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INFRASTRUCTURE PLANNING USING A DYNAMIC SIMULATION TO IMPROVE SUSTAINABILITY AND RESILIENCE: CASE STUDY FOR A COASTAL WATERSHED

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ABSTRACT

Climate change presents a significant challenge for many coastal communities as sea level rise is expected to cause widespread and chronic flood inundation. This study examines the case of a coastal watershed of ecological importance, which is threatened by sea level rise and land subsidence, as well as seasonal severe storms. The health of the watershed and flood inundation protection to the community depends on water outflow; something which sea level rise will further restrict. Infrastructure planning for an active water management solution resilient to severe storms and electrical grid disruptions is needed. A dynamic simulation is used to evaluate microgrid energy system design performance and effectiveness in powering a critical infrastructure pumping station during storm related electrical grid outage and restoration scenarios.

1 INTRODUCTION

Coastal communities in the United States, and globally, are confronting the reality that climate change will cause sea levels to rise and flood inundation risk to increase. To make matters worse, many of these same coastal communities are experiencing the additive effect of land subsidence. Along the coastal inner banks region of North Carolina, the Albemarle-Pamlico Peninsula, comprised of Dare, Hyde, and Tyrrell counties, is one of the most threatened regions in the United States in terms of potential landmass loss because of sea level rise and land subsidence. Rising sea levels in Hyde County pose a direct threat to the Lake Mattamuskeet watershed, which contains the state's largest freshwater lake. The lake is a 40,000-acre, shallow coastal lake, with a water depth ranging from 0.5 to 4 feet and a bottom that is below sea level. The watershed depends upon passive water outflow through four canals to the adjacent Pamlico Sound. Tide gate water control structures on each canal to prevent the backflow of salt water from entering the lake.

High water levels caused by seasonal precipitation in late winter and severe storms during hurricane season pose an increased risk of flood inundation to the community. Sea level rise affecting the Pamlico Sound is projected to further restrict outflow; the resulting higher water levels will cause a further decline in overall water quality and increase the risk of flood inundation. Active water management by pumping water is an expensive proposition, and the capacity needed to provide adequate protection is uncertain. Infrastructure planning considered in this study consists of a solar-powered microgrid energy system with localized battery storage and an electric grid connection to power a pumping station. The solar-powered microgrid energy system will provide power to the pumping station during periods where the electrical grid suffers disruption because of severe storms, such as hurricanes and tropical storms that frequent the coast of North Carolina. Electrical grid restoration following a severe storm can take many days to several weeks in this rural coastal region. During these events, the immediate evacuation of flood water, facilitated through pumping, is critically necessary for emergency response and community recovery. Dynamic simulation is used to evaluate the microgrid energy system design and pump configuration performance and effectiveness under varied electrical grid outage and restoration scenarios.

2 MATERIALS AND METHODS

The method used to evaluate trade-offs in the microgrid energy system's component size, capacity, and configuration includes the following steps: (1) determine pumping demand profiles based on storm-related impacts and electrical disruption; (2) configure microgrid energy system capacity based on expected power load demand, demand duration and grid outage, and seasonal solar exposure; and (3) conduct dynamic simulation experiments using the hydrologic process model developed for the Lake Mattamuskeet watershed to evaluate the performance. Figure 2 illustrates the relationship between these steps, the corresponding inputs, resulting performance, and cost. The National Renewable Energy Laboratory's (NREL) System Model Advisor (SAM) was used to develop the microgrid system designs. The watershed hydrologic process model is a dynamic simulation constructed using STELLA Architect. A retrospective approach is used to examine how varied microgrid powered pumping configurations would have performed.

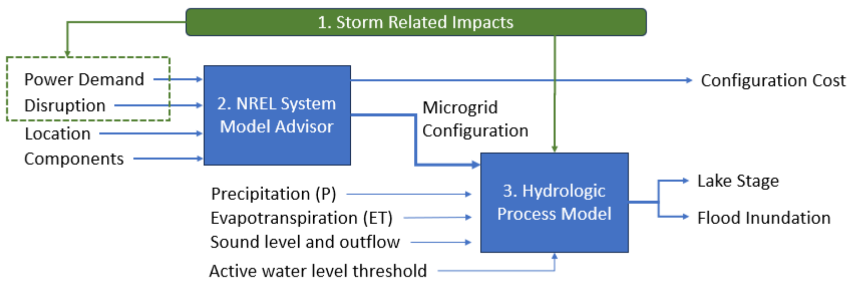

Figure 1: Methodology to evaluate trade-offs in microgrid system design and flood inundation risk.

3 RESULTS AND DISCUSSION

Model results show that a microgrid energy system design can satisfy the load demand for evacuation pumping where short disruptions (5-10 days) to the electric grid are experienced, which are characteristic of moderate storms such as a category 1 hurricane. Figure 2 illustrates the retrospective period (2015-2021) for lake stage water level under passive and active water management schemes relative to the flood stage. During this period, several named storms, hurricanes and tropical storms, passed through the region.

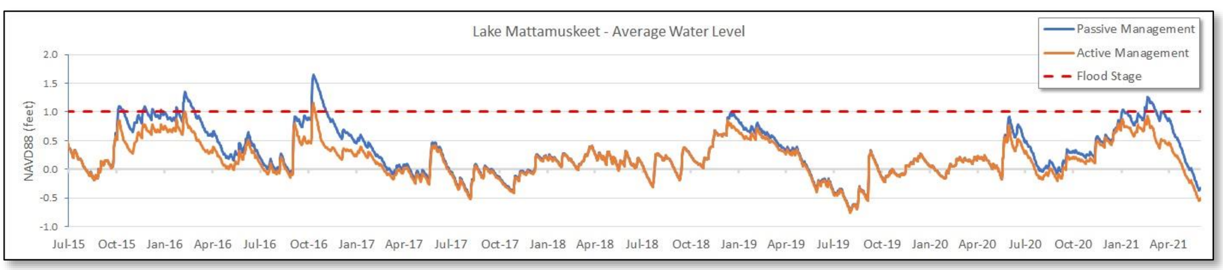

Figure 2: Average water level (NAVD88 feet) for active management versus passive water management.

More severe storms, however, require additional pumping capacity to manage the water levels and for extended durations of grid disruption (>15 days). Microgrid energy system capacity needed to responsively meet these demand profiles is prohibitively expensive. Expected sea level rise further exacerbates the situation. The study revealed that efforts to actively manage water levels toward seasonal water level targets through ongoing pumping, rather than being reactive to high water, may be the best approach to reduce infrastructure capacity requirements and protect against flood inundation risk. A future study is planned to examine if seasonal water level targets could be established given the balance of lake use and biodiversity requirements. Enhancements are planned for the hydrologic process model to incorporate stochastic behavior for environmental factors to reflect climate changes affecting precipitation frequency and intensity. The study shows an effective use of dynamic simulation to evaluate infrastructure capacity planning and design for a watershed subject to the uncertainties of severe storms and sea level rise.