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A HYDROLOGIC PROCESS MODEL FOR WATERSHED SUSTAINABILITY: A SYSTEM DYNAMICS APPROACH

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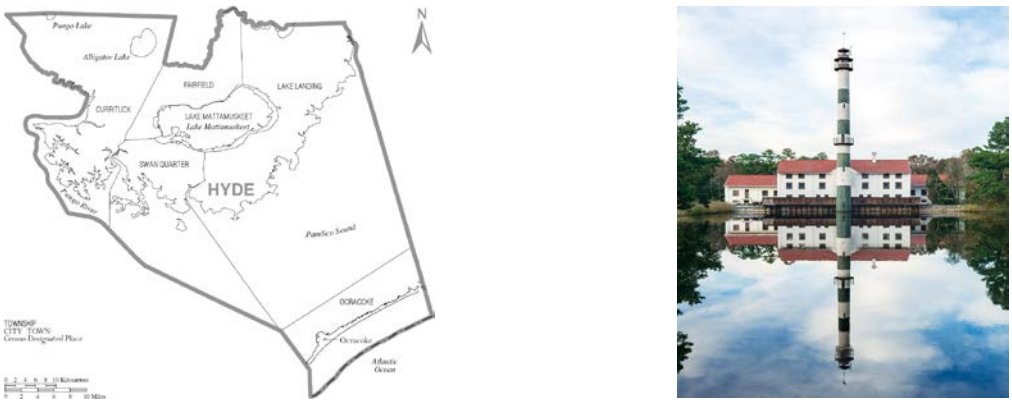
ABSTRACT

Lake Mattamuskeet is a coastal watershed located in eastern North Carolina that contributes to the economic, social, agricultural, environmental, and natural wildlife of the region. Declining water quality issues, chronic inundation events, significant water fluctuation, poor flushing, and sea-level rise threaten this resource. Community stakeholders have suggested numerous proposals to restore the watershed; however, due to the complexities involved with this human-modified natural system, estimating the benefits of these proposals, which are very expensive, can be challenging. Supporting the restoration effort, a hydrologic process model for the watershed using a water budget was constructed using a system dynamics approach. This presentation examines the stakeholder favored solution of dredging the outflow canals aimed at increasing flow rate. The impact of sea-level rise is also considered. The hydrologic process model provides a valuable resource to discuss solutions and tradeoffs with a diverse stakeholder group.

1 INTRODUCTION

This study attempts to provide insight in addressing a compromised watershed in eastern North Carolina located in Hyde County, as shown in Figure 1(a). Lake Mattamuskeet, the state's largest natural fresh-water lake, is a shallow coastal lake, averaging only 2 to 3 feet in water depth with a bottom below sea level. The land surrounding the lake is well known for its productive, fertile soil, which is highly coveted for agricultural activities. In the early 1900s three private investment companies partnered to build the world's largest capacity pumping plant, pictured in Figure 1(b), and dredge 130 miles of navigable canals to drain the lake and increase the agricultural acreage. Efforts to drain the lake failed, and the partnership went bankrupt. Eventually, the federal government acquired the lake and created the Mattamuskeet National Wildlife Refuge (NWR) which provides a habitat for migratory waterfowl utilizing the Atlantic Flyway. The lake contributes significantly to the rural prosperity of the region in numerous ways ranging from the tourism attracting hunters, anglers and birdwatchers to the farming of the surrounding acreage.

More recently, Lake Mattamuskeet has experienced a significant decline in water quality and the disappearance of the submerged aquatic vegetation (SAV), a primary food source for the migratory waterfowl. Additionally, the lake has experienced dramatic water level fluctuations making conditions unattractive for anglers. Furthermore, due to the near sea-level elevation, the region frequently suffers from severe storm driven inundation. Anticipated sea-level rise is expected to contribute to increased inundation in the region within the next decade as a result of stronger storm events. These issues led to the development of a proposed watershed restoration plan for identifying various practical management options to help address water quality and inundation issues. This modeling work supports the restoration plan by creating a hydrologic process model using a system dynamics approach to examine the watershed water level (lake stage), management control options, and future sea-level rise impact.



(a) (b)

Figure 1: (a) Map of Hyde County, North Carolina, USA, and (b) the Lake Mattamuskeet pump station

2 MATERIALS AND METHODS

A hydrologic process model has been developed to better understand the water volumetric fluctuations, which contribute to community flooding and water quality issues, and to improve the decision and analysis process for the restoration plan. The model incorporates the shallow underwater topography, seasonal water movements to and from waterfowl impoundments, interactions with adjacent agricultural regions, and hydraulic features that connect a vast network of outflow canals with modulating tide gates leading to the Pamlico Sound. Stella Architect from isee systems was used to construct the stock and flow representation for all water movements. Five years of daily environmental data was used to calibrate and validate model water level predictions, as illustrated in Figure 2. Calibration was performed, using a sum-of-squares error (SSE) approach, by comparing the model predicted versus actual lake stage for the first 2.5 years of data.

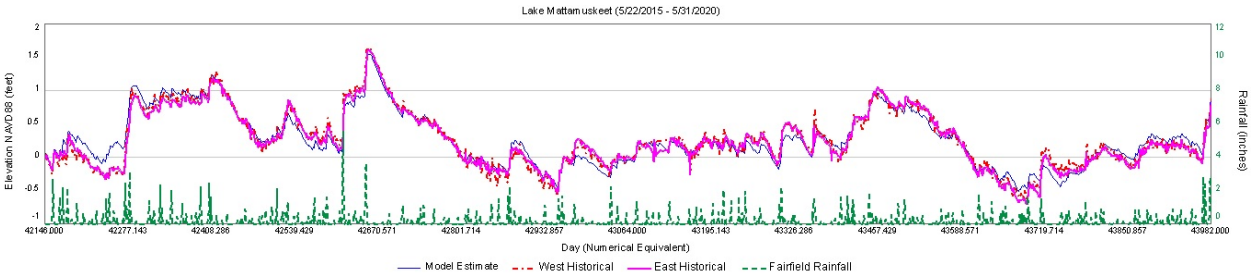


Figure 2: Calibrated model for Lake Mattamuskeet estimating stage level (5/2015 to 5/2020)

3 RESULTS AND DISCUSSION

The calibrated model provides an accurate prediction for the watershed water level utilizing precipitation, evaporation, evapotranspiration, sound stage water level data. The stakeholder favored solution of improving the canal infrastructure through dredging was examined. Simulation results demonstrate improvements would substantially increase outflow from the lake to the Pamlico Sound; however, these benefits would be marginal gains due to the limitations of the passive tidal gate infrastructure. As the Pamlico Sound stage level increases with sea-level rise the canal outflow will become less significant. Resulting flood inundation can be expected to worsen. The majority of all water leaving the watershed will occur through evaporation and evapotranspiration processes. Further study demonstrates the need for some type of water pumping infrastructure, which can be regulated, to stabilize the watershed water level. The model provides a useful resource for discussing with stakeholders potential solutions and tradeoffs in a very challenged region with a complex human-modified natural system.