Lake Superior South Shore Bluff Recession Rate Study

Douglas and Iron Counties

December, 2012

Introduction

The study of erosion along the Lake Superior shoreline began in the 1970s with an analysis of bluff materials, shoreline recession rates, and additional information collected in a survey published by the Wisconsin Coastal Management Program (Need, et al., 1976). The study covered the shoreline from the City of Superior to Bark Point in Bayfield County. A follow-up to this study was conducted in 2001 and 2002 (Anderson, 2003). The purpose of the Anderson study was to evaluate the changes that had taken place since the 1970s, describe the condition of the bluff and beach, and update the description of sediments contained in the bluff. In 2005 Mickelson started working with the Bayfield County Planning and Zoning staff to develop setback rules for new construction that would be more defensible and realistic than the standard 75 feet required by state law. The final result of a series of studies was a safe setback line based on the knowledge of geology, engineering properties of materials, recession rate, bluff height, and bluff angle for all of the bluff shoreline in Bayfield County.

In 2010 and 2011, Northwest Regional Planning Commission and Mickelson began a project to create a similar safe setback line in Iron and Douglas Counties. This line is based on characteristics of the bluff and recession rates, as well as slope height and angle calculated from recently acquired LIDAR (Light Detection and Ranging) data. It can be viewed on a parcel by parcel basis. We recognize that field checking and interpretation by Iron and Douglas County Planning and Zoning staff members will still be required in certain instances. This will be true especially in high bluff areas in Douglas County where gullies complicate the setback issue.

Determining stable slope angles

The angle at which bluffs fail is determined by the sediments making up the bluff as well as environmental factors such as water content, weathering, etc. Characterizing the sediments in a bluff in detail is difficult without a large number of drill holes. Bluffs were better exposed in the 1970s than in the early 2000s, but there were still areas where vegetation covered the bluffs. We have done geologically reasonable correlation across the unexposed areas. It may be that drilling would produce a somewhat different unit thickness at a particular site if it is done. However, the properties of the materials for the stable slope calculations should remain the same. There may also be places where springs or other groundwater factors affect soil conditions locally.

Determining the safe setback distance

Reasons for setback requirements

Lake Superior bluff shorelines have been eroding for thousands of years and will continue to do so. Because the erosion is often episodic, land owners may not observe bluff recession over periods of a few years. There may be periods of ten or more years with little or no erosion followed by several years of rapid erosion. To protect a structure from this erosion and resulting bluff retreat, it is necessary to have sufficient building setbacks to account for this continuing process. This will minimize the future chances of a building having to be moved or even destroyed because of an unsafe location at the top of the bluff.

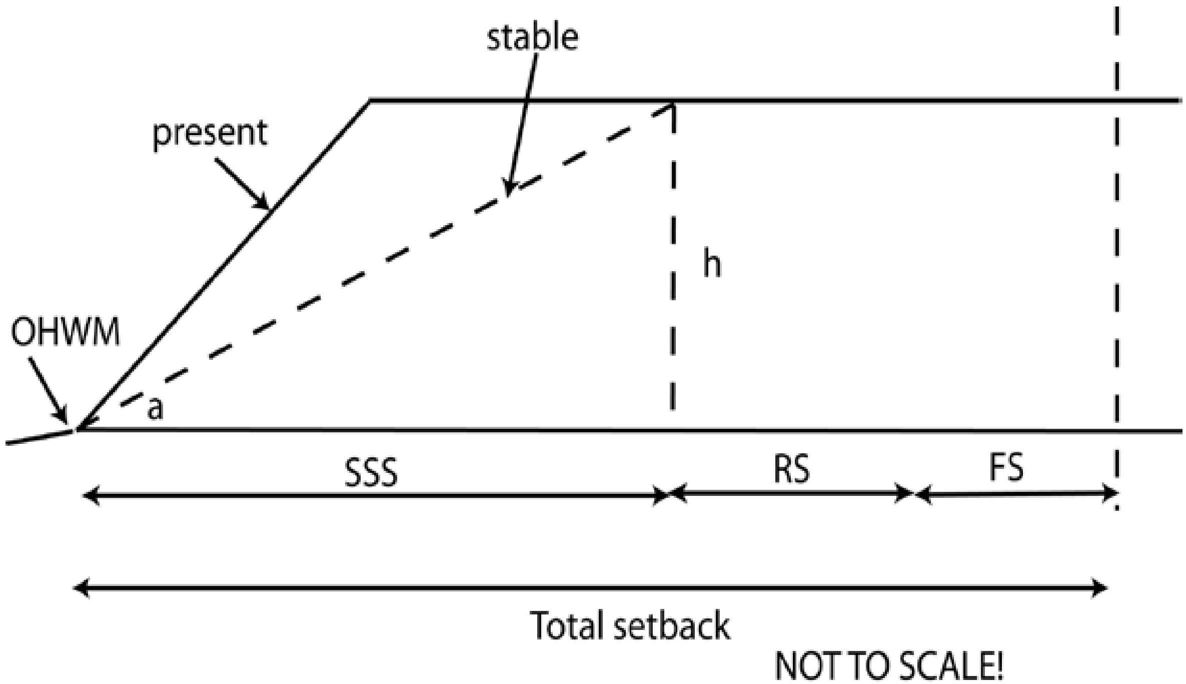
Approach

Setbacks for new buildings can be determined by Planning and Zoning departments based on the approach described below. A stability line has been developed that is based our knowledge of the geology and the formula described below. All of this information, including the stability line, is available on the project DVD and online at www.nwrpc.com/LakeSuperior.

Calculation of setbacks and the stability line position

There are three components that, added together, produce a setback distance used to map the safe setback zone (see fig. 1):

Figure 1: Setback Calculation



Total setback = stable slope setback (SS) + recession setback (RS) + facility setback (FS)

1. Stable slope setback component (SSS)

Slopes eventually attain a stable slope angle if they are not undercut by waves or otherwise disturbed for many years. Bluffs along the lakeshore are kept in an unstable state by erosion of sediment at the base of the slope by waves. Even if all wave erosion were to cease, bluffs that are steeper than the stable slope angle will continue to experience bluff-top recession as they adjust to this stable slope angle. Stable slope setback is the distance between the ordinary high water mark and the position of the bluff top where the slope of the bluff would be at a stable angle (fig. 1). Thus, even if the toe of the slope is being protected from future wave erosion, this component of setback is necessary to ensure building safety.

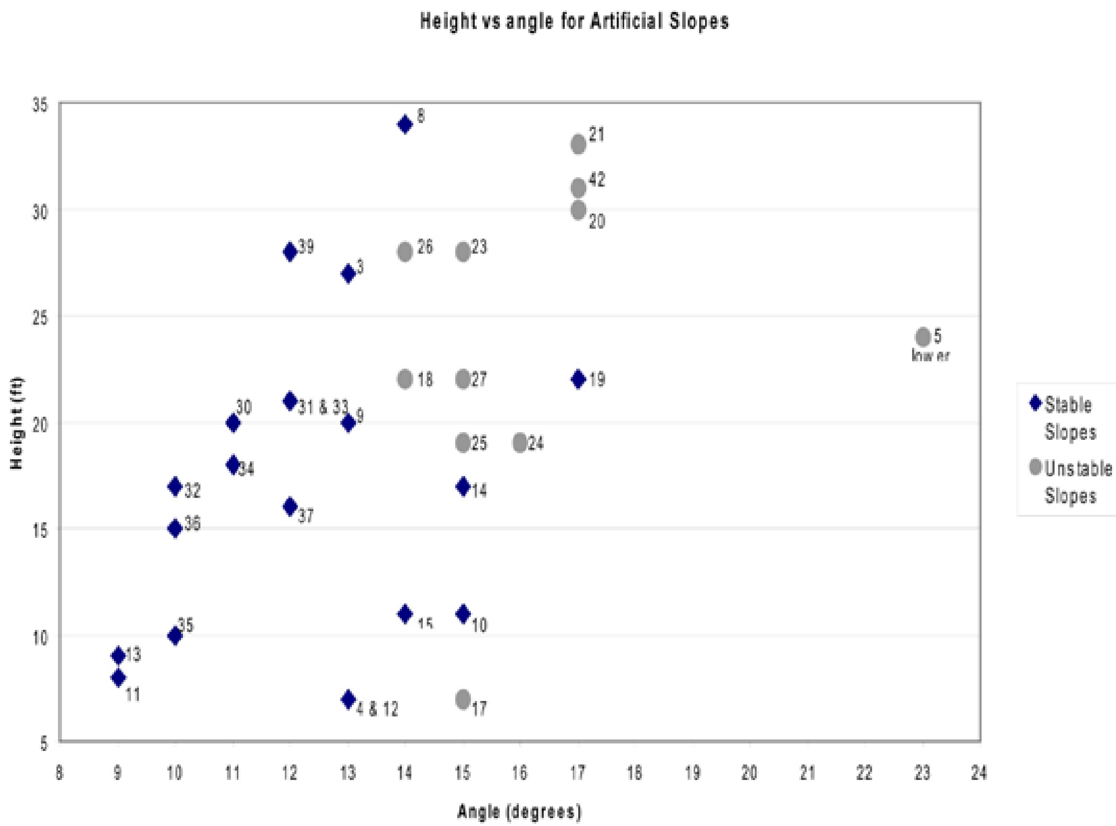
The stable slope angle depends of the type of soil (or rock) material in the bluff. Not all bluff materials have the same stable slope angle. In addition, abnormally high or low groundwater levels or other conditions may cause exceptions. Material types have been mapped and translated into a stable slope angle.

The following bluff material types can be characterized by these stable slope angles:

Bluff materials	Degrees	Tangent
clay till (Douglas and Hanson Creek)	14	0.2493
sandy till (Jardine Creek) (Copper Falls Formation)	26	0.4877
sand and/or gravel	30	0.5774

The above numbers were determined by several studies. For a senior thesis, Marty (2004) measured numerous artificial and natural slopes on red clay (Douglas and Hanson Creek tills). As can be seen in figure 2, slopes on clay greater than 14° tend to unstable. In addition, the USACE demonstration project that was constructed more that 40 years ago on STH 13 in western Bayfield County has a stable slope angle of around 14°and it is fairly stable.

Figure 2: Height vs. angle for Artificial Slopes



Stable slope angles for sandy Copper Falls formation till (26°) and sand and gravel (30°) were determined by Mickelson by measuring natural slopes and are presented in Tables 1 and 2 respectively. A stable angle of 60° was chosen for bedrock in Bayfield County, but there is no bedrock to speak of in Douglas or Iron County except right at the mouth of the Montreal River.

Table 1: Measured slope angles and condition of slopes for Copper Falls Formation sandy till slopes in northern Wisconsin

UTM-N	UTM-E	Type	Degrees	Status
5035252	300716	road cut	42	unstable
5034378	300819	road cut	41	unstable
5032105	305540	road cut	38	unstable
5035091	300744	road cut	36	unstable
5033286	306078	road cut	36	unstable
5034384	300816	road cut	32	marginally unstable
5033654	306920	road cut	32	marginally unstable
5032105	305540	road cut	31	marginally unstable
5033274	302006	road cut	29	marginally unstable
5034896	300854	road cut	28	marginally unstable
5032951	302417	natural	28	marginally stable
5035204	306463	natural	28	stable
5033607	303390	natural	27	stable
5032243	3055722	natural	27	stable
5034802	305232	natural	27	stable
5034794	305250	natural	27	marginally stable
5032963	302737	natural	26	stable
5034794	305250	natural	26	stable
5022085	701216	natural	26	stable
5015530	700426	natural	26	stable
5009261	686998	road cut	26	marginally stable
5005163	688327	natural	26	marginally stable
5033096	302234	natural	25	stable
5034802	305232	road cut	25	stable
5017289	700561	natural	25	stable
5015530	700426	natural	25	stable
5006149	688007	road cut	25	stable
5033424	304539	road cut	24	stable
5034289	306742	natural	24	stable
5017352	700443	natural	24	stable
5016200	700348	natural	24	stable
5035491	300791	natural	23	stable
5035267	305524	natural	23	stable
5022361	701204	natural	23	stable
5017333	700466	natural	23	stable
5016200	700348	natural	23	stable
5035336	305750	natural	22	stable

Table 2: Measured slope angles and condition of slopes for sand and gravel

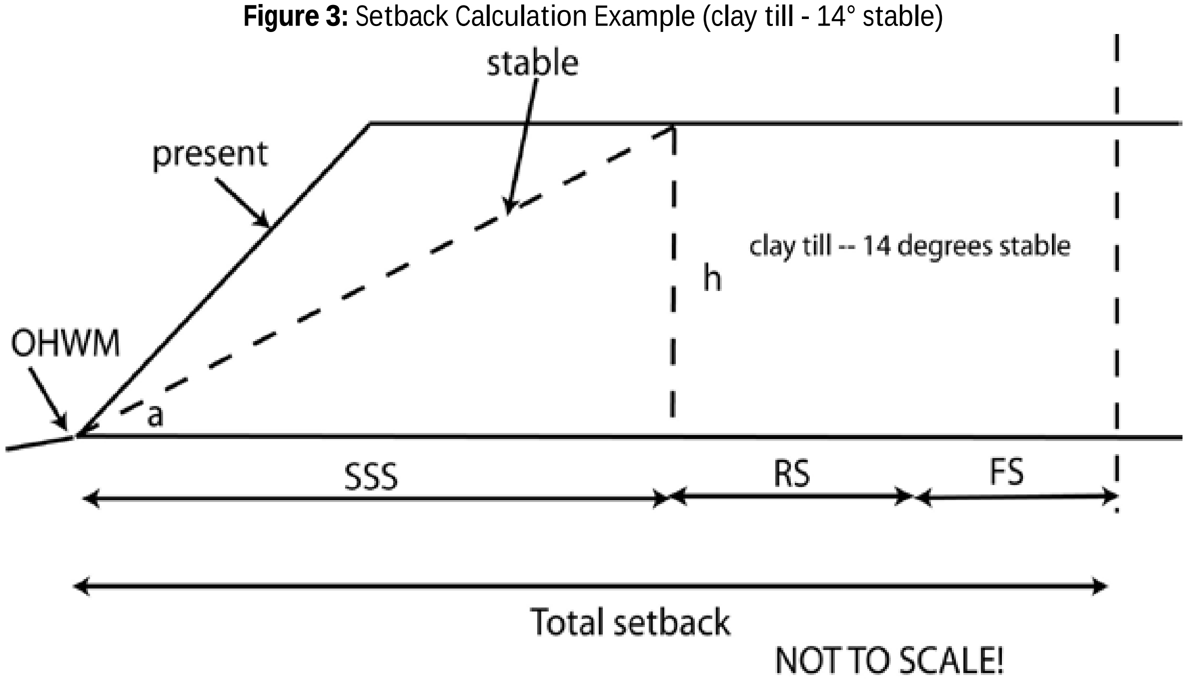
UTM-N	UTM-E	Type	Degrees	Status
5187550	629779	natural	43	unstable
5175619	650439	road cut	36	unstable
5175565	649084	cut slope	33	marginally unstable
5172143	648266	natural	33	stable
5171093	653759	natural	32	stable
5173994	654227	natural	32	marginally unstable

5172587	656496	road cut	32	stable
5172349	658859	natural	32	stable
5187550	629779	natural	31	marginally stable
5175565	649084	natural	31	stable
5172143	648266	road cut	31	stable
5173899	654514	natural	31	marginally stable
5187267	629821	natural	30	stable
5187339	630411	natural	29	stable
5174064	654003	natural	29	stable
5171934	659276	natural	29	stable
5172349	658859	natural	28	stable
5172229	648075	natural	27	stable
5171859	648863	natural	27	stable
5172399	653770	natural	27	stable
5181012	646421	road cut	24	marginally stable
5181012	646421	road cut	19	unstable

In cases where the present slope is less than the stable slope angle, there is no stable slope component of setback.

In order to calculate the stable slope setback from the Ordinary High Water Mark (OHWM), it is necessary to know the present slope angle and bluff height. In this study slope height and angle were calculated from recently acquired LIDAR data. Stable slope setback can also be calculated by hand for any site, however the bluff height and present slope angle must be known. These are difficult to measure in the field on vegetated bluffs. The distance of stable slope setback from the OHWM is bluff height (h) divided by the tangent of angle a in figure 3.

Figure 3: Setback Calculation Example (clay till - 14° stable)



For example, in figure 3, if the bluff is 20 feet high (h=20), and composed of clayey material with a 14° stable slope (tan= 0.2493), the SSS would be 20/0.2493, or 112 feet.

If in figure 3, the bluff is 20 feet high (h=20) and composed of sandy till with a stable slope angle of 26° (tan 26 = 0.4877), the SSS would be 20/0.4887, or 41 feet.

For composite bluffs, with more than one material, the percentage of each is given in Tables 3 and 4. In that case, the setback for each material is calculated, and then they are added together. For instance in figure 4, 50 feet of sand with a stable angle of 30° is overlain by 20 feet of clayey till with a stable angle of 14°. The setback would be (50/tan 30°) + (20/tan 14°), or (20/0.2493) + (50/0.5773) or 167 feet.

Table 3: Iron County proportions of sediments with various stable slope angles
(Reaches numbered from east to west)

Reach #				(East edge of reaches is state line)	
	Percent of sediment type in bluff			UTM coordinates of boundary	
	(see stable slope angles below)*			EAST edge of reach	
	sand	**clay till**	**loam till**		
1	20	20	60	697830	5160200
2	harbor			696509	5159640
3	60	40		696060	5159735
4	90	10		695933	5159796
5	100			695426	5160002
6	80	20		694431	5160492
7	90	10		693339	5161120

***Stable slope angles**		**(degrees)**
clayey till		14
sand		30
loam till		26

Note: The county shoreline has been divided into 7 segments based only on bluff materials and type. There may be other appropriate divisions based on non-bluff shore or gullies that can be better mapped with LIDAR.

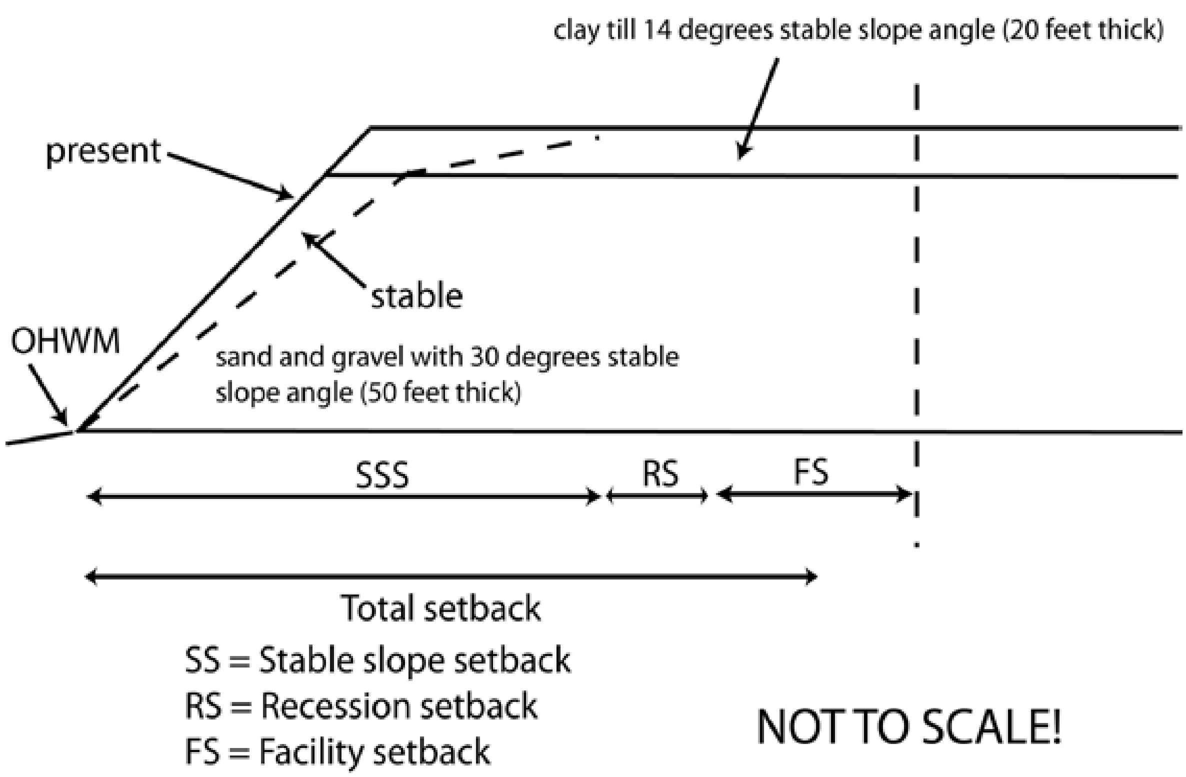
Table 4. Douglas County proportions of sediments in 27 reaches
(Reaches numbered from east to west)

Reach #				UTM coordinates of boundary	
	Percent of sediment type in bluff			WEST edge of reach	
	(see stable slope angles below)*				
	sand	**clay till**	**silt**	East edge is county line	
1		100		607008	5178527
2	36	64		606734	5178370
3	47	53		606572	5178296
4	36	64		606459	5178256
5		100		606330	5178210
6	100			606185	5178116
7	N/A			605863	5177887
8	100			605718	5177776
9	N/A			605583	5177746

10		100		605352	5177607
11	20	80		605255	5177567
12	33	67		604535	5177130
13	20	80		604433	5177091
14		100		598553	5174748
15	20	80		597986	5174575
16	50	50		597273	5174303
17		75	25	595401	5173529
18		85	15	594933	5173261
19		100		592168	5171843
20		100		591762	5171734
21		100		589805	5171395
22		100		589545	5171358
23		100		587407	5171517
24		100		587098	5171513
25		100		579806	5170254
26	N/A			578478	5170824
27	N/A			575756	5172967
***Stable slope angles**		**(degrees)**			
clayey till		14			
sand		30			
silt		22			

Note: The county shoreline has been divided into 27 segments based only on bluff materials and type. There may be other appropriate divisions based on smaller gullies, non-bluff shores, etc.

Figure 4: Setback Calculation Example (complex bluff)



Some sites will need to be field inspected, especially properties with large gullies.
For shorelines with no bluff, there is no stable slope setback, and only a recession setback and a structure setback would be applied. The stable slope component of setback at a site could be reduced by a potential user by making the slope more stable (possibly by removing water from the soil, regrading, etc.).

2. Recession rate component (RS)

The purpose of this aspect of the project was to try to delineate and determine a shoreline recession rate that can be used in setback (RS) and zoning policy decisions along the sensitive Lake Superior shoreline areas of Douglas and Iron counties, Wisconsin. This is a follow up to the project completed in 2001 along Bayfield County. Two years of photography, one in the 1960's and the other in the 1990's were compared using traditional photogrammetric means. The same basic methodology was used as the first project. The process steps, results, and recommendations are listed below.

Approach

Data Gathering/Research
The first step in the project was to try and find two suitable photo sets. Many factors need to be taken into account, including, scale, time of year, availability, stereo coverage and who flew it. This was a significant problem to find similar data sets for this project.

Scale
Many older aerial photograph missions were flown at a higher altitude creating a smaller size scale. The scale of both years should be similar, as this will determine the accuracy that is created. If one scale is significantly better than the other, it will be hard to compare the two.

Time of Year
If possible, the flight should be in spring or fall with leaf off. This will allow the analyst to see the ground better and create a more accurate result. A lot of flights are flown in summer to do various forestry related studies, and can make it difficult to find a leaf off flight

Stereo Coverage
The data must be in stereo coverage. Most aerial missions are flown with 60% forward overlap and 30% sidelap. This overlap is what allows the stereoscopic coverage to occur. Sometimes only mono coverage was flown to save money if orthophotographs were the only product. Other times, the agency that holds the film or prints may only have mono coverage.

Availability/Source of Data
This is probably the most important factor as it determines how easily it will be to access the data. Many agencies have flights including the USDA, USGS, DNR, and DOT. There are different places that house data, and that can affect the cost and timeframe of the project. If the data is from the National Archives, there are only a few companies that can mine the data from the archives, and this greatly increases the cost. Also, depending on who flew the data, various information about the flight might be missing. The most important being the camera calibration reports. Cameras before the 1950's were not calibrated, but after that various specs of the camera were measured

and recorded. This data is important when doing the aerotriangulation. Another factor is whether the film is available or just contact prints. Film is preferred as you can get a better resolution and more accurate scan rather than scanning the contact prints. Unfortunately for this project, only contact prints were available.

Aerotriangluation

The Aerotriangulation or AT process involves stitching the photos together and tying them to the ground using control points. Points need to be found that can be found on both years of photography and are currently there. Someone goes out to these points with a GPS and captures the geographic location of each of these spots. For this project, it was difficult to find suitable control points, since the area of interest was mostly forested. Using Image Station AT software by Intergraph, the photos were tied together using control points collected by NWRPC. Wisconsin State Plane North NAD83 Feet coordinate system was used for both counties. The same control was used in both years to tie the two years together. In the case of this project the relative accuracy (the accuracy between the two years) is actually more important than the absolute accuracy (how close it is to actual ground).

Compilation

Once the AT is completed, the compilation begins. The analyst will view the data in 3D using photogrammetric software (DAT/EM Summit Evolution). The analyst collected the bluff line, toe line and shoreline for each year. They also collected a break line about 150 feet back to have the ability to make a TIN surface. In areas where the bluff is open, such as stream inlets, the compilers followed the bluff line down to the shore, left a gap where the stream was and picked up the line on the other side and compiled it back up to the bluff top.

Orthophotography

Using the scans and a surface, the photos are ortho-rectified. This process takes out the distortion from relief and stitches the photos together into one seamless mosaic. Orthos were created for both years for each county. In ArcMap software, the two years can be overlaid on top of each other to see the shoreline recession. It is also a good check to compare the relative accuracy of each mosaic when you compare a hard feature such as a road, house or other object that hasn't moved. Using Intergraph's Ortho Pro software the photos were rectified, stitched and mosaicked. Based on the photo scale and scan resolution a pixel resolution of 1.5 feet was used.

Analysis

To determine the recession rate stereo compiled bluff lines were compared. Using ArcINFO a point was created every 15 feet along the 1990 bluff line. Then points were created every 6 inches along the 1960 bluff line. Using the near feature, the nearest point was calculated along the entire shoreline. The data was reviewed for outliers and areas along switchbacks where the data was skewed (this happened most often in the river delta areas). In these cases the data was removed to not skew the final results.

Results

AT

The AT results were very hit or miss. Douglas was better than Iron County due to the fact that there was more and better control available. Even with the high residuals and RMS numbers, the relative accuracy between the two years is pretty good as evident by the orthos. There was one area in the middle of Iron County where the residuals were bad and it was hard to tighten that area up (as you can see in the chart below. That area skewed the entire solution. Overall taking into account the RMS results, the scale and scan resolution of the photos, the overall relative accuracy of the data is probably between 2-8 feet.

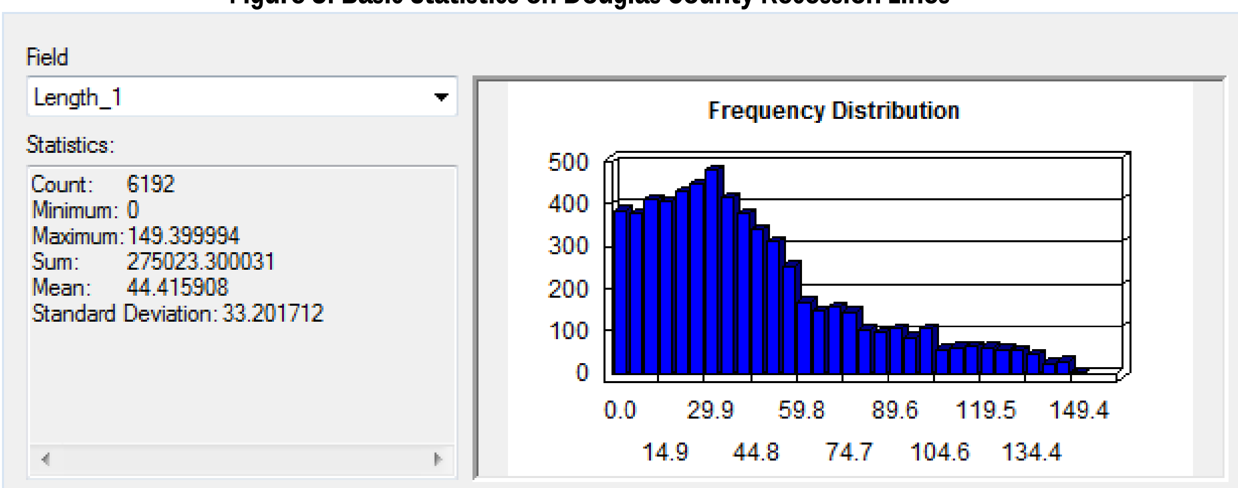
RMS Control Results

	XY	Z
Douglas 1990	4.73	2.91
Douglas 1966	12.63	1.87
Iron 1991	4.26	1.58
Iron 1963	26.08	30.30

Douglas County

There were 6192 samples along the Douglas County shoreline with a maximum recession of 149.4 feet. The average of these lines was 44.4 feet. Douglas County had a 24 year span (1990 and 1966), which computes to a 1.85 feet per year recession rate. The highest rates were by the mouth of the Amnicon River, and moving north along that western edge. The lowest rates were closest to the City of Superior where the bluff is not as pronounced.

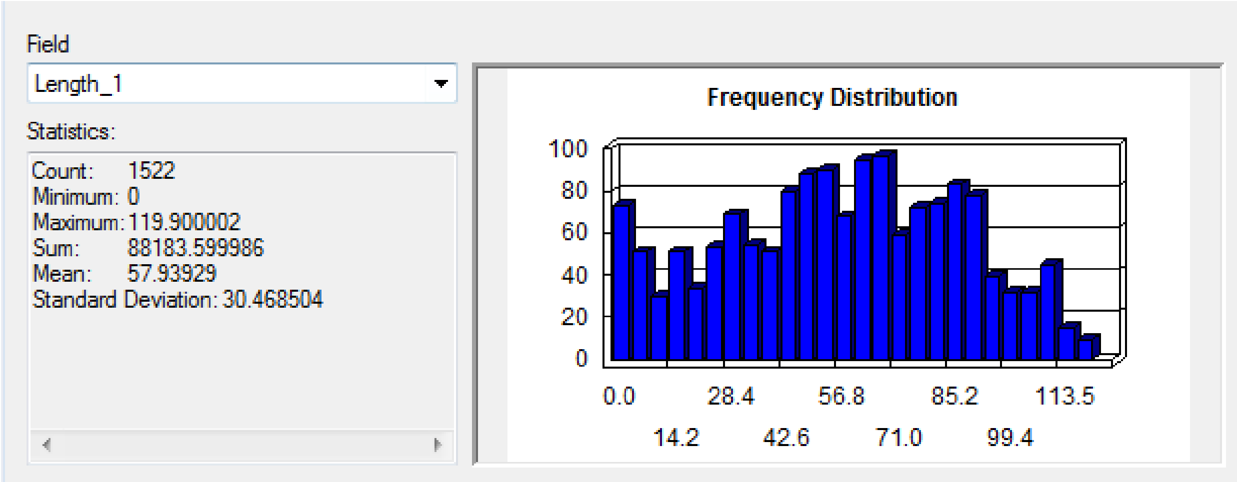
Figure 5: Basic Statistics on Douglas County Recession Lines



Iron County

There were 1522 samples along the Iron County shoreline with a maximum difference of 120 feet. The average of these lines was 57.9 feet. Using this average and dividing it by the span of 28 years (1991 and 1963), it gives an average setback of 2.07 feet per year. The largest recession areas were along the west side of the main point and probably have to do with prevailing winds and wave action. The lowest amount of recession was on the eastern edge of that point.

Figure 6: Basic Statistics on Iron County Recession Lines



Any project using historical data is going to have some problems encounter. For this project it was the remoteness of the project area, which resulted in a lack of available data sets to choose from. If at all possible, data should be scanned from film. With older datums, this becomes more difficult and expensive. If film is not available, scanning at the highest resolution possible will help with the AT process, and increase the overall accuracy of the project.

3. Facility setback (FS)

The above two parts of the equation predict where the bluff edge will likely be at some point in the future based on past erosion history. If either county wishes to require a facility setback as well, which would statistically, at least, put the structure 75 feet back from the bluff at that time in the future, then that would have to be added as well.

Some examples using an assumption of 50 years building life, same lake level as today, and a 75 foot facility setback are outlined below.

Setback examples

Examples of <u>total</u> setbacks using all three components:

1) a lot with a 30-foot high clay till bluff, with a recession rate of 1 foot/year, which is at 30 degrees now would have a setback from the ordinary high water mark (not from top of bluff!) of:

120+50+75 = 245 feet

2) a 20 foot high bluff, with a recession rate of 1 foot/year, which is at 20 degrees now would have a setback from the ordinary high water mark of:

80+50+75 = 205 feet

Effects of future lake level change on recession rates

At this point in time it is not clear how the lake level of Lake Superior will change in the future in response to likely climate change. Most early predictions are that the level of Lake Superior will fall in general. However, storminess is likely to increase and there will still be periods of high water. In an effort to examine potential effects of water level change on erosion rates, Swenson (2005; Swenson, et al., 2006) calculated recession rates from several different sets of air photos. Using wave impact studies, he predicted likely changes in recession rates at a number of sites in western Bayfield, Douglas and Ashland Counties for three different water level scenarios:1) 0.5 meters above present lake level, 2) 0.5 meters below present level and 3) present level (fig. 7). In the future, if either county decides to incorporate the effects of climate change on lake level and its impact on bluff recession rate, this study (Swenson, 2005; Swenson, and others, 2006) could form the basis for decision making.

Status of project

As of December 31, 2012 the map showing the safe setback zone measured from the ordinary high water mark is complete. Random checks have been made in the field to assure that the results are consistent with setback calculations based on measurements using LIDAR. Because the map showing the safe setback line is in a GIS it can be viewed at the individual parcel level. A sample for the shore in Douglas County is provided in figure 6 and all of the shape files are provided on the DVD. Individual property owners can see the map covering their parcel upon request and will be able to see it on line.

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