Erosion
Performance Indicator Summary

Performance indicator: Erosion impacts for riparian property on Lake Ontario and the Upper St. Lawrence River

Technical Workgroup: Coastal TWG

Research by: Baird & Associates

Modeled by: Complex algorithm in Flood and Erosion Prediction System (FEPS) linked directly to the Shared Vision Model

Activity represented by this indicator: Erosion of riparian property

Link to water levels: In general, erosion occurs at all water levels, and as such, water levels alone are not a driving force causing shoreline erosion. Rather, fluctuations in lake and river levels distribute energy from breaking waves across the nearshore zone, beach and bluff. In other words, during low lake levels wave energy is dissipated on the nearshore zone leading to a process known as lakebed downcutting (progressive erosion or deepening of the water depths in front of riparian property). During high lake levels, energy from breaking waves is dissipated directly on the bluff or dune leading to erosion or retreat of the shoreline. Over long time periods, such as 50 to 100 years, the erosion associated with low, average and high lake levels produces the long-term recession rate or background erosion rate. This retreat of the shoreline is often annualized for the term Average Annual Recession Rate (AARR). For example, 50 m (164 ft) of erosion over 100 years results in an AARR of 0.5 m/yr (1.6 ft/yr).

Lakebed downcutting is the principal process that sustains long-term erosion rates for a retreating shoreline and the rate of downcutting is at its maximum during low lake levels. Conversely, since most of the incoming wave energy is dissipated on the lake bed, very little reaches the shoreline, dune or bluff and consequently shore erosion rates are lower during low lake levels. The downcutting process is difficult for riparian land owners to understand, observe and especially measure. However, they can certainly observe the reduced rates of shore erosion during low lake levels. They then incorrectly assume that there is no erosion during low lake levels.

During high lake levels, less wave energy is expended on lake bed downcutting and more energy reaches the bluff or dune resulting in accelerated shoreline erosion and retreat. Riparian land owners are able to see the immediate impact of high lake levels on erosion rates and thus these conditions are the least desirable.

Importance: Erosion is an important natural process and it has been modifying the shoreline of Lake Ontario since the retreat of the Wisconsin glaciers approximately 12,000 Years Before Present. The goal of this PI is not to stop all future erosion, but rather to minimize high lake levels that accelerate shoreline recession rates above the long term average or background erosion rate.

Further, a significant percentage of the shoreline property on Lake Ontario and Upper St. Lawrence River is privately held by riparian owners. The Boundary Waters Treaty of 1909 and the current Regulation Plan (1958D) does not specifically recognize the needs of this stakeholder and the economic costs associated with high lake levels. If the frequency of high lake levels is reduced in the future and the current upper limit of the operating range is reduced, erosion rates and the associated economic loses will decrease.

Performance Indicator Metrics: Maximum monthly mean lake levels are the metric for the Erosion PI on Lake Ontario. The table below summarizes the upper threshold for monthly lake levels (recommendations current as of spring 2004):

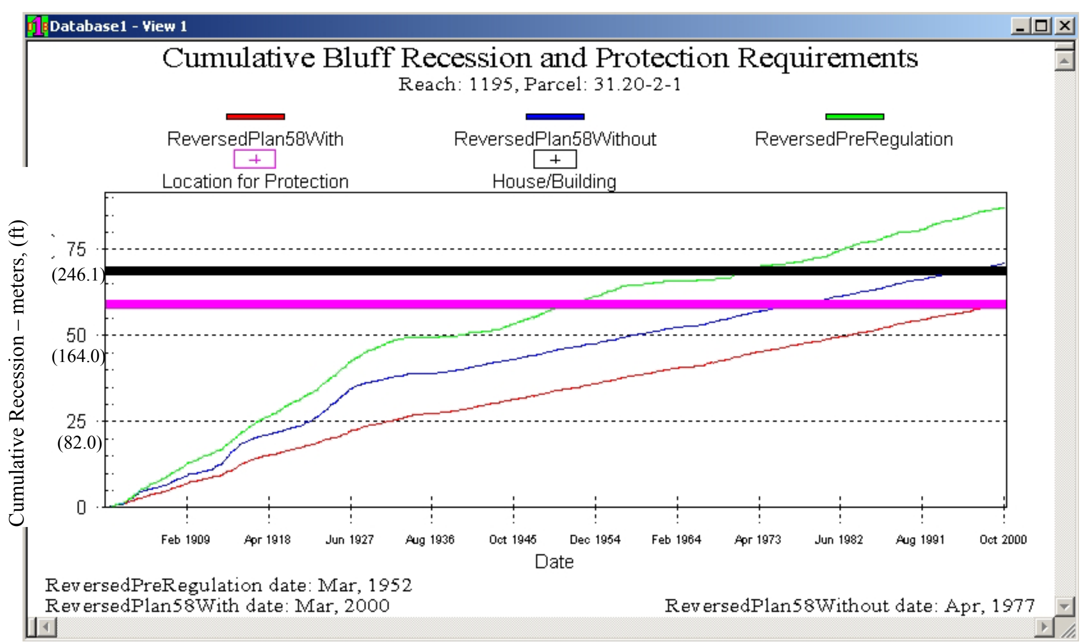
Upper	**Jan.**	**Feb.**	**Mar.**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Meters	74.70	74.70	74.87	75.04	75.20	75.20	75.20	75.20	75.04	74.87	74.7	74.7
Feet	245.1	245.1	245.6	246.2	246.7	246.7	246.7	246.7	246.2	245.6	245.1	245.1

Recommendations are in progress for the Upper St. Lawrence River, specifically the Lake St. Lawrence Region. It is anticipated that a similar upper threshold will be recommended for this region of the study area.

Temporal validity: The metric is valid throughout the year.

Spatial validity: The monthly water levels presented above are valid for Lake Ontario.

Links with hydrology used to create the PI algorithm:
The Erosion PI algorithm is applied to all of the 1 km shoreline reaches on Lake Ontario and the Upper St. Lawrence River that feature a long-term recession rate. If the shoreline does not erode or has a long-term accretion trend, the function is not applied. Regulation Plans that feature higher lake levels have higher long term erosion rates. A sample of the cumulative recession rate predicted for Reach 1195 in Niagara County is presented below



for Plan 1958D with Deviations, Plan 1958D without Deviations and the Pre-Project water levels (all time series water levels run in reverse). The location of the home on Parcel 31.20-2-1 is noted with the thick black line at approximately 70 m (229.7 ft) from the shoreline. The thick pink line represents the location of future shoreline protection, which is constructed 10 m (32.8 ft) from the existing home or 60 m (196.9 ft) from the lake.

If the location of the home and shore protection is ignored for the moment, after the 101 year simulation, the Pre-Project water levels and waves would result in approximately 90 m (295.3 ft) of recession, while the same wave with the water levels for Plan 1958D with Deviations would lead to only 60 m (196.9 ft) of recession. This example illustrates clearly the impact of high lake levels on recession.

The form of the erosion equation is described in the next section. For a given County, 'a' and 'b' coefficients were developed for each 0.25 m (0.8 ft) water level bin ((for example, 0.0 m (0.0 ft) to 0.25 m (0.8 ft) is one water level bin, the next bin is 0.25 m (0.8 ft) to 0.5 m (1.6 ft)). Collectively, the erosion equation and a set of coefficients is referred to as a 'Family of Equations'. While the form of the erosion equation is always the same, new 'a' and 'b' coefficients were developed for each County or Regional Municipality on the lake and river. In some cases, several Family of Equations were developed for one County.

Therefore, there is a directly link between hydrology and the Erosion PI. Different lake levels result in different erosion rates and the Erosion PI algorithm is sensitive to these changes.

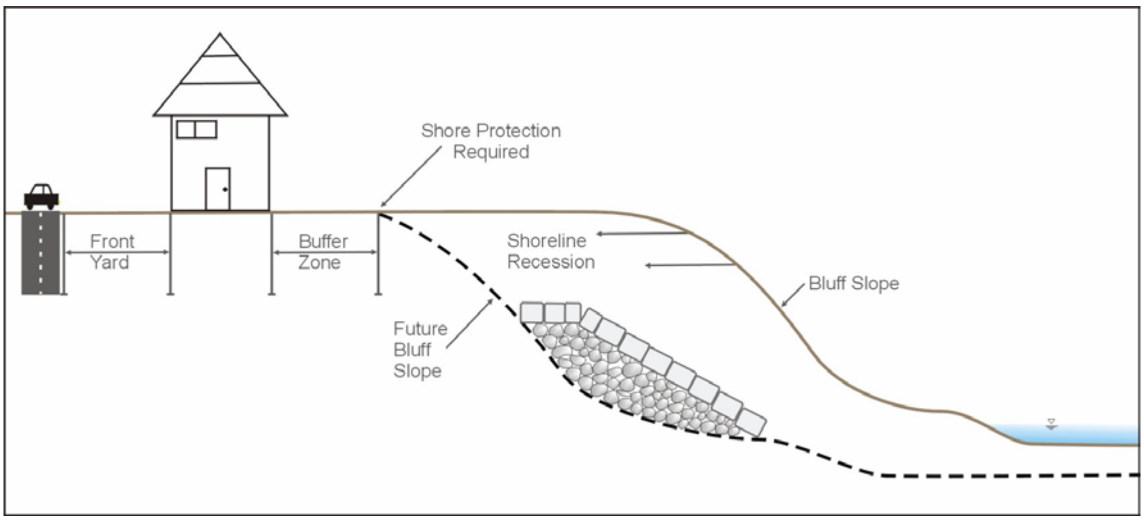
The Algorithm: There are several components to the Erosion PI algorithm which was programmed in the FEPS and linked directly to the SVM. The form of the recession equation is presented below:

Recession = (a x $ln(E)$ + b) x *AARR*

Where: a = coefficient (varies by county)
E = Normal Wave Energy (Joules), calculated monthly (varies by county)
b = coefficient (varies by county)
AARR = Average Annual Recession Rate (specific to each 1 km reach)

Once shoreline recession is predicted for a given reach and regulation plan, the second component of the Erosion PI is the economic calculation. For example, the cumulative recession estimates presented for Reach 1195 above are used to determine when a riparian land owner would be forced to construct shoreline protection to save their home from erosion. As seen in the example above, if the erosion hazard is not addressed, the erosion associated with the Pre-Project water levels would destroy the home around 1973 (location where the thin green lines crosses the thick black line). However, in reality, most riparian landowners don't let their homes fall into the lake – they take action to protect them. Although homes can be moved, the most common form of mitigation is the

construction of a shoreline protection structure to stop or slow down the loss of land. This premise forms the basis for our economic methodology.
For the example above (Reach 1195), we assume the riparian owner would let erosion occur until the minimum backyard distance from the home to eroding shoreline is 10 m (32.8 ft). This distance is also referred to as the Buffer Zone in the graphic below. At this point, the riparian owner is forced to build protection and accept the economic cost of the structure. Since the Pre-Project water levels accelerate the background erosion rate, protection is required in March 1952 (location where green cumulative recession line crosses the solid pink horizontal line). For Plan 1958D the economic cost associated with building shoreline protection is delayed until April 1977. Protection is not required until March 2000 for the current regulation plan (1958D with Deviations).



The frontage of Parcel 31.20-2-1 is significant at 91.67 m (300.8 ft). Using a unit cost of $1,889/m of shore protection, the protection for this particular riparian property would cost $173,165. Since the liability of constructing the shoreline protection can be delayed further into the future for plans with lower lake levels, the riparian has longer to save to pay for the protection (see table below). Using the three interest rates outlined it the economic methodology for the study, the algorithm calculates the required initial investment the riparian must make in order to pay for the protection in the future. Since this savings is analogous to a Savings Account at a bank, the 2% interest rate is likely the most appropriate.

	Year Protection Built in Future	Investment with 2% Interest	Investment with 3.1% Interest	Investment with 10% Interest
Pre-Project	52	$61,837	$35,400	$1,219
1958D	77	$37,692	$16,502	$113
1958D without	100	$23,902	$8,177	$13

For the Pre-Project condition, the riparian must make an initial investment of $61,837 to pay for the protection 52 years in the future. For regulation plan 1958D the initial investment using the 2% interest rate decreases to $37,692 since the protection is not required until 77 years in the future. The current regulation plan (1958D with deviations) does not require protection for 100 years and thus the initial investment is $23,902, or approximately a third of the cost associated with Pre-Project water levels.

The Erosion PI algorithm completes this series of calculations for every applicable parcel in the database and the summation of the economic calculations is used to compare and rank alternative regulation plans.

Validation: The predictive capabilities of the Erosion PI algorithm were extensively tested, calibrated and verified during the developmental stages of the methodology. For example, in each County and Regional Municipality three reaches were selected for testing. Erosion predictions were made with the algorithm for four different regulation plans and these results were compared against the COSMOS model, the detailed process based program in the FEPS to predict recession. In most cases, the algorithm was capable of reproducing the results from the detailed COSMOS model with less than 10% error. For further details on the validation process, refer to the PI report in the Reference section below (Baird, 2004a).

The economic methodology has been peer reviewed by the Coastal TWG and the Economics Advisory Committee.

Documentation and References:

Baird, (in preparation). *Lake Ontario and Upper St. Lawrence River Detailed Coastal Study Sites*. Prepared for the Coastal TWG.

Baird, 2004a. *Erosion Performance Indicator: Methodology and Shared Vision Model Application*. Prepared for the Coastal TWG, February 2004.

Christian J. Stewart Consulting, 2004. *A Summary of Existing Land Use, Land Use Trends and Land Use Management Policies Along the Lake Ontario – St. Lawrence River Shoreline: Implications for Future Water Level Management*. Prepared for the Coastal TWG, International Joint Commission.

Nairn, R.B. *Erosion, Transport, and Deposition of Cohesive Sediments, Chapter 5, Part III, Coastal Engineering Manual*. Prepared for the USACE.

Zuzek, P.J., Nairn, R.B., and Thieme, S.J., 2003. *Spatial and Temporal Considerations for Calculating Shoreline Change Rates in the Great Lakes Basin*. Journal of Coastal Research, Special Edition 38, p.125-146.

Risk and uncertainty assessment: There is uncertainty associated with all types of computer modeling. The predictive capabilities of the Erosion PI algorithm have been extensively tested, calibrated and verified. The function will accurately predict the erosion response for alternative regulation plans developed by the PFEG and tested in the SVM.

The premise of the economic methodology in the algorithm is the construction of shoreline protection structures to mitigate the erosion hazard. This response is well documented in the detailed Land Use Report prepared by CJSC (2004) and in the contextual narrative for the Erosion PI.