Developing a Legally Defensible Setback Ordinance
for Bayfield County, Wisconsin
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Introduction

<u>Note</u>: All supporting materials except the 1976 study are provided on a DVD accompanying this report.

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. At this time the Bayfield County Planning and Zoning staff recognized that there was sufficient information 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 over the past six years is 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. Two color brochures and companion posters were published by Bayfield County based on research done by the erosion hazards team at the University of Wisconsin-Madison. The first titled, "*Lake Superior Safe Building Setbacks: A guide to developing coastal property in Bayfield County*", focused on safe setback calculations; the second titled, "*Managing Stormwater on Coastal Bluffs: A Guide for Property owners on Bayfield County's Lake Superior shore*" focused on stormwater runoff in bluff regions.

This most recent project is the culmination of all of these previous studies. Much of the Lake Superior shoreline in Bayfield County is characterized by bluffs that stand above the beach. This study makes available a <u>safe setback line</u> by projecting stable slope angles from the ordinary high water mark to where it intersects the land surface and adding to those angles a component based of past recession rate. Between this line and the ordinary high water mark there are specific requirements for creation of lots and placement of improvements. Most recently, the Bayfield County Department of Land Records has used GIS to project this safe setback line on a map that is available to the public. This line is

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based on characteristics of the bluff and recession rates calculated in previous studies, 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 Bayfield County Planning and Zoning staff will still be required is certain instances. This will be true especially in high bluff areas where gullies complicate the setback issue, as well as in the eastern part of the county where bedrock and non-bedrock bluffs are in close proximity.

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 will be determined by Bayfield County Planning and Zoning 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. The shoreline has been subdivided into 154 reaches based of the composition of the bluff, generalized bluff height, presence of gullies, etc. Calculations for determining the stability line are based on the dominant shoreline characteristics in each of the reaches. All of this information, including the stability line, is available and will eventually be placed on the Bayfield County web site (under the link to Land Records or Planning and Zoning Departments). A site visit to the property in question and further refinement of the setback distance will still be necessary in some cases because there can be substantial variability within each shoreline reach.

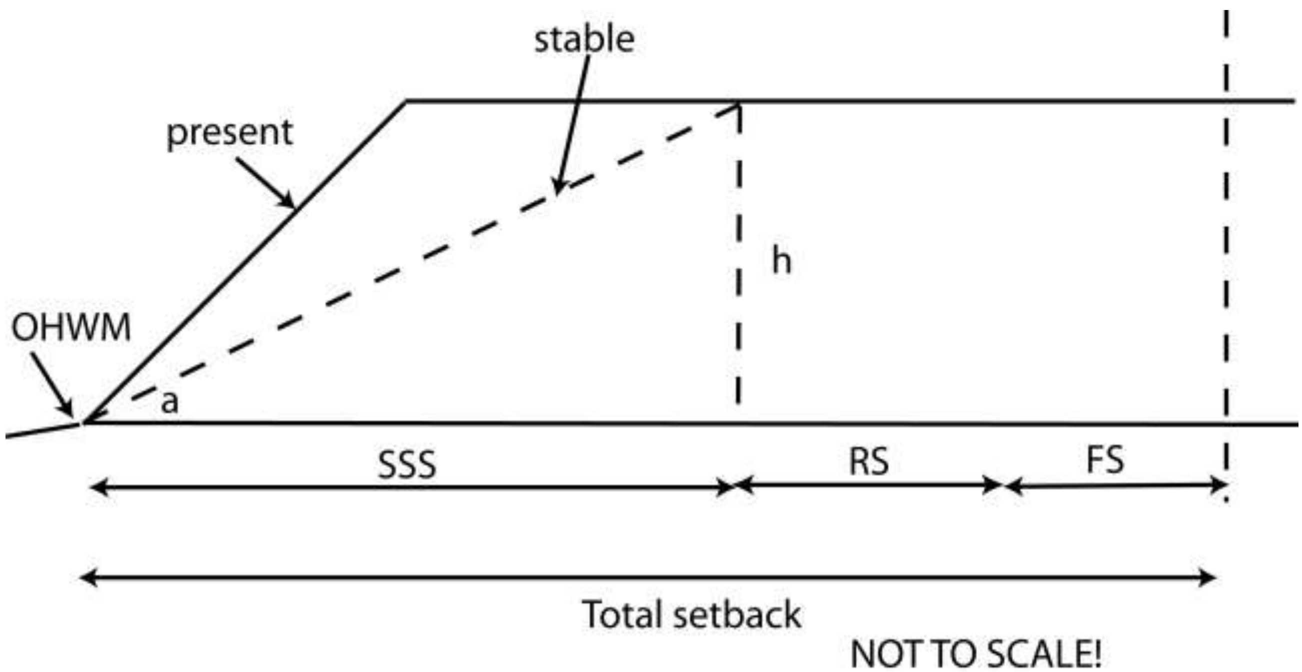
Parts of the county treated differently

The Bayfield County shoreline west of Bayfield Township is dominated by clayey and sandy soils with some areas of bedrock. The clayey soils are the most unstable and present the biggest threat to property. From Bayfield Township eastward and southward around the peninsula the coast is dominated by rocky shore that erodes much more slowly. Although there are some areas of clayey and sandy soils, they tend to be isolated, and due to substantial costs involved, have not been studied intensively. Many sites along this portion of the county will require a field visit by Planning and Zoning staff before the approval of a building permit application.

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):

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

Figure 1.

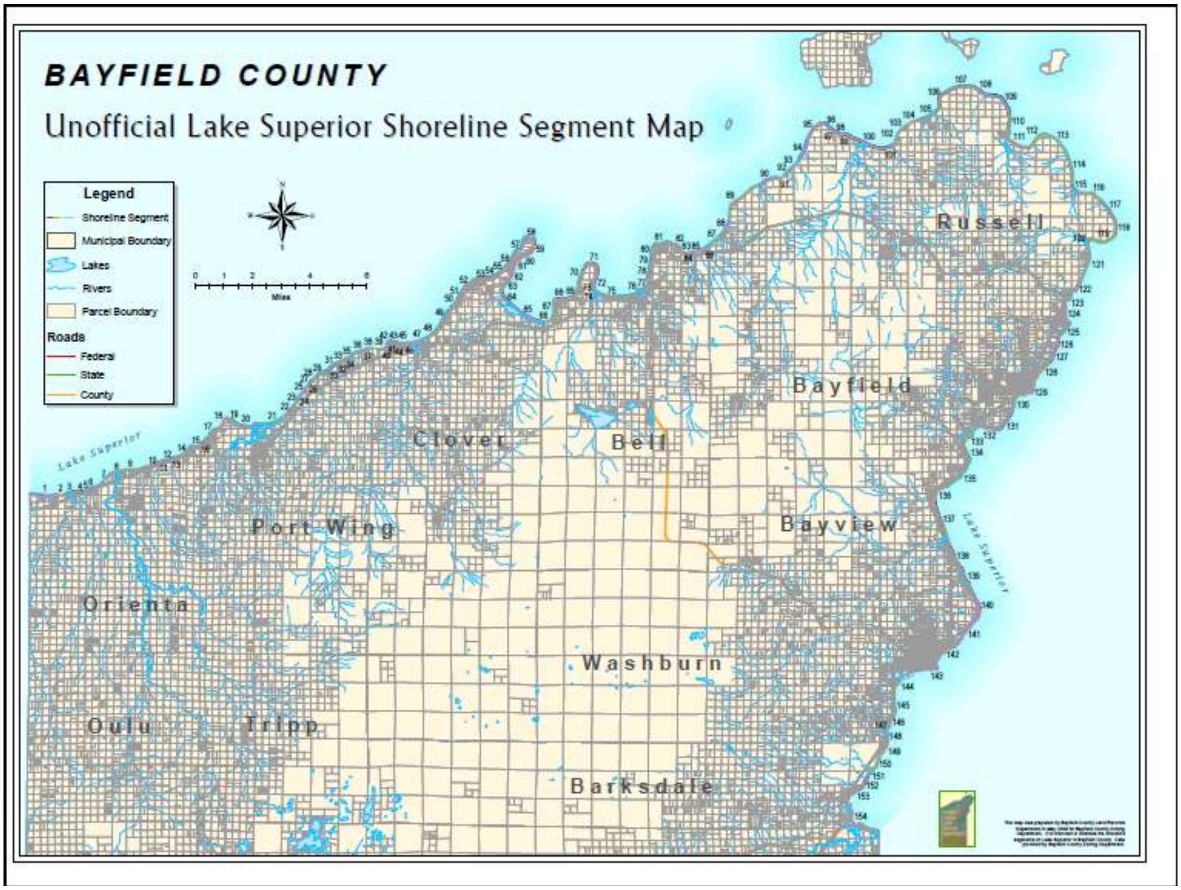


1. Stable slope setback component (SS)

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 or angles for all 154 reaches (fig. 2; see attached CD for detailed reach maps or Bayfield County web site) of shoreline in Bayfield County except for non-bluff segments.

Figure 2.

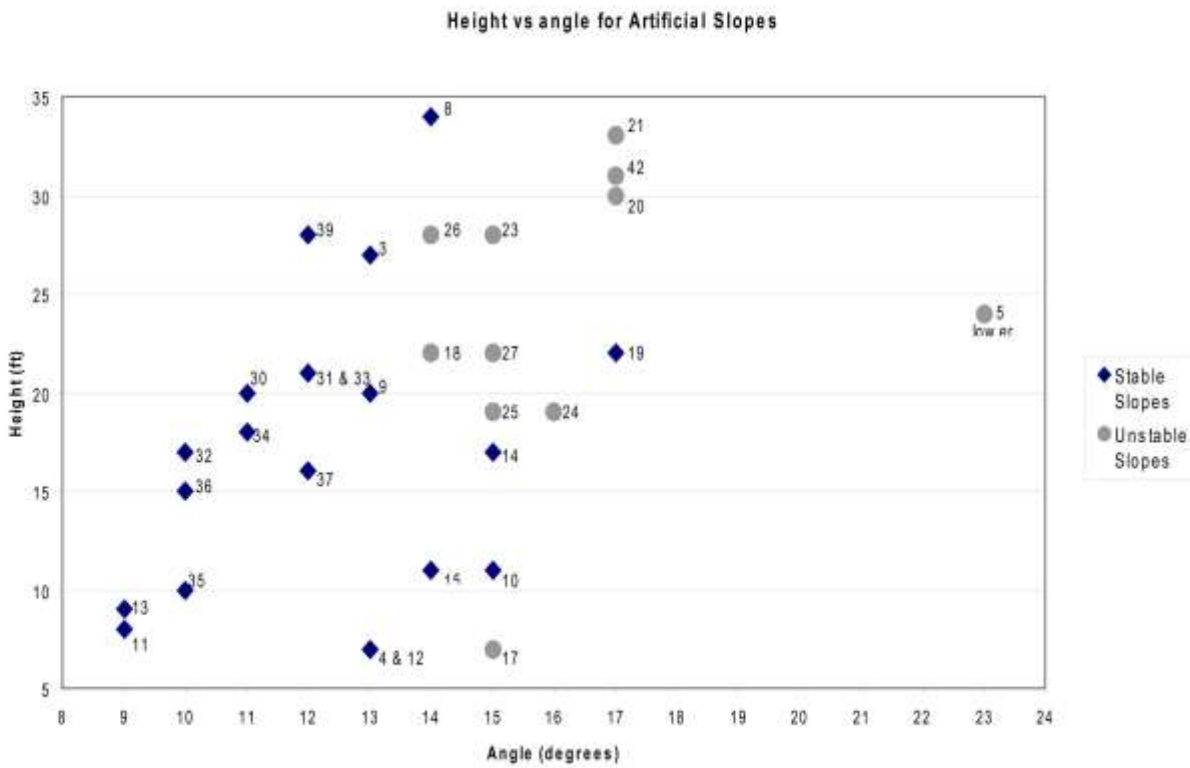


The following bluff materials types can be characterized by these stable slope angles:

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
bedrock	60	1.7321

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 3, 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 3.



Stable slopes for sandy till (26°) and sand and gravel (30°) were determined by Mickelson and are presented in Tables 1 and 2. A stable angle of 60° was chosen for bedrock. Clearly rock can stand at steeper angles for many years. But rock slopes do collapse at times. In addition, they are undercut by waves. We believe 60° is a reasonably conservative estimate, but site specific investigation might provide a better stable slope angle for rock.

The amount of stable slope setback was determined by the Bayfield County Land Records office using detailed maps with 2-foot contours obtained from LIDAR to calculate bluff height and angle. This is done in a GIS environment and more information on the details of the calculations within the GIS can be learned from the Department of Land Records. In cases where the present slope is less than the stable slope angle, there is no stable slope component of setback.

Table 1: Measured slope angles and condition of slopes for sand and gravel.

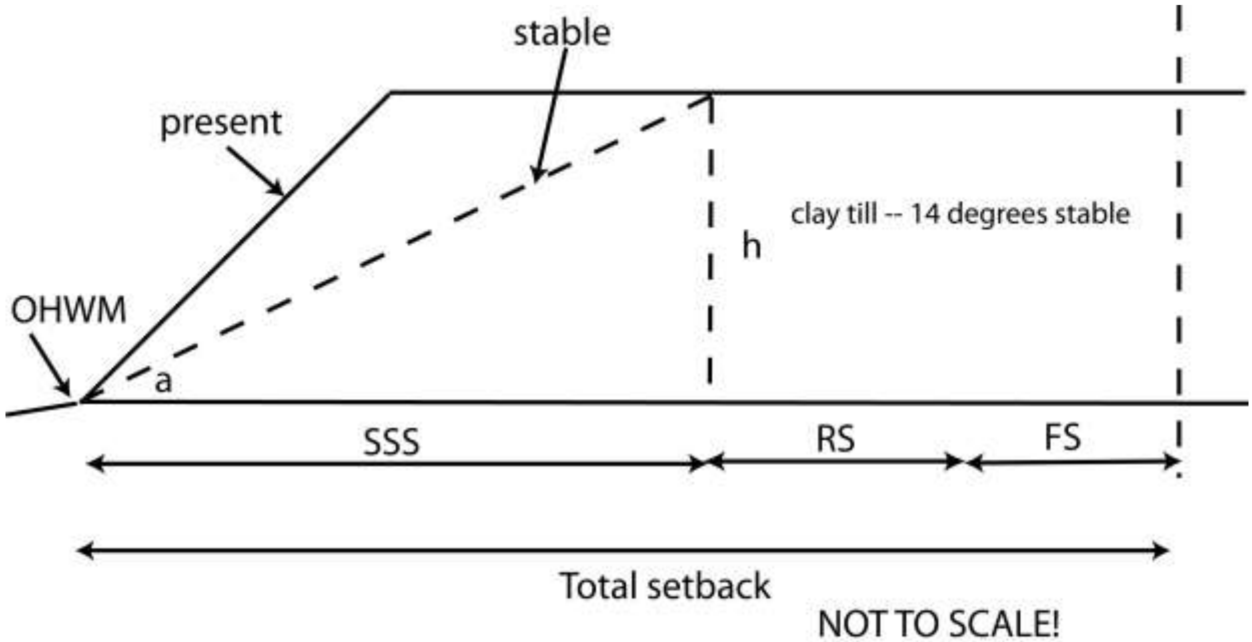
UTM-N	UTM-E	Type	Degrees	Status
5187550	629779	natural	43	unstable
5175619	650439	road cut	36	unstable
5175565	649084	cut slope	33	marginally unstable
5172143	648266	natural	33	stable
5171093	653759	natural	32	stable
5173994	654227	natural	32	marginally unstable
5172587	656496	road cut	32	stable
5172349	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

Table 2: 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	305572	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

Stable slope setback can also be calculated by hand for any site, however the bluff height and present slope angle must be known. The distance of stable slope setback is bluff height (h) divided by the tangent of angle a in figure 4.

Figure 4.

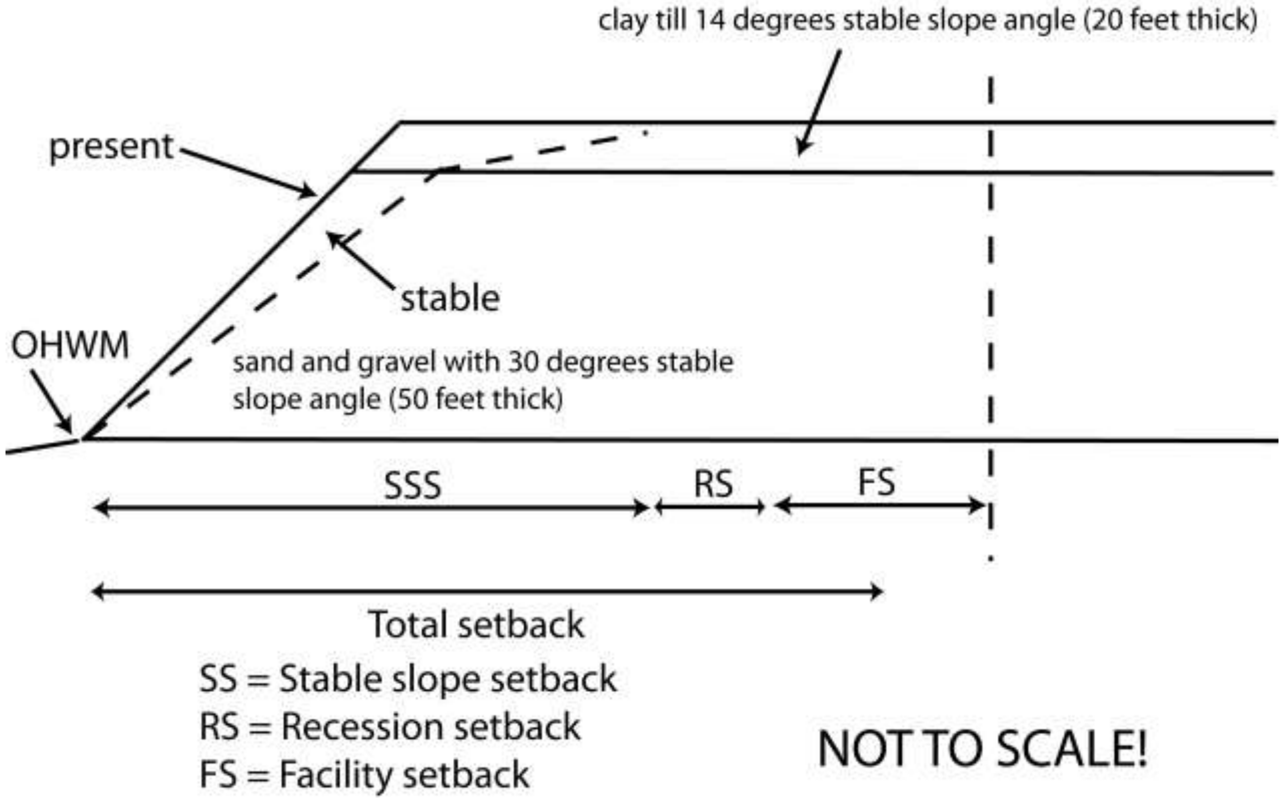


For example, in figure 4, if the bluff is 20 feet high (h=20), and composed of clayey material with a 14° stable slope (tan= 0.2493), the SS would be 20/0.2493, or 112 feet.

If in figure 4, 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 SS would be 20/0.4887, or 41 feet.

For composite bluffs, with more than one material, the percentage of each is given in Appendix 1. In that case, the setback for each material is calculated, and then they are added together. For instance in figure 5, 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.

Figure 5.



Some sites will need to be field inspected. Bedrock bluffs need to be inspected for undercutting. The distance of undercutting should be added to the setback distance after the calculation based on angle is made. Reaches with large gullies will also have to be field inspected.

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.).

All of the stable slope

2. Recession rate component (RS)

The shore recession rate was determined from the comparison of vertical air photos taken at different times. The shoreline west of Bark Point was analyzed by Benchmark (2003) using 1966 and 1999 photos. Because shoreline erosion was not as serious a problem in Bayfield County east of Bark Point, the remainder of the county was not analyzed in 2003. An engineering student (Spear, 2006) attempted to measure recession rates between 1966 and 2005. Because recession rates are all quite low it is conservatively estimated in some reaches. In areas of bedrock cliffs we know the recession rate is not zero, so we used 0.1 foot/year even though it is not measurable over the time span covered by the photos. Most of the eastern part of the county has sandy till, not the clayey till that occurs on the western side of the county.

Recession rates for each reach (Appendix 2) are an average of the measurements taken in that reach, or where numbers are very small, they are an estimate. All recession rate GIS files are on the DVD. Recession rates and recession rate setbacks using a structure life of 50 years are given in Table Appendix 2.

Some shorelines have experienced no recession. In particular, many sandy shorelines with no bluff are commonly stable over the long term. In fact, some of these shorelines are gaining sand and actually building lake-ward. For these shorelines, there would be no stable slope or recession rate setback, and the setback would be 75 feet or the predetermined standard setback distance.

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 the 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 total 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

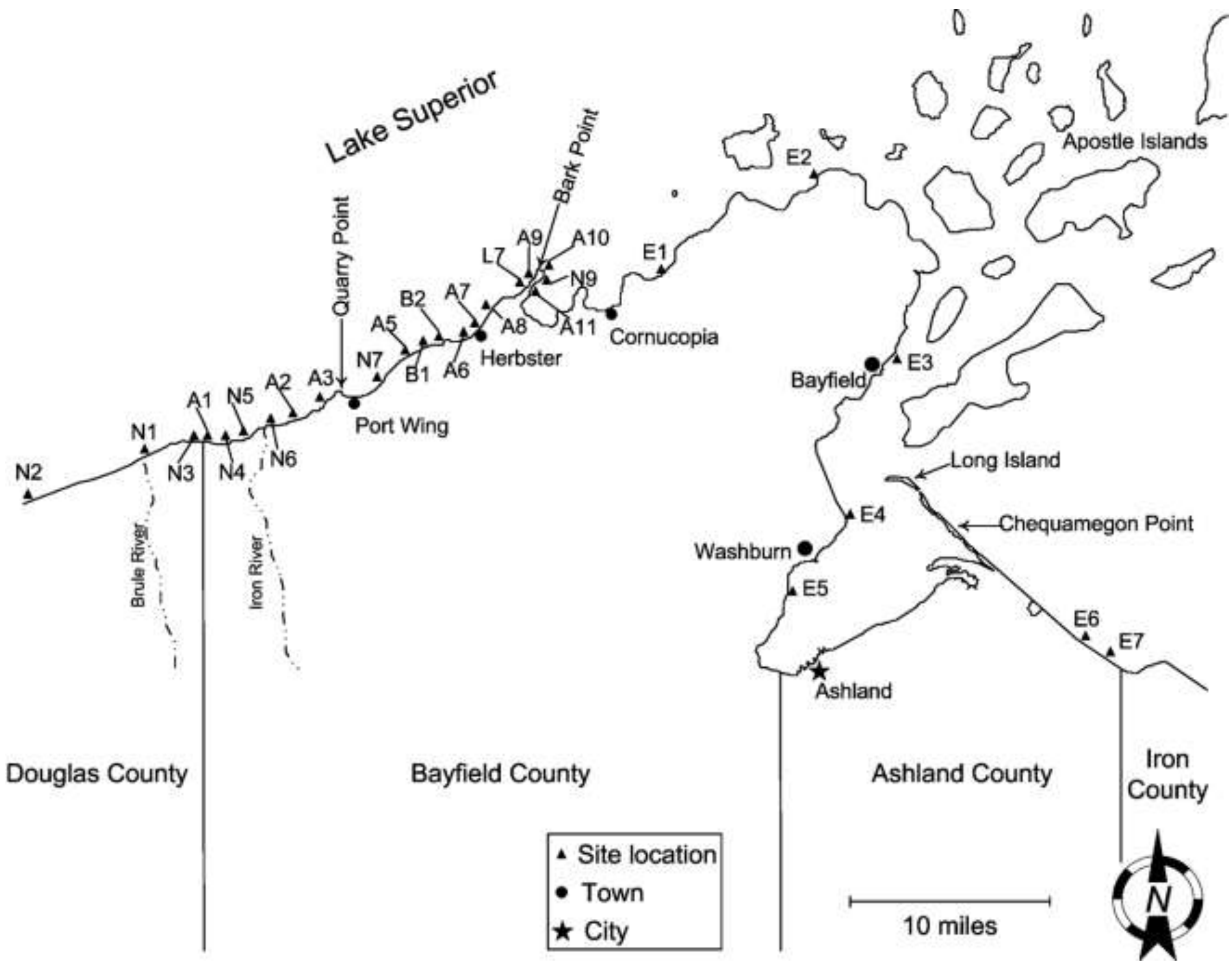
2) a 20 foot high bluff, with a recession rate of 1 foot/year, which is at 20 degrees now would have a setback from the ordinary high water mark of:

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 County 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. 6). In the future, if the 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.

Figure 6.



Status of project

As of June 15, 2011 the map showing the safe setback zone measured from the ordinary high water mark is complete. Representative setback distances from the ordinary high water mark for each shore segment are given in Table 3. Random checks have been made in the field to assure that the results are consistent with setback calculations done previously based on measurements from the bluff top. Note that the numbers in Table 3 are only representative numbers for each shore segment. 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 eastern Bayfield County is provided in figure 7 and all of the shape files are provided on the DVD. Ordinance language that incorporates the present methodology for calculating the distance of the safe setback line from the ordinary high water mark is written and will be given a public hearing in July. Individual property owners can see the map covering their parcel upon request and will be able to see it on line.

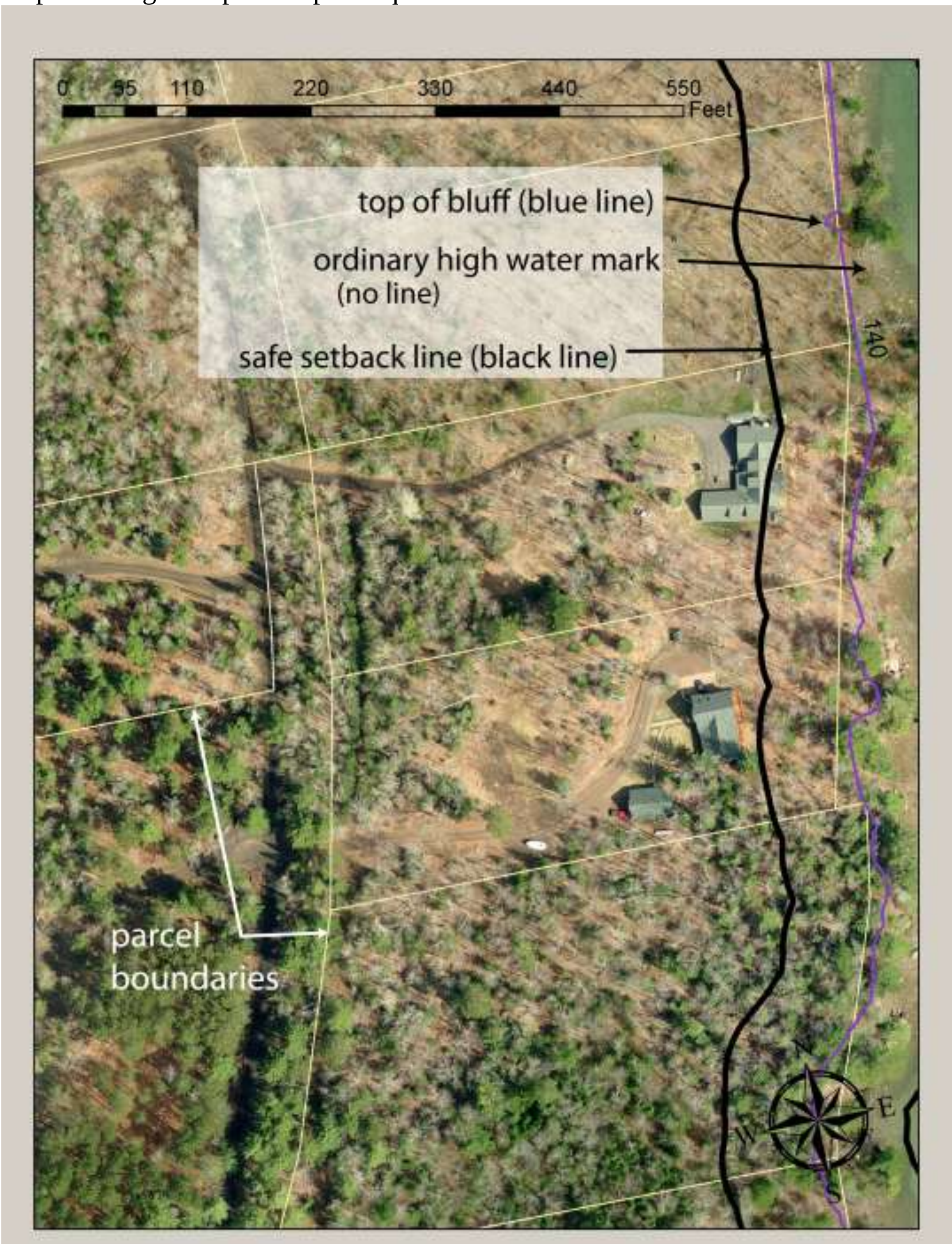


Table 3. Representative Lake Superior shoreline setbacks

Segment Number	Total Setback in feet	Segment Number	Total Setback in feet	Segment Number	Total Setback in feet	Segment Number	Total Setback in feet
1	282	40	NA	79	129	118	162
2	184	41	163	80	151	119	164
3	NA	42	242	81	142	120	113
4	260	43	149	82	175	121	160
5	205	44	269	83	260	122	181
<u>*6*</u>	*NA*	45	282	84	298	123	86
7	195	46	226	85	331	124	156
8	NA	47	233	86	NA	125	132
9	228	48	174	87	217	126	189
10	200	49	148	88	250	127	202
11	NA	50	169	89	178	128	170
12	140	51	191	90	164	129	NA
13	150	52	175	91	NA	130	152
14	130	53	402	92	170	131	142
15	148	54	353	93	242	132	160
16	200	*55*	*216*	94	206	133	100
17	140	*56*	*129*	95	132	134	NA
18	133	57	132	96	160	135	138
19	130	58	125	97	125	136	153
20	171	59	142	98	193	137	85
21	80	60	121	99	337	138	NA
22	116	61	180	100	82	139	NA
23	240	62	210	101	125	140	133
24	NA	63	198	102	214	141	NA
25	210	64	79	103	209	142	145
26	NA	65	80	104	154	143	NA
27	286	66	80	105	183	144	82
28	NA	67	312	106	180	NA	174
29	253	68	203	107	160	NA	140
30	NA	69	212	108	194	147	160
31	340	70	161	109	161	148	151
32	NA	71	155	110	178	149	116
33	328	72	200	111	113	150	127
34	354	73	195	112	147	151	193
35	NA	74	79	113	184	152	85
36	420	75	80	114	193	153	100
37	NA	76	80	115	80	154	83
38	547	77	159	116	160		
39	341	78	200	117	170		

NA = Contact Planning & Zoning Department for on site determination.

<u>*Note: These are representative numbers. Consult the Shoreline Safe Setback map for site specific setback distances.*</u>

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Appendix 1. Characteristics of shoreline reaches in Bayfield County. Stable angle of material and percent of bluff height made up of that material is also shown (updated 6/15/11).

Reach #	Township	Range	Section	Stable Angle of Material	% of bluff height that is material 1	% of bluff height that is material 2	Material one stable angle	Material two stable angle	Notes:
1	49	9	6	14	1	0	14	na	clay till
2	49	9	5	14	1	0	14	na	clay till
3	49	9	5	14	1	0	14	na	stream mouth
4	49	9	5	14	1	0	14	na	clay till
5	49	9	4, 33	14	1	0	14	na	clay till
6	49	9	4, 33	14	1	0	14	na	no bluff
7	49, 50	9	4, 33	14	1	0	14	na	clay till
8	50	9	34	14	1	0	14	na	stream mouth
9	50	9	34	14	1	0	14	na	clay till
10	50	9	35	50%14/50%26	0.5	0.5	14	26	clay till/sandy till
11	50	9	35	no bluff	0	0	na	na	stream mouth
12	50	9	35	25%14/75%30	0.25	0.75	14	30	clay till/sand
13	50	9	25, 36	25%14/75%30	0.25	0.75	14	30	clay till/sand
14	50	9	25, 36	50% 14/50% 30	0.5	0.5	14	30	clay till/disturbed bedr
15	50	9	25, 36	30% 14/70% 30	0.3	0.7	14	30	clay till/disturbed bedr
16	50	8	30, 19	20% 14/80% 30	0.2	0.8	14	30	clay till/sand and grav
17	50	8	30, 19	20% 14/80% 60	0.2	0.8	14	60	clay till/rock
18	50	8	30, 19	30% 14/70% 60	0.3	0.7	14	60	clay till/rock
19	50	8	20	30% 14/70% 60	0.3	0.7	14	60	clay till/rock
20	50	8	20	no bluff	0	0	na	na	terrace
21	50	8	21	no bluff	0	0	na	na	terrace
22	50	8	22, 15	no bluff	0	0	na	na	terrace
23	50	8	22, 15	30	1	0	30	na	sand
24	50	8	22, 15	gully	0	0	na	na	gully
25	50	8	22, 15	30	1	0	30	na	sand
26	50	8	22, 15	gully	0	0	na	na	gully
27	50	8	22, 15	30	1	0	30	na	sand
28	50	8	22, 15	gully	0	0	na	na	gully
29	50	8	14, 11	10%14/90%30	0.1	0.9	14	30	clay till/sand and grav
30	50	8	14, 11	gully	0	0	na	na	gully
31	50	8	14, 11	10%14/90%30	0.1	0.9	14	30	clay till/sand and grav

32	50	8	14, 11	gully	0	0	na	na	gully
33	50	8	14, 11	10%14/90%30	0.1	0.9	14	30	clay till/sand and grav
34	50	8	12	10%14/90%30	0.1	0.9	14	30	clay till/sand and grav
35	50	8	12	gully	0	0	na	na	gully
36	50	8	12	10%14/90%30	0.1	0.9	14	30	clay till/sand and grav
37	50	8	12	gully	0	0	na	na	gully
38	50	7	12	10%14/90%30	0.1	0.9	14	30	clay till/sand and grav
39	50	7	7, 6	10%14/90%30	0.1	0.9	14	30	clay till/sand and grav
40	50	7	7, 6	gully	0	0	na	na	gully
41	50	7	7, 6	10% 14/90% 30	0.1	0.9	14	30	clay till/sand and grav
42	50	7	7, 6	25% 14/75% 30	0.25	0.75	14	30	clay till/sand and grav
43	50	7	7, 6	50% 30/50% 60	0.5	0.5	30	60	clay till/rock
44	50	7	7, 6	20%14/80%30	0.2	0.8	14	30	clay till/sand and grav
45	50	7	8, 5	30% 14/70% 30	0.3	0.7	14	30	clay till/sand and grav
46	50	7	8, 5	30% 14/70% 30	0.3	0.7	14	30	clay till/sand and grav
47	50	7	8, 5	na	0	0	na	na	stream mouth
48	50	7	4, 33	30	1	0	30	na	sand terrace
49	50, 51	7	4, 33	50% 26/50% 30	0.5	0.5	26	30	clayey sand/sand
50	51	7	4, 33	50% 26/50% 30	0.5	0.5	26	30	clayey sand/sand and g
51	51	7	27, 34	25% 26/75% 30	0.25	0.75	26	30	clayey sand/sand and g
52	51	7	27, 34	25% 26/75% 30	0.25	0.75	26	30	clayey sand/sand and g
53	51	7	27, 34	10% 26/90% 30	0.1	0.9	26	30	clayey sand/sand and g
54	51	7	26	80% 30/20%26	0.8	0.2	30	26	sand /clayey sand
55	51	7	26	30	1	0	30	na	sand
56	51	7	26	26	1	0	26	na	clayey sand
57	51	7	24	25% 14/75% 26	0.25	0.75	14	26	clay till/clayey sand
58	51	7	24	20% 26/80% 60	0.2	0.8	26	60	clayey sand/rock
59	51	7	24	26	1	0	26	na	clayey sand
60	51	7	24	26	1	0	26	na	clayey sand
61	51	7	25	26	1	0	26	na	clayey sand
62	51	7	26, 35	20% 14/80% 26	0.2	0.8	14	26	clay till/clayey sand
63	51	7	26, 35	20% 14/80% 26	0.2	0.8	14	26	clay till/clayey sand
64	51	7	26, 35	no bluff	0	0	na	na	beach/lagoon
65	50, 51	6	36, 1	no bluff	0	0	na	na	beach/lagoon
66	50	6	31, 6	no bluff	0	0	na	na	beach/lagoon
67	50, 51	6	31, 6	26	1	0	26	na	Jardine Cr. Till
68	51	6	31, 6	25%26/75%30	0.25	0.75	26	30	Jardine Cr. Till/broken
69	51	6	32	60	1	0	60	na	rock
70	51	6	29	60	1	0	60	na	rock
71	51	6	29	60	1	0	60	na	rock
72	51	6	29	20% 26/80% 60	0.2	0.8	26	60	jardine Cr. Till/rock
73	51	6	32	26	1	0	26	na	Jardine Cr.
74	51	6	32	no bluff	0	0	na	na	stream mouth
75	51	6	33	no bluff	0	0	na	na	beach/lagoon
76	51	6	34a	no bluff	0	0	na	na	beach
77	51	6	27	no bluff	0	0	na	na	beach
78	51	6	27	60% 14/40% 60	0.6	0.4	14	60	clay till/rock
79	51	6	27	40%14/60%60	0.4	0.6	14	60	clay till/rock
80	51	6	22	40%14/60%60	0.4	0.6	14	60	clay till/rock
81	51	6	23	60	1	0	60	na	rock

82	51	6	23	50% 14/50% 60	0.5	0.5	14	60	clay till/rock
83	51	6	24	14	1	0	14	na	clay till
84	51	6	24	no bluff	0	0	na	na	stream mouth
85	51	6	24	14	1	0	14	na	clay till
86	51	6	24	14	1	0	14	na	clay till
87	51	5	19	14	1	0	14	na	clay till
88	51	5	18	60% 14/40%60	0.6	0.4	14	60	clay till/rock
89	51	5	18, 7, 8	60	1	0	60	na	all rock
90	51	5	8, 9	30%14/70%60	0.3	0.7	14	60	clay till/rock
91	51	5	9	14	1	0	14	na	clay till
92	51	5	4, 9	14	1	0	14	na	clay till
93	51	5	3	14	1	0	14	na	clay till
94	51	5	3	14	1	0	14	na	clay till
95	52	5	34	60	1	0	60	na	rock
96	52	5	35	no bluff	0	0	na	na	beach
97	52	5	35	14	1	0	14	na	clay till
98	52	5	35	no bluff	0	0	na	na	beach
99	52	5	35	14	1	0	14	na	clay till
100	52, 51	5	36, 1	no bluff	0	0	na	na	beach, marsh
101	51	4	6	14	1	0	14	na	clay till
102	52	4	31	14	1	0	14	na	clay till
103	52	4	31	80%14/20%60	0.8	0.2	14	60	clay till/rock
104	52	4	32	50%14/50%60	0.5	0.5	14	60	clay till/rock
105	52	4	32, 29, 28	no bluff	0	0	na	na	beach
106	52	4	28	14	1	0	14	na	clay till
107	52	4	28, 21, 22, 27	80%14/20%60	0.8	0.2	14	60	clay till/rock
108	52	4	41	30	1	0	30	na	sand
109	52	4	27, 26	60	1	0	60	na	rock
110	52	4	26, 35	50%14/50%60	0.5	0.5	14	60	clay till/rock
111	52	4	35, 1, 2	no bluff	0	0	na	na	Raspberry Bay
112	51, 52	3,4	1, 36	60	1	0	60	na	rock
113	51, 52	3,4	6, 31	50%14/50%60	0.5	0.5	14	60	clay till/rock
114	51	3	6	60	1	0	60	na	all rock
115	51	3	7	no bluff	0	0	na	na	Frog Bay
116	51	3	8	60	1	0	60	na	rock
117	51	3	16, 17	60	1	0	60	na	rock
118	51	3	21, 16	60	1	0	60	na	rock
119	51	3	20, 21	60	1	0	60	na	rock
120	51	3	20	no bluff	0	0	na	na	Red Cliff Bay
121	51	3	20, 29	60	1	0	60	na	all rock
122	51	3	31	50%14/50%60	0.5	0.5	14	60	clay till/rock
123	51	3	31	14	1	0	14	na	Red Cliff Village
124	50	3	6	14	1	0	14	na	rock
125	50	3	6	no bluff	0	0	na	na	sand
126	50	3	7	26	1	0	26	na	sandy till
127	50	3	7	no bluff	0	0	na	na	sand
128	50	4	13	26	1	0	26	na	sandy till
129	50	4	13, 14	no bluff	0	0	na	na	Bayfield
130	50	4	14, 23	50%14/50%60	0.5	0.5	26	60	sandy till/rock
131	50	4	23	60	1	0	60	na	rock undercut

132	50	4	22	26	1	0	26	na	sandy till
133	50	4	21, 22	no bluff	0	0	na	na	sand
134	50	4	34	alt. clay-rock	field	determine			alternating rock and ti
135	50	4	33	60	1	0	60	na	undercut
136	49	4	4, 5	26	1	0	26	na	protected
137	49	4	5, 9, 16	no bluff	0	0	na	na	sand
138	49	4	16	alt. clay-rock	field	determine			alternating rock and ti
139	49	4	22, 21	alt. clay-rock	field	determine			alternating rock and ti
140	49	4	22, 27	60	1	0	60	na	rock, some undercut
141	49	4	27, 33	alt. clay-rock	field	determine			alternating rock and ti
142	49	4	33	50%14/50%60	0.5	0.5	26	60	sandy till/rock
143	49	4	5	no bluff	0	0	na	na	Washburn
144	48	4	6, 7	no bluff	0	0	na	na	sand
145	48	4	7, 18	50%14/50%60	0.5	0.5	26	60	sandy till/rock
146	48	4	18	50%14/50%60	0.5	0.5	26	60	sandy till/rock
147	48	4	18	26	1	0	26	na	sandy till
148	48	4	18	26	1	0	26	na	sandy till
149	48	4	19, 24	26	1	0	26	na	sandy till
150	48	4	24, 25	26	1	0	26	na	sandy till
151	48	4	25	no bluff	0	0	na	na	sand
152	48	4	25	no bluff	0	0	na	na	stream mouth
153	48	4	25	no bluff	0	0	na	na	sand
154	48	4	25, 26, 32	no bluff	0	0	na	na	wetland

Appendix 2. Recession rates for each reach where it can be measured. NA indicates a stream
or gully mouth where recession is difficult to measure and where building is unlikely.
Recession rate setback uses 50 year time span (annual rate x 50). "na" indicates field visit will be required, but most are stream mouths where no one will build.

Reach #	estimated recession rate (ft/yr)	recession rate setback	Reach #	estimated recession rate (ft/yr)	recession rate setback
1	2	100	44	1	50
2	0.5	25	45	1	50
3	NA	na	46	1	50
4	1.5	75	47	NA	na
5	1	50	48	0.5	25
6	NA	na	49	0.5	25
7	1	50	50	0.5	25
8	NA	na	51	1	50
9	2	100	52	1	50
10	1.5	75	53	1	50
11	NA	na	54	0.5	25
12	0.5	25	55	0.5	25
13	0.5	25	56	0.5	25
14	0.5	25	57	0.5	25
15	0.5	25	58	1	50
16	1	50	59	0.5	25
17	0.5	25	60	0.5	25
18	0.5	25	61	1.5	75
19	0.5	25	62	1.5	75
20	0.5	25	63	1	50
21	0.5	25	64	0.1	5
22	0.5	25	65	0.1	5
23	0.5	25	66	0.1	5
24	NA	na	67	0.5	25
25	0.5	25	68	0.5	25
26	NA	na	69	1	50
27	1	50	70	1	50
28	NA	na	71	0.5	25
29	1	50	72	0.5	25
30	NA	na	73	0.5	25
31	1	50	74	0.1	5
32	NA	na	75	0.1	5
33	0.5	25	76	0.1	5
34	0.5	25	77	0.1	5
35	NA	na	78	0.5	25

36	1	50	79	0.5	25
37	NA	na	80	0.5	25
38	0.5	25	81	0.5	25
39	0.5	25	82	1	50
40	0.5	25	83	1.5	75
41	0.5	25	84	0.1	5
42	0.5	25	85	0.1	5
43	0.5	25	86	0.1	5