HUDSON RIVER PHYSICAL FORCES ANALYSIS: DATA SOURCES AND METHODS

Prepared for:

The Hudson River Sustainable Shorelines Project

NYSDEC HRNERR

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About the Hudson River Sustainable Shorelines Project

The Hudson River Sustainable Shorelines Project is a multi-year effort led by the New York State Department of Environmental Conservation Hudson River National Estuarine Research Reserve, in cooperation with the Greenway Conservancy for the Hudson River Valley. Partners in the Project include Cary Institute of Ecosystem Studies, NYSDEC Hudson River Estuary Program and Stevens Institute of Technology. The Project is facilitated by The Consensus Building Institute. The Project fulfills aspects of Goal 2 of the Action Agenda of the Hudson River Estuary Program. The Project is supported by the National Estuarine Research Reserve System Science Collaborative, a partnership of the National Oceanic and Atmospheric Administration and the University of New Hampshire. The Science Collaborative puts Reserve-based science to work for coastal communities coping with the impacts of land use change, pollution, and habitat degradation in the context of a changing climate.

Disclaimer

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EXECUTIVE SUMMARY

This document describes the physical forces analyses undertaken by Steven Institute of Technology as a part of the Hudson River Sustainable Shorelines Project. The overall objective of the physical forces work was to provide a more complete description, and hence understanding of the physical forces experienced by shorelines within the Hudson River Estuary. It is hoped that this information will be used to help identify priority areas where ecologically enhanced shoreline stabilization projects might represent a viable alternative to traditionally designed, hard engineering options. Due to differences in the availability of data and our ability to model the physical processes involved, two different approaches were used to quantify the physical forces. An extensively calibrated and validated three-dimensional circulation model of the Hudson River Estuary was used to develop a one year climatology of relevant hydrodynamic parameters such as wind waves, water levels, and currents. Observational data on wakes and ice were used to complete the physical forces data set. The ice data set consists of a statistical summary of ice records collected by the U.S. Coast Guard over a ten year period. The wake data were collected specifically for this project, and consist of measurements made at 32 sites along the Hudson. The model derived hydrodynamic data and ice data are available as GIS layers on the NY State GIS clearinghouse (https://gis.ny.gov/), while the wake data is available as a report on the Sustainable Shorelines Project website (https://www.hrnerr.org/hudson-river-sustainable-shorelines/).

INTRODUCTION

An analysis of the physical forces impacting the shorelines of the Hudson River Estuary was completed by Stevens Institute of Technology as a part of the ongoing Hudson River Sustainable Shorelines Project, led by the NYSDEC Hudson River National Estuarine Research Reserve. The Sustainable Shorelines Project works to generate and make available science-based information about the best shoreline management options for preserving important natural functions in the Hudson River Estuary's shore zone. The physical forces analysis was undertaken to provide critical but often lacking information about several of the parameters required for the proper design of ecologically enhanced shoreline stabilization projects. In particular, the physical forces analyses that were undertaken focus on wind waves, vessel wakes, currents and ice. A brief discussion of the importance of each of these forces as well as the methods used to derive information about them is presented in this report. The actual data regarding the physical forces is presented at: https://www.hrnerr.org/geospatial/. An example application of the data is discussed in Pierson et al. (2015, in review), which is included as an Appendix.

HUDSON RIVER ENVIRONMENTAL FORCES

Wind generated waves, vessel wakes, currents and ice conditions comprise the predominant environmental forces impacting shorelines and waterfront structures along the Hudson River. These forces can cause scouring and erosion of shorelines and damage to structures, and must be accounted for when designing shoreline stabilization and environmental restoration projects. This section provides a brief description of these forces and the conditions driving them.

Wind Generated Wave Forces

Wind generated waves are formed when wind blowing over a stretch of open water, called the fetch, transfers a portion of its energy to the water. The height and period of the created wave is dependent on the duration and intensity of the wind (wind speed) and the length of the fetch. In shallow water, the surface wind waves feel the influence of the bottom and are modified as they come ashore. When the wind waves approach the shoreline, they impart a force or loading on the shoreline and/or any structure they encounter. Total wave forces include both the hydrostatic force (weight) of the water column and the hydrodynamic force (pressure) of the wave itself. The magnitude of the wave forces primarily depends on the wave height, wave length, and whether or not the wave is broken or unbroken. Non-breaking wave forces differ from breaking wave forces in that they do not generate the impulse force that is released during the wave breaking (Photo 1).

Photo 1. Wave breaking and overtopping a bulkhead in Irvington, NY (John Stark, 2012).

Vessel-generated Wave Forces (Wakes)

The movement of a vessel through a water body generates a displacement of water. This displaced water propagates away from the sailing line of the vessel in the form of vessel generated waves which are referred to as the vessel's wake. Wake generation is dependent upon the vessel geometry (length and draft), operating characteristics (e.g., displacement, vessel speed, planing and transition) and water depth. Vessel wakes can be separated into two components: a long period drawdown wave generated by the displacement of water around the hull of the vessel, and short period diverging and transverse waves (secondary waves) generated by the motion of the vessel through the water (Figure 1, Herrington et al. 2009). Drawdown waves, with their higher wave heights and longer wave lengths propagate towards the shore and interact with the shoreline similar to the way a fast moving tide would (see *Forces Due to Currents*, next paragraph). The smaller and shorter secondary waves (Photo 2) propagate toward the shoreline similarly to the way in which surface wind-waves do (see *Wind Generated Wave Forces*, above). The relative importance of vessel wakes is magnified in some reaches of the Upper Hudson where the river is narrow, the wind-waves are smaller, and the navigational channels tend to be closer to shore.

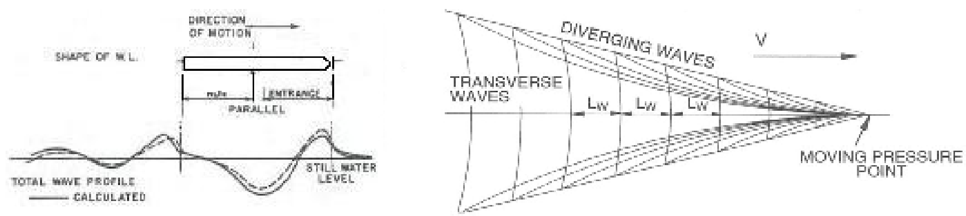


Figure 1. Left: Cross-sectional view of drawdown of water surface along vessel hull creating a long period wake.
Right: Plan view of propagation pattern of diverging and transverse wakes (Herrington et al. 2009).

Photo 2. Secondary wakes near Poughkeepsie, NY (Mike Caldwell, 2012).

Forces Due to Currents

The currents in the Hudson River Estuary are generated by a complex combination of winds, tributary inflows, and other meteorological and hydrological forces that act to push water from one location to another (Photo 3). The magnitude of the currents is strongly dependent on water depth, and is affected by friction both at the river bottom and at the surface during periods of ice cover (Georgas 2012). Currents create a force or loading on submerged portions of the shoreline, structures, and vegetation, the magnitude of which is dependent on the current speed (momentum) and the submerged cross-sectional area of the "body" encountered. The shape of the object encountered also has an effect, as smooth curved surfaces have lower drag coefficients and thus experience less current force. In general, the current velocity and thus force on "bodies" located within coves is reduced, making coves favorable sites for the application of ecologically enhanced shoreline stabilization techniques.

Photo 3. Tidal currents impose horizontal forces on an East River buoy (J. Apicella, 2012).

Ice Forces

Ice can generate several types of loads on a structure. Usually, the most critical type of dynamic force imposed by ice is the horizontal load on vertical and sloping structures. The magnitude of these loads depends on the point at which the ice fails by crushing or splitting, which is dependent upon ice thickness (USACE, 2011). This type of loading is exacerbated on vertical structures such as walls, because the vertical face and height of the wall prevent ice from overtopping the structure before breaking apart. The force imposed by ice riding up and over sloping structures, such as revetments is much less than the direct horizontal loading on the face of the revetment. Vertical ice forces include the weight of ice piling up on a structure and the cyclic stresses of the freeze and thaw cycles. These forces tend to be smaller and have minimal impact on established vegetated shorelines. Adfreeze loads are pressure forces applied to a structure that has become encased in ice. Ice jams (when ice passage in a river section is blocked and the ice piles up upstream) are an important consideration for in-stream structures in the Hudson River. The USACE ice jam database contains records of historical ice jams in the Hudson River watershed in 2007 and 1996 at Catskill, NY and Troy, NY, respectively.

METHODOLOGY

Two fundamental approaches were used to characterize the physical forces within the Hudson River Estuary. Wind waves and currents were characterized with the help of an ultra-high resolution, hydrodynamic model of the estuary. The model was used to hindcast the conditions during a typical year (2010) and to develop a statistical climatology of the forces based on that one-year simulation. Ice and wakes were characterized using physical observations. Ice data was collected from a publicly available data source, while wakes were measured during the course of the present work.

Wave and Current Modeling

Wind waves and currents were characterized on the basis of a numerical hindcast of a typical year, performed using the New York Harbor Observing and Prediction System (NYHOPS, Bruno et al 2006). This fully calibrated and validated hydrodynamic model utilizes a network of sensors installed and operated by Stevens Institute of Technology, and external data acquisition from databases and federal agency forecasts, to create input forcing to a three-dimensional hydrodynamic operational forecast model. External data sources include the National Ocean Service (NOS), the United States Geological Survey (USGS), the Hudson River Environmental Conditions Observing System (HRECOS), and other agencies and universities with whom Stevens has data sharing agreements. A high-resolution curvilinear model grid is used to encompass the entire Hudson-Raritan (New York/New Jersey Harbor) Estuary, the Long Island Sound, and the New Jersey and Long Island coastal ocean. The operational version of NYHOPS is initiated at 0 hr local every day, and completes a 24-hour hindcast cycle based on observed forcing, followed by a 48-hour forecast cycle based on forecast forcing. The output from NYHOPS includes forecasts of water level, 3D circulation fields, and waves.

For this project, an ultra-high resolution version of the NYHOPS model was developed (Georgas 2012), to provide information at the scale required for siting and designing ecologically enhanced shoreline projects. The ultra-high resolution version of NYHOPS contains over 58,000 grid cells in the study area. A hindcast was run for a typical year (2010) such that a representative statistical distribution of the hydrodynamics could be developed. After the numerical model runs were completed, the model results were statistically analyzed and geo-referenced to provide a gridded physical forces climatology consisting of:

- the spatial and temporal variation of total water levels (tides+surge),
- currents,
- vertical current shear,
- mixing, and
- wind waves.

Relevant statistical quantities such as the mean, median standard deviation, 75th, 95th, and 99th percentiles of the various parameters were extracted from the fit distributions. The resulting data was extracted to a GIS layer which is accessible from the NY State GIS clearinghouse website (https://gis.ny.gov/).

Wake Measurements

Wakes are difficult to model due to their dependence not only on the river and vessel geometry, but also on the operational characteristics of the vessel (speed, distance from shore, etc.). The existing data on wakes in the Hudson is sparse; therefore the decision was made to collect measurements specifically for this project. The primary objective of the wake study was to document vessel traffic and the resulting wakes along the Hudson River. The wake study took place over the course of 4 days in 2012 (June 26-28/ July 19) and 3 days in 2013 (June 28-29/July 1). Thirty-two observation sites were chosen from the *Hudson River Estuary Public Fishing and Boating Access Guide* (http://www.dec.ny.gov/lands/41728.html), at approximately equal intervals within the study area between the Tappan-Zee Bridge and the federal dam at Troy. Sites were selected on both the east and west bank of the river. At each site, four primary data parameters were collected, including wake height, vessel type, vessel speed and vessel size. Additional data recorded included the time of boat passage, the direction of travel, the approximate distance of the boat from the shoreline, the wake period, and the weather conditions at the site, including a characterization of the wind waves. The number of wakes recorded at each site during the two year study ranged from a minimum of three at Coxsackie, NY, to fifty-nine in Highland

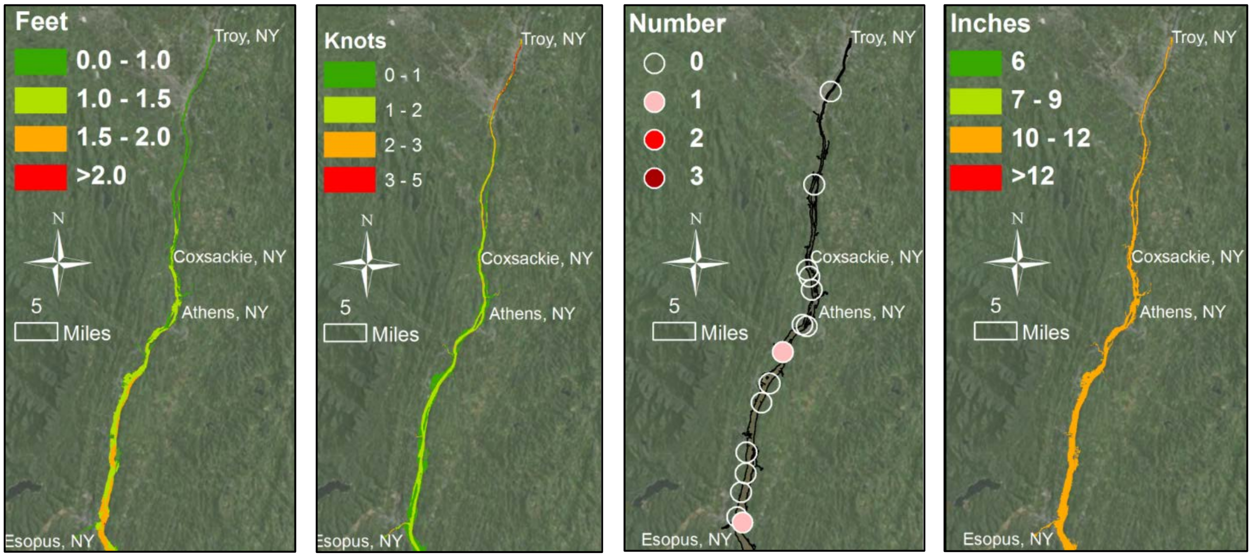
Falls, NY. The average number of observations at each site was twenty-five, while the maximum number of boats recorded on a single day was forty-five at the Chelsea Yacht Club, in Wappinger, NY. The size of the recorded wakes ranged from a minimum of zero inches (observed at several sites), to as high as forty-two inches at Kingston, NY. Overall, the average recorded wake was 4.2 inches. Full details of the wake study can be found in Rella et al. (2014).

Ice Data Compilation

In spite of the fact that ice is known to generate forces capable of causing extensive damage and bank erosion, quantitative ice data is typically very sparse. In the Upper Hudson, quasi-quantitative ice data is collected daily by the US Coast Guard (USCG). USCG Sector NY is responsible for keeping the Hudson River navigational channels open to commercial traffic during the official ice breaking season between 15 December and 31 March each year. During this period, and for at least the past ten years (LCDR Ed Munoz, personal comm.), daily ice reports have been generated by officers onboard the "140-ft" ice breakers and ice breaking tugs that service the Hudson. These reports include a classification of the type of ice, visually-observed ice thickness, and approximate extent of ice cover within the navigational channel. As a part of the physical forces analysis, the daily ice reports for the last ten years were obtained from the USCG and digitized. Statistical distributions were fit to the data and used to populate a GIS database containing information on ice type, percent navigational channel area covered, and mean ice thickness (mean of the noted thickness range). Time series of daily mean statistics were summarized as an area-weighted average for the regions of the river north of West Point. These statistics provide semi-quantitative insight on winter ice cover conditions in the Hudson.

RESULTS

The results of the physical forces analyses, which consists of GIS data layers containing wave, current, and ice information, and a report summarizing the wake data are available on the Hudson River Sustainable Shorelines website (https://www.hrnerr.org/hudson-river-sustainable-shorelines/). Examples of the result are shown below in Figures 2a-d, where the data displayed is a subset of the information available online. An example application of the data is discussed in Pierson et al. (2015, in review), which is included as an Appendix.



(a) (b) (c) (d)

Figure 2: (a) Maximum wave heights in 2010; (b) Maximum current speed in 2010; (c) Observed number of wakes greater than 18.5 inches; (d) Daily ice thickness exceeded 5% of the time during the ice season, based on daily USCG observations over the 2005-2012 ice seasons (December-March) (Georgas et al. 2013).

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