flows on the roof using SWMM and HYDRUS. The EPA model SWMM was first applied to the OnCenter green roof using physically representative parameter values. Results showed poor agreement between simulated and measured runoff for a number of storms, indicating the need for a manual calibration of the model parameters. Using data from a 9 cm storm on October 28, 2017, the parameters were adjusted to optimize agreement between modeled and measured runoff throughout the storm. Applying the calibrated model to several additional storms demonstrated good results for predicting runoff. However, the calibrated model could not replicate the observed soil moisture time series between storm events.

SWMM was also used to investigate the sensitivity of the various model parameters in influencing the simulated outputs, using one-at-a-time analysis by holding all parameters except one constant; the target parameter was then varied to determine the sensitivity of this parameter. Sensitivity varied among the 14 parameters, and the sensitivity depended on whether the original physically-based parameters or the calibrated parameter values were used. The insensitivity of some parameters is a partial explanation of the occurrence of equifinality, when a simulated output can be obtained by many different combinations of parameter values. Equifinality in SWMM complicates the interpretation of agreement between measured and simulated results.

HYDRUS-1D has been used to simulate runoff, infiltration, evaporation and soil moisture for a number of rain events on the OnCenter green roof. Statistical tests were conducted to compare the measured and modeled time series for drainage from the roof, which showed that green roof performance could be simulated successfully for rainstorms of sufficient size. The statistical criteria were satisfied for 8 out of the 10 large storms examined but were satisfied for only 4 out of 18 medium storms and 0 out of 7 small storms. HYDRUS was also used to model three key parameters related to roof performance: percent retention by the roof, reduction of peak runoff relative to peak rainfall, and lag time between peak runoff and peak rainfall. Statistical tests are underway to determine the success of HYDRUS in predicting these three parameters.

Energy flow through the green roof. The flow of energy through the roof has been estimated using data from temperature sensors in the layers of the green roof (Yang et al., 2021). Temperatures within the growth medium and below the roof membrane can exceed the air temperature during the summer, especially on cloudless days when direct sunlight can reach the roof surface. During the winter, temperatures at these locations can also exceed the air temperature due to direct sunlight and heat rising from the interior of the building. The presence of plants and growth medium nevertheless reduce the temperature variations of the roof membrane in both summer and winter. The CHAMPS BES model can successfully predict heat flow through different layers of the roof and can be used to estimate heat loss from the building in winter and heat gain to the building in summer.

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Stormwater Capture/Infiltration/Reuse Case Studies: Improving Regional Sustainability and Watershed Resiliency

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Keywords: Climate Change, Flood, Groundwater, Resiliency, Stormwater, Sustainability

ABSTRACT

Would you like to make a difference in the sustainability and resiliency of water supplies and flood control? Watearth has investigated a range of case studies involving environmental quality projects as well as master plans and design. Across dozens of projects, we have learned how best to incorporate sustainable and resilient water strategies. Multi-benefit projects like those that Watearth develops range from watershed-level stormwater capture projects to site-specific 100% stormwater infiltration projects to solve structural flooding, improve water quality, and increase groundwater supplies.

On one regional stormwater capture project, Watearth identified the most efficient intersection of combined on-site and offsite treatment to manage a complex system of flood control channel, storage, and sewer diversions that improve both regional water quality and the availability of irrigation water. Elsewhere, Watearth designed an implementation of permeable pavement to reduce localized ponding and flooding, restoring safe parking access to a community building. Watearth assessed a positive cost-benefit.

Watearth staff are Envision-certified and work on watershed-level projects, site-specific projects, campus-wide projects, and system-wide projects to provide diverse benefits at a range of project scales and levels of complexity. As engineers, scientists, and communicators, we strive to provide clear analyses of take-away planning and design concepts for implementation into future projects. On many projects, particularly at the environmental documentation level (such as OCTA Systemwide Rail Resilience, studying green solutions to improving rider/commuter safety) and at the planning level (such as the City of Austin Drainage Criteria Manual, studying updated rainfall data), Watearth practices the reader-friendly document format, ensuring that recommendations pertaining to sustainability and resilience do not "sit on the shelf."

Track 3: Vulnerable Communities

Moderated by Eric Bill

Hurricane Dorian's Impact on The Bahamas: Making the Case for a Risk Management Based Approach to Infrastructure in a Small Island Developing State

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Keywords: Climate Change, Infrastructure, Resilience, Risk Management, Stormwater, Storm Surge

ABSTRACT

The Bahamas, like many Small Island Developing States (SIDS) in the Caribbean, is especially vulnerable to the impacts of climate change. Characteristically low-lying land coupled with a high ground-water table contribute to an acute sensitivity to the effects of sea level rise (SLR) and storm surge during hurricanes. These physical vulnerabilities are exacerbated by limited availability of funds and a culture of dependency on foreign investment and external post-disaster assistance.

The relatively small land mass of most of the Bahamian islands places the majority of the population within one to two miles of the coastline. The archipelagic nature of The Bahamas presents significant challenges to effectively implementing meaningful hazard mitigation policies and effecting responses during and immediately following a crisis event. Moving persons from one island to another is logistically challenging, forcing most to adopt a "shelter in place" approach to hurricane preparation.

Hurricane Dorian hit the Bahamas in September of 2019. The devastation caused by Dorian resulted in significant human, social, and financial impacts that will have lingering effects for years to come. Dorian exposed the vulnerability of The Bahamas to natural disasters and underscored the need to implement policies based on proactive and adaptive risk management.

In the aftermath of Dorian (and similar storms before it) lives were lost, buildings and infrastructure were destroyed, business were crippled and entire communities were decimated. While it is impossible to accurately calculate the toll on the social and psychological health of disaster victims or to put a value on human lives, it is vital that means of mitigating the impacts on a community are explored from a risk management perspective in order to minimize the long-term effects.

Two years after Hurricane Dorian struck The Bahamas a considerable amount of work remains to be done in some of the communities most impacted by the storm. Many of the buildings damaged have not been reconstructed and electricity has not been fully restored. There is no clearly articulated plan for recovery of the once thriving community of Marsh

Harbour Abaco, which was perhaps the most significantly impacted of the affected areas. This scenario prevents persons who were displaced from the community from returning home and resuming their lives.

Climate change has introduced a new range of uncertainties and potential risk to small island communities. While the protection of life is clearly paramount, it is also clear that attention must be paid to increasing the resilience of a community in the face of natural disasters. SIDS must seek new and sustainable means of increasing resilience in the face of hazard events such as hurricanes and the chronic threat of sea level rise. Historically building codes and by extension building regulatory departments have focused on the preservation of life, guided by the assumption of stationarity of climate conditions. The inability of The Bahamas to recover in the aftermath of Hurricane Dorian has made it obvious that from both an economic and social perspective, a reactive approach to disaster management is not sustainable. A risk-management based approach to handling infrastructure decisions will involve identification of potential risk, examination of impact vulnerability, and incorporation of a cost benefit analysis to drive implementation of avoidance, mitigation, recovery and adaptive measures.

A risk-management based approach which also recognizes the concept of non-stationarity and incorporates an element of adaptive design will increase a community's resilience to hazard impact and will promote a greater ability to quickly recover after a natural disaster. Adoption of a framework for adaptative designs and risk management such as that described in ASCE MOP 140 would provide a standardized basis for assessing risks and methodically examining the means, implications, and costs for mitigating them.

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Humanitarian Crisis Engineering at a Refugee Camp

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Keywords: Emergency Response, Engineering, Humanitarian Aid, Refugee, Stormwater Infrastructure, Water Sanitation and Hygiene

ABSTRACT

From January 2019 through March 2021, a refugee camp was formed in Matamoros, Mexico, immediately across the US border and within the floodplain of the Rio Grande River. The over-3000 Central American refugees living in the camp relied on relatively small, local humanitarian aid organizations for food, shelter, water, sanitation, healthcare, and more.

Solidarity Engineering was created when three women engineers met at the Matamoros refugee camp after they individually heard about the conditions there, and decided to uproot their lives, move to the border, and volunteer there full time. Between March 2020 and March 2021, this engineering team – which was unassociated with any established non-governmental organization (NGO) at the beginning of their time there, and only formalized as Solidarity Engineering after 6 months working together – tackled many of the camp's needs pertaining to water filtration, stormwater management, emergency hurricane response, COVID-19 response, and site infrastructure including building a shower block, school, playground, and soccer field. Each project required the team to partner with other local NGOs, as well as the refugee community itself, to identify and implement projects. More information on each project is on the Solidarity Engineering website, www.solidarityengineering.org.

A less-than-perfect emergency response at the camp to Hurricane Hanna by the NGO collaborative in July 2020 prompted the team to officially establish themselves as Solidarity Engineering, and adopt a model that included holding community meetings before, during, and after a project to ensure that community input is incorporated into each design. The team also committed to hiring local refugee community members to help with the construction, as well as the operation and maintenance, of all infrastructure.

Each project included fundraising through GoFundMe, designing, community feedback, redesigning, sourcing materials, construction, and modifications. Some design restrictions were enforced by the local Mexican authority (Instituto Nacional de Migración), such as all work being "temporary", using local Mexican vendors for building materials, and maintaining as much of the natural park landscape and protective flood levee as possible. Additionally, limited funding played a major role in what could and could not be accomplished. These constraints led to creative designs, utilizing and incorporating the existing aspects of the park in which the camp was located, which resulted in more sustainable projects with less environmental impact.

Green-Gray Infrastructure for Coastal Climate Resilience

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Keywords: Adaptation, Ecosystems, Infrastructure, Innovation, Nature-Based Solutions, Sustainability

ABSTRACT

Globally, coastal regions make up 9% of our land area, house 28% of our population (1.9 billion people) and produce 42% of our GDP. Every year $1.8 trillion is invested in coastal infrastructure, like roads, seaports, water, and wastewater treatment. At the same time, an estimated 150 million people and US$9.1 trillion in coastal assets are vulnerable to climate change impacts including rising sea levels, storm impacts, erosion, and coastal flooding. Coastal ecosystems like wetlands, coral reefs, and mangroves provide natural protection for coastal communities. However, this ‘green infrastructure’ alone is often inadequate to fully safeguard people and physical assets from the increasing threats associated with climate change. Conventional ‘gray’ infrastructure (e.g., seawalls, breakwaters, etc.) alternatively offers immediate protection, but is often prohibitively expensive to build, maintain, and replace, and can create unintended negative impacts. Blending “green” conservation and restoration with “gray” engineering techniques capitalizes on the best of both and has the potential to create a new generation of climate resilient coastal infrastructure. However, these approaches are not yet commonly used by engineers and practitioners globally.

The Global Green-Gray Infrastructure Community of Practice, led by Conservation International, is a forum for collaboration across the conservation, engineering, finance, and construction sectors to generate and scale green-gray climate adaptation solutions. The Community has grown to over 100 member organizations, including AECOM, Bechtel, Deltares, Arup, Caterpillar, World Resources Institute, IUCN, TNC, RARE, and many academic partners. This multidisciplinary community has identified key barriers to implementing green-gray projects:

1. Engineers, developers, industry, and governments lack experience, familiarity and, consequently, confidence in the reliability and application of green-gray approaches;
2. Technical knowledge and data needed to standardize reliable green-gray solutions is not broadly or equitably available;
3. Most infrastructure policies and regulations do not currently incentivize green-gray solutions; and
4. Real and perceived risks constrain investments in developing economies despite significant opportunities for achieving social, economic, and climate mitigation and adaptation objectives at a competitive cost.

The community has identified strategic and collaborative initiatives to address these barriers.

Comprehensive Stakeholder Engagement in an Emergency Management and Debris Project

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Keywords: Emergency Management, Hurricane, Stakeholder Engagement, Social Surveys

ABSTRACT

This study addresses the need for comprehensive stakeholder engagement, taking as an example a disaster recovery emergency management project at a landfill (dump). Phillispburg, Sint Maarten received uncontrolled debris from the clean-up after hurricanes Maria and Irma devasted the island in 2017. The landfill now contains burnable and non-burnable waste, and the periodic, toxic dump fires at the landfill that had occurred sporadically in the decades before Irma became almost a constant as the post-hurricane debris mounted. Prior to starting the engineering works required to suppress the fires (oxygen starvation, water, foam) and close the landfill, a disadvantaged community that resides in closed proximity/adjacent to the landfill needs to be relocated. To provide the client with the tools and information necessary to develop a resettlement plan that earned the community's trust and buy-in, we developed a comprehensive stakeholder engagement plan and detailed census survey of the affected persons. The study addresses the methodology employed to conduct the census survey and the engagement with the affected community.

Track 4: Sustainable Infrastructure: The Big Picture

Moderated by Krishna Reddy

From Results-Oriented to Process-Oriented: Leveraging Disruptive Practices to Face Complex and Uncertain Futures

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Keywords: Alternative Project Delivery, Envision, Integrated Design, Risk Management

ABSTRACT

Infrastructure projects are defined by unique challenges and opportunities, including diverse funding streams, contrasting stakeholder priorities, and a variety of triple-bottom line impacts. The way the engineering industry has traditionally approached infrastructure projects has been through a step-by-step process with very little engagement and collaboration. These approaches can result in unproductive silos and segmentation – leading to unnecessary rework, change orders, and an inherent disconnect from the true desired outcomes of the project. To address increasing complexities, interconnection, and interdependence, a disruptive shift in how we approach infrastructure must occur.

Taking a process-based versus a results-based approach to infrastructure problems fundamentally changes the way we approach project delivery. It also produces outcomes that are well-suited to address the root-problems communities face in this time of growing uncertainty and complexity.

The Envision framework, Integrated Design Process (IDP), and alternative project delivery are tools and methods that project teams can use to apply process-oriented solutions to create more resilient and sustainable infrastructure. They facilitate early involvement from specialists, contractors, and stakeholders to leverage opportunities, address challenges, and mitigate risks. Process-based approaches to sustainability and resilience can help project teams break the cycle of reactive project design and construction and contribute to a more effective project. Examples of this can be found across sectors and regions, including port and airport development, campus infrastructure renewal, flood management and resilience, and public transit.

Defining a Sustainability Path to Meet Short and Long-Term Goals

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Keywords: Evaluation, Goals, Metrics, Review, Sustainability

ABSTRACT

Sustainability and resiliency are a journey, rather than a destination. The practice is organic, evolving and changing. For organizations that have been incorporating sustainability for a long time, it can be challenging to update processes and for organizations that want to be more sustainable it can be intimidating to know where to start and how to implement a broad sustainability program across an organization.
Whether creating or enhancing processes, it is helpful for an organization to examine how a broad range of sustainability and resiliency factors are taken into consideration for projects and operational processes to determine where resources can best improve sustainability within the organization.

This presentation will provide examples of how we worked with two organizations to assess their sustainability approach, reveal gaps and opportunities, and define a path forward to meet their short and long-term sustainability and resiliency goals.
The goals of the presentation will be to describe a scalable processes for evaluating sustainability in projects and programs, illustrate how sustainability rating systems can be employed as a tool in programmatic sustainability evaluations, convey case studies that demonstrate analysis used to compile sustainability "best practices" that can be applied across an organization's projects and practices, and explain resulting actions used to integrate sustainability into organizational processes.

Tiered Quantitative Assessment of Life Cycle Sustainability and Resilience (TQUALICSR): Framework for Sustainable Design Assessment

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Keywords: Decision-making, Engineering Design, Environmental, Economic and Social Sustainability, Framework, Resilience, Sustainability

ABSTRACT

Considerable efforts have been made recently to incorporate sustainable practices into the design of engineering projects (e.g., civil infrastructure) with an aim to minimize the net negative environmental, economic, and social impacts of the project. There have been several tools developed to assess and compare the sustainability of potential design alternatives; however, most of the developed tools focus on assessing the environmental impacts, with minimal regards to the broader social and economic dimensions. Moreover, the increased occurrence of climate change-related events and impacts have challenged the function of engineered systems and their ability to achieve sustainable development, forcing policy makers and stakeholders to consider resilience in engineering designs and projects. Resilience and sustainability are inseparable, as an engineering system cannot be sustainable if it is not resilient. Nevertheless, few tools and frameworks integrate resilience and sustainability. In this study, a tiered quantitative assessment of life cycle sustainability and resilience (TQUALICSR) is proposed with the following key features: (1) a flexible, tier-based selection of tools to assess the environmental, economic, and social impacts of a project and its resilience; (2) integration of resilience and sustainability into an unified assessment framework ; (3) integration of interdependencies among the technical, environmental, social, economic, and resilience dimensions; and (4) applicability to various stages of an engineering project, from planning to decommissioning. The different steps involved in the framework, useful triple bottom line quantification tools, and application challenges are highlighted.

Incorporating Sustainability in an Undergraduate Environmental Engineering Curriculum

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Keywords: Environmental Engineering, ENVISION, SDG 17, Sustainability, Undergraduate Curriculum

ABSTRACT

In the past decade, sustainability has become a core element in civil engineering projects. This need has urged the civil and environmental engineering programs to introduce or increase sustainability components in their curricula. This study presents the effort of an environmental engineering program to incorporate sustainability in its curriculum. The Accreditation Board for Engineering and Technology (ABET) requires sustainability components to be addressed in the senior capstone design in an environmental engineering program.

This particular environmental program has been developed from a water resources management program by including non-water courses such as Solid and Hazardous Waste Management and Air Quality Engineering. The concept of sustainability is introduced in the course, Introduction to Environmental Engineering with the concepts of vertical and horizontal sustainability and SDG 17, and the introduction of ENVISION and LEED certifications. The core courses, Air Quality Engineering and Solid and Hazardous Waste Management, include sections that address sustainability and introduce them in modeling and practice. The course, Senior Capstone Project I, dedicates lectures on SDG 17 and ENVISION. The students are expected to analyze an environmental engineering project case study with their acquired knowledge on ENVISION.

In addition, the students are also encouraged to become members of ISI. Senior Capstone Project II mandates to include the brief ENVISION-based analysis of the students' senior design in their final report and project presentation.

Creating More Gender-Responsive Infrastructure: Major Opportunities Ahead

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Keywords: Equality, Gender, Gender-Blind Infrastructure, Sustainable Development, SDG5

ABSTRACT

Delivering sustainable infrastructure requires a holistic involvement of the stakeholders that will potentially benefit or be impacted by the projects. However, despite the growing interest in gender-inclusive infrastructure, historically this field has been biased towards men as women have been disproportionately left out of planning, design, and execution of infrastructure projects. Inevitably, women's gender-specific needs are unmet and an economic opportunity is seen as 3.2% of the world´s development GDP is unrealized. Actionable guidance is needed in this field as most of the existing literature on this topic focuses on recommendations for policymakers.

This study is aimed to address key questions such as: Why is infrastructure not gender-neutral? What are the main considerations to incorporate gender-responsive strategies through the project lifecycle? and What are the key tools to implement to quantify progress? This study incorporates specific information regarding the business case for gender-inclusive infrastructure. Selected case studies highlight good practices used in different parts of the world to scale up solutions in this area.

Track 5: Energy Resilience & Reliability

Moderated by Anthony Kane

Design of Interconnected Infrastructure Systems for Resilient and Sustainable Communities

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ABSTRACT

Resilient and sustainable infrastructures, including buildings, bridges, and lifeline systems, play a central role in the socio-economic development of our communities. Regardless of size and population number, communities rely on critical infrastructures to serve their basic needs during normal circumstances and in the aftermath of a natural disaster (e.g., earthquake, hurricane, tornado, flooding, fire). This work investigates the interconnection between infrastructures and their relation to community resilience. Case studies of critical interconnected infrastructures are first introduced. Then, the effects of the failure of a single infrastructure system on the whole infrastructure network and the community are discussed. Finally, design recommendations on how to holistically enhance the resiliency and sustainability of critical infrastructures are presented. Figure 1 shows a schematic representation of the topics covered in this work.

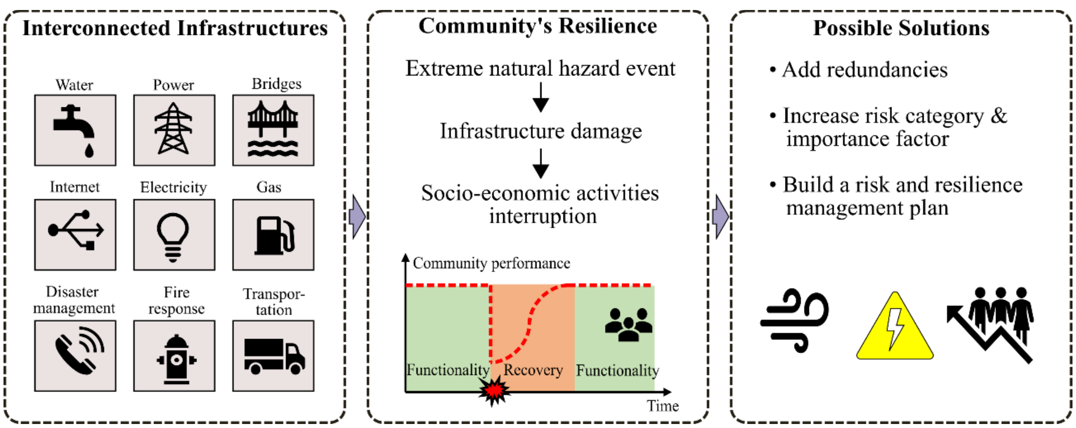

Figure 1. Representation of interconnected infrastructures, their relation to community recovery, and possible solutions to enhance the resilience of infrastructures and community as a whole

Civil infrastructure lifeline systems, such as power transmission, water pipes, natural gas lines, communication, and public transportation networks, *are traditionally designed as independent systems*. However, the failure of one of the infrastructure systems might generate service disruption in other infrastructures, impacting post-disaster management operations and interrupting daily activities in the whole community. For instance, natural gas pipelines can fracture during earthquakes due to fault ruptures, lateral spreading, and land sliding. The failure of natural gas pipelines could negatively impact power generation and the gas released from the pipelines can lead to post-earthquake fires. To extinguish fires, communities need water, a fire station facility, and enough electricity and power to pump the water. If an earthquake causes a failure in one of these infrastructures, it may affect managing the disaster at a community level. For example, the failure of power transmission lines may cause malfunction of water pumps necessary to extinguish fires and perform rescue operations. If the water pumping station provides potable water to a nearby hospital, water service would also be disrupted in the hospital. While the failure of the power transmission line is not directly disruptive to the fire station and hospital operations, the consequent loss of water service would be. It follows that to reduce recovery time of communities, *interconnections between various infrastructures should be considered in the design phase*, thus enhancing the community's resilience.

Community resilience can be defined as "the ability to prepare and plan for, absorb, recover from, and successfully adapt to adverse events" (National Research Council 2012). Because of the interconnections between infrastructures, the resilience of a community is related not only to the resilience of a single infrastructure but to the resilience of the whole system of critical infrastructures. It follows that a resilient community's design must be guided by understanding the interconnections and correlations among infrastructure systems. The current design and operation of infrastructure systems are compartmentalized, and the community tends to overlook such interdependencies, which in turn might create vulnerable infrastructure links, negatively affecting daily and post-disaster response operations. For example, during Hurricane Matthew (2016), water pumping stations in Lumberton, North Carolina, were flooded. Although the hospital in Lumberton was equipped with an emergency power generator, the operations in the hospital were disrupted by the unavailability of potable water. During Hurricane Sandy (2012), damage to the transportation infrastructure resulted in tanker trucks not being able to supply gasoline and diesel fuels to service stations. Although the service stations were not physically damaged by the hurricane, their service to the community was interrupted in the aftermath of the disaster by a breakdown in the transportation network. Another example of the interconnection between infrastructures is emergency management during seismic hazard events. Most utility companies in California use ShakeMap to determine the area of concern in order to perform detailed post-earthquake inspections. To use ShakeMap applications, employees of utility companies need access to the internet and electricity. Any damage to the internet and electricity infrastructures would cause delays in access to ShakeMap, and therefore hinder the initiation of proper seismic emergency operations, affecting the recovery time of a community.

These examples show how the performance of the social infrastructure (e.g., health care, gas stations, post-disaster management) is connected to the performance of critical civil infrastructure systems (e.g., power transmission lines, transportation networks, gas lines), and how the failure of one or more components of the infrastructure system can provoke undesired cascading effects on community recovery. It is therefore paramount to consider interdependencies between different infrastructure systems, including civil and social infrastructures. Such interconnections need to be accounted for in the planning and design phase by adding redundancies or enhanced performance with critical components, thus making the whole infrastructure system more robust to prevent possible cascading failures.

Redundancies can be valuable during an extreme natural hazard event. For example, during Hurricane Harvey, a significant number of electrical transmission lines failed, and the Houston area experienced a large blackout. However, natural gas lines performed relatively well, with minor disruptions. Communities were, therefore, able to maintain minimal functionality in the aftermath of the hurricane. If the whole city were to have become more dependent on electricity in order to reduce its carbon footprint, the consequences of hurricane Harvey might have been more severe. This example shows the importance of having redundancy and having different sources of energy, as an advantage to communities vulnerable to natural disasters.

Another solution to achieve the goal of resilient infrastructure could be to add a *new risk category tailored for critical infrastructures, their functions, and the services they provide*. Typically, structural engineers use ASCE 7-16 (ASCE 2017) to determine the risk category and associated importance factors for buildings and other structures. Applying a higher risk category and importance factors to the design of the most critical infrastructures could reduce the damage to lifeline systems and their consequences on the interconnected networks. For example, a water facility or transmission line supporting a fire station could be designed as a Risk Category V and associated importance factor of 1.5.

A *Risk and Resilience Management Plan* (RRMP) that includes the linkages between critical infrastructure systems could be an essential tool for managing the risk on individual projects and systems. A standard RRMP identifies a list of hazards and threats to the function of the infrastructure system for its lifetime. This requires looking forward and accounting for the effects of climate change. The RRMP is a living document to be updated through the operational life of the system. Critical assets of the facility/system are identified and evaluated along with the full facility. An owner or operator may know some or all the hazards/threats to the facility. It is recommended that an authority/city/region considers minimum hazards/threats that shall be addressed during the preliminary design phase (e.g., hurricane, earthquake events). Then, the design team needs to develop a risk assessment of the critical assets of the facilities and identify the interdependency on other infrastructure systems, such as the electrical grid for power. The risk assessment needs to consider the functional and design lifespan of the critical linkages. The design team should also address management, mitigation, and avoidance of disruption of service. For example, some natural hazard events can be accounted for in the design load cases used for designing the facility. Other events will be managed during operation with mitigation strategies, such as deployable flood protection. Some events could be avoided by adding redundancy to the system, such as an electric generator for emergency backup power. All this information must be contained in the RRMP.

Advancing equity, social justice, and the development of disadvantaged communities are among the main goals of *sustainable design*. Community leaders should develop *resiliency management plans* to address all aspects of infrastructures, such as livability, social injustice, climate change, and natural hazard resiliency. The interconnections between critical infrastructures should be considered in such plans, with the goal of maintaining communities' basic needs during normal circumstances and in the aftermath of a natural disaster.

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Inspection Planning for Transmission Line Systems Exposed to Hurricanes using Reinforcement Learning

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ABSTRACT

Recent hurricanes and extreme weather conditions and their impacts on aging power transmission infrastructures, particularly transmission line systems (TLSs), have magnified the growing need for optimal risk management policies for the grid infrastructure. Decisions based on optimal policies improve the sustainability and resilience of electrical power systems against gradual deteriorations as well as hurricane events. In real-world infrastructure systems, these decisions are often made based on limited information or unreliable observations of systems' conditions. To enhance the quality of information in the decision-making process, operators need to perform inspection and obtain reliable information about the state of systems prior to deciding maintenance actions. However, the costs and resources associated with inspection and monitoring limit the number of these actions. In this study, to address the conundrum of planning optimal inspection and monitoring policies for TLSs under uncertainty, a reinforcement learning (RL) framework is developed. In this RL framework, the optimal inspection policy is achieved through minimizing the incurred costs due to operation, maintenance, and inspection. Furthermore, this framework accounts for the quality of information obtained through inspection actions. High-fidelity models of TLSs are used for performance evaluation of these systems against hurricanes. The performance of the RL framework in achieving an optimal inspection policy for a TLS exposed to hurricane events is illustrated and compared to the performance of expert-based policies in allocation of resources. The results of this analysis assist stakeholders in inspection planning and management of TLSs.

Feasibility of Pumped Hydroelectric Storage Within Existing United States Army Corps of Engineers' Facilities: A Methodological Approach

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Keywords: Duck Curve, Energy Storage, Hydropower, Pumped Storage, Reliability, Renewable Energy, United States Army Corps of Engineers

ABSTRACT

Variable, renewable energy (VRE) generation such as wind and solar power has seen a rapid increase in usage over the past decades. These power generation sources offer benefits due to their low marginal costs and reduced emissions. However, VRE assets are not dispatchable due to their variable nature, which can result in a mismatch of the supply and demand curves for electricity. Pumped-storage hydropower (PSH) seeks to solve this by pumping water uphill during times of excess energy production and releasing the water back downhill through turbines during energy shortages, thus serving as a rechargeable battery. Creating new PSH systems, however, requires a large amount of capital in addition to the challenge of finding suitable locations. The United States Army Corps of Engineers (USACE) is the largest producer of hydroelectric power within the United States, and as such, may have favorable sites for the addition of PSH. This study seeks to develop a method for evaluating these existing hydroelectric facilities using techno-economic methods to assess the potential for adding PSH. Each USACE facility was evaluated based on available head, flow rates, and reservoir size from previously unpublished data to estimate the power generation and energy storage potential. The temporal nature of local wholesale electricity prices was accounted for in the method to help estimate the financial feasibility of varying locations. Sensitivity analysis was performed on select installations to highlight how the method would identify the viability of facilities with different operational conditions. The methodologies detailed in this study will inform decision-making processes, toward enabling a sustainable electric grid.

Grid-Interactive Efficient Buildings: Leveraging the Federal Building Stock to Support the Future Grid – A Case Study from Central Islip, New York

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Keywords: Alternative Energy, Demand Response, Grid-Interactive Efficient Building, Metering, Sustainable Infrastructure

ABSTRACT

The General Services Administration (GSA) owns and maintains the largest portfolio of facilities in the United States. This infrastructure stock requires significant resources to operate, including ample, reliable access to electricity, natural gas, and water. The Department of Civil and Mechanical Engineering at the United States Military Academy has partnered with the GSA to study the opportunity to better integrate building assets with local energy infrastructure. The project is part of the GSA's Grid-Interactive Efficient Buildings (GEB) program and is focused on the Central Islip Federal Courthouse complex. Using a case-study approach, the project explores the capability for the courthouse to improve how energy is produced and consumed with the goals of reducing operating expenses, improving environmental impacts, and integrating more intelligently with the local grid. A technoeconomic model was built and a sensitivity analysis completed to consider the tradeoffs of conceptual design alternatives, including solar photovoltaics and energy storage. The solutions presented are placed in context with the broader literature on GEB, providing an overview of the most promising opportunities for buildings to become critical assets to support the future of energy infrastructure. The findings of the project show that a carport style photovoltaic array in an existing parking lot at the courthouse has an estimated payback period of 19 years, while the best ground mounted array has a payback of eight years, albeit a lower generation capacity compared with the larger carport array.

Thermal Energy Corporation: Real Life Benefits of Microgrids

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Keywords: Energy, Harvey, Infrastructure, Microgrid, Reliability, Uri

ABSTRACT

This study focuses on the planning, development, proven results and best practices garnered throughout the execution of Thermal Energy Corporation (TECO)'s Master Plan Implementation Project, an expansion rooted in the concepts of sustainability and resiliency.

The $377 million project was designed to meet the growing cooling and heating needs of the rapidly expanding Texas Medical Center, the world's largest medical city. The expansion made TECO's district cooling system the largest in the U.S., doubling its operating efficiency while reducing carbon dioxide (CO_2) emissions by 302,000 tons annually compared to previous operations. The CO_2 reduction is equivalent to taking 52,000 vehicles off the road or planting 72,000 acres of new trees.

Moreover, this project installed systems and equipment to better prepare TECO to be able to continuously provide thermal services for heating and cooling to the Texas Medical Center even through tropical storms and hurricanes that frequent the region. These upgrades proved effective during all of the various weather events that occurred after the project, including the most significant flood event on record in the United States, Hurricane Harvey and the recent winter storm, Uri.

When Hurricane Harvey hit Houston in 2017, the region faced record-setting rains and widespread flooding, severely impacting the community and putting those upgrades to the test. In spite of the 62+ inches of rain that inundated the city during the multi-day storm, TECO's steam and chilled water services remained uninterrupted, even as energy needs skyrocketed for those requiring medical care in a time of widespread community power outages and heavy flooding.