IJC Information Note: Storm Surge and Wave Application in FEPS for Lake Ontario Water Level Analysis

The Flood and Erosion Prediction Tool (FEPS) used within the Lake Ontario – St. Lawrence River (LOSLR) water level regulation plan analysis incorporates storm surge and wave conditions in various ways. This document briefly outlines how storm surge and wave conditions are incorporated within the model, first with a basic overview, and then using more detailed information applicable to the overall FEPS modelling. Unique features of the incorporation of storm surge and waves for the three main impact areas of flooding, erosion, shore protection will then be discussed.

Overview

The FEPS model estimates water level impacts related to flooding of buildings, erosion of developed properties that are not protected, and shore protection replacement costs for land parcels that are already protected (e.g. buildings, infrastructure and coastal roads). The importance of waves and storm surge were recognized throughout the model development. Detailed wave hindcast modelling of historical wave conditions was undertaken early in the study for the temporal period 1961 to 2000 (Baird, 2003). These hourly wave conditions generated with the model still represent the best available wave data for Lake Ontario and are available for download from the USACE web site (http://wis.usace.army.mil/WIS_Documentation.shtml). These wave data were incorporated into the FEPS database. Storm surge values were also included in the database. In the flooding analysis, a storm surge component is added to the quarter-monthly water level based on the modelled wave conditions. The wave data is also used to estimate direct wave impacts on the buildings along the shoreline. For shore protection, the wave data is used to estimate downcutting at the toe of the structure and wave and storm surge data are required to determine potential overtopping damages. Finally, in the erosion portion of the model, time series of wave energy are fundamental to estimating future recession rates for alternative regulation plans.

General Background – Common for All Three Impact Areas

The FEPS database contains a series of quarter-month wave height, period and direction sequences representing offshore wave conditions at various locations around the Lake Ontario shoreline. The wave locations are provided in Figure 1. Within the FEPS database, each 1 km shoreline reach is associated with a particular wave location. Average and maximum significant wave height time series are provided by quarter-month, for waves that were propagating in an onshore direction. As discussed above, the wave sequences were developed through hindcasting procedures documented in *Lake Ontario WAVAD Hindcast for IJC Study* (Baird, 2003) for the period 1961 to 2000. The 40 year wave sequences were then extended to create 101 year wave sequences by randomly selecting actual yearly data from 1961 to 2000 to represent conditions in 1900, 1901, 1902, etc. (see flooding PI description for example graphic). The resulting time series was then used to evaluate the 101 year water level sequences. In addition, the historic 40 year wave sequences at each location were analyzed to derive “statistical” characteristics, by quarter-month, over the course of a year. For example, average, minimum, maximum, and standard deviation values for offshore wave heights were identified for each of the wave locations for each quarter-month. The annual series could then be used throughout the simulation.

The FEPS database also contains monthly time series values of wave energy density (Joules/m^2) for each wave location noted in Figure 1. The wave energy information was calculated by Baird & Associates based on their wave time series data and is required for the erosion modelling.

Storm surge conditions are also incorporated within the FEPS database. Storm surge conditions were characterized by Baird & Associates based on an analysis of historical measured water level data at the recording gages. Storm surge varies around the lake and as a result, the surge conditions are classified so that each County/Regional Municipality is associated with an appropriate storm surge value (see Figure 1 for values). The database uses 2 year return period values (the 50% probability value). The values represent the storm surge condition that would have a 50% chance of occurring in any given year based on observed historical conditions. The FEPS model does not utilize more extreme (less probable) surge events beyond the 2 year return period event.

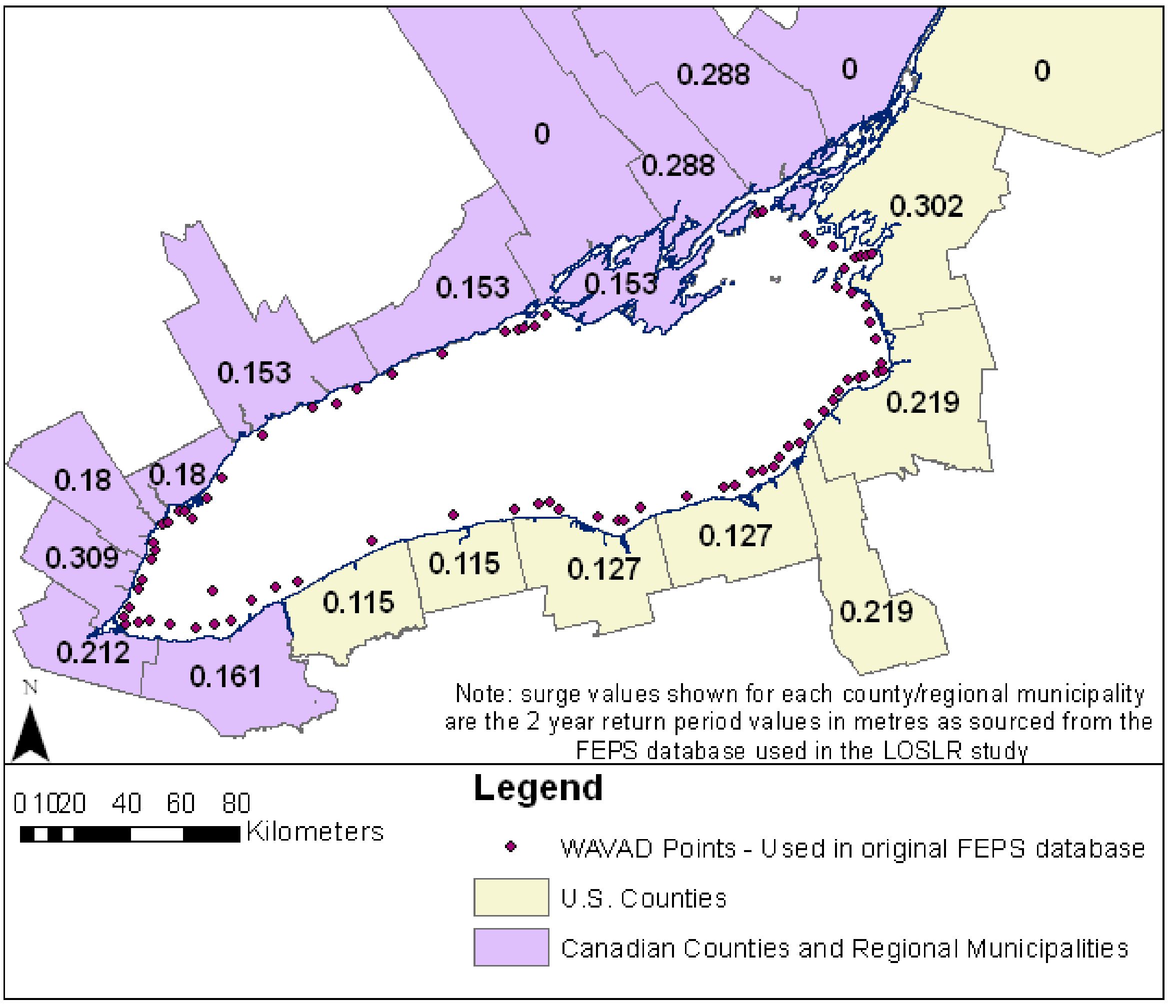

Figure 1: Map showing location of wave time series and the 2 year return period surge (m) by County and Regional Municipality (data sourced from the LOSLR Study FEPS database)

Flooding (see Baird's Flooding Performance Indicator documentation for supplemental information)

Wave and storm surge conditions are incorporated within the flooding component of the FEPS model. As mentioned above, each shoreline reach has an associated wave dataset which is used to represent wave conditions on that stretch of shoreline. When the FEPS model estimates potential flood damages at a particular parcel, it uses the wave height from the 101 year database or the statistical series (whichever is chosen by the user) as the wave input for each quarter-month of the simulation. If the wave condition in the particular quarter-month exceeds a minimum threshold (established by Baird & Associates on a County/Regional Municipality level), the 2 year return period storm surge is added to the average quarter-monthly water level for the flood impact assessments. Based on the combined quarter-month average water level and the additional storm surge, an evaluation is made to determine if storm water level would reach the building foundation and main floor elevation for the particular parcel as identified in the FEPS database. The minimum building elevation is the interface between the ground and the lowest corner of the building. Where the combined quarter-month average water level and the 2 year return period storm surge do not reach the building, the model does not calculate flood damages. If the combined level does reach the building, the FEPS model estimates the wave height at the building using wave attenuation matrices based on the offshore wave height, the depth of water at the building and the distance the building is set back from the edge of the lake under non-storm conditions. The estimated wave height is then used to calculate the wave energy flux striking the building which can then be used to calculate potential damages to the building. Even if wave damages are not occurring, inundation impacts are calculated if the combined quarter-month average water level and 2 year storm surge exceed the main floor elevation of the building.

Erosion (see Baird's Erosion Performance Indicator documentation for supplemental information)

The erosion performance indicator utilizes the monthly time series of wave energy described previously. Wave energy varies by location around the lake and also by the time of year. Figure 2 comes from the FEPS erosion model description and illustrates the seasonal variability in monthly wave energy for Niagara County, New York State. The various coloured bars on the graph represent the wave energy at different wave hindcast locations along the Niagara shoreline. For all unprotected parcels that feature buildings and erodible glacial sediments (e.g. banks and high bluffs), the average monthly water level is identified for the regulation plan being evaluate and an estimate of erosion in that month is determined based on the associated wave energy input and erodibility of the soils. Because the erosion model utilizes monthly water level and wave energy estimates, storm surge is not directly incorporated as it is a short-term phenomenon (i.e. not a monthly process).

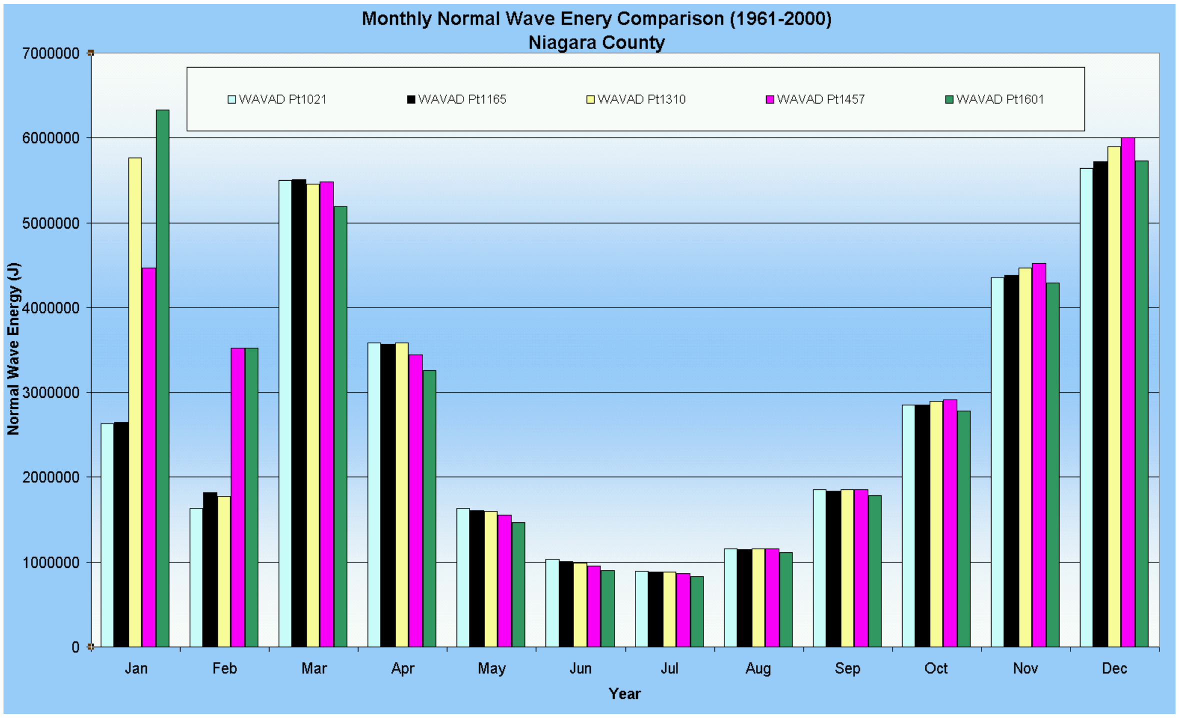

Figure 2: Example of wave energy, by month, for Niagara County sites (From Baird Erosion Performance Indicator Methodology Document) – note that different coloured bars represent unique wave hindcast locations along the Niagara County shoreline.

Shore Protection (see Baird's Shore Protection Performance Indicator documentation for supplemental information)

The shore protection component of the FEPS model incorporates the average and maximum significant wave height quarter-monthly data series as well as storm surge conditions (both described previously) for portions of the failure and economic calculations.

For the downcutting component of the shore protection model, the quarter-monthly water level and the average offshore wave height for that particular quarter month are used to estimate downcutting of the erodible glacial substrate in front of the structure. The downcutting for each quarter-month is used to estimate an undermining value since the last structure replacement (i.e. the cumulative undermining of the structure). Storm surge is not used in the undermining calculations.

For the overtopping component of the shore protection damage model, the quarter-monthly water level is combined with the 2 year return period storm surge to establish the lake level. The cumulative undermining of the structure toe is calculated in time (as discussed earlier) and collectively these two variables are used to determine the absolute water depth at the structure toe for that particular time step of the model. In the shore protection component, the 2 year surge is added in all quarter-months (unlike flooding where a minimum wave height is required to include surge). Wave conditions are combined with the absolute water depth to estimate overtopping values for all the coastal structures around the perimeter of the lake. In this case, the maximum offshore quarter-monthly wave height is used as an input parameter, to ensure the extreme condition is simulated.

References

Baird, 2003. Lake Ontario WAVAD Hindcast for IJC Study. Prepared for the International Joint Commission and the USACE.

Baird, 2004a. Shore Protection Performance Indicator: Methodology and Shared Vision Model Application. Prepared for the IJC Plan Formulation and Evaluation Group, 30pgs.

Baird, 2004b. Erosion Performance Indicator: Methodology and Shared Vision Model Application. Prepared for the IJC Plan Formulation and Evaluation Group, 27pgs.

Baird, 2004c. Flooding Performance Indicator: Methodology and Shared Vision Model Application. Prepared for the IJC Plan Formulation and Evaluation Group, 30pgs.