Bluff Erosion Monitoring on Puget Sound:

A Guide for Volunteers

BEACH WATCHERS

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1998

In cooperation with:

Island County
Washington State University
Beach Watchers

Island County
Department of Public Works

Washington Department of Ecology
Shorelands and Environmental
Assistance Program
Ecology Publication No. 98-122

Acknowledgments

The idea for a training guide and field testing was enthusiastically received by Beach Watcher organizers, Susan Berta, Program Director, and Don Meehan, Washington State University Extension Agent, as well as by many of the volunteers. Eric Nussbaum and other Island County Beach Watchers made helpful suggestions. Mike Morton, then Shoreline Planner for Island County, also offered encouragement. Lew Legat, Assistant County Engineer, presented the idea to the Island County Commissioners and later administered that portion of the project. Commissioners Mike Shelton, Mac McDowell, and Tom Shaughnessy approved seed money for the project.

Alice Schisel, Washington Department of Ecology, diligently pursued the additional funding from NOAA that made this project possible. Ecology's Shorelands and Environmental Assistance Program, through Douglas Canning, provided valuable suggestions and a "reality check" on the schedule.

Connie Manson, Rebecca Christie, Janet Phillips, and Keith Kaler of the Department of Natural Resources provided copies of important reference materials. Kitty Reed, Editor for DNR's Geology and Earth Resources Division, provided encouragement, advice, and valuable editing assistance.

Beryl Thorsen provided essential field and office support as well as prodding and encouragement throughout the project.

All photographs by Gerald Thorsen, unless otherwise noted.

This report manual was funded in part through a cooperative agreement with the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

The recommended bibliographic citation for this publication is:

Thorsen, Gerald, and Shipman, Hugh. 1998. *Bluff Erosion Monitoring on Puget Sound: A Guide for Volunteers*. Shorelands and Environmental Assistance Program, Washington Department of Ecology, 79 pages [prepared for Island County Beach Watchers].

FOREWORD

Erosion of Puget Sound's coastal bluffs is slow enough that few lives are at serious risk. On the other hand, population growth in this region, combined with the popularity of view property, results in ever-increasing pressure to build houses along bluff tops. Homes that appear to be safe today may be on the beach in 50 years. Expensive lots may become worthless in much less time.

What we learn about bluff erosion rates through this monitoring program can increase our understanding of natural shoreline process and can provide a solid basis for anticipating future risks to coastal properties. Measuring the rate of retreat can be difficult, however, and it requires both knowledge and persistence. Deciding where to measure, what to measure, and how to measure is not always straightforward. Maintaining records long enough to observe a measurable change, let alone determine a long-term rate, requires good record-keeping and patience. During most years, nothing measurable happens.

We hope this guide will enhance your understanding of local erosional processes and help you be better informed about shoreline development policies and practices. Although this guide was developed and tested on Whidbey and Camano Islands, it is generally applicable to other non-bedrock bluff shorelines around Puget Sound, the Strait of Georgia, and the Strait of Juan de Fuca.

We encourage you to apply what you learn in this guide to your favorite shoreline and, please, let us know what you find.

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INTRODUCTION

We prepared this booklet as an aid to the Island County WSU "Beach Watchers" as they begin their new program to monitor the rate of erosion of shoreline bluffs. This group of volunteers, organized and trained through the cooperative efforts of the county and Washington State University Extension, will field test this manual. Together, we hope to (1) refine this guidebook, (2) begin this program of bluff erosion monitoring in Island County, and (3) demonstrate a methodology that can be useful throughout Puget Sound coastal area.

Our intent was to develop a guidebook that could stand alone without supplemental references. With the booklet and an appropriate measuring **tape** the average person should be able to compile data that could eventually be very useful for themselves as well as the general public. However, for efforts beyond an individual homesite, we encourage a group approach, not only to help in planning and safety but to provide the essential continuity.

We chose in the title of this guide to use the term Puget Sound in its broadest sense to describe the marine waters of the Strait of Georgia, the Strait of Juan de Fuca, and other parts of Washington's Inland Sea, including those limited portions originally designated by George Vancouver as Puget Sound.

Discussion

About 665 miles of actively eroding bluffs fringe the 2,000 miles of inland marine shorelines of northwestern Washington (Coastal Zone Atlas series, Washington Department of Ecology, 1978-80). These bluffs are cut in **sediments** laid down during and between advances of glaciers and commonly exceed 200 feet in height. They include 135 miles of large landslides, both active and dormant. Hundreds of other slides were too small to show at the **scale** of the atlases (1 inch = 2,000 feet). Each year, such landslides and other forms of erosion cause hundreds of thousands of dollars in property damage and indirect loss of value.

Island County provides an excellent sample of Washington's coastal erosion problems. The county's approximately 200 miles of shoreline include bluffs more than 300 feet high, along which estimated erosion rates range from a fraction of an inch to more than 2 feet per year. The spectacular views and access to beaches make the county one off the most rapidly growing areas in the state. Demand for such property means more and more pressure to build on difficult sites.

To evaluate land use along eroding shoreline bluffs we need to get a human perspective of the natural geologic processes. To begin with, we need a time unit long enough for noticeable erosion to occur but also short enough that changes due to erosion might be recorded during a lifetime. A decade is a time span too short for noticeable change in areas where erosion is slow. A generation, though longer, is too vague a term. We propose a new time unit, a "mortgage", and hereby define it as 30 years.

Among those who might be concerned about erosion during the time span of one mortgage, and why, are:

- The homeowner: Should I be concerned about erosion? What can I do about it?
- The lot purchaser: Will my lot still be buildable when I retire?
- The investor: Could the property be a loss when the kids need college money?
- The real estate professional: Will this property meet the needs of this particular client?
- The developer: Assuming a prudent setback, what is the minimum depth for my bluff-edge lots?
- The contractor: How long will this beach stairway last (i.e., when might it be damaged by erosion)?
- The engineer: When will this road or utility corridor require protection or relocation?
- The banker: Will the property value be here as long as the term of the mortgage?
- The insurance agent: Is landslide insurance an option, and at what cost?
- The building official: What is a safe building setback?
- The tax assessor: Is this property really a potential homesite, or should it be taxed as "recreation only"?

Bluff erosion monitoring won't be easy. Like pioneering in other fields of observing natural phenomenon, for example, weather, stream flow (flooding), or tides, there are few opportunities for instant gratification. A body of data must first be accumulated. The toughest part of such studies is establishing what is normal, the baseline. The difficulty of this chore is compounded by the fact that erosion, like other natural phenomena, is commonly episodic rather than gradual.

As with other monitoring of natural on-site phenomena, you, the local observer of bluff erosion, have advantages over the government or academic researcher trying to do this work from afar:

- You have no travel or lodging expenses.
- You can quickly respond to major erosional events such as storms or landslides.
- You can revisit a site at optimum conditions of weather and tide.
- You have a personal interest in your territory, which can make the work fun.
- Your friends and neighbors can readily take over when you are away.

Before we get into some basic geological concepts and monitoring techniques, we want to alert you to the glossary. Terms that are in bold type in the booklet text are discussed in the glossary; those pages may provide you a better understanding of some of the subjects in this guide.

Previous Work

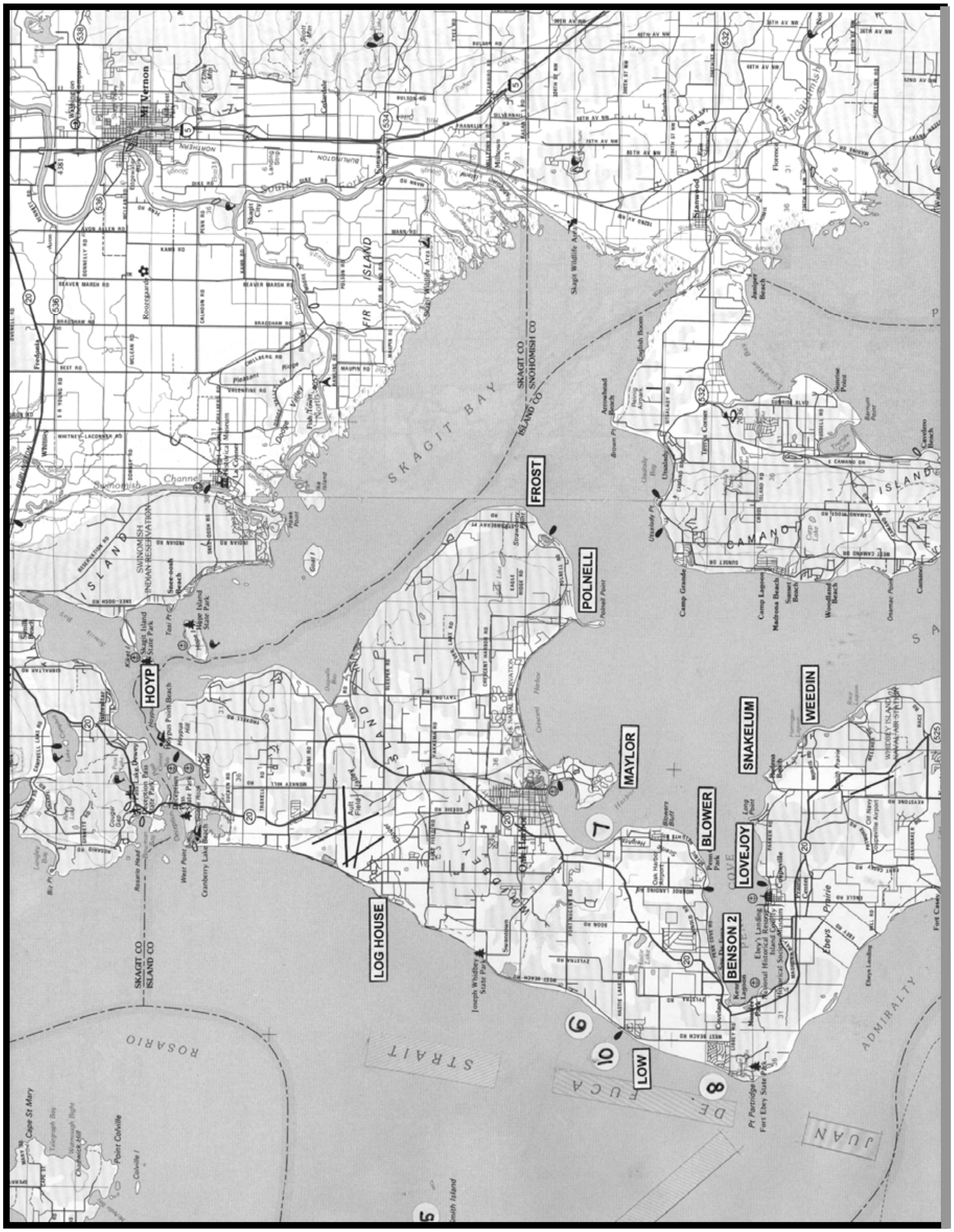
The only published study of erosion rates that includes Island County shorelines (Keuler, 1988) does not extend south of Mutiny Bay (latitude $48^{o}00'$). Fifteen unpublished measurements by Paul Heller, including one on Camano Island and two data points south of Keuler's study area, are included in Table 1. Some of these sites are indicated in Figure 1. Both Keuler's and Heller's studies were based largely on direct measurements from the same reference points, monuments that were emplaced by surveyors of U.S. government agencies. Some of the limitations of using such reference points are discussed in the section about Site Selection.

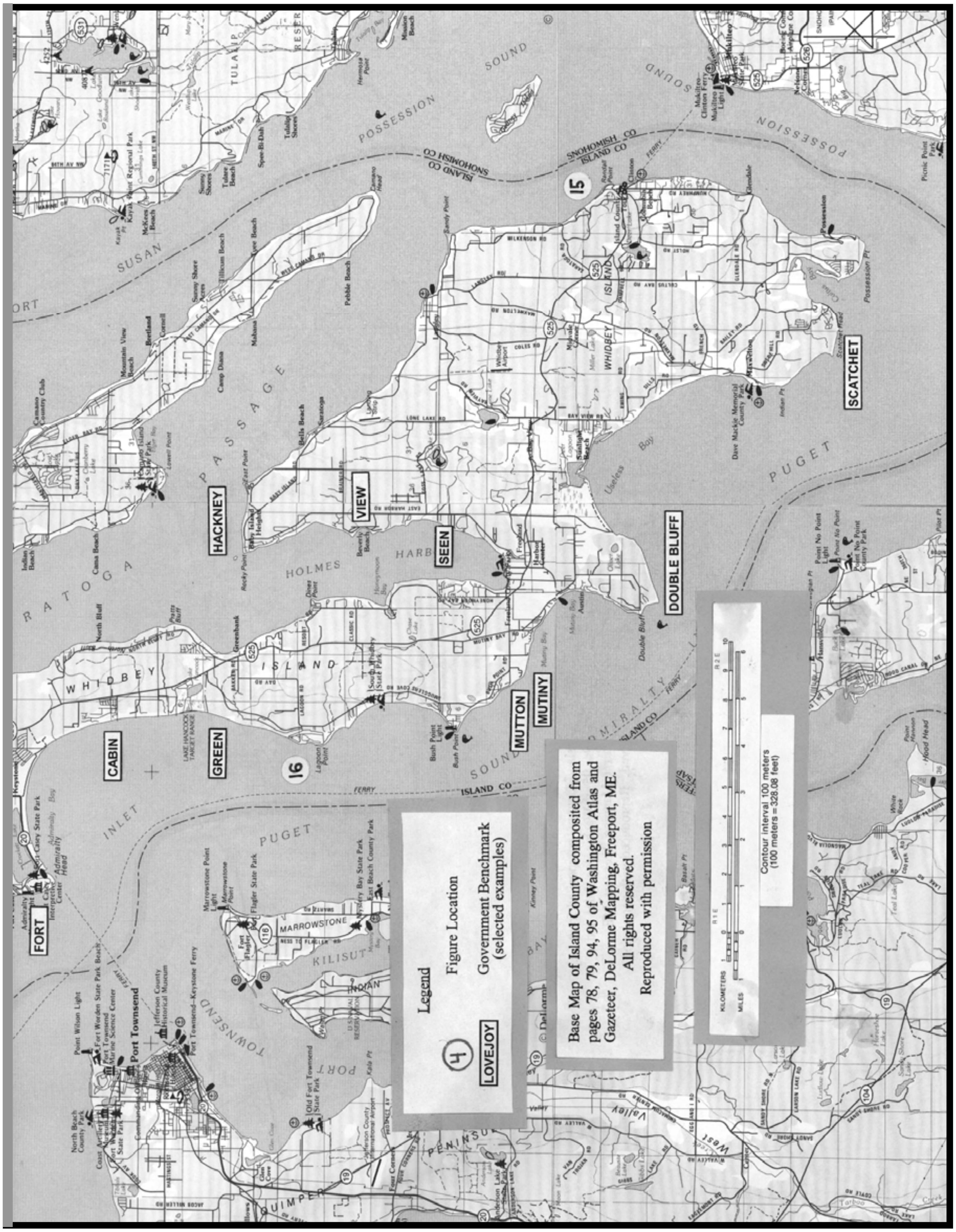
Table 1. Some established survey stations and erosion rates

Station name	**Site position**	**Date est.**	**Dist. (ft)**	**Last meas'd**	**Dist. (ft)**	**Erosion (ft/yr)**	**Comment**
Benson 2	Bluff top	1944	10.5	1977	8.0	.0761	
Blower	Bluff top	1920	6.0	1977	<1 ft??	0.162	Av. based on 1944 msmt.
Double Bluff	Bluff top	1921	16.4	1977	6'5"	0.198	Av. based on '27-'77 msmt.
Frost	?	1939	25.0	1977	30.0	0.132	Much veg.; 1939 dist. underestimated?
Green	Bluff top	1960	20.0	1977	20.0	0?	"Difficult to measure"
Libby #1	Bluff top	1952	13.0	1977	9.0	0.016	One of two Libby
Loghouse	Bluff top	1951	18.0	1977	5.5	0.48	Check for small slides
Lovejoy	Bluff top	1920	5.0	1977	4.4	0.01	Till at top
Low	Beach	1940	15.0	1977	46.0	0.837	Seems excessive; boulder moved?
Mayor 2	Bluff top	1924	5.0	1952	3.0	0.071	Eroded away in 1977
Munroe	Bluff top	1920	23.0	1960	18.0	0.125	Couldn't find in brush 1977
Mutiny	Bluff top	1934	10.0	1969	3.5	0.185	Couldn't find in 1977
Pom	Bluff top	1942	52.0	1995	30.0	0.42	Not found in '77; dense brush
				1997	22.4		
Rockwell	Bluff top	1944	8.0	1964	4.0	0.20	Not checked in 1977
Scatchet	Beach	1921	98.0	1961	142.0	1.1	Reported destroyed 1966
Snakelum	Bluff top	1920	6.0	1977	5.5	0.008	Vegetated bank +/- 40 degrees
Tidal	Beach	1952	6.0	1977	17.5	0.460	Small slides
View	Beach	1943	25.0	1977	40.0	0.441	"Up to 50'"

It should be emphasized that the location of government survey monuments is commonly chosen for ease of access and maximum visibility from other sites in the survey network, not for erosion monitoring purposes. The relatively few established sites that might be usable for bluff erosion monitoring commonly have limitations due to extensive gaps, commonly of more than 10 miles, between stations (Figure 1). (Neither study shows a useable site on eastern Camano Island.) Also, some locations are not representative of local geology or wave action.

Figure 1. Map of Island County showing selected survey monuments and photo locations.





Legend
Figure Location
Government Benchmark (selected examples)
LOVEJOY
Base Map of Island County composited from pages 78, 79, 94, 95 of Washington Atlas and Gazeteer, DeLorme Mapping, Freeport, ME.
All rights reserved.
Reproduced with permission
Contour interval 100 meters (100 meters = 328.08 feet)
FORT
CABIN
GREEN
HACKNEY
VIEW
SEEN
MUTTON
MUTINY
DOUBLE BLUFF
SCATCHET
15
16

Reliable erosion rates have been obtained elsewhere by measuring the changes shown on maps or aerial photos over a succession of years. This technique can work if one has a sequence of photos or maps that:

- are detailed and accurate (scale of 1 inch = 1,000 ft or larger)
- have permanent landmarks close to the bluff
- show areas of rapid (greater than 4 inches per year?) erosion
- cover a long time span (at least 50 years?)

Such photos or map sequences are available for few if any Puget Sound bluffs.

GLACIAL HISTORY

Continental glaciation shaped Puget Sound as well as the Straits of Georgia and Juan de Fuca. The present topography of the floors of those inlets and their adjacent **uplands** was either carved by the ice itself or by water that melted from the ice or was built up by deposits left by such meltwater. About the only significant exceptions are our modern (post-glacial) shoreline bluffs, beaches, and river-valley bluffs and flood plains, which were shaped by marine wave action and by rivers and streams.

Ice sheets from Canada moved south into lowland areas of northwest Washington and southeastern British Columbia at least three, and possibly half a dozen times. Each of these episodes rearranged the landscape and eroded much of the sediment left by the passage of earlier glaciers. The geologic record of the most recent glaciation is the best preserved of these events, so we will focus on it.

This glaciation, called the Fraser (after the river and valley in Canada), deposited Vashon sediments (named for the island in Puget Sound where they were first described) throughout the lowlands of northwest Washington. Geologists might indicate on their maps where such deposits are found by areas labeled as Qvt (Quaternary Vashon **till**).

Organic debris, like wood, bark, or even shells, have provided radiocarbon dates that indicate that, during the Fraser glaciation, ice reached the Fraser Lowland along the international boundary between 20,000 and 21,000 years ago. The ice tongue that extended down Puget Sound (the Puget lobe) reached its limit, south of Olympia, between 14,000 and 15,000 years ago (Figure 2).

This ice front averaged a (geologically) breathtaking speed of about 130 feet per year as it moved south in those 6,000 years. As the ice broke up, it retreated to Canada at about the same speed. However, we need to keep that rate in perspective. Probably ten or more consecutive old-growth forests could grow and die in 6,000 years. The mammoth who lived in the Fraser Lowland, or their descendants, had ample time to migrate to Whidbey and Vancouver Islands, where their remains are now found, ahead of the advancing ice.

In places, such migrations could have been made easier by geologic processes of the time. Note the thickness of the glacial **outwash** sand that forms the mid-bluff **slope** in the cover photo. Such sands are deposited as broad blankets ("sandurs" in Iceland) by the sediment-laden streams of meltwater flowing from the advancing ice. The sediments tend to fill depressions and level the terrain into a broad plain. Thus, the deep marine inlets of the region did not exist during this time. Animals could cross the landscape without encountering the barriers we have today.

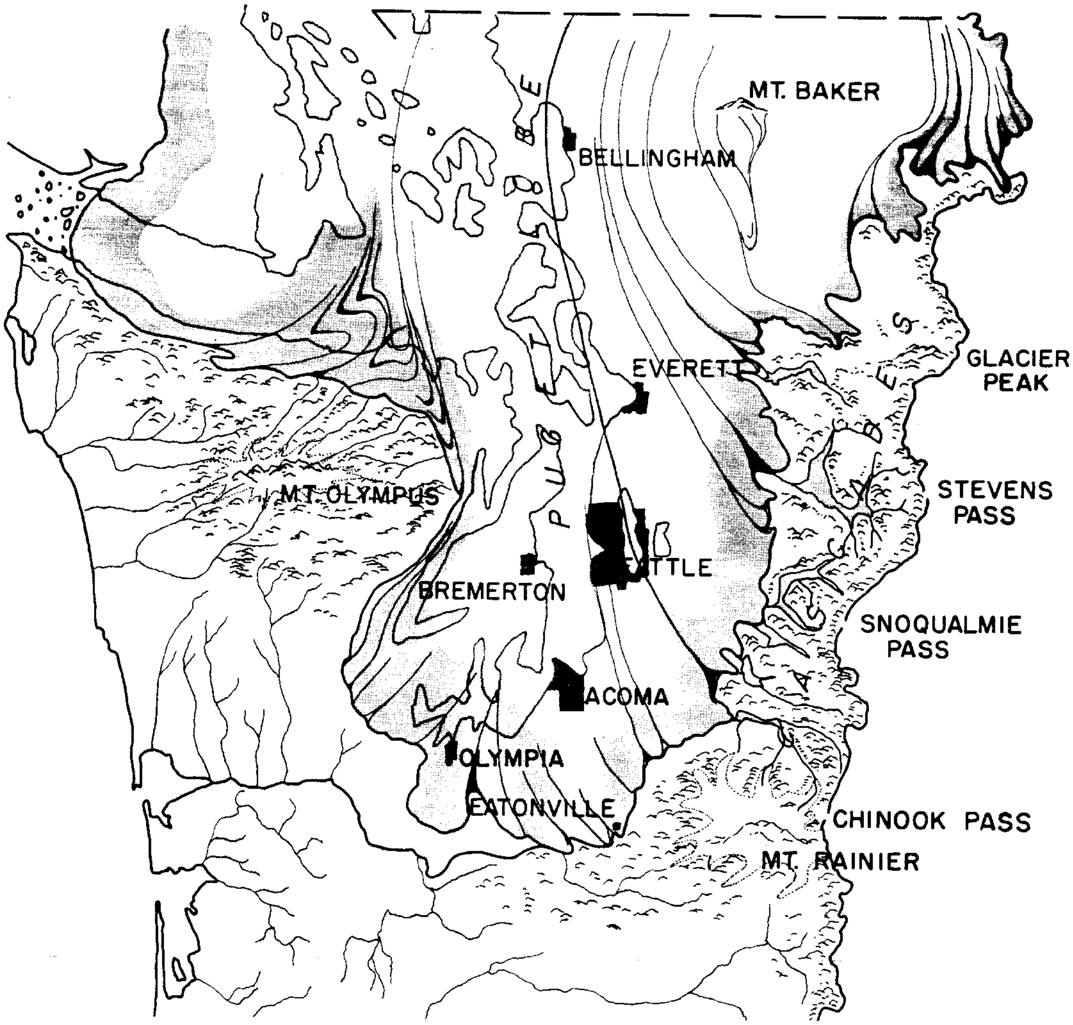


Figure 2. Maximum advance of ice in the Puget Sound region.
The Olympic Mountains split the advancing continental ice sheet into the Puget and the Juan de Fuca lobes. The Puget lobe is shown here at its maximum southward position, which it reached about 15,000 years ago. Eventually, the Juan de Fuca lobe extended far beyond the modern coastline, shown here for reference only. (Modified from a drawing by Allen Cary, U.S. Army Corps of Engineers)

When the advancing ice sheet reached the latitude of central Whidbey Island and Port Townsend, it pushed up against the foothills of the Olympic Mountains and split it into the Juan de Fuca and Puget Sound lobes. The Puget lobe blocked the flow of all northerly drainage from rivers of the area as well as its own meltwater flow, forming large ice-dammed lakes. In those lakes, extensive blankets of glacial lakebed silt (seen today as "blue clay") were deposited throughout the Puget Lowland.

When it was at its maximum extent (Figure 2), the ice sheet was about 7,000 feet thick at the international boundary, tapering to about 4,000 feet at Port Townsend, and further thinning to the south. During the thousands of years the ice lobe occupied the lowlands, its weight caused the earth's crust to sag. The amount of surface depression depended on how thick this ice was and how long it covered a particular area. Near Coupeville, crustal sag was about 200 feet.

Meanwhile, far greater ice sheets had also formed in the mid-continent of North America and in northern areas of Europe and Asia. So much water was "tied up" as ice that the worldwide sea level was almost 400 feet lower than it is today. Thus, Washington's ocean beaches were nearly 30 miles to the west in places, and a broad coastal plain existed for more than 9,000 years (Figure 2).

The Puget lobe "combed" much of the topography into low parallel ridges that are oriented in the direction of local ice flow. These ridges are best preserved in the southern lowland, but "streamlined hills" (known as drumlins) remain here and there to the north also. The glacial meltwater locally deposited thick accumulations of gravel, which buried detached blocks of ice along the retreating glacial front. As these blocks melted, they left steep-sided depressions (called kettles), for example between Penn Cove and Point Partridge.

Researchers estimate that multiple meltwater streams, some as large as the present Skagit River, also flowed under the ice during recession of the Puget lobe. The water in these streams was under enormous pressure--it originated perhaps thousands of feet above on the surface of the glacier and trickled or dropped through crevasses and cracks to where it could escape, at the bottom of the ice. Such high-pressure streams could account for the **scouring** of some of the narrow, deep channels of Puget Sound. The bottoms of some of these channels are hundreds of feet below sea level.

As the ice sheet continued to melt, marine waters re-entered the Strait of Juan de Fuca. Sea water is denser than fresh water, and the sea gradually lifted the glacier off the floor of the strait. When debris-laden floating ice melted, the contained sediments rained onto the shallow sea floor. At the same time, the earth's crust, now relieved of the weight of the ice as it retreated, began to rebound. In time, these glacial-marine sediments were raised from near sea level where they were deposited to the elevations of some bluff edges, where we see them today.

Crustal rebound was rather rapid at first. For that reason, wave action had time to cut only narrow beaches in places. Remnants of one beach at 120 feet elevation can still be seen west of San de Fuca (Penn Cove on Whidbey Island), and many, less prominent ones are visible near Cattle Pass on San Juan Island.

The drop of local sea level caused by rebound was at the same time being partially offset by the concurrent rise in world sea level. The interplay between global sea level and local crustal rebound essentially ceased about

5,000 years ago. Not until this relative stability was reached could wave action “focus” at a single elevation and begin to cut the bluffs and deposit the beaches we see today.

A word (or two...) about fossils. You, as Beach Watchers, have opportunities to contribute to what we know about the life of vertebrates during the Ice Age (the Pleistocene to geologists). From time to time, fossils erode out of the bluffs and fall onto the beaches. When you find the bones or tusks or other remains, note where they were found and look for others in the bluff wall.

The dilemma with vertebrate fossils is they are rather rare and if you do not recover them, someone else may--and that person may not know about their potential value. Or the fossils may be washed away by the next high tide and lost. Technically, the fossils belong to owner of the land on which they were found, which is why you need to know where you found them.

If you can lift these remains, carefully put them in a backpack (if you have one), and take them to the Beach Watchers program headquarters or your home. As soon as you can, notify both the Department of Natural Resources Regional office in Sedro-Woolley (360 856-3500) and the Burke Museum (206 543-7907; ask for the staff paleontologist), and tell them about your find. These people will advise you about the next steps.

The centerfold map shows some of the areas where Island County sediments left during this history can be examined in the field.

If you want to go into these topics in greater depth, the Department of Natural Resources’ Division of Geology and Earth Resources in Olympia has compiled bibliographies that will help you find relevant books and articles.

MODERN GEOLOGICAL PROCESSES

The bluffs and beaches that formed during the last 5,000 years of relatively stable sea level are the long-term result of a very dynamic and evolving system. Wave action began the cutting that has resulted in the modern bluffs. However, once the bluffs are steepened beyond their normal range of stability, in many areas they may react to factors independent of wave action--for example, rainfall or human development.

The bluff and beach system is not only dynamic but is also in delicate equilibrium. Geologic processes that impact one can influence the other. For example, a large slug of sediment dropping to a beach from a **landslide** can broaden and raise a beach, temporarily protecting the **bank** from wave action. On the other hand, a beach starved of sediment by nearby bulkheads, can become lower and narrower and allow waves to increase their attack on the adjacent bank.

Beach Processes

Our primary concerns in regard to the wave component of bluff erosion relate to the cutting at the base of the bank and the **transport** of the resulting loose sediment. Here, we are not concerned with the complexities of wave generation or propagation. Readers interested in wave theory may find "The Coast of Puget Sound" (Downing, 1983) a good place to start.

Wave Impact

In general, the bigger the wave hitting the **toe** of a given bank and the longer the duration of the impact, the more the bank erodes. Very large waves from distant Pacific storms (**swells**) are an erosional factor only along the Strait of Juan de Fuca. Within the more protected waters of Puget Sound and the islands to the north, waves are smaller and are caused by local winds.

Local wind-generated waves are largely limited in size by the relatively small size of the water bodies. The wind velocity and the distance (**fetch**) of water over which the wind blows largely determine wave height in such areas. For this reason, waves in narrow inlets tend to be small, especially in those waters protected by high bluffs where wind forces are limited not only by the short fetch but also by wind shadows and turbulence.

Once generated, the wave still must reach the bluff in order to erode it. In nature, the bluff's primary defense against wave attack is the beach. Beaches have the capacity to dissipate wave energy over the width of the exposed beach. Thus, we don't see the spectacular spray and other effects associated with rocky shorelines.

Assuming the presence of a beach, the stage of the tide can also be critical. The waves of a particular storm can have more effect on the toe of a bluff at high tide than at low. Wind storms that coincide with unusually high tides, sometimes augmented by low-pressure atmospheric conditions, can be especially erosive.

The nature of the beach is also a factor in wave attack. Some beaches are highly erodible and can fluctuate in profile as much as 3 feet or more during a storm. (See for example the beach shown in Figure 12.) Other beaches, commonly those fronting headlands, may be hiding an erosion-resistant **platform**, possibly made of glacial till. This kind of setting can provide considerable wave protection to an adjacent bank, which helps explain why a point or headland exists at these places.

Sediment Supply

The local geology determines the type of sediment (for example, silt, sand, gravel, or boulders) that is delivered to a beach from an eroding bank. The height of the bank and its rate of retreat determines the amount or volume of sediment delivered to the beach. Both sediment type and volume influence not only the texture of the beach that develops but also whether a beach exists at all. For example, a shoreline that is starved of sediment may simply consist of a **wave-cut platform** studded with boulders.

Keep in mind that not all material from an eroding bank will necessarily be added to or stay on a beach. For example, bank sediments rich in silt (for example, glacial till or lakebed sediments) may contribute much less material to a beach than would a gravel bank of the same height eroding at the same rate. This is because wave energy can pick up and suspend silt as turbidity, move it away from the beach, and disperse it in deeper water. Sediment too coarse for waves to move, such as cobbles and boulders, may remain as a “lag” while sand and gravel migrate along the beach as “**longshore drift**”.

The distribution of these lag deposits can alert us to the presence of deep-seated landslides or changes in the geology underlying the beach.

Longshore Drift

Longshore drift, or longshore sediment transport, is the result of waves that come ashore diagonally; their backwash flows perpendicular to the beach. Sediment **particles** travel in a zigzag path as they are moved along the beach. In the process they are tumbled and ground to smooth rounded shapes while at the same time grinding against, rounding, and polishing any boulders too big for the waves to move.

Drift can move sediment from areas of active bluff erosion to shorelines miles away, where sand and gravel may be deposited as a wide protective beach or even a sand spit.

The general direction of sediment movement along a beach can reverse seasonally or during a single storm. However, over the course of a year or more there will be a dominant direction of longshore drift. If this long-term or net sediment transport is interrupted, beaches down-drift of that point will begin to erode. Net shore-drift directions have been mapped in Island County by Keuler (1988) and by Johannessen (1992).

Shore Protection

When people choose to build near a shoreline, this development can change erosion rates in a variety of ways. Disposal of land-clearing debris or storm drainage onto the bank can greatly accelerate natural erosion rates. Other forms of development, such as the construction of shoreline erosion protection structures, can slow or even temporarily stop wave erosion of a bank. Multiple development factors can compound or cancel each other, sometimes in unpredictable ways.

Superimposing these human influences on an already dynamic natural system can result in on-site and (or) downdrift impacts. In areas of development, erosion rates may be changing as we attempt to measure them. You should be aware of such complications because they may help explain some puzzling results of your efforts.

Probably the most common important impact of development on erosion is disruption of the sediment supply. Obviously, if sediment moving along the beach is cut off at its source or blocked by some barrier, the downdrift beach will not be getting its natural supply. As a result the beach gets narrower, the beach **profile** is lower, and beach materials become coarser, or, more likely, all three.

Where longshore transport does not replenish a beach or where it is interrupted, fine sediment is moved away by waves and not replaced. The coarsening of a beach may be more than a question of esthetics. For example, smelt require small gravel to spawn. If it is removed, the spawning beds disappear. Clams, oysters and other marine organisms also have special sediment-size requirements.

More important to bank erosion rates and erosion monitoring than coarsening is beach lowering. As a beach is lowered because it is not replenished, the natural banks and developed (erosion protected or bulkheaded) banks are affected differently. The toe of an adjacent natural bank is exposed to direct wave attack more often and for longer periods. “Wave protection” commonly results in accelerated erosion of unprotected natural banks downdrift.

But beach lowering can have even more dramatic effects on the very structures that caused it. Erosion resulting from the lowering can expose the footings of those shore protection structures. For example, bulkheads along semi-protected shorelines commonly have footings that are buried only a few feet into the upper beach. Long-term lowering of the beach by that amount can not only expose the structure's foundations to wave erosion but can also enable waves to erode fill from underneath and behind the structure.

Because common bulkhead designs deflect much wave energy so that it "jets" downward into loose beach sediments, significant damage can also occur during a single storm. The effects are, of course, obscured at the time by waves, and later the evidence is commonly hidden by natural "reconstruction" of the beach during the waning storm and (or) tidal withdrawal. Often the only evidence of the process is a loss of fill from behind the bulkhead. The resulting settlement of the fill may be subtle, but such erosion can remove a structure's support and result in cracking concrete and, eventually, major damage.

Bank Erosion

The nature or mode of erosion depends not only on the wave action at a particular site but also on local geology and climate. All three factors vary widely within the Puget Sound region, so it should not be a surprise that average bank erosion *rates* here can range from a fraction of an inch to more than 2 feet per year. Depending on the erosion *mode*, the erosion rate for a given bank can be quite uniform over the years, or it can change from near zero for decades to tens of feet in a matter of seconds.

Once they are steepened to an unstable angle, banks can continue to erode without wave action. For example, the high bluffs between Seattle and Everett have been protected from wave erosion by a seawall for nearly a century. Yet, landslides continue to be a major problem for rail traffic along the toe of the bank there.

An added complication in the study of shoreline erosion is that the same bank may be eroding at different rates from top to bottom. At least some of this variation may be due to gradual sea-level rise. The result appears to be historically unprecedented erosion along the toe of some bluffs, but "normal" erosion along their upper edges (Figure 3). Everything else equal (and it seldom is in nature), the effects of this change in rate will eventually work their way up the bluff. Possibly decades or centuries from now, depending on the site, we may be able to detect that accelerated erosion at the bank edge fringing the uplands.

The foregoing discussion may explain why we may want to monitor erosion of some banks both from the beach and from the upland surface. For example, Figure 3 shows an upper bluff with mature conifer and a bare, near-vertical lower bank. The presence of such trees suggests that where they are growing has had only negligible erosion for perhaps 100 years or more. In contrast, the lower one-third of the bank is actively eroding.

Figure 3. Accelerated erosion of bluff toe.
The 100+-year-old tree at mid-bank indicates negligible erosion of the upper bank. In contrast, the lower bank here has eroded almost 30 feet. How long will it take for this accelerated erosion to reach the upper edge of the bluff?

Surficial Erosion

Particle-by-particle erosion of unconsolidated sediments is generally not very spectacular, but it can be cumulatively important. That is in part because it commonly occurs year round, or at least seasonally, and over extensive areas. The local geology determines whether or not rain soaks into local rocks and sediments or runs off.

In dry weather the wind can erode bare banks. In wet weather, the impact of raindrops and surface runoff (sometimes destructively concentrated by drainage from roofs and streets) will cause banks of finer sediments to erode. In cold weather bare banks of silt and sand are susceptible to freeze/thaw cycles. Banks of wet silty sediments commonly “slab off” after a thaw. The depth or thickness of the slab equals that of freezing. The disturbed sediment eventually breaks up on the beach or can move down the bluff as small mudflows.

Surface erosion tends to be slow and gradual in the long term. However, concentration and careless disposal of runoff can erode a “canyon” the size of several railroad freight cars in a single storm. Lesser concentrations of natural runoff can erode parallel rills or steep, V-shaped draws. The upland bank edges left by such erosion modes are commonly irregular, and that can make upland monitoring difficult. Such areas commonly have a straight shoreline amenable to erosion measurement from beach monuments.

Soil Creep

The term “**soil**” refers to the layer of weathered material in which plants grow. (See the Glossary.) On shoreline banks along Puget Sound such soil is typically a veneer of loose sediments, commonly reinforced and held together by roots, that lies on glacially compacted materials. These soils may receive additions of windblown sand and silt from nearby bare patches of bank as well as sediments loosened by rain that dribble or flow from upper banks and become entrapped by vegetation.

This surficial layer of soil is commonly 2 to 5 feet thick. The roots bind the loose sediments together as a soil/vegetation mat. The force of gravity causes this mat to slide slowly (“**creep**”) downslope. In places, the roots of mature trees penetrate the mat and anchor the trees into the undisturbed subsoils. Where such trees are abundant, the rate of soil creep is substantially reduced. Where large trees are isolated, creeping soil simply flows around them, piling up a “bow wave” upslope of the trees and leaving a lowered “wake” downslope. The tree creates an effect much like that of a boat moving through the water.

Creep alone is benign. Creeping soils tend to thicken from the upper bank edge to its toe, especially where they buttress against the upper beach. Rainstorms may accelerate creep in places by causing the mat to suddenly break away, disintegrate, and move to the beach as a rapid **debris avalanche** of mud, brush, and broken trees. Such “events” are unrelated to wave erosion. Debris avalanches can damage homes along the base of bluffs, but both debris avalanches and creep are individually too thin to erode into adjacent uplands.

Landslides

Landslides locally cause more bank erosion than all the other modes combined, and slides line many stretches of Puget Sound’s shoreline bluffs. Maps in the Coastal Zone Atlases (Washington Dept. of Ecology, 1978-80) of the 12 Washington counties that have inland marine shorelines show a total of 71 miles of recently active landslides and 65 miles of apparently dormant slides. Both totals are understated.

For example, slides smaller than about 200 feet across were essentially unmappable at the scale of the atlases (1 inch = 2,000 feet). These slides were included in the general category of “unstable” ground. Extensive areas of ancient dormant slides were undoubtedly overlooked because they were covered by trees or eroded materials when mappers were doing the reconnaissance-level work for the atlases.

As an illustration of the importance of landsliding to questions of erosion rates and land use, we need look no farther than Island County. The atlas maps show about 2.5 miles of recent slides and 6.5 miles of old slides (some which have been partially reactivated). In addition, the approximately 110.5 miles of bluffs in the county mapped simply as “unstable” contain many landslides too small to map individually. A large landslide complex, possibly the largest one along Puget Sound, is 7,100 feet long and fronts the residential developments of Ledgewood, Bon Air, and Teronda West on Whidbey Island.

EROSION RATE MONITORING

In this chapter we describe the steps necessary for you to successfully monitor erosion of coastal bluffs. These steps include identifying an appropriate site, establishing a permanent reference station, measuring the shoreline's position, and documenting and maintaining records.

The key to monitoring erosion and to establishing erosion rates for a particular site is establishing a reference point from which you can make--and repeat--accurate measurements. Because erosion is both slow and episodic, you may need to remeasure a site several times, over a lengthy period of time, before useful data emerge.

The differences between subsequent measurements may be small, so consistency and accuracy are important. Without both, results may even be contradictory. As we discuss later, natural variation can make both factors subject to considerable judgement. Six inches of erosion in five years is useful data, but if your measurement is one foot in error, what conclusions can you draw?

Your most accurate rates will be those based on a long (20+ years) period of observation. This may mean that later observers are not the ones who established the site. Good documentation and record-keeping are important because future observers must be able to locate the early records and make comparable measurements.

Where reference points are not already available, you will need to establish a fixed reference point from which to make your measurements. Such a reference "station" commonly consists of a large immovable object or a "monument" upon which a permanent mark has been placed. Even where a natural monument can be found, marking the reference point on it may not be easy. Your mark must be quite precisely made, because simply saying 20 feet from the 'big boulder' is not adequate for the data you are collecting.

Site Selection

The first task in monitoring is to identify an appropriate stretch of shoreline and a practical site at which to establish a monitoring station. Obviously, a shoreline has an infinite number of possible measuring sites, but some sites may be more appropriate for monitoring or more amenable to observation. You should consider several factors:

- Does a permanent survey station already exist?
- Will it be difficult to establish a new station?
- Is the bluff representative of natural conditions?
- Is there something unusual about the site?
- Will the measurements be difficult or dangerous to make?
- Is the site best monitored from the beach or from the upland--or both?

In general, then, you need a permanent reference "point" to measure from and a bluff or bluff edge to measure to. Thus, a given site consists of the bluff as well as a nearby survey marker "station". The station can be on the beach or on the upland surface. The station will consist of a precise and readily identifiable point or mark on a larger monument or natural surface. A good permanent upland monument might be a large, existing concrete structure (such as an old gun emplacement) or a building foundation. Where one of these is not available, a monument can be a block, pyramid, or inverted mushroom of concrete. Smaller concrete monuments, whether emplaced intact or poured on-site, should be largely buried (Figure 4) to minimize the chances of disturbance.

Figure 4. U.S. Coast and Geodetic Survey Monument.
The arrow on this bronze reference mark plaque points to **triangulation** station "FORT" about 30 feet away. Some reference marks may still be useful for erosion measurement, even though the actual station mark has been destroyed by erosion. This station plaque is affixed to a large, buried, inverted mushroom of concrete that is not likely to be disturbed by mowing, ground freezing, or vandalism.

You can also make your marks for survey stations on natural surfaces. A permanent marker might be affixed to a **bedrock** surface (by drilling a hole in it and placing a station there). In areas such as Island County where there is little bedrock, large glacial boulders are commonly used as monuments. A boulder you might select needs to be large enough to resist movement when it is rammed by wave-driven drift logs.

Existing Stations

Where the hard work has already been done and a permanent station exists along an eroding shoreline, you should use it for monitoring. This is especially true at sites where there is a long history of erosion data. Not all these sites will be representative of adjacent stretches of shoreline, but they can still be useful for determining local erosion patterns.

Surveyors for various agencies of the U.S. government have been establishing survey stations along Puget Sound shorelines since the early 1800s. Most stations were placed during the preparation of accurate navigational charts, such as the map of Port Townsend (the bay, not the town) first published in 1858. These earliest survey stations were generally temporary sites, established for a specific purpose, and little attempt was made to establish “permanent” stations that might be suitable for resurveying.

Many surveys were also done in the 1800s and 1900s by the General Land Office (or GLO) to establish corners for sections and government lots and for boundaries (meander lines) along shorelines and rivers. Where a monument or witness post was established near a coastal bluff, there may have been reference to landmarks that could be useful in determining subsequent erosion rates. The Public Land Survey office of the Washington Department of Natural Resources is a good place to start a search for such early records. This kind of detective work is by no means necessary to begin a monitoring program, however.

Most of the still usable stations along the shorelines were established between 1920 and 1970 by the U.S. Coast and Geodetic Survey. (Since 1970 additional stations have been established by their successor agency, the National Ocean Survey.) These markers can be either “triangulation stations” or “reference marks” installed to help find the stations (Figure 4). The U.S. Geological Survey has installed “**benchmarks**” for determining elevations in places. These are circular bronze plates attached to a large boulder, bedrock, or a concrete monument. Distances logged to nearby bluffs when the stations were established (Table 1) were intended to help people find them later, rather than for erosion monitoring; these distances were commonly recorded only to the nearest foot. See Appendix 4 for more information about these established monuments and sample descriptions.

Other government agencies may also have established survey monuments near the shoreline for specific projects. For example, the U.S. Army Corps of Engineers may have established survey stations for construction of harbor improvements or early military structures. In addition, the Washington Department of Transportation or the Office of the County Engineer may have survey data that relates old bridges, roads, or other structures to nearby shoreline bluffs.

Utility companies, land developers, or even individual homeowners may have survey monuments with descriptions that refer to distances from the bluff. Local professional land surveyors may be able to offer additional suggestions regarding survey stations they have used and that might provide good erosion monitoring sites. If you found even one reliable long-term data point, you can consider your detective work worthwhile.

Unfortunately, many permanent stations established for land surveying are too far from the shoreline for convenient erosion monitoring. In addition, government stations or landmarks with a long record of nearby erosion may now be threatened by that same erosion (Figure 5) or by development.

If no reference mark (such as in Figure 4) for such a station already exists, you should give high priority to establishing one. By doing this, a continuous record can be maintained even if the primary reference mark or station is lost to erosion.

Establishing New Sites

Establishing a new erosion monitoring station can require considerable effort. For example, you may find that some bluffs lack any permanent surface or monument upon which to establish a station. (For this reason, monitors need to consider not only the effort required for ongoing monitoring but also the effort that will be required to establish a new station.)

Bluff erosion can be monitored from either the top or bottom of the bluff; local geologic factors will govern the choice. At some sites, monitoring from both the top and bottom may be useful (such as at a site like that shown in Figure 3). Factors affecting your choice of a new monitoring site may be different, however, between upland and beach-level stations.

Obviously, your team would get permission to establish or even monitor a site on the uplands. What about beach-level sites? Tidelands also belong to somebody. Some belong to the state, but others belong to the adjacent upland property owner.

Representative Sites

One of the most important factors in establishing a new monitoring station is the degree to which the site is representative of local geology and wave conditions. Some sites provide data that is more applicable nearby and less subject to misinterpretation or criticism.

Obviously, the erosion rates at a bedrock headland would provide little information applicable to adjacent banks of glacial sediments. Sites on sharp promontories or subject to development impacts can be interesting but should be low on your priority list. Ask yourself “why does that point exist?” The answer is likely to be that it is made up of materials more resistant to erosion (Figure 6) than banks on either side and therefore not representative of broader conditions. The ultimate selection of a good site will be based on a series of compromises (except for some special purpose, such as where it might be desirable to project the useful life of a specific existing structure, such as a segment of road or your own house).

Figure 5. Smith Island lighthouse (1979 photo).
The lighthouse is essentially gone today. Anticipating erosion rates (here more than 2 ft/yr) and the vulnerability of such landmarks can guide your decisions about when and where to install a reference station.

In areas of fairly active erosion with lots of bare bluffs, you can easily pick a good site. (Banks covered by dense vegetation and/or where little is known about the local geology will be more difficult to use.) In general, bluffs and shorelines with abrupt changes in direction indicate changes in geology, and you should avoid them.

Possibly the best way to illustrate the question of representative shorelines is to consider a natural *non*representative stretch of bluff. A bank north of the County parking/boat launch area at the end of Hastie Lake Road is a good example (Figure 6). Here, a “dogleg” in a generally straight shoreline marks a rather abrupt change in geology.

Figure 6. Shoreline 'dogleg' on West Beach.
This ‘dogleg’ results from an abrupt change in the geology of these bluffs a short distance north of the end of Hastie Lake Road. Erosion-resistant glacial till forms the bluff in the foreground, whereas more erodible sediments are found to the north (upper left).

Beach-level reference stations should not be located on features that in themselves affect the rate of erosion. You may find boulders, boulder fields, or bedrock knobs that are too big and too close to the bank. Such a combination may interfere enough with longshore transport and bank erosion to render the site nonrepresentative. In other words, bank geology may be consistent, but shore processes are interfered with.

As an example of this situation, Kloochman Rock, along the western shore of Oak Harbor, marks an abrupt change in the erosion rates along its adjacent banks (Figure 7). The rock is so large and so close to the bank that it interrupts longshore drift. The resulting beach on the south protects the bank, while the sediment-starved beach to the north provides little bank protection. The result is an abrupt jog of many feet in an otherwise straight shoreline. On the other hand, if the rock is smaller or farther offshore, it may not significantly impact erosion rates.

Figure 7. Kloochman Rock, western Oak Harbor, is large enough and close enough to the bluff to slow longshore sediment transport.
Longshore drift from the left (south) is reduced, lowering the beach on the right and exposing the bluff there to greater erosion. Erosion rates on either side would not be representative of more distant banks of essentially identical geology and wave action.

Obviously, a bank or shoreline that has been modified by development may not be representative of anything but itself. Signs of such modification may be subtle. For example, the bank may not have direct wave protection in the form of a bulkhead or seawall, but the sediment supply for the beach that is fronting and helping to protect that bank may be influenced by development nearby or updrift. Figure 8 shows a not-so-subtle example of the potential affects of such structures.

Figure 8. The now-defunct boat launch at west end of Libbey Road.
The ramp has been acting as a beach **groin**, slowing right-to-left longshore drift. Note differences in elevation of people standing on upper beach on either side of the ramp. The bank on left has no beach to protect it and is eroding faster than on the right. What will happen when the ramp is totally destroyed?

Figure 1 suggests some tentative areas for new erosion monitoring sites (note the large gaps between established stations). Aerial reconnaissance, either in person or via aerial photos, can be helpful in selecting good sites. Oblique aerial photos are especially good for this purpose (large-scale color oblique photos of Island County shorelines were flown for the Department of Ecology in 1977 and 1993.) Ultimately, each site should be checked on the ground for representative conditions and monument options unless good local knowledge is already available.

MONUMENTS AND MARKING

After selecting a representative stretch of shoreline and appropriate bluff monitoring site along that shoreline, your next step will be to establish the measuring station. The monument component of a new station, such as a durable boulder large enough not to be moved by the battering of drift logs, may already exist. Boulders or permanent structures may also make good upland monuments. In most situations, you will need to mark either a natural or manmade monument with a permanent measuring point.

In some places, a durable two-dimensional surface, rather than a distinct monument, may be available. For example, you may find a paved road within a reasonable (200 feet or so) distance of the bluff edge or a wave-cut platform. (See the glossary.) These surfaces may be relatively permanent, but you still need to establish a reference point from which to make your measurements.

Another common setting is an extensive stretch of beach that has neither boulders nor a resistant wave-cut platform. (See the cover photo.) In some of these places you can monitor erosion of adjacent bluffs from the uplands, but there is evidence that some bank toes may be eroding at a different rate than the upper edges (Figure 3). In places like that, you may want both upland and beach-level marks.

It is likely that you will need special tools and skills to mark an existing boulder or to establish a complete new marked monument on a sandy beach. Those two situations seem to warrant a more detailed discussion, which we have put in Appendices 2 and 3. Such challenges need not concern or intimidate your erosion monitoring team once you have established your reference points.

Selecting the Monument

As we mentioned, a suitable monument must be both durable and immovable. The monument must be durable so as to resist the influences of weather, wave action, abrasion, and vandalism. It must also be as immovable as practical so that it will not be displaced by natural processes or by development. A monument too close to the edge of an eroding bank is little value if it will be lost to erosion in 10 years or so.

Requirements for monuments may be different for beach-level sites than for upland (landward from the bluff) sites. For example, a good upland surface for marking might be a concrete slab (Figure 4) or foundation wall. Where no good site exists, you might consider employing a precast monument (Figure 4) at a suitable location.

Suitable natural boulders may make good monuments on either upland or beach surfaces. On most of these, you will need to make a mark that provides the permanent and consistent measuring point so that you can remeasure from it in the future. (See Appendix 2). Otherwise, you may need to use concrete monuments. However, on beaches where boulders are small or absent, the precast concrete monument will not be an option because in the dynamic environment of the beach (see Geologic Processes) the monuments may be exhumed or moved by storm waves.

Professional surveyors often establish supplemental reference points for their own survey stations and you might consider doing this too. These reference points may simply help locate the primary monument (if, for example, an upland monument is obscured by brush or a beach monument is covered by sand). You should also make sure these secondary monuments are precisely surveyed so that you can use them for erosion monitoring in case the primary mark is lost.

Where you need to establish a monitoring point close to the edge of a rapidly eroding bluff, or where a measurement point might be disturbed by development, an artificial "witness point" may be in order. You will need to describe these secondary references (preferably two) and record their distance and direction from the primary point. In the old days large trees were commonly the handiest "permanent" references, hence the term "witness tree".

Marking Monuments

Some "monuments," such as the corner of a house foundation, can serve as permanent measuring points without your having to actually mark them. A careful description, preferably supplemented by a photo, may be all that you need. However, many potential monuments, either structural or natural, will need an identifiable mark to enable monitoring teams to make consistent measurements over the years.

With luck, you might find a boulder with a distinctive natural mark, such as the intersection of two veins of white quartz or an inclusion of a darker rock in a light-colored granite. A careful description or photograph of this reference point in your county's file of erosion monitoring monuments may be sufficient and save someone a lot of work. (Remember, you might not be on the team when it re-measures that site in 5 to 10 years.)

In some (probably rare) instances, you may not even have to mark a beach boulder. An example might be a very large (8-ft diameter), rather round boulder, which is unlikely to be covered above the mid-point by shifting sand. Here you can simply measure from the most "shoreward" point.

Where you have no alternative, probably the best way to permanently mark a boulder in the hostile beach environment is to drill a hole. This sounds simple until you realize that most boulders tough enough to withstand glacial transport are composed of minerals that are harder than glass! The mechanics of drilling such holes are important, yet complex enough to warrant separate and detailed consideration. (See Appendix 2.)

Monuments on Upland Surfaces

Marking a concrete or asphalt driveway, launching ramp, or other surface with paint or with surficial scratches will seldom do. Modern epoxy adhesives can fix in place “highway bumps” or similar reference points where there may be street traffic, but these “marks” would be vulnerable to vandalism in public areas. An inconspicuous mark that has minimal protrusion might be the best compromise in these places (Figure 9).

Monuments on Wave-cut Platforms in Bedrock

Most distinct **wave-cut platforms** in bedrock are cut into relatively “soft” rock, such as sedimentary rocks like sandstone or siltstone. Good examples of bedrock platforms can be seen on Sucia Island and along shorelines of western Clallam County. Where the shoreline rocks are more resistant, such as on Fidalgo Island or in the San Juans, waves may not be energetic enough to carve a significant platform.

You can establish a tide-level reference mark on these platforms. In some rocks you may be able to hammer in a marker, but this may weaken the rock and make it more likely the marker will be lost. Whether installed in a drilled hole or a natural crevice, any marker pin will be more durable if it is embedded in a hard-setting filler or adhesive such as you would use to repair concrete.

Monuments on Platforms in Unconsolidated Sediments

In many areas on Whidbey and Camano Islands, the tides have cut a platform into silt or silty peat. Much of the Whidbey **Formation** (Figure 10) is made up of sediments like these. If there are no boulders large enough to resist movement by waves, you may have to establish a reference mark directly into these platform sediments.

Although such sediments are erosion resistant and “tough” because they were compacted by the passage of a glacier, they are not even as hard as soft sandstone bedrock. However, you may still find it difficult to simply pound in a steel pipe or pin. You may want to use a carpenter s hand auger (used for drilling wood) to make a hole in these sediments (Figure 11).

Once a hole is drilled, a tight-fitting peg can be driven in flush with the surface. You can cut a suitable peg from concrete-reinforcing bar, galvanized pipe, or a large bolt. (Use a bolt with at least a half-inch diameter in case you need to use a metal detector to find it.) In most places where there will be little shifting sediment to cover it, your marker can be inconspicuous, but you will need to describe the location and mark well and provide complete directions to help find it if it should ever be covered by sand . (You could make a small map of the area to help others locate the marker.)

Figure 9. A slab of concrete used to test marking techniques.
Gloves and goggles were the only tools that worked “as advertised”. Most glacial boulders are much harder and tougher than concrete. The inset shows a close-up of four holes drilled in a scrap of concrete to demonstrate some options for marking monuments. A common galvanized “carriage bolt” (upper left) is embedded in patching compound. Surveyor s “P.K. nails”, right, can be hammered into asphalt pavement without drilling. A hole (lower left) simply filled with hard-setting compound may be your most durable and vandal-free option.

Figure 10. A wave-cut platform with “lag” of cobbles south of Hastie Lake Road. Because there are no large, stable boulders, you might mark a site like this by drilling a hole in the silt or peat and driving a stake flush with the surface. Platforms like this may be seasonally covered by a veneer of sand. A metal detector might be helpful in locating your reference point.

Figure 11. Some tools for marking a wave-cut platform.
The carpenter's auger was used here to bore a hole in the glacially-compacted, peaty soil of the Whidbey Formation. The pencil points to the top of a piece of “rebar” (cut with a hacksaw), which has been driven flush with the wave platform surface. If erosion begins to expose the reference pin, you can simply pound it deeper.

Monuments on Sandy Beaches

Establishing a permanent monument on a sand or gravelly sand beach that is exposed to strong wave action is greatly complicated by vertical changes in beach profile (Figure 12). (See Appendix 3.) A monument buried too shallowly or cast into a beach like this could be totally exhumed and moved in a single severe storm. Thus, any artificial monument you select should be massive as well as buried below the lowest beach level.

Bluffs fronted only by sandy beaches can be subject to heavy development pressures. You may need to give some extra effort to these places if you decide to mark and monitor them. Placing a “permanent” reference mark in a sandy beach that may change 3 feet or more in elevation during a single storm will require your ingenuity and some hard work. (See Potential Monitoring Problems and Appendix 3). In some places, it may be impractical or futile to try to establish a mark.

Figure 12a. Difficulties presented by changes in beach level.
Arrow marks the location of the boulder (your potential monument?) behind Beryl. This photo was taken in July 1995. Also, pretend that this is a 100+-foot-hig bluff that you are monitoring. Where is "the edge"? Is it safe to approach?

Figure 12b. The same boulder as in Figure 12a in February 1997 had been exhumed by beach lowering and apparently moved shoreward. Note how the toe of the bank is sweeping seaward to merge with the platform of glacial sediment. Where is "the toe"? Wookie (left), about 2 feet long, and Odie provide scale here.

THE JOB OF MEASURING

Measuring Distances

Almost all distance measurements relevant to erosion monitoring can be made with a measuring tape. Although most of us have used such devices since childhood, we may not have thought much about the problems inherent to tapes or we simply may not have experience using longer tapes in rough terrain, so a review seems appropriate.

Textbooks about surveying commonly devote an entire chapter to "taping". (It was called "chaining" in the days when professional surveyors used a measuring device called a "Gunter's Chain", literally a chain 66 feet long, made up of 100 links.) Technology outpaced language as the chain later evolved into a steel tape (still called a **chain**). Now we can buy simple, reasonably accurate, and rust-free plastic devices called "rope chains".

An important aspect of measuring natural surfaces is to maintain perspective between the *precision* of the measuring tools and the nature of the surfaces to be measured. Your tools can be very precise, but the *true* surface of a natural broken and uneven surface is open to considerable judgement. For example, your measuring tape may be marked in fractions of an inch or millimeters, but an eroding bank may have lumps, rills, or overhangs of a foot or more.

Now that the issue of personal judgement (where does the "edge" end and the overhang of grass and roots begin?) has been raised, we need to mention that it may be the most important component in your measurement. Phrased another way, if people may disagree by half a foot on where the edge is, then reporting the distance to the nearest hundredth of a foot could give a misleading sense of *accuracy*. Natural uncertainties due to judgement calls can be compounded by mechanical and/or human error if you should get careless.

Mechanical Error

Taping distances is fraught with complications you will not encounter while using the common retractable carpenter's tape around your home. Among potential mechanical sources of error are:

- sag (vertical, from the weight of the tape)
- wind (like sag, but horizontal)
- stretch (from pulling taut to eliminate sag)
- temperature (steel tapes, especially, lengthen in hot weather)

Professional surveyors have various techniques to minimize or compensate for these errors. If you are interested in these, check out a book on surveying from the local library and become better acquainted with the measurement of distances. Evett's book (see References Cited) will provide you with more information than you will ever need and a minimum of theory.

You can largely minimize the mechanical sources of error by using a good-quality tape and common sense. (Most erosion monitors will use a modern 100-foot plastic-coated fiberglass tape.) For example, if the wind is strong enough to cause your tape to flutter and bow, go to a less exposed site (or home) and come back later. With care, mechanical errors should be negligible compared to natural factors such as roughness of the bank face.

Human Error

One potential human error can be eliminated by selecting reference points within a single tape length. This eliminates potential errors of addition. Some other sources of human error include:

- misreading (Is it 69 feet or an upside down 96?)
- disregarding calibration (Is your tape subdivided in tenths of feet or in inches?)
- twist (Are you reading the front or back of a "two-faced" tape?)
- misrecording (Did the note-taker hear you correctly?)
- misalignment (Is the tape straight and horizontal and perpendicular to the bank?)

Most of these errors can be eliminated by repeat measurements, good communication, and common sense. Re-tension and reread the tape at least twice, and repeat your readings loud and clear. Tension should only be applied by the tape reader - the person at the "zero end" should concentrate on holding the tape in place (Figure 13b).

Tape misalignment is an obvious source of human error. Obviously, a distance measured on an upland site where the tape must weave around trees and brush will be longer than the true distance. Distances that require totaling two or more measurements that do not both follow the same line will also be too long.

Another potential source of horizontal misalignment is where the bank edge is scalloped or has a promontory. This can be especially confusing if the edge was straight during previous measurements and there has since been a small landslide. In the long term such squiggles will average out through erosion, so it is important to measure perpendicular to the local general trend of the bank. Consistency can be maintained if you make the measurement along the same compass bearing. Make notes and sketches if in doubt.

Figure 13a. Measuring distances.
Here, Jerry measures an upland site. The plumb bob assures that the position of the monument is accurately located. Note the end of the tape pinned in place by a T-handled probe at the bank edge. The probe was used to find "solid ground" and avoid considerable overhangs of sod that can be found at some bluff edges.

Figure 13b. At this beach-level site, Katie measures the distance to the face of the undisturbed glacial sediments "above" the loose, weathered debris. The tape is level and straight. Courtney could use a plumb bob to help ensure that her end is directly over the reference mark in the boulder. They measured 12.50 feet in July 1996. The distance was 11.95 feet in March 1997. Is this bank "growing" instead of eroding? See the section on Potential Monitoring Problems.

Vertical misalignment can also cause significant taping errors for the unwary. Obviously, the distance measured along a slope will be longer than if a tape is held horizontally. All map distances are horizontal. To avoid vertical misalignment on slopes, use a plumb bob each time to locate the ground surface below the high end of the tape (Figure 13). An appropriately shaped lead fishing sinker might serve as a plumb bob if you can find one without a bent eye; use braided (not twisted) line to minimize spinning.

Beach slopes commonly average about 5 degrees, an angle that can be easily accommodated by careful taping over short (less than 100 feet) distances. Usually, all that is necessary to achieve a level or horizontal tape is for the person at the reference point (beach boulder or concrete monument) to hold the tape higher and the person at the toe of the bank to hold it lower (Figure 13b). (The height above the reference point should be noted.) Errors caused by vertical misalignment of a few degrees are not significant for your monitoring purposes.

When your have made your measurement, check to see if your numbers make sense. While you are still on site, discuss your findings in relation to previous measurements. (Carry copies of previous surveys and photographs when you can.) Calculate the erosion rate since the last measurement. Did the bank really "grow" (i.e., experience "negative erosion")? If this seems to be the case, you have a problem.

Re-measure to see if it could be your error. If not, is the apparent error within the limits of potential mechanical error based on different people using slightly different equipment? It may also be possible that the previous team made a human error and their findings may need to be disregarded. Make notes about any unresolved ambiguities.

Alternatively, your reference point could have moved. Check upland sites for signs of human activity (such as land clearing). Were witness posts, trees, or other reference points (Figure 4) described by earlier teams? Are they still in the described locations? Check beach sites for possible reorientation of the monument (boulder) by the battering of drift logs. A site with reference point disturbance may still be usable, but erosion rate calculations would need to be started over.

Finally, if you can find no other explanation to negative erosion at a beach site, your bank may be "growing" rather than eroding! You could be measuring to the toe of an active landslide. (See the section titled Potential Measuring Problems.) Look around for other evidence of activity. Your data may still be useful as an indication of slide movement, but the records need to be clearly labeled as such and not included with "normal" erosion data.

Monitoring Tools

This seems an appropriate place to remind ourselves that the basic concept of this project is to perform a critical but now neglected service--using volunteers of widely varying backgrounds, who cannot rely on outside financial support, to compile accurate data for use by future generations, while experiencing enough personal satisfaction to sustain the effort from year to year. This is a tall order, so try to make it interesting (maybe even fun!).

In order to meet the foregoing requirements, we need to strive for economy and simplicity. Tools need to be so inexpensive that a small group of people, say three teams of three each, could afford to purchase and share a set. (Presumably, at least one person per team will already have a camera.) The tools need to be light and compact enough to carry them a mile or more along the beach or transport them in a small boat. They should be rugged enough to lie neglected for a year or so in the trunk of someone's car or in the corner of a garage.

Your team may be lucky enough to include a retired land surveyor with access to theodolites and laser range finders and knowledge of how to use them. A mariner friend may have a state-of-the-art Global Positioning System (**GPS**). (Most marine GPS units will help locate your site on a map but are not sufficiently precise to make actual measurements or locate buried monuments). By all means use whatever electronic gizmo is appropriate, but keep in mind the limitations imposed by nature and the fact that such tools may not be available to the next team to remeasure that site.

Table 2 lists the tools that erosion monitors might select from. The list includes numerous optional items that might make the job easier or the data somewhat more complete. However, we emphasize that the only essentials are notebook, pencil, measuring tape, and common sense.

We strongly recommended that you use a modern open-reel fiberglass tape. (See the section titled Measuring Distances.) Old cotton tapes stretch and rapidly abrade in sand; steel tapes are prone to rust, flaking paint, and permanent kinks. Closed reel (totally encased) tapes readily clog with mud and sand, making retraction difficult.

You may want to avoid tapes calibrated in inches. Tapes with feet and tenths of feet markings are just as easy to read, and it is much easier to add and subtract decimals than inches. If you are striving to "think metric", you can buy tapes with an English scale on one face and a metric on the other. If you use one of these tapes, though, make sure the "reader" on your field team is aware of the hazards of inadvertently reading the wrong side of the tape. (All tapes are subject to twist; see the section on Human Error.)

Table 2. Some tools for shoreline bluff erosion monitoring

Tool	Need	Cost	Purpose or comments
Measuring tape (100 ft)	Essential	$30-40	Fiberglass models do not rust, chip; open reel preferred to avoid sand jamming
Card forms, notebook	Essential	?	Share printing costs, use moisture-proof paper
Plumb bob	Advisable	$15-20	Project tape measurements to lower mark
Compass	Advisable	$5+	Bearings to landmarks; aid in finding site
Maps or charts	Advisable	$5 - ?	For location, measuring coordinates, repeat measurements; local volunteers may not need
Map scale(s)	Advisable	$2-5	Measuring distances on maps
Rope, climbing gear	Optional	personal	Safety at some upland sites. For trained climbers only
Shovel	Optional	$15-25	Removing minor debris at bluff toe; uncover beach monuments
Clinometer	Optional	$0-140	Measure vertical angles for bank profile sketches
Flags, survey ribbon	Optional	$0-2	Marking upland sites for study from beach
Camera (with wide- angle lens?)	Optional	personal	Initial photo of site; not essential for remeasurement?
Probe(home-made)	Optional	?	Detecting turf overhangs along edge of bluff
Latitude/longitude template	Optional	$5-10	Measuring coordinates on charts
Binoculars	Optional	personal	Examination of high bluff-top sites from beach
Global positioning system (GPS)	Optional	$200++	Describing new location; relocating established locations
Metal detector	Optional	$100++	Locating buried, “lost” monuments

A device to measure vertical angles (inclines) can be quite handy. An inclinometer, more commonly just called a clinometer, will help you describe a bluff as well as to determine a level line for accurately measuring horizontal distances. Clinometers, like measuring tapes, are rather simple devices, but also like tapes they come in various forms.

Be sure to get a clinometer that reads in degrees of slope and will measure as much as 90 degrees (vertical). Some clinometers have scales in both degrees and percent (don’t confuse the two). Using percent as an angle measurement has serious limitations because many clinometers have no scale beyond 100 percent (45 degrees) and most shoreline bluffs are steeper than that.

A clinometer may be useful for estimating the height of a bluff, but this requires either a knowledge of basic trigonometry or a careful sketch on paper using a scale and a protractor. Basically, one notes the angle to the top of the bluff from a position on the beach a known distance away from the bluff. For example, if you stand 100 feet away from a vertical bluff and measure an angle to the top of 45 degrees, the bluff can be estimated to be about 100 feet high -- but for accuracy one must also consider the slope of the beach, the slope of the bluff, and your own eye height.

A few words about cameras are also appropriate. Along many shorelines you can't get far enough away from the bluff to capture the whole bluff with a standard 50 mm focal length lens. A 28mm lens can often do the job, especially if you use the vertical format. Whether using a fixed focus or zoom lens, record the focal length in you notes so that future photographers can duplicate your view.

Try to include a permanent landmark in your photo, or better yet, two that can be aligned. Remember, your pictures can be much more useful if they can be compared to a later picture taken from the same place with a lens of similar focal length. It may be useful to add other notes, such as "view north 35 degrees west, 80 feet from granite boulder in foreground."

Your most important tools are really your interest and dedication, common sense, and patience. Remember that year-to-year erosion rates at some sites will be undetectable or ambiguous! Without such mental tools all the hardware in the world will be useless.

Data Recording

We encourage you to adopt a standard form for describing site. Figure 14 shows a sample form. Forms have many advantages over random notes. They can have background data already printed, saving you time. A good form will serve as a useful checklist and reminder. A form should be designed so that its data can be readily entered into a computer so it can be easily stored, transferred to other users, or processed. There should eventually be enough data available from your forms so that erosion rate trends could be detected, or you could compare sites with different geology or wave conditions.

Obviously, comparisons through time and in different settings of wave action and geology are simplified if there is some standardization of units as well as forms. English units are more familiar to most volunteers than metric units, and you should usually use them. Unfamiliar conversions can introduce errors. (Let the scientist using your data decades hence make the conversion!)

The actual format of the data form is not critical as long as it is complete and unambiguous. You should not have to guess what is being asked for. There should always be a place for comments, so you can record unanticipated observations. Two examples of filled out data forms are shown in Appendix 1. The card format is easier to use in wind and rain, than a full-sized clipboard page, which will be difficult to protect, and the card can be easily stored with photos that are in a standard format. We encourage volunteers to make improvements to these forms.

FRONT OF CARD

Ref.Pt.Id#________ Established by: ________ Date: ________
Area: ________ Name/ Number: ________ Upland: __ Beach: ________
Background: ________
County: ________ Lat. ________ Lon. ______ Distance: ____
Location/Access: ________

Ownership: ________ Phone: ________
Address: ________

Description: ________

Distance: ________ Date: ________ Team: ________
Distance: ________ Date: ________ Team: ________
Distance: ________ Date: ________ Team: ________
Distance: ________ Date: ________ Team: ________

BACK OF CARD

use grid below to sketch beach/bluff or bluff/upland profile

date:	scale:	date:	scale:
date:	scale:	date:	scale:

Figure 14. Sample Data Card (front and back sides).

Safety

Spending time along eroding bluffs can be hazardous. Observant beach walkers may have noticed fragile overhangs of the upper bank (Figure 12) or fallen boulders imbedded into footprints on the beach. Hazards at either bluff top or beach warrant thoughtful planning, especially when selecting a new monitoring site. (See the section titled Site Selection.)

Whenever approaching the edge of a bank or bluff from the upland, take great care. Footing may be poor on steep slopes, or brush may hide the actual edge. Even a 15-foot fall to the beach can be serious. If there is any doubt about the safety of the bank edge, you should study it from beach level before approaching it from above.

Scouting from below is a useful exercise anyway, but first you must be able to recognize the site from beach level. Even large landmarks close to the edge, such as trees or buildings, may not be visible from below. Take note of distinctive trees or structures that might be seen from the beach. If none are found, mark the place by extending a long pole that has a bright cloth or ribbon tied to the end.

From beach level, carefully study the upper bank edge for cracks and overhangs (Figure 12). How are similar materials nearby eroding? Is it particle-by-particle or sudden failure as thick slabs? Commonly, fresh debris along the toe of the bank can provide clues as to the nature of erosion.

If there is a hazardous overhang, you should select a safer site close by and note its distance from your bank-top landmark. (An overhanging bank would generally be a poor site for monitoring from the upland anyway because it could be ripe for failure and thus could provide a misleading example of local erosion rates.) Sod overhangs can be difficult to measure with consistency.

In some places, you may be well advised to have a belay. (It is beyond the scope of this booklet to discuss basic mountaineering techniques and equipment, but we should point out that “safety equipment” can compound hazards when they are in inexperienced hands.) Solo measurements on higher bluffs can put you in real danger. At such site, work in groups, preferably with at least one climber.

Finally, don’t take chances. Even if your team is comfortable with the site, a future less experienced team may not be. If you don t feel comfortable about a site, note your observations and move on to the next site.

Beach level sites pose a different set of hazards. Falling rocks are a potential danger in some areas. (A hardhat might be advisable, since even a small pebble bounding down a 200-foot bluff could ruin your day. But don’t expect a hardhat to make you invulnerable.) Of course, beware of slick rocks and unstable drift logs as well as rising tides that can trap you at the base of a bluff between headlands.

Incidentally, there are additional reasons to check out potential upland monitoring sites from the beach. Burrowing nesters such as pigeon guillemots commonly take advantage of the extra cover provided by an overhanging soil/vegetation mat on high bluffs. Their burrows may be shallow enough to be disturbed or even crushed by foot traffic (one more reason for homeowners to leave a buffer strip of native vegetation along the bluff edge...).

If you check the bluff with binoculars from beach level, you can usually identify telltale holes and (or) bird droppings that mark nesting areas. An equally good erosion-monitoring site can usually be found a few hundred feet either side of a nest area. If not, at least time your remeasurement of that particular site to avoid nesting season.

POTENTIAL MONITORING PROBLEMS

Establishing and monitoring erosion measurement sites can involve a variety of natural as well as social factors. Fortunately, your care and forethought can generally prevent such factors from becoming problems. Some stretches of shoreline are best avoided, and others may require special care due to some unique factor. In some places a problem, such as slide debris obscuring the lower bank, will simply "go away" in time through normal wave action. Once again, the advantage of local, thoughtful, and patient volunteers becomes obvious.

Fundamental to measuring any line is being able to precisely locate the two end points. This is not always as simple as it may seem. The location of a suitable reference point can require a lot of work and planning (explained in "Establishing New Sites"), but it is a rather straightforward problem. What about the other end of the measuring tape, the eroding bank? Whether monitoring bank erosion from the beach or from the uplands, you will face questions such as what is the "edge", where is the "toe", again and again (Figure 12). Judging where to place the other end of the tape will not be so simple.

Geological Factors

Changes in Beach Profile

Beach-level monitoring in areas of strong wave action requires an awareness of vertical beach changes. The beach profile may rise and fall several feet seasonally, and even its basic shape may change in a single storm. Such vertical beach changes can expose or bury the lower bank or your reference boulder. Depth of burial can "determine" the shape of the boulder as well as the profile of the adjacent bank.

For example, if a team decided to choose the boulder in Figure 12a as a reference, it would be easy, and possibly most accurate, to use the near-vertical face closest to the bank. The problem is that this face is buried much of the year. (See the same boulder in Figure 12b.) Thus, measuring from the apex or an artificial mark high on the boulder would be a better option.

This same set of photos shows how the bank shape changes as a result of changes in the depth (thickness) of the beach materials. The "toe" of the bank here is not at all distinct from the wave-cut platform that underlies the beach (Figure 12b). Fortunately, the volunteers who chose to measure this bank earlier used its mid-point (maximum concavity, see Figure 13b). This would not be an option at a higher bank.

Probably the best way to avoid the problem of an endlessly changing bank toe would be to always measure it at the same elevation. That elevation should be above any possible influence from changes in beach profile.

Obviously, you should record this so that later measurements can be consistent.

Migrating Monuments

The section on Monuments and Marking discusses the selection of beach boulders as reference points for erosion monitoring. Appropriate boulders can be invaluable as references, but obviously only if they are stationary. Figure 12 suggests that in shorelines with strong wave action, you cannot always take the stability of these reference points for granted.

This granite boulder is roughly 4 feet by 4 feet at it base and more than 3 feet high. It weighs more than a ton. Its pyramidal shape makes its top a natural measuring point that doesn’t require special marking. Two stripes of rust on the west side make it unique among other granite boulders in the area.

Unfortunately, when the 1995 photo (Figure 12a) was taken, no measurement of distance to the bank was made. However, comparison of the photos in that figure indicates that it has moved shoreward. The 1996 measurement is more than 6 inches longer than the 1997 measurement, confirming that the monument is moving. (You could get a similar measurement if the boulder were stationary and the bank were slowly moving toward it—which might alert you to a deep-seated landslide at the site.)

Deep-seated landslides

These landslides are common in the bluffs of glacial and interglacial sediments that fringe Puget Sound. Nearly all the larger ones are mapped in the Department of Ecology’s Coastal Zone Atlas of the various counties. Most of these slides have been dormant for centuries, although some undergo piecemeal reactivation during unusually wet years.

Older, larger, and less active slide areas can be difficult to recognize if you are not familiar with the various topographic and vegetative “signs”. As we discussed, they can present a variety of problems for unwary erosion monitors, especially those using reference points on the beach. In such situations you may actually measure a ‘negative’ erosion rate as the entire bluff moves seaward, similar to the reference boulder moving toward the bluff.

Although these large landslides may not be representative of erosion conditions in undisturbed sediments, measurements of erosion may provide useful information about reactivation of the slide or about the amount of slope movement. Remember, many of these large slides have been developed; residential subdivisions, public roads, or parks are on their surfaces. Monitoring their movement can be useful, but such sites should be clearly identified so that you will not confuse the data with "normal" erosion.

Recognizing an area of deep-seated landsliding from the beach alone can be difficult. This is why we urge you to study available literature (for example, the Coastal Zone Atlas) as well as aerial photos before going in the field to establish monitoring points. Identifying very large dormant slides often depends on recognizing subtle vegetative, topographic, or structural signs, no single one of which is diagnostic. Recruit your friendly neighborhood geologist for photo interpretation, even if that person can't be induced to do field measurements.

Some signs of deep-seated landslide activity are:

- low bank in an area of high banks
- a slight seaward bow in an otherwise straight shoreline
- a seaward bow of the cobble/boulder beach lag
- lateral elevation changes (uplift) on the beach
- tilted silt or peat beds exposed among beach gravels
- benches on which the vegetation is of a uniform age
- areas with jack-strawed trees, groups with kinked trunks, particularly conifers
- a bowl-shaped indentation in the bluff edge or hummocky topography on the bluff

A combination of several of these signs, especially if there is corroborating upland topographic and/or vegetative evidence, should alert you that this site may not be reliable for erosion monitoring. (It might, however, be interesting to establish multiple reference points in order to determine if, when, or how fast the slide is moving. An experienced geologist or soils engineer can give you some guidance.)

Burial of Bluff Toe

Slide Debris

You will commonly find superficial **weathering** or debris from small landslides along the toe of eroding banks (Figure 12b). Along a particular stretch of beach, this can consist of an isolated pile of debris from a soil fall or flow or from gradual wet/dry and freeze/thaw cycles. On the other hand, a debris avalanche can obscure the bank toe by leaving a chaotic mixture of broken trees, soil, and brush. Such avalanche deposits erode from the beach more slowly because the vegetative debris acts as a reinforcing binder for the mass. It may take several years for wave action to remove even a small debris avalanche. In contrast, a cone of loose sand resulting from the breakup of soil fall may be removed during a single storm. For these reasons, you should take note of the type and size of debris obscuring the toe. You may be able to estimate when you can revisit the site--that is, how long it will take erosion to remove the slide debris.

Soil Creep

Debris aprons are usually obvious and do not necessarily rule out a site for meaningful long-term monitoring. A more widespread problem relates to sites where soil creep obscures the bank materials. Creep is an important component of bank erosion in many areas, especially along stretches of bank where erosion is relatively slow. There are miles of shoreline where the in-place glacial and nonglacial geologic materials that make up the bank are veneered by creeping soils.

Consistent measurements of sites with slowly moving soil, vegetation, and debris are nearly impossible to perform accurately. The movement of such materials can occur in "spurts", and uppermost "layers" commonly move faster than lower layers. Bluff erosion measurements along such banks are usually not meaningful at beach level. (Measurements along the upland edge can, however, be quite useful.)

Where wave erosion is slow, creep materials may accumulate on the upper beach, even trapping drift logs under the debris. It is difficult to get an accurate erosion measurement on such an amorphous glob of debris and vegetation. This is why such sites are not recommended. (See the section on Site Selection.) Coming back a year later sometimes might give you an opportunity for an accurate measurement, a peek at the underlying undisturbed sediments.

Wave action can remove the debris from creep and reveal in-place bank sediments. Such sites may provide a temporary measuring point along a lengthy stretch of vegetated bank. Thus, the erosion monitor should plan on "losing" sites subject to burial by creep, sometimes for several years. The sites may, however, represent geologic processes on miles of vegetated shoreline bluffs, so they are well worth revisiting.

Historical Changes

Bluff erosion monitors need to be aware of past human activity within the coastal zone that may influence erosion rates. As such activity can have delayed, as well as long-term impacts on bank erosion, you need to know about the human as well as the geologic history of your area. Such background can help you select representative sites as well as interpret trends of recent and potential impacts of erosion.

Shoreline bluffs in Island County and throughout the Puget Sound region have been modified by major grading operations. The more obvious and large scale operations were large enough to show on topographic maps, and some have been misinterpreted as large landslides. Most such operations date back to WWII or earlier, to their impacts on nearby bluffs and beaches are probably over. However, shorelines with less spectacular but more recent modifications are also common and are currently influencing bank erosion.

Among the less obvious examples of such operations are places where excavations of natural bank materials were made to provide fill for beach-level lots. The lots consist of fill, retained by pre excavation bulkheads (Figure 15). These excavations were generally made by “hydraulicking” with water cannons (similar to those used in placer mining operations), or by teams of bulldozers.

Figure 15. Waterfront homes built on fill obtained by excavation of lower bank. Bulkheads built on the beach retained the fill as it was placed. The lower bank is now nearly vertical. The removal of erosional debris from the access road along the toe of this bank has now replaced wave action as an “agent of erosion”.

Beach operations like these would not be permitted under current land development regulations, but they were common in the 1950s and 1960s. The resulting beach-level fills obviously protect the toe of adjacent bluffs from wave action, but what about the uplands? Uplands fronted by newly excavated banks may be subject to accelerated erosion as the banks “adjust” (for decades) to the new conditions of steeper angle and the loss of older deeply rooted trees. A bank that has been denuded of vegetation and probably oversteepened by excavation is, everything else equal, eventually going to erode at a greater rate.

Also, as eroding sediment no longer reaches the beach, it contributes nothing to beaches and their form of bank protection downdrift of the site.

As discussed, historical changes in the supply of sediment to a local beach can have direct as well as indirect impacts on bank erosion rates. It is also well worth noting that such changes can impact beaches (and bluff erosion) at considerable distances downdrift. Figure 16 shows a typical impact of the interruption of beach sediment transport.

Figure 16. Erosion caused by interrupted littoral drift.
Sand that has eroded from bluffs in the upper left created Lagoon Point. Now, the jetty intercepts that supply, so the beach on the right is “starving”. Note the bulkheads and quarry rock. Is this also impacting bluffs farther downdrift?

To sum up, to make meaningful long-term erosion determinations for certain areas, you will need to take into account local history. This is one more reason that a carefully planned and organized team approach is essential for most erosion monitoring. An individual homeowner’s recorded observations could be useful but possibly misleading if not considered in the context of local development and land use.

Practical Difficulties

Access

Some of the best erosion-monitoring sites are on, or may be most accessible from, private property. This need not be a problem for a local erosion-monitoring team. (In fact, it is one more example of where the local volunteer has an advantage over the federal or state surveyor or university student.)

Most property owners are happy to grant you access for basic research efforts once they understand the importance of the work and that the data are “neutral”. A little patience, common sense, and application of the

Golden Rule can usually win over even the staunchest skeptic. Each situation is different, so we offer the following thoughts only as guidelines:

- Identify yourself and your project immediately.
- Make previous contact when you can.
- Bring along a brief handout that explains your mission.
- Listen for “windfalls” of information or a chance to see old photos.

Some expansion on these tips:

A one-page handout or folder, complete with a local phone number, may be helpful in further explaining who you are and what you are trying to do. If homeowners have later questions or suggestions, they will appreciate having a way to find you.

If one is available, bring an aerial photo. Many people are fascinated by a view of their home and area from the air, especially an oblique view. (Vertical views tend to be alien to many people). Also, be prepared to tell them how they can order a copy. Almost any commercial aerial photography can be obtained through the Photos and Maps Division of the Department of Natural Resources in Olympia.

Finally, be ready to spend some time, especially for your first visit. A property owner, especially an “old-timer”, may be able to offer valuable insights that will be of direct importance to erosion monitoring. For example, an old family snapshot that includes the bank edge and some nearby landmark may provide priceless long-term erosion data. Stories of landslides in response to storms or earthquakes may also be useful. Take notes, record dates--they may help you to later differentiate facts from well-meaning but misleading embellishments.

Vandalism

Long before the Vandals invaded southern Europe about 500 A.D. there were people who took pleasure in destroying whatever they couldn’t steal. We see the results of the same traits today. Former government benchmarks in boulders at Coupeville (Figure 17) and south of the beach parking area at the end of Hastie Lake Road Park illustrate the results of such thoughtless action.

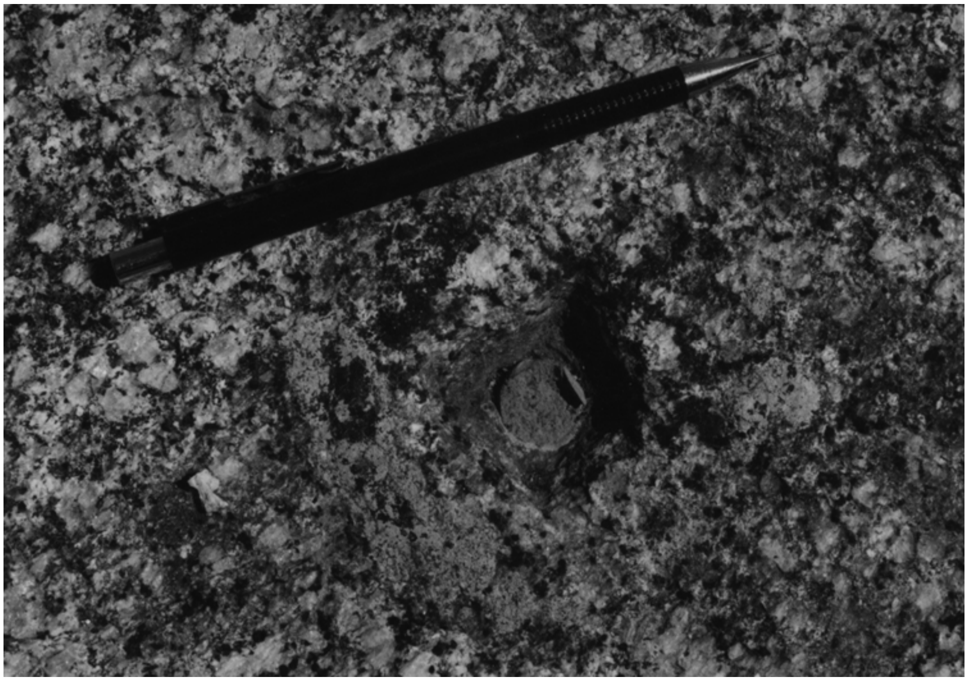


Figure 17. Remaining stem of broken off government survey mark can still be seen in the bottom of this hole in a granite boulder.
These bronze plaques (Figure 3) are attractive targets for vandals. However, even the empty hole can still provide a reference point for erosion measurements. Filling the hole with colored concrete patching could help protect it from weathering processes.

Among the options for minimizing vandalism is to make reference marks both inconspicuous and of no value. The bronze medallions long used by the USGS and USC & GS (Figure 4) are neither. Thus, they are susceptible to loss or destruction by a persistent vandal. Some suggestions for less attractive marks are offered in “Selecting the Monument” and Marking Monuments”.

ORGANIZATION

For monitoring extensive shorelines, for example, those of an entire county, an established group such as the WSU/Island County Beach Watchers might be more appropriate than even dedicated individuals. Depending on the particular situation, some of the following may be irrelevant. Here, we outline some of the potential needs for an erosion monitoring group and offer a partial "wish list" for meeting those needs. We emphasize that (1) the task is often more complicated than first imagined and (2) in most areas there is so little erosion data that almost anything you do will be of help.

Support

A group as large as the Beach Watchers is certain to encompass a broad spectrum of interests and skills, even before their extra training. Other existing organizations such as historical societies can provide important background data. A range of skills will be useful in monitoring bluff erosion along shorelines of such length and complexity as Island County's. Support needs may include:

- knowledge of local history, knowing which shorelines are natural, which disturbed and when?
- management of financial arrangements with state agencies, adjoining counties
- liaison between and assignments for field teams, maintenance and control of specialized equipment
- public education, explaining what you are doing and why
- contacts with property owners for access, or new monuments
- data storage and access for the public and researchers

Except for the historical research, most of these support needs are ongoing. Thus, it is easy to see why several volunteers could be kept busy in support roles. (This would be a good opportunity to involve volunteers who are interested but might have difficulty with beach travel--for example, someone who is wheelchair bound.)

Field Teams

Monitoring erosion, like monitoring weather or stream flow, is by definition a long-term effort. The longer the time baseline, the better the data. We can get some quick vignettes on bluff erosion rates by good detective work regarding historic landmarks and by simply remeasuring long-established government reference points.

After that, however, the real work of monitoring begins. Establishing new reference points and a program for monitoring them seems a task ideally suited to local, trained volunteers. There is room for almost any talent or interest on your monitoring team. Those with special skills (such as mountaineering, surveying, site sketching, or rock drilling) could “float” among various field teams.

In addition to those with special skills, volunteers with valuable personal equipment can be of great service to regular field teams, especially for establishing new monitoring sites. For example, a boat may be the best means to transport the dry concrete, fresh water, reinforcing steel, and tools needed to cast a monument on a remote sandy beach. Boats can be rented, but an experienced operator with local knowledge may need to be wooed. The owner of a metal detector could be a valuable resource.

Patience is another of the needed skills. “Watching grass grow” is often quoted as a lack of concern for time. Grass grows at lightning speed compared to long-term bank erosion rates in some areas. Thus, the volunteer monitor will only rarely get the gratification of detecting a spurt of erosion. It’s being there for the long haul to “pass the baton” that can assure program success.

Field teams of three or four would seem to be optimal for efficient data-gathering and safety. True, the note taker or “recorder” could also handle one end of the tape. However, such multiple roles for members of a two person team could compromise safety at some sites. The team of three or four can offer a broader variety of skills, and be more apt to include someone who had been there before than would a skeleton crew of two.

Skills commonly needed at a monitoring site include:

- measuring
- data recording
- sketching/photography
- lookout or belaying (see the section about Safety)

Data Storage and Continuity

We have already discussed field data forms (in the “measuring” section).

Useful erosion information takes many years to accumulate. You’ll need to store records so that future workers can update them or compare them. Remember, shoreline erosion is commonly episodic. Spurts of activity may be followed by years or decades of little change. You will need to know where your records are and not lose interest in keeping them updated.

Raw data from the field, whether in file card, sheet, or electronic format, must be safely stored until it can be logged into some permanent file. If possible, include photos, field notes, or other raw data in the permanent file, at least until the site can be revisited.

Remember to make duplicates of your electronic files, and plan to bring them into new programs as the hardware and software you use evolves.

Consider adopting a permanent repository that will assure both access and protection.

Files should be organized so that future workers can easily locate records for a particular site. Consider filing by location, not by date--generally a good practice for any type of site-specific monitoring data.

Even after filing, there may be justification for temporary storage of original field sheets. Sketches or comments that may not fit into a permanent or electronic file could be important, at least until a given site is revisited. Some data, such as photos or detailed maps of a particular site, may warrant permanent storage even though they may be awkward or space-consuming. Each site will be unique, and you will not be able to anticipate what may occur there years in the future.

While the data you collect may seem of most relevance to your particular stretch of shoreline, their greatest value may be to government or university researchers who study erosion. You might wish to identify a state or university archive for the data or copies of your data.

You may also want to select some central repository that will be open to the public, homeowners, planners in local government, and researchers, but that is also controlled. Select an established organization that will be there 50 years from now.

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GLOSSARY

Not all terms in this list appear in the text, but these definitions may be helpful in understanding basic concepts presented in this booklet.

Accretion The gradual addition of new land to old by the deposition of sediment carried by streams, or by longshore sediment transport via beaches. (See Longshore Drift.) Accretion and erosion are natural processes, but either can be accelerated by shore-protection structures.

Accuracy An accurate measurement is one that is correct, true, or exact. With care we can minimize mistakes, as well as "built in" errors such as the stretch or sag of our measuring tape. Absolute accuracy is not attainable, especially in measuring to an uneven surface such as the face of a bluff. (See Precision.)

Angle of repose The angle, measured from horizontal, at which rock debris comes to rest. The term should be applied only to loose (i.e., noncohesive, noncemented, dry) materials. For example, moisture can make sand "defy" this "law" (illustrated in sand castle construction). The angle of repose is about 34 degrees for sand, 37 degrees for gravel, and as much as 45 degrees for angular boulders.

Bank The generally steeper, in places bare, eroding area between the beach and the upland. The base (toe) of the bank along the beach and the top of the bank (edge of the upland surface) are of primary interest to erosion monitors.

Beach profile The profile or trace of the beach surface on a vertical plane perpendicular to the shoreline. A beach surface may rise or lower (and thus change profile) as much as several feet seasonally or even during a single storm. Thus, shore-protection structures such as bulkheads can be undermined if their footings are not deep enough. (See **Scour.**)

Bedrock The mass or continuous surface of rock that makes up the earth's crust. Bedrock is exposed at the surface (appears as "outcrops") in places, but along Puget Sound is more commonly buried by sediment. (See **Soil**.)

Benchmark An elevation marker, most commonly a circular bronze plate attached to a boulder, concrete monument, or structure. (See **Triangulation mark.**)

Capillary water Water held as a continuous film on soil particles. The particles in soils rich in silt and/or clay have more surface area than coarser soils and thus retain more ground water as capillary water. This water, held by molecular attraction stronger than the force of gravity, may be available to plants but cannot drain to the water table.

Chain, rope chain The modern surveyor s "chain" is not a chain at all, but a strong narrow measuring tape without a reel. Thus, modern chains may can be longer (200-300 feet) but still lighter than is practical for a tape (but the chain is subject to knots if not carefully handled).

Cohesion, cohesive Sediments with abundant fine particles (silt, clay) are called cohesive because the particles tend to stick together. Cohesive materials can stand in vertical bluffs, whereas noncohesive materials (such as gravel) tend to ravel or flow to their **angle of repose**.

Compaction The decrease in pore space within a mass of soil or sediment brought about by the tighter packing of particles. In general, the process results in a denser, stronger, and more stable soil. (An example is **till**, which has been compacted by the weight of the depositing ice; engineered fill is compacted by heavy equipment such as rollers.) However, some materials compact poorly. (See **Sorting**).

Contact The surface where two different kinds of rocks or sediments come into contact. Contacts are especially important in soils or unconsolidated sediments because the marked changes in physical properties that may occur there are common sites for saturation or **perched ground water** (and thereby sometimes the site of landslides). See **Formation**.)

Coordinates A system of coordinates such as **latitude** and **longitude** can be used to designate the location of any point on the planet. Sets of coordinates can also be used to describe the corners and therefore the areas encompassed by maps.

Creep, Soil creep The imperceptible down slope movement of soil. In banks of glacially compacted sediment common along Puget Sound only the upper few feet of **soil** and vegetation are involved in creep. Such a soil/vegetation mat "flows" slowly around mature trees that have roots anchored in the subsoil. Creep rates can range from 0.02 to 10 millimeters/year.

Cross section, Section The profile of the beach and/or bluff surface but with additional information about the composition of those surfaces and what lies beneath them. Sections can provide much more information than a simple **profile**.

Debris avalanche A common form of small rapidly moving landslide on vegetated Puget Sound bluffs. Such avalanches generally involve only shallow **creeping soils** and are triggered by **perched ground water** during or after severe rainstorms.

Diffraction The ability of a wave to repropagate its lost "wing" into the shadow zone of an obstruction. Were it not for diffraction, sediment would also accumulate behind the "protected" area behind or downdrift from beach groins.

Drift, Glacial drift Sediment originating from glaciers, whether directly deposited by ice in the form of concrete-like **till**, as a rain of sediment onto the sea floor from melting ice, by meltwater streams glacial **outwash**, or as silt (blue clay) settling on the floors of glacial lakes.

Drift sector See **Transport cell**.

Drift, Longshore drift, Littoral drift The net movement of sediments along the shore or beach. Not to be confused with **Drift, Glacial drift**.

Energy level The energy that existed or exists in the water of a particular sedimentary environment. For example, beaches commonly subjected to large storm waves would be considered "high-energy" environments. The higher velocity currents and the turbulence in such settings are capable of removing finer particles, leaving only a cobbly beach. A mudflat or a lakebed is an example of a low-energy environment (and thus sites for deposition of fine sediments).

Erratic (Latin for "wanderer".) Glacially deposited rocks or "erratics", some of them house-size, are commonly of a different composition than local bedrock. If we know the source of such rocks, we will also know the direction from which the ice came. The thickness of a glacier or ice sheet can be indicated by the elevation at which erratics were left stranded on valley walls or mountain fronts by melting of the ice that transported them.

Feeder bluff An eroding bluff that supplies sediment or "nourishment" to a beach. Obviously, the amount and texture (which depends on the mix of particle sizes**)** of sediment available to the beach will depend not only on the erosion rate but the composition of the bluff. (For example, a bluff of sand will not provide much gravel to the beach.)

Fetch, fetch length The distance over water in which waves are generated by wind of constant direction and speed. In protected waters such as those in much of Puget Sound, channel width and (or) the height of bluffs across the particular body of water can also be a major factor in wave generation.

Formation A layer, collection of layers, or mass of soils or rock distinctive enough to constitute a basic unit for geologic mapping. A formation can be a single rock or soil type, or it can contain a distinct assemblage of geologic materials. For example, the Whidbey Formation contains sediments ranging from silt, sand, and gravel to peat, but this collection of ancient floodplain sediments is unique enough to be recognizable over a considerable area and constitutes a mappable unit.

GLO Government Land Office. Established in 1812 as custodian and disposal agency for public lands; it was also responsible for early land surveys such as establishing section corners.

GPS, Global Positioning System Portable devices for determining one's location. They rely on satellite signals to calculate latitude and longitude. GPS units are now available for as little as $200. Units currently available to civilians are not accurate enough for erosion measurement but could be useful for finding a monument.

Grain size Same as particle size. The size of fragments that make up a layer or mass of sediment, or the size of individual mineral grains in a rock. For example, gravel is a coarse sediment, granite is a coarse-grained rock. Grain size is a factor critical to many important characteristics of sediments (such as how easily they are transported by erosive agents or how well they transmit ground water). (See **Sorting**.)

Groin (Groyne in Britain) A low wall across a beach generally perpendicular to the bank, built to trap sediment and increase the beach elevation and width. The enhanced beach resulting from a groin can provide some erosion protection for adjacent shorelands. However, the disruption of longshore drift commonly results in increased erosion downdrift.

Ice sheet An ice mass covering thousands of square miles that is thick enough to flow under its own weight. (Also called a continental glacier.) Near its source (area of accumulation) it may be thick enough to cover mountain ranges. The last ice sheet from Canada to reach western Washington was about 7,000 feet thick at the international boundary. At the latitude of Port Townsend, it had thinned so that it did not overwhelm the Olympic Mountains; rather, it split into a Puget Sound lobe and a Juan de Fuca lobe.

Landslide A general term covering the whole spectrum of the mass movement of earth materials. It includes falls, slumps, slides, and flows. Such terms only describe the mode of initial failure of a landslide mass (that is, how it broke away from its original slope). Actually, landslides commonly travel in modes different than that of the initial failure. (A slump may break up and travel as a flow.) (The term does not cover particle-by-particle erosion.)

Latitude, Parallel of latitude Latitude lines on maps and charts are oriented east-west. (The boundary between the U.S. and Canada generally follows the 49th parallel.) Latitude (like **Longitude**) is measured in degrees, minutes, and seconds, but **GPS** navigation uses fractions of a minute instead of seconds. One minute of latitude equals 1 nautical mile. (See **Longitudes, Coordinates**.)

Littoral cell See **Transport cell.**

Longitude, Meridian of longitude Longitude lines on maps and charts are oriented north-south. Like minutes of **latitudes**, minutes of longitude are a nautical mile apart at the equator; however, they converge toward the north and south poles. Latitude and longitude **coordinates** are ideal for locating the position of erosion monitoring monuments.

Longshore drift The movement of sediment parallel to a shoreline as a result of wave action and tidal currents. Drift direction can reverse temporarily during a given storm or seasonally but will have a net long-term trend.

Outwash Generally sand, gravel, or gravelly sand, but the term includes all stratified glacial drift deposited by meltwater. The term “glacial outwash” is sometimes used for emphasis, but technically “glacial” is redundant. (See **Drift**.)

Particle size See **Grain size**.

Perched ground water A zone of saturation along the top of a relatively impermeable layer of sediment (such as silt). Such saturation occurring temporarily during rainstorms at the sloping **contact** between the **creeping soil**/vegetation mat is a common trigger for **debris avalanches**. Seasonally perched water, commonly indicated by a horizon of seeps or water-loving plants (such as horsetail), is also a trigger for deep-seated landslides on shoreline bluffs.

Percolation The downward movement of ground water within saturated sediments or bedrock. Percolation rates are much faster in coarse sediment such as gravel than in fine, less permeable sediments such as silt. See **Grain size, Permeability**.

Permeability The capability of a sediment or rock to transmit fluids (for our purposes, water). Good permeability depends not only on relatively large and abundant openings (good porosity), but on how well those openings are connected. Coarse gravel without much sand or silt between its particles has excellent permeability. Sediments rich in fine material, such as **till**, have low permeability.

Platform See **Wave-cut platform**.

Porosity The proportion of bedrock or soil that consists of openings (pore spaces). A fine soil may have a high porosity (much pore space), but still be highly impermeable because the spaces are not well connected or are too small to allow free passage of water.

Precision The term precision commonly implies a measurement with lots of numbers after the decimal and (or) one where repeated measurements yield nearly identical results. The former can easily be misleading. (See **Accuracy**.) The latter can be simply the repetition of an error, such as recording inches as tenths of feet.

Profile An outline of the land surface drawn in a vertical plane. (See **Cross section, Section**.) The profile of a beach commonly changes shape as well as general elevation in response to wave action.

Reflection Where wave energy is not absorbed or dissipated by the gentle slopes and/or surface roughness of a beach, much of it can be reflected. Waves reflected from vertical surfaces such as a floating bridge or a bulkhead at high tide can reinforce incoming waves, almost doubling their height. (See **Scour**.)

Refraction, wave refraction The change in direction of a wave front as the portion in shallower water nearer the shore begins to "feel bottom", slow, and build in height. Waves begin to feel bottom in water depths of about half their wavelength. They begin to break when that height is about 80 percent of water depth. (A 5-foot wave will break in about 6.5 feet of water.)

Scale, map scale Maps and nautical charts must have a scale to enable the user to relate a map or chart measurement to the real world. Most erosion monitors will probably use maps published by the U.S. Geological Survey with a scale of 1 map unit equal to 24,000 land units of the same length (referred to as 1:24,000). A ruler calibrated to measure such maps (also called a scale) will show 1 inch equal to 2,000 feet.

Scour The removal of underwater material by waves and (or) currents. The most common example of scour is where a large wave impacts a vertical bulkhead and a portion is deflected violently into the beach. The resulting scour may undermine the bulkhead or even remove supporting fill from behind it.

Sediment Rock particles and (or) vegetal matter that has been transported by erosive agents such as streams, wind, glacial action, or waves. Because these erosive agents have widely varying abilities to transport rock particles of different sizes, the sediments in a given area will reflect these differences as distinctive layers. (See **Strata/stratification**.)

Slope A surface inclined from the horizontal or, in this case, its angle of inclination. Slope can be expressed as a ratio (1.5:1), as percent (67%), or as degrees (33.6°). The different units each have advantages and are used by different professions.

Slump A specific type of landslide in which the moving mass rotates on a horizontal axis. Thus, the top or head of a slump goes down, whereas the toe at or under the beach is uplifted. The term is commonly misused to refer to any landslide.

Soil Engineers and many geologists use the term "soil" to mean all natural material that overlies bedrock. Thus, an entire shoreline bluff may be considered soil. The term is used by agronomists, soil scientists, and some geologists to describe the veneer of weathered sediments and rock, and vegetal material, that supports plant life. This second usage of the term soil, in general, applies only to the upper 3 to 5 feet of material. (See **Creep**.)

Sorting A process that results in sediment made up of particles of similar size. (For example, well-sorted gravel contains little sand or particles of other sizes.) Thus, well-sorted sediments have high porosity and, in coarser materials, good **permeability**. "Drainfield gravel" is one example of such material. Another characteristic of well-sorted sediments is that they are difficult to **compact**. ("Pea gravel" provides a good cushion under playground equipment, but makes a poor surface for driveways.)

Storm surge, surge A rise in water level above predicted tides due to onshore wind and/or low barometric pressure. (See **Wave setup**.)

Strata/stratification Layers or the layered state of sediments and sedimentary rock. Contrasts in particle size are among the most obvious characteristics that distinguish one stratum from another. Such contrasts can have profound affects on permeability, and thus ground-water movement and/or landslides. (See **Perched ground water**.)

Swell(s) Wind-generated waves that have traveled far beyond their source area, in contrast to locally generated waves or "seas". Swells from ocean storms can be significant to bluff erosion and sediment transport along the Strait of Juan de Fuca but do not travel far into more protected waters.

Tape A measuring tape. Measuring tapes of fiberglass and plastic are accurate enough for erosion monitoring and avoid the potential rusting and paint chipping problems of steel tapes. "Open reel" tapes are not as readily jammed by sand as those with enclosed cases. (See **Chain**.)

Till A sediment deposited directly by and (or) beneath a glacier. The generally wide range of particle sizes and lack of **stratification** in till give it a concrete-like appearance. Those same factors, and the fact that it has been compacted by the weight of the ice, make it very hard (for example, it is commonly called "hardpan" by well drillers), strong (capable of standing in high vertical banks), impermeable, and erosion-resistant. (Till is sometimes called glacial till for emphasis.)

Toe The base of a bank, bluff, or landslide mass. The term is sometimes used to refer to the base of a structure such as a rock seawall.

Transport cell, drift sector littoral cell A segment of shore that includes a source of sediment, an uninterrupted path of movement, and an area of sediment accumulation. An example of such a cell might be an eroding headland, a downdrift accreting spit, and the beach between upon which sediment travels.

Triangulation mark A position or location marker, most commonly a circular bronze plate attached to a permanent survey monument. Triangulation is a survey method based on the precise measurement of horizontal angles. (See **Benchmark**.)

Upland See **Bank**.

USGS, United States Geological Survey In addition to its geologic research, the USGS is a major publisher of maps. Their 7.5-minute quadrangle map series, for example, consists of maps bounded by 7.5 minutes of **latitude** and **longitude**.

Water table For a regional body of ground water, that is the upper surface of the saturated zone. In its downward movement, infiltrating precipitation may pause at finer grained layers, causing **perched ground water**, but eventually most reaches the water table. The water "table" is not necessarily flat and horizontal. Where the surface of the water table is higher than the surface of the land, a lake or pond occurs.

Wave-cut platform A nearly horizontal erosional surface. Platforms are common fronting shoreline bluffs of compact sediments or erodible bedrock. Platforms may be permanently or secondarily covered by beach deposits.

Wave setup Rise in water level cause by the piling up of water along the shore by onshore winds and resulting waves. (See **Storm surge**.)

Weathering The decomposition of bedrock and soils by chemical and mechanical action. Among the more obvious chemical reactions is the oxidation (rusting) of iron minerals. Mechanical weathering consists largely of loosening by freeze/thaw and wet/dry cycles and by the roots of vegetation. Such loosened material and its vegetation tends to move downslope slowly by **creep** or rapidly as a **debris avalanche.**

APPENDIX 1: Sample Data Forms

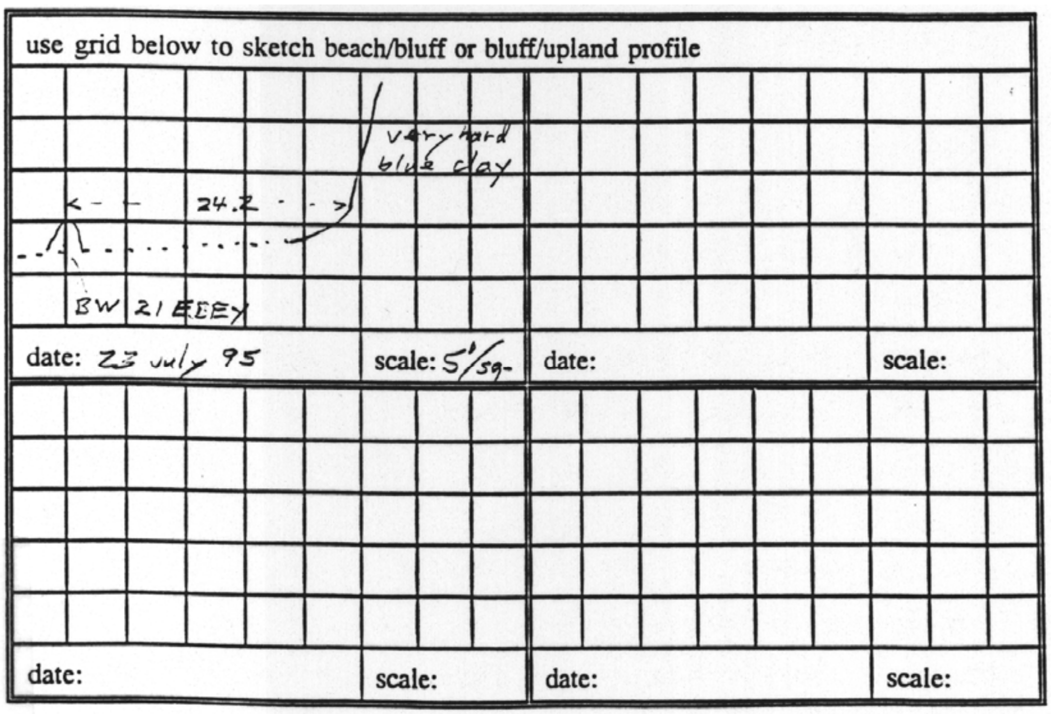
Sample Data Card: Beach level monitoring site (hypothetical)

Ref.Pt.Id# BW 21 EBEY Established by: Beach Watchers Date: 23 July 95
Area: Ebey's Landing S Name/ Number: same Upland: __ Beach: ✓
Background:
County: Island Lat. 48° Lon. ____ Distance: 24.2
Location/Access: About 1100 ft south of culvert under road at Ebey's Landing. 2 mi SW of Coupeville

Ownership: Public tidelands Phone:
Address:

Description: 3/8 in diam hole in top of boulder. Hole filled with gray epoxy. Boulder is 3 x 5 ft diam. elongated parallel shoreline. Boulder is greenish black & protrudes about 3 ft above gravelly beach. (4 ft d. granite boulder about 40 ft to north.)

Distance: same Date: same Team: BW #1 SB, DJH,
Distance: ____ Date: ____ Team: ____
Distance: ____ Date: ____ Team: ____
Distance: ____ Date: ____ Team: ____



Sample Data Card: Bluff top monitoring site (hypothetical)

FRONT OF CARD

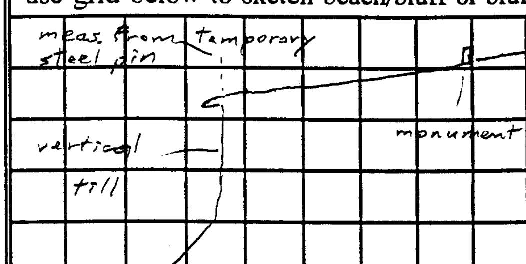
Ref.Pt.Id# USCG **Established by:** U.S. Coast-Geod. Surv. **Date:** June 1948
Area: Whidbey, W. Bch **Name/ Number:** ALEX 2 **Upland:** ✓ **Beach:**
Background:
County: Island **Lat.** 47° 17.23' N **Lon/** 122° 21' W **Distance:** 57 ft
Location/Access: About 100 ft west of the centerline of West Beach Rd, 1.3 mi north of its intersection with Hastie Lake Rd. Short trail to north leaves Jones driveway about 60 ft in.
Ownership: Betty + John Jones **Phone:** 360 2?7-1234
Address: 1534 West Beach Rd Oak Harbor

Description: Bronze disc on 1 ft high concrete monument. Approx 28' NW of 3 ft spruce. Monument is 57 ft from edge of bank

Distance: 42.1 ft	**Date:** 2 Aug 95	**Team:** BW#3 RWT, PEG, JKF
Distance:	**Date:**	**Team:**
Distance:	**Date:**	**Team:**
Distance:	**Date:**	**Team:**

BACK OF CARD

use grid below to sketch beach/bluff or bluff/upland profile



date: 2 Aug 95	scale: 10'/sq.	date:	scale:
date:	scale:	date:	scale:

APPENDIX 2: Marking Bedrock or Boulders

Probably the most versatile and durable means of permanently marking either a natural or a structural monument is drilling a hole in it. Even where “permanent” bronze plaques have been chiseled out by vandals, the hole drilled to affix them can still be used as a measuring point (Figure 17). Thus, a marking system based on a drilled hole should be an option available to any erosion monitoring team.

The mechanics of drilling a hole in bedrock, a boulder, or in existing concrete or masonry structures will depend on the tools and skills available. Your erosion monitoring team may include or have access to people who are already knowledgeable about such processes. For example, anyone with a mason s, carpenter s, or building contractor's background can be helpful. The objective is to drill a hole that is large enough to be readily seen into a monument, without causing cracks or other damage.

Much of Table A-1 is devoted to tools for drilling glacial boulders (erratics). You may think “What’s the big deal ? I’ll just go to my local hardware store and buy a chisel or star drill”. The short answer is “go ahead, try it”. We have, and it isn’t easy.

Table A-1. Some tool options for marking new stations

	Item	Estimated Cost	Purpose/Comments
Option 1	Rotary drill gas-powered Pump, can, hose Industrial diamond bit	$1,400-1,800 $80-100 $100-150	Full power operation of professional size diamond drill bits (3/8-1-in.+) Supply of pressure water for cooling bit, removing cuttings Efficient cutting of holes to 1-in. diameter, 8-in. depth in any rock
Option 2	Electric drill, ½-in. minimum capacity Generator, gas-powered Coolant head, swivel Garden sprayer Industrial diamond bit	$300-500 $500+ $160-220 $25? $100-150	Possible substitute for gas drill? Must have adequate generator Power for electric drill; possible hazard near saltwater Chucks between drill and bit providing pressure water to bit Provide pressure water to makeshift drilling rig Efficient cutting of holes to 1-in. diameter, 8-in. depth in any rock
Option 3	Electric drill, 3/8-in., battery powered, heavy duty Hobby (lapidary) diamond bits Modeling clay, Play-doh Squirt bottle (plastic)	$200-300 $5-35 $5 $10?	Can turn small (0.1 - 3/8-in.) diamond bits for holes to 1 in. deep; bit life will be short without proper cooling Not recommended for freehand drilling. One hole per bit??? Form circular dam around the hobby bits to retain cooling water Water jet to clean rock dust from hole
Option 4	Electric hammer drill (½-in. minimum) Carbide bit Generator	$500+ $10 $500+	Dry drilling of masonry, possibly concrete, and soft rock Bits larger than 3/8-in. cost more; carry spares See option 2
Option 5	Hammer drill, 3/8-in minimum Carbide bits (3/8-in.) Spare battery (?)	$300 $10 $40-50	Dry drilling of masonry, possibly concrete, and soft rock Dry drilling generates much heat, Smaller bits dull or break more easily than larger ones Supplemental power when working in remote areas

Erratics on uplands and beaches have been slowly tumbled, scraped, and abraded during miles of transport in grit-laden glaciers. In general, only the hardest and toughest rock types survived. Most of them are composed of minerals harder than glass. Drilling even a small hole (Figure 9) in rock using hand tools can challenge a stone mason. Few amateurs will have the skill, strength, patience, and endurance to do much more than mar the surface. Cuts, bruises, imbedded metal chips, and frustration will be the only rewards for some.

Once a hole has been made, by whatever means, it should be filled to avoid weathering and to contrast with the original surface. The marking material you choose need not be conspicuous (large or bright). Your description of the monument, (for example, a boulder), should be good enough so that some one else can identify it for later. You (and they) should be able to find a small mark that contrasts with the surrounding colors or texture near the top or center of a monument.

We have not tested the hundreds of products on the market that could be suitable for marking monuments. We chose to work with water-based products designed for patching cracks or attaching hardware to concrete. If you find an inexpensive, non toxic material that pours readily, cleans up with water, bonds to dusty or damp surfaces, sets as hard as concrete without shrinking, and won't deteriorate in less than 50 years, by all means use it and pass the word to your colleagues.

If you are responsible for marking new monuments, you should try out techniques and equipment at home to be sure they work before you go in the field to do the marking. We urge you to experiment. One guideline for experimentation when faced with a problem is to ask "how do the professionals do it? Who drills small holes in very hard rock with equipment one person can carry?" Research geologists!

Scientists who study, among other things, records of our planet's ancient magnetic fields now "frozen" in rock need precisely oriented samples to study in the laboratory. They developed small portable drills to cut small cylinders from the rock using a diamond-rimmed coring bit that is turned by a small gasoline motor (Figure A-1). Why "reinvent the wheel"?

Such "professional grade" tools are seldom cheap, and these are no exceptions (Table A-1). However, if time and certainty of results are important, the best tool is often the least expensive in the long term. The cost of the drill could be shared by several counties, with each monitoring team purchasing their own diamond bits.

Because you, as bluff erosion monitors, will be drilling relatively few holes, there may be opportunities to improvise. The professional-quality diamond bit is probably not one of them, however. Diamond bits used in the lapidary hobby are rather fragile and not intended for hand-held drills. While each bit might be cheaper, it will take a lot more of them to get the job done.

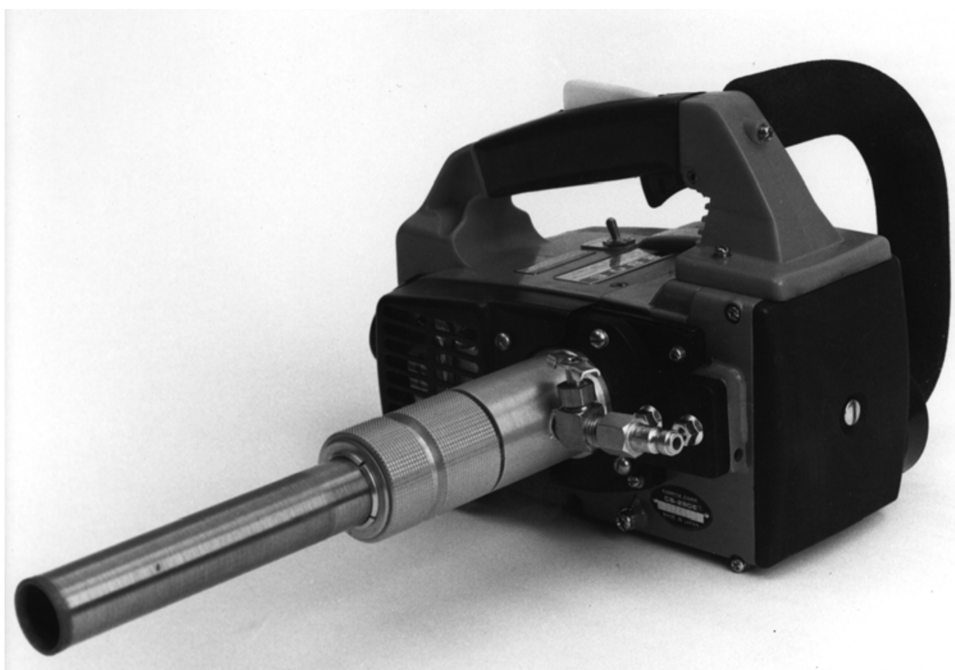


Figure A-1. Gas-powered drill for establishing monuments in hard rock. Marks in boulders could be drilled by a gasoline-powered drill such as this. Pressurized water cools the bit via its hollow stem and swivel. (Photos courtesy of David Stone, University of Alaska and ASC Scientific, Carlsbad, Calif.)

On the other hand, there may be room to improvise in regard to powering the bit. A modern heavy-duty electric drill might turn such a bit if not pushed against the rock too hard. (No erosion monitor should be in a hurry!) The trick will be to provide water to cool and remove “rock dust” from the bit.

Diamond bits used in industry rely on circulating coolant under pressure down the hollow drill stem. Obviously, such a system requires a hollow swivel arrangement to avoid winding the water hose around the drill stem. Such swivels are available, but not intended for portable electric drills. If other problems can be surmounted, water under pressure can be supplied by a common garden sprayer.

It is possible to drill shallow (1 inch or less?) holes on horizontal surfaces with diamond bits without pressured water. This can be done by drilling through water impounded by a circular dam of clay stuck to the rock surface. We urge anyone experimenting with this technique to use light pressure for a short period and to clean the hole often with a jet of water.

Once the hole is drilled, you can fill it with a tough, hard-setting, vandal-resistant substance in order to protect the hole from weathering, as well as to serve as a permanent mark. The diameter of such a hole need be no larger than a mechanical pencil and no more than 1 to 2 inches deep. Actual dimensions will be largely dependent on the composition of the monument, available drilling tools, and the method you chose to make the mark.

A few caveats:

- A hole smaller than a common wood pencil will be difficult to fill with viscous liquid--it will be difficult to get the fluid in and the air out.
- Less viscous fluids may be poured in, but avoiding bubbles and air pockets in holes less than half an inch in diameter will require considerable care.

APPENDIX 3: Establishing Monuments on Sandy Beaches

As mentioned in the text and illustrated in the cover photo and Figure 3, there are various reasons why erosion measurements along a stretch of sandy beach can be important. Yet creating a permanent reference monument on sandy beaches that are exposed to strong wave action could be one of the most difficult tasks facing an erosion monitoring team.

The primary problem is the shifting nature of sand and gravel beaches. The annual net flow of finer sediments as longshore drift is not the problem. The real problem relates to the vertical fluctuations of the beach surface (Figure 12), which might be as much as several feet during a single storm or tidal cycle. Before you decide to cast a new monument on a sandy beach, probe the sand to see if the sand is thick enough for the monument and that there is no compact platform lurking a few feet down.

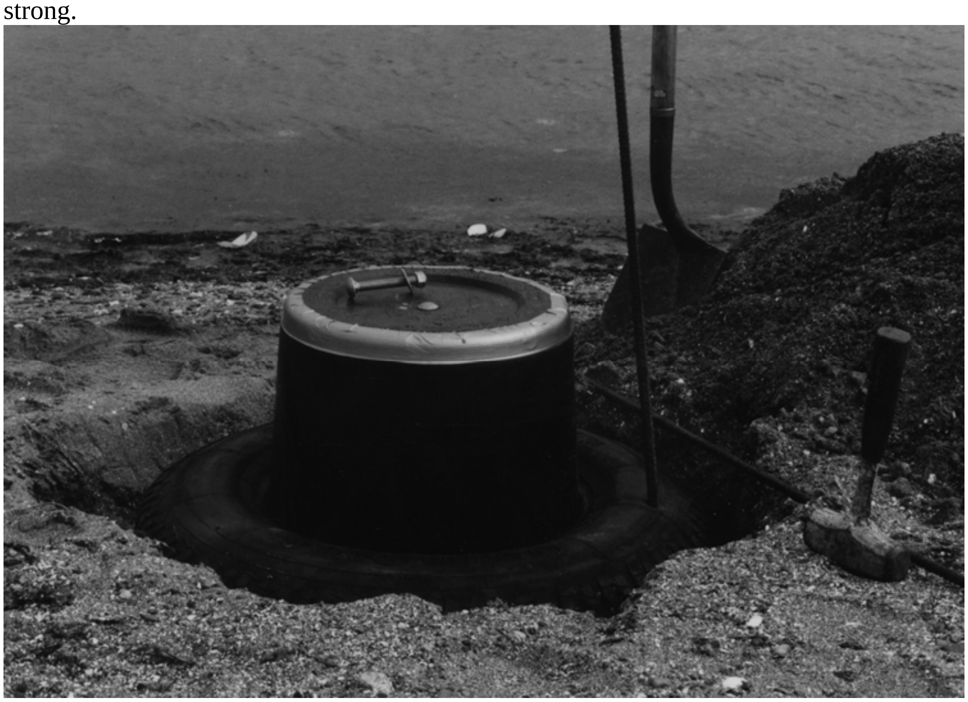
Wave action itself can exhume a large boulder or monument from the sand, but waves probably won't move it. However, any object that is exposed in this way is subjected to tremendous forces if pounded by storm-wave-driven drift logs. Therefore, your home-made monument has to be not only massive but also (ideally) deeply buried.

Obviously, there must be a compromise between burial depth and the need to find the monument and use it in later years for re-measuring local bluff erosion. In addition to its placement, a well-designed monument should be:

- inexpensive
- portable (at least as components)
- durable and massive
- locatable when buried

A cast-in-place concrete monument would seem to best meet these criteria. One approach is illustrated in Figure A-2. Erosion monitor volunteers, especially those who have some construction experience, will be able to suggest other options, possibly including reusable forms.

Figure A-2. Concrete monument for monitoring sandy beaches.
A. This concrete form uses a tapered plastic planter tub wedged into the upper tire. The hole cut here for pouring concrete is probably too small, but it could be made larger if the reference mark (here a galvanized carriage bolt) were simply placed off-center. Add a third, larger tire at the bottom if the monument will be placed where wave action is strong.



B. The form for the concrete monument is only partially buried here for illustrative purposes. (This might be acceptable for a mud beach in protected waters.) In an area of strong wave action, the monument's top should be flush with or below the beach surface. Note the slanted reinforcing bars to pin the tires together and to pin the form to the beach so that it will not "float" when filled with concrete.

One advantage of a concrete form of tires is that it can be made higher (deeper) as needed simply by adding another larger tire to the bottom before you place it in the beach. All the tires must be securely wired together, of course, to prevent their moving before the concrete sets. The reinforcing bars shown in the figure will also stabilize the form. Whether you use tires, plywood, or other forms for the concrete, your team will need the following for establishing the new monument:

- tidebook and shovels
- form materials (tires, plywood, etc.)
- bags of dry-mix concrete
- fresh water for making the concrete
- additives to speed the setting of the concrete
- reinforcing bar, hacksaw, heavy hammer
- wire cutters, extra wire (if a tire form is used)
- beachable boat, light RV, or back packs
- weather-proof clothing (and food and beverages) appropriate for a fairly long chore

Whether you are establishing a new erosion monitoring reference point in hard rock or in shifting sand, you will find that people with construction or engineering experience can make unique contributions. County (or regional) bluff erosion monitoring groups may want to ration such skills by assigning these experts to a “roving” team of on-call specialists and leave the ongoing and long-term monitoring to the dedicated volunteers.

APPENDIX 4: National Geodetic Survey Datasheets

Among the best monuments for measuring erosion rates are those established by the US Geological Survey, the Coast and Geodetic Survey, and the National Geodetic Survey. These stations are described in the section on existing stations.

Not only do these stations represent stable reference points from which to measure erosion rates, they have been accurately surveyed and information about their location and history is available from the National Geodetic Survey (part of the National Ocean Service (NOS) and ultimately part of NOAA, the National Oceanic and Atmospheric Administration).

If you are interested in pursuing this topic and have access to the World Wide Web, the National Geodetic Survey has put much of this information online. At the time of this writing, NGS Datasheets could be obtained at **http://www.ngs.noaa.gov/datasheet.html.** Datasheets can be retrieved by their name, by a localized geographic search, or by their Permanent Identifier.

Much of the information is only relevant to professional surveyors or geodesists (people who study the shape and elevation of the earth's surface), but the descriptive information is often useful in finding the monuments and in interpreting historic erosion. We include below two examples, for the stations **LOW** and **LOVEJOY**, on Whidbey Island.

LOW. Located on West Beach, south of the west end of Hastie Lake Road.

```
TR1781 ********************************************************************
 TR1781  DESIGNATION -  LOW
 TR1781  PID         -  TR1781
 TR1781  STATE/COUNTY-  WA/ISLAND
 TR1781  USGS QUAD   -  SMITH ISLAND (1981)
 TR1781
 TR1781                         *CURRENT SURVEY CONTROL
 TR1781  ___________________________________________________________________
 TR1781* NAD 83(1991)-  48 15 39.61014(N)    122 45 06.69389(W)     ADJUSTED
 TR1781* NAVD 88     -          9.     (meters)      30.     (feet)  SCALED
 TR1781  ___________________________________________________________________
 TR1781  LAPLACE CORR-          -7.02  (seconds)                    DEFLEC96
 TR1781  GEOID HEIGHT-         -21.98  (meters)                     GEOID96
 TR1781
 TR1781  HORZ ORDER  -  SECOND
 TR1781
 TR1781.The horizontal coordinates were established by classical geodetic methods
 TR1781.and adjusted by the National Geodetic Survey in December 1991.
 TR1781
 TR1781.The orthometric height was scaled from a topographic map.
 TR1781
 TR1781.The Laplace correction was computed from DEFLEC96 derived deflections.
 TR1781
 TR1781.The geoid height was determined by GEOID96.
 TR1781
 TR1781;                    North         East     Units   Scale      Converg.
 TR1781;SPC WA N     -   141,977.387   357,575.500   MT  0.99994537 -1 25 42.2
 TR1781;UTM  10      - 5,345,340.023   518,416.607   MT  0.99960417 +0 11 06.6
 TR1781
 TR1781:                Primary Azimuth Mark                      Grid Az
 TR1781:SPC WA N     -  SMITH 2                                   315 29 45.4
 TR1781:UTM  10      -  SMITH 2                                   313 52 56.6
 TR1781
 TR1781|---------------------------------------------------------------------|
 TR1781| PID    Reference Object                     Distance      Geod. Az  |
 TR1781|                                                           dddmmss.s |
 TR1781|        LOW RM 1                             13.300 METERS 04501     |
 TR1781|        LOW RM 2                              5.316 METERS 17817     |
 TR1781| TR1777 SMITH 2                            APPROX. 9.5 KM 3140403.2 |
 TR1781|---------------------------------------------------------------------|
 TR1781
 TR1781                          SUPERSEDED SURVEY CONTROL
 TR1781
 TR1781  NAD 83(1986)-  48 15 39.61055(N)    122 45 06.69652(W)     ADJUSTED
 TR1781  NAD 27      -  48 15 40.25200(N)    122 45 02.07100(W)     ADJUSTED
 TR1781
 TR1781.Superseded values are not recommended for survey control.
 TR1781.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
 TR1781.See file format.dat to determine how the superseded data were derived.
 TR1781
 TR1781  HISTORY     - Date     Condition        Recov. By
 TR1781  HISTORY     - 1940     MONUMENTED       CGS
 TR1781  HISTORY     - 1960     MONUMENTED       CGS
 TR1781  HISTORY     - 1962     MONUMENTED       IBC
 TR1781  HISTORY     - 1973     MONUMENTED       USGS
 TR1781  HISTORY     - 1981     SEE DESCRIPTION  USGS
 TR1781
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TR1781 STATION DESCRIPTION

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TR1781
TR1781'DESCRIBED BY COAST AND GEODETIC SURVEY 1940 (RWK)
TR1781'ALONG THE WEST SIDE OF WHIDBEY ISLAND, ABOUT 2.3 MILES NORTHEAST
TR1781'FROM PARTRIDGE POINT, ABOUT 15 FEET NORTHWEST OF THE TOE OF
TR1781'BLUFF, AT THE MEAN HIGH WATER LINE, IN THE TOP OF GRANITE BOULDER
TR1781'WHICH PROJECTS 1/2 FOOT ABOVE THE SAND.  R.M. 1 IS NORTHEAST FROM
TR1781'THE STATION, 10 FEET SOUTHEAST OF THE MEAN HIGH WATER LINE, AND
TR1781'5 FEET NORTHWEST FROM THE FOOT OF THE BLUFF.  R.M. 2 IS SOUTH
TR1781'FROM THE STATION, 6 FEET NORTHWEST OF THE FOOT OF THE BLUFF, A
TR1781'5 BY 8-INCH CONCRETE POST THAT PROJECTS 1 FOOT ABOVE THE SAND.
TR1781'
TR1781'STATION AND REFERENCE MARKS ARE STANDARD DISK MARKS, STATION
TR1781'MARK AS DESCRIBED IN NOTE 4, R.M. 1 AS DESCRIBED IN NOTE 12C, AND
TR1781'R.M. 2 AS DESCRIBED IN NOTE 11A.
TR1781'
TR1781'HEIGHT OF LIGHT ABOVE STATION MARK 1-1/2 METERS.
TR1781
```

TR1781 STATION RECOVERY (1960)

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TR1781
TR1781'RECOVERY NOTE BY COAST AND GEODETIC SURVEY 1960 (LGT)
TR1781'THE STATION WAS RECOVERED IN GOOD CONDITION AS DESCRIBED.  NEITHER
TR1781'REFERENCE MARK 1 OR REFERENCE MARK 2 WERE FOUND.  IT IS BELIEVED
TR1781'THAT THEY HAVE BEEN DESTROYED BY WAVE ACTION.  THE DESCRIPTION IS
TR1781'ADEQUATE AND COMPLETE EXCEPT FOR THE REFERENCE MARK DATA.
TR1781
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TR1781 STATION RECOVERY (1962)

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TR1781
TR1781'RECOVERY NOTE BY INTERNATIONAL BOUNDARY COMMISSION 1962 (FXP)
TR1781'THE STATION WAS RECOVERED IN GOOD CONDITION.  THE ORIGINAL
TR1781'DESCRIPTION IS ADEQUATE EXCEPT THAT THE STATION IS 12 FEET FROM
TR1781'THE FOOT OF THE BLUFF.
TR1781'
TR1781'AN EXTENSIVE SEARCH WAS MADE FOR THE REFERENCE MARKS BY TWO MEN
TR1781'WITH TAPES BUT THE MARKS COULD NOT BE FOUND.  THE MARKS WERE
TR1781'SUPPOSED TO BE 5 FEET FROM THE BLUFF AND IT IS BELIEVED THAT THE
TR1781'BLUFF SLOUGHED OFF ON THEM.
TR1781
```

TR1781 STATION RECOVERY (1973)

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TR1781
TR1781'RECOVERY NOTE BY US GEOLOGICAL SURVEY 1973
TR1781'THE MARK WAS FOUND IN A GRANITE BOULDER WHICH NOW PROJECTS ABOUT
TR1781'2 FEET ABOVE THE BEACH.  THE BOULDER WAS LOCATED ABOUT 40 FEET
TR1781'WEST OF THE FOOT OF THE BLUFF.  BASED UPON THE LATEST RECOVERY
TR1781'NOTE, THIS MARK HAS MOVED.  NO RMS WERE FOUND.
TR1781
```

TR1781 STATION RECOVERY (1981)

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TR1781
TR1781'RECOVERY NOTE BY US GEOLOGICAL SURVEY 1981 (RFK)
TR1781'(SEE NOTE) STAMPING ON DISC IS ALMOST OBLITERATED DUE TO GRAVEL
TR1781'WASHING OVER MARK.  THE STATION MARK SYMBOL IS STILL VISIBLE (SEE
TR1781'ATTACHED SHEET FOR NEW DIRECTIONS AND OTHER NOTES).
TR1781'
TR1781'DISTANCE AND DIRECTION FROM NEAREST TOWN--APPROX. 9 KM SW OF
TR1781'OAK HARBOR.
```

LOVEJOY. Located (or was located) on private property along Penn Cove bluffs, east of Coupeville.

```
TR1590 ***********************************************************************
 TR1590  DESIGNATION -  LOVEJOY
 TR1590  PID         -  TR1590
 TR1590  STATE/COUNTY-  WA/ISLAND
 TR1590  USGS QUAD   -  COUPEVILLE (1976)
 TR1590
 TR1590                         *CURRENT SURVEY CONTROL
 TR1590  ___________________________________________________________________
 TR1590* NAD 83(1991)-  48 13 26.17010(N)    122 40 17.19182(W)     ADJUSTED
 TR1590* NAVD 88     -        17.1    (meters)      56.     (feet)  VERTCON
 TR1590  ___________________________________________________________________
 TR1590  LAPLACE CORR-          -7.65  (seconds)                    DEFLEC96
 TR1590  GEOID HEIGHT-         -22.23  (meters)                     GEOID96
 TR1590
 TR1590  HORZ ORDER  -  SECOND
 TR1590
 TR1590.The horizontal coordinates were established by classical geodetic methods
 TR1590.and adjusted by the National Geodetic Survey in December 1991.
 TR1590
 TR1590.The NAVD 88 height was computed by applying the VERTCON shift value to
 TR1590.the NGVD 29 height (displayed under SUPERSEDED SURVEY CONTROL.)
 TR1590
 TR1590.The Laplace correction was computed from DEFLEC96 derived deflections.
 TR1590
 TR1590.The geoid height was determined by GEOID96.
 TR1590
 TR1590;                    North         East     Units   Scale      Converg.
 TR1590;SPC WA N     -   137,711.450   363,445.797   MT  0.99994396 -1 22 06.6
 TR1590;UTM  10      - 5,341,242.462   524,402.666   MT  0.99960732 +0 14 42.1
 TR1590
 TR1590:                Primary Azimuth Mark                     Grid Az
 TR1590:SPC WA N     -  BLOWER RESET                             019 10 50.1
 TR1590:UTM  10      -  BLOWER RESET                             017 34 01.4
 TR1590
 TR1590|---------------------------------------------------------------------|
 TR1590| PID    Reference Object                     Distance      Geod. Az  |
 TR1590|                                                           dddmmss.s |
 TR1590| TR1603 BLOWER RESET                       APPROX. 2.3 KM 0174843.5 |
 TR1590|        LOVEJOY RM                           2.195 METERS 11424     |
 TR1590|        LOVEJOY RM 1                         7.930 METERS 13042     |
 TR1590|        LOVEJOY RM 2                         8.590 METERS 22350     |
 TR1590| TR1598 SAN DE FUCA BARN CUPOLA            APPROX. 4.2 KM 2975032.5 |
 TR1590|---------------------------------------------------------------------|
 TR1590
 TR1590                          SUPERSEDED SURVEY CONTROL
 TR1590
 TR1590  NAD 83(1986)-  48 13 26.17207(N)    122 40 17.19682(W)     ADJUSTED
 TR1590  NAD 27      -  48 13 26.82800(N)    122 40 12.57800(W)     ADJUSTED
 TR1590  NGVD 29     -        16.0    (meters)      52.     (feet)  VERT ANG
 TR1590
 TR1590.Superseded values are not recommended for survey control.
 TR1590.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
 TR1590.See file format.dat to determine how the superseded data were derived.
 TR1590
 TR1590  HISTORY     - Date     Condition        Recov. By
 TR1590  HISTORY     - 1920     MONUMENTED       USE
 TR1590  HISTORY     - 1944     MONUMENTED       CGS
 TR1590  HISTORY     - 1960     MONUMENTED       CGS
 TR1590  HISTORY     - 1974     MONUMENTED       LOCENG
 TR1590
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TR1590 STATION DESCRIPTION

TR1590'DESCRIBED BY US ENGINEERS 1920
TR1590'STATION IS LOCATED ON END OF LOVEJOYS POINT, 1/2 MILE E OF
TR1590'COUPEVILLE, WHIDBEY ISLAND. IT IS LOCATED 5 FEET FROM EDGE OF
TR1590'BLUFF, 30 FEET E OF FENCE, 7.2 FEET NW OF CEDAR REFERENCE POST AND
TR1590'NE OF LOVEJOYS HOUSE.
TR1590'
TR1590'STATION IS MARKED WITH A STANDARD CONCRETE MONUMENT, SIGNAL AND
TR1590'CEDAR REFERENCE POST.
TR1590'
TR1590'ELEVATION 54.0 FEET ABOVE MEAN LOW WATER.
TR1590

TR1590 STATION RECOVERY (1944)

TR1590'RECOVERY NOTE BY COAST AND GEODETIC SURVEY 1944 (CP)
TR1590'STATION IS LOCATED ON THE S SHORE OF PENN COVE, ABOUT 3/4 MILE E
TR1590'OF COUPEVILLE, ABOUT 250 YARDS E OF THE WOODED POINT, ON THE TOP
TR1590'OF A WOODED BLUFF ABOUT 54.0 FEET ABOVE MEAN LOW WATER, 5.7 FEET
TR1590'BACK FROM EDGE OF BLUFF, 39.8 FEET NW OF NW CORNER OF SHACK, AND
TR1590'43 FEET N OF WAGON ROAD RUNNING TO ORCHARD BACK OF STATION. IT
TR1590'IS 2.08 METERS NW OF TRIANGULAR BLAZE IN A 1-FOOT FIR TREE AND
TR1590'2.24 METERS NW OF WOODEN POST, STAMPED U.S.E.D.
TR1590'
TR1590'STATION IS MARKED WITH A 4-INCH SQUARE CONCRETE POST WITH BRASS
TR1590'PLUG WITH HOLE IN ITS CENTER, STAMPED U.S.E.D.
TR1590'
TR1590'REFERENCE MARKS 1 AND 2 ARE BRONZE REFERENCE DISKS SET IN THE
TR1590'TOPS OF CONCRETE POSTS, STAMPED LOVEJOY 1920-44 NO 1 AND LOVEJOY
TR1590'1920-44 NO 2 RESPECTIVELY.
TR1590'
TR1590'SOME CLEARING NECESSARY ON LINES TO LONG, LIBBY, AND BENSON 2.
TR1590

TR1590 STATION RECOVERY (1960)

TR1590'RECOVERY NOTE BY COAST AND GEODETIC SURVEY 1960 (LGT)
TR1590'THE STATION AND BOTH REFERENCE MARKS WERE RECOVERED IN GOOD
TR1590'CONDITION AS DESCRIBED BY C.P. IN 1944. THE DISTANCES TO THE
TR1590'REFERENCE MARKS WERE MEASURED AND FOUND TO BE CORRECT. ANGLES TO
TR1590'THE REFERENCE MARKS WERE NOT OBSERVED.
TR1590'
TR1590'THE STATION IS A CROSS CUT IN A SQUARE BRASS ROD WHICH IS SET
TR1590'IN TOP OF A 5 INCH SQUARE CONCRETE POST IN WHICH IS CAST THE
TR1590'LETTERING USED. A 1/2 INCH SQUARE BOLT IS SET IN THE SOUTHEAST
TR1590'CORNER OF THE POST.
TR1590'
TR1590'REFERENCE MARK 1 IS A STANDARD REFERENCE DISK STAMPED LOVEJOY
TR1590'USED NO 1 1920 1944 SET IN TOP OF A 5 INCH SQUARE CONCRETE POST
TR1590'WHICH PROJECTS 5 INCHES.
TR1590'
TR1590'REFERENCE MARK 2 IS A STANDARD REFERENCE DISK STAMPED LOVEJOY
TR1590'USED NO 2 1920 1944 SET IN TOP OF A 5 INCH SQUARE CONCRETE POST
TR1590'WHICH PROJECTS 4 INCHES.
TR1590'
TR1590'TO REACH THE STATION FROM THE ISLAND COUNTY COURTHOUSE IN
TR1590'COUPEVILLE, GO NORTH ON STATE HIGHWAY 1 D FOR 0.1 MILE TO FIRST
TR1590'ST. TURN RIGHT (EAST) ON FIRST ST. FOR 0.55 MILE TO LEACH
TR1590'ST. TURN LEFT (NORTH) ON LEACH ST. FOR 0.35 MILES TO FARM AND
TR1590'STATION.
TR1590

TR1590 STATION RECOVERY (1974)

TR1590'RECOVERY NOTE BY LOCAL ENGINEER (INDIVIDUAL OR FIRM) 1974
TR1590'STATION RECOVERED IN GOOD CONDITION. R.M. 1 RECOVERED IN GOOD
TR1590'CONDITION, R.M. 2 NOT SEARCHED FOR.