COASTAL EROSION RESPONSES
FOR ALASKA

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Introduction

Orson P. Smith
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(Workshop Organizing Committee Chair)

Coastal erosion and its physical causes are as old as the oceans. As a concern, coastal erosion is as old as civilization. This is not a workshop on climate change. Global warming is a contributing factor to current trends in coastal erosion, but should not become an alibi for short-sighted human use of the shoreline.

Alaska is a young state. Our oldest infrastructure is barely a century in age. Most existing shoreline construction is a few decades old or less. Compared to thousands of years of coastal development in other areas of the world, we in Alaska have little knowledge of our impact on the natural processes and little recorded information about the processes themselves. Our records of winds, waves, and water levels are short. Where coastal weather data exist, measurements have often been made at an airstrip substantially removed from the shore and strongly affected by the land between.

Our situation as North America's developing country provides both challenges and opportunities with regard to coastal erosion responses. We may not know the trends as well as our sister coastal states, but we can learn from tribulations elsewhere. We need not educate ourselves solely by trial and error. We can study the design and history of older coastal developments and seek coastal erosion responses suited to our Alaska circumstances.

This workshop is the ninth in an annual series with the bridging theme of science-to-engineering. You can argue that engineering is never more than applied science and I would agree. Coastal engineering is a specialty with particularly strong ties to scientific disciplines including meteorology, oceanography, geology, and physics. The first three are fairly obvious to relate and we mustn't forget that the twenty-first century is an era of dependence on exotic instrumentation applying esoteric principles of physics. A passing knowledge of coastal processes and measurements is not sufficient for the best decisions in response to coastal erosion. Coastal engineering is a risky business with plenty of opportunity to make matters worse, in spite of good intentions.

Engineers are required by ethics codes of their professional societies and by their licensing boards to do good work and protect the public safety.

Inherent in these mandates is a choice among alternatives, including options involving no construction. Changes in coastal zone management policy may provide the wisest response to coastal erosion. This can mean adverse consequences to a few for the good of many others.

The presentations that follow will address coastal processes and trends that drive shoreline retreat and coastal erosion. Non-structural coastal zone management responses will be discussed, along with successfully proven constructed responses. Constructed works will be presented with a view toward their particular limitations. Each alternative response has its pros and cons. With the impressions you gain today from our highly qualified presenters, you will be able to use your time efficiently to read further to learn more of what you need to know for wise decisions regarding coastal erosion responses for Alaska.

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We also appreciate very much the contributions of the presenters and their employers who paid their way to Anchorage for the workshop and invested valuable time and energy in their preparations.

Our gratitude also goes to the administration and staff of the University of Alaska Corporate Programs office, the UAA Advancement office, and the UAA School of Engineering for their hard work to make this workshop happen. The efforts of JeNae Christiansen of the Department of Civil Engineering were invaluable and to her we owe special thanks.

Lastly, I add my personal thanks to my colleagues on the workshop organizing committee: Robert Pawlowski, Christy Miller, and John Oswald.

Living with the Coast of Alaska Revisited: The Good, the Bad, and the Ugly

Owen K. Mason
Geoarch Alaska, Anchorage, Alaska

Alaska, like most coastal states, lives by its coast. If one includes the Mat-Su Borough, nearly ¾ of Alaskans reside in immediate proximity to coastal property. However, even most of the interior communities confront an erosion problem, albeit if it is alluvial in causation. Fairbanks routinely flooded at breakup and several towns have had to consider relocation—most recently Huslia and Alakaket on the Koyukuk River. In this talk, I have added the subtitle: The Good, the Bad, and the Ugly. Aesthetics must be part of the solution; creating an ugly coast should not be a goal.

The Alaska shore is roughly divisible in half. In the south, the predominantly deeply embayed and formerly glaciated bedrock southern rim along the Gulf of Alaska from Ketchikan to Cold Bay; and in the north, the mostly unconsolidated and unglaciated Bering, Chukchi, and Beaufort sea coasts, from Naknek and Dillingham to Kaktovik. The soft shores of eastern Cook Inlet serve as an important exception and suffer a number of erosion threats. Nonetheless, most of the severe problems with erosion are inevitably in the north, although most of the cities on the bedrock coastlines are located on "soft" sediments like deltas and alluvial fans and are subject to a plethora of coastal hazards, like avalanches, debris flows, tsunamis, earthquakes, and volcanic eruptions.

My involvement in coastal issues commenced in 1991 when Orrin Pilkey recruited me after an erosion workshop in Barrow, enticing me with fame and glory, to craft a volume in his *Living with the Shore* series. The series, funded by FEMA, aimed to educate the real estate buying and renting public as families and businesses decided where to live. The volumes strived to be site-specific with detailed road maps. The optimistic goal was that by educating the public to coastal threats to life, limb, and property, fewer poor choices would be made and problems would be avoided. As a North Carolina resident, Orrin Pilkey focused on barrier island geomorphology and development. Barrier islands are ubiquitous on much of the East Coast and suffer from repeated storms, hurricane force winds, and storm surge. Large-scale development of the coast (e.g., Atlantic City, Bogue Bay, or Pensacola) over the last century has fostered and conditioned the engineering solutions to nature's challenges. Once the terrestrial frontier was closed, the Army and its Corps of Engineers turned to block the sea. Similar operations were conducted on the eastern rivers, especially during the progressive decades of the 1930s and 1940s. In a struggle worthy of America's Manifest Destiny, engineers launched one of the greatest efforts to contain nature, straightening rivers, heightening levees, blocking inlets, exhuming and filling marshes. A number of geomorphologists argue that Hurricane Katrina is Nature's payback and even suggest refilling the marshes and allowing the Mississippi its will.

Alaska presented a considerable challenge as a subject for the coastal hazards treatment developed by Pilkey at Duke University. Virtually no coastal community in Alaska was hazard-free. In fact, Barrow, only subject to bluff erosion and storm surge, seemed the safest place to live! The threats to life and limb were most severe in Seward ranging from imminent tsunami up Resurrection Bay, flooding from several sources, including temporary snow dams above town, and earthquake. Equally ominous threats face Anchorage, Homer, Juneau, Kodiak, Valdez, and Sitka. Who could sleep at night in Alaska if aware of the underlying hazards? I would love to live downtown but geologic-induced guilt keeps me away. In fact, Orrin once commented that if the series had started with Alaska, the problems of the East Coast would not have even warranted a look, by comparison.

One topic is largely missing from the first edition of the book: Global Change. In the last decade, anthropogenic global change, greenhouse warming, etc., has outpaced any other public awareness of the natural world. Too often the debate over Global Change is fueled by anecdotal accounts which frequently wend their way into public policy. For example, in 2004 the Government Accounting Office pronounced that nearly 40 m (>120 ft) erosion had afflicted Shishmaref in one single storm in 1997. Until the Army Corps study, no such documentation has existed. The source for such rates of change is likely the anecdotal accounts in the press; for example, my examination of the Anchorage *Daily News* from 1997 to 2004 indicates the routine erosion of 10 m (30 ft) of bluff. However, a comparison of photos from 1992 to 2004 shows a different story. But in order to know Global Change, we need a baseline—climate records extend barely 100 years. Several efforts are on the horizon to tackle this mission: Bill Manley and a host of others have signed on with the Arctic Coastal Monitoring program headed by Diane Sanzone of the National Park Service; the product will be a photogrammetric documentation of erosion in Kotzebue Sound and to ground truth these interpretations in the field.

One huge complication is the possibility that we have entered a "no-analog" situation in relation to the effects of greenhouse warming—a time like no other in recent earth history. Why? Because the geologic record in the north, and I include the Atlantic, indicates that storms were stronger and more powerful during the Little Ice Age (and other cold periods), owing to the heightened contrasts between a colder Arctic and the tropics. Some of the LIA North Sea storms in the 1500s-1700s were awesome, flooding the Netherlands and Britain. Evidence of stronger storms can be found in northern Alaska, as well. In 1884 Capt. Hooper commented on the ferocity of northerly storms that routinely pummeled the Yukon Delta during winter, scattering ice blocks well inland. Nothing like this has occurred in the last generation. The barrier islands around Shishmaref also show evidence of hurricane force storms that cut wash-around channels into the islands, landforms reminiscent of hurricane effects on Padre Island, Texas. Again, the recent spate of storms has not reached such extremes. That is why we need to exercise caution in extrapolating about global change from the effects of storms on developed shorelines such as Shishmaref or Barrow or Nome

So, moving counter-clockwise around the Alaska coast, I will discuss the principal problem areas from Kaktovik to Unalakleet, followed by a leap to the Kenai Peninsula, deferring discussion of Anchorage to others.

As we consider bluff erosion, let's pause to examine the processes that operate on permafrost bluffs, most of which are seen in more temperate zones, as well. Four principal processes undermine a bluff. (a) Waves can cut a niche into the frozen bluff and remove material; depending on the length of wave action and the carving distance, a very sizable block can collapse. (b) Slope wash from the top. (c) Melt-out of ice bodies causes slump—high rainfall can do something similar. And (d) channelized flow in gullies. Quite possibly, global warming will mean that as permafrost-laden bluffs warm, thermo-niching will be less frequent and melt-out will be more frequent.

Coastal protection measures have a lengthy history on the North Slope, the legacy of the humble 55 gallon fuel drum, discarded on the ice and tundra by the thousands after 1945. The 55 gallon drum lends itself to use as shoreline protection; it was used in the earliest efforts at Kaktovik, Barrow, Shishmaref, and Kotzebue.

Another legacy of the Cold War years is the frequent placement of dump facilities adjacent to eroding shorelines: convenience more than logic or awareness of geomorphic process explains this "decision" making. Several communities continue to defend dumps: Kaktovik, Barrow, Kotzebue, and Dillingham.

Kaktovik (pop. 400) is situated on Barter Island, composed both of residual Pleistocene "mainland" and an eroded and re-deposited gravel spit.

Originally, Inupiaq people settled on the spit, which was later appropriated for a DEW-line station airstrip. The principal erosion problem facing this community involves an Air Force and community dump. The irony is that several million dollars are projected to erect a bulkhead to protect a dump along the coast. A better course would seem to be moving the dump away from the storm impacts of the coast.

Located on low and chronically eroding bluffs, **Barrow**, the capital and metro-village of the North Slope, has a long history of beach modification and a series of low tech engineering and heavy equipment operations. The bluffs at Barrow have undergone erosion for several hundred years; even nineteenth century explorers mention massive storms and erosion, especially in the 1880s and 1890s. Barrow rests upon sands and gravels of a beach ridge and spit that formed at higher sea levels about 125,000 years ago. Beach mining commenced in the 1950s, in order to construct the airstrip south of town. This act also very quickly removed the inheritance of 1,000 years of storm-related construction downdrift from the bluffs.

On the positive side, the proximity of NARL (Naval Arctic Research Laboratory) has fostered several generations of scientific studies of the erosion problem, the first employing measurements from fixed markers in 1950, following a series of intense storms. The even more intense October 1963 storm with its 3 m surge led to a number of pioneering studies of both erosion and deposition in the Barrow area by Hume and Schalk. The finding of the 1960s has been confirmed repeatedly since then: most erosion in the Barrow region occurs during and in association with the most massive storms. In the late 1970s, Harper first used aerial photographs to obtain baseline data outside of the developed shoreline of Barrow. A series of large storms in the 1980s induced the city to place a limited stretch of low tech revetment of gravel-filled plastic bags just south of downtown. This structure has had mixed success and was partially succeeded by a gabion tower placed in the last few years. Material from the shelf, possibly of finer consistency than the beach, has had some positive impact on increasing beach width south of downtown, but at considerable expense. Erosion rates are fairly minimal along the Chukchi coast, the conclusion of the latest large and sophisticated effort at documenting bluff erosion. This effort, termed the BIG STORMS Initiative, represents the efforts of a sizable interdisciplinary team from INSTAAR (Institute of Arctic and Alpine Research) of atmospheric scientists such as Amanda Lynch and geographical and geological specialists such as Bill Manley. The BIG STORMS project not only employed serial sets of aerial photographs; rectified, it also analyzed climate data to model atmospheric and oceanographic conditions that foster erosion. The INSTAAR project has documented very huge rates, >100 m, of bluff retreat in the last 40 years on the lagoon coast east of Barrow on the Beaufort Sea. In this case, undercutting of permafrost-rich silts are likely causal. Bluff erosion on the scale of tens of meters per year was occurring even 100 years ago in the eastern Beaufort Sea, as de Leffingwell observed. High rates of erosion occurred throughout the 1970s between the Colville River and Prudhoe Bay, as documented by Erk Reimnitz and Peter Barnes for USGS, based only on map comparisons. One concrete result of the BIG STORMS project is the very detailed hazard map of the 1963 storm, available to residents on the Web, which has engendered considerable interest at community meetings.

Wainwright and **Point Lay** also have erosion problems. At Wainwright, people can retreat as bluff erosion proceeds with permafrost melting. Beach nourishment at Wainwright may have had some ameliorating effects in the short term. Point Lay, at its re-founding in the 1970s, elected to move to the mainland, away from the eroding barrier island: at least one problem was solved!

Although not presently under siege by erosion, **Point Hope** suffers from the same free-floating global change angst that has captured most north Alaska communities: fear of entrapment without an evacuation route and the possibility of storm surge flooding through the beach ridge swales near town. Point Hope, home to nearly 900 people, moved east in the mid 1970s, about 2 km from its ancestral locale of Tikigaq at the eroding north margin of the spit. Fierce storms have occurred repeatedly at Point Hope, although the storm of record occurred in 1893, when a surge of at least 3 m flooded the town site. Point Hope community members have had occasion and partial funding to employ a number of folk-based and half-baked engineering remedies to the perennial erosion on the north margin, that now lacks any structures to protect (except for the unprotected margin of the concrete air strip. Erosion acts differentially on the north margin of the Point Hope spit, related to the percentage of silt and frozen ground that is higher within the middens of Tikigaq (dating to AD 1400-1950) than in the dunes that cap the older settlement of Ipiutak on the oldest ridges of the spit. An incompletely realized revetment, consisting of sizable Nome boulders, was laid atop several stretches of the north shore of Point Hope in 1997. Funding (via a no-bid contract to Tikigaq Corporation, NSB resolution #41-97 dated June 3, 1997) and design for this project arose from within the North Slope Borough with minimal (if any) oversight from the Army Corps or other agencies; apparently no EIS was prepared for this project. The original design parameters were not met, so that a series of groins were not placed along with the rock revetment. Nonetheless, the revetment, as it stood in 2004, did not offer protection to the airstrip—instead it exposed it to erosion—and only extended landward of a portion of the two threatened archaeological sites. One of the foremost concerns to Point Hope residents involves the erosion of archaeological sites employed as cache pits to properly season muktuk. While cultural pejoratives should be respected, it seems extravagant and ill-advised to expend many millions of dollars to conserve ice cellars, and endanger the spit, the community, and the other archaeological sites on them. As a result of the ill-founded measures of 1997, Point Hope now faces more and faster erosion; perhaps it is time to stop feeding the seawall beast!

In the book *Living with the Coast of Alaska* we spent several pages discussing the barrier island community of **Kivalina**, whose effort to move had already surfaced in conversation and planning. While the seaward beach was wide and erosion seemed a minimal threat, only a minor amount of erosion was observed along the inlet margin. The concerns voiced in 1993 were mostly about evacuation during storms and room for growth. The relocation of Kivalina seems to have become a cottage industry for consultants and the price keeps rising; informally, I just heard that the cost may be several hundred million dollars. Not having seen the problem for several years, I remain optimistic that the island still offers a livable location. After all, river flooding from the Wulik is still occurring. Evacuation concerns should be met by maintaining a viable response presence from the federal government. We should not fall prey to the expectation that no aid will come, the legacy that the present administration wishes to foist on its constituents.

Kotzebue, center of the Northwest Arctic Borough, spreads across the several beach ridges that issue from the glacial deposits of Baldwin Peninsula. Spit growth depends on intense westerly storms coupled with long-shore transport to the north. In addition, a considerable amount of gravel lies offshore and serves to damp wave energy affecting the beach. As recently as the 1930s, the village was restricted to the active beach ridge, along Shoreline Drive; however, most residential development has occurred inland in the last several decades. But the shoreline still contains several facilities—the post office, the Nulagvik Hotel, and various restaurants and markets—although I understand that Hanson's has recently closed. Although the Kotzebue ridges are barely 1 m above mean sea level, comparatively little erosion has occurred (Fig. 1). Historic photos on the city Web site indicate storms in the 1970s and 1980s cut only 1 m davits into the roadway. On the plus side, shoreline stabilization efforts, including barrels placed upright in the 1960s, have had little or no impact. The concrete block revetment extends along only parts of the shore, restricted to residential property and allowing the seasonal expansion of the beach to the seaward side of the commercial properties. The relative stasis in Kotzebue may not last. Apparently the Alaska Department of Transportation plans a major expansion of Shoreline Drive, doubling its width to the seaward by placing a bulkhead and gravel fill (Alan DePew, 2005, Office of History and Archaeology, State of Alaska, pers. comm.). The impact on the beach is uncertain, but it is hoped that the scale of this project will not turn Kotzebue into a problem. To this observer, the better course of action would be to restrict car traffic, move the post office, and preserve the beach at Kotzebue.

Figure 1. In Kotzebue, Alaska, structures built in the 1960s are still at the shorefront.

Located within the protected inner reaches of Kotzebue Sound, **Deering**, home to only 150 people, rests atop a barrier spit, formerly capped by a high storm ridge that was removed in 1950 when an airstrip was built. Hopefully, the sewage lagoon located close to the coast will not be breached by erosion.

Barrier islands are temporary land forms in geologic time, subject to the pressures of storms and eustatic (i.e., post-glacial) sea level rise. This fact cannot be denied, even in the face of global change. The public relations initiative that has propelled **Shishmaref** into the limelight should not deny this transitoriness: no one goes to Atlantic City for evidence of global change. Shishmaref hostels over 600 people on the most active portion of a sandy barrier island at the southern margin of the Chukchi Sea. The community has suffered bluff erosion over the last 50 years; however, although the extent has not been established, possibly until this year a considerable amount of engineering has been emplaced on the shorefront of Shishmaref (Fig. 2). The community was severely impacted by a 1974 storm, which led to the first serious discussion of relocating the community. The Shishmaref community lies atop a low barrier island that is eroding on its western margin and aggrading to the northeastern. The evolution of the island can be documented from radiocarbon dated peat beds that cap the dune cover. The island was reshaped during the centuries AD 800

CURTIS NAYOKPUK

CURTIS NAYOKPUK

Figure 2. In Shishmaref, Alaska, engineering "solutions" have been ineffective.

to 1400, probably in response to storms from the west. Dune building occurred after AD 1600 at the mouth of the inlet north of town. The ancestors of the Shishmaref people apparently recognized the dynamic nature of the island and situated their community on the most landward, safest part of the island. In the 1920s, to ease barge off-loading, Shishmaref shifted to its present location—on the very most active eroding face of the island. This is the crux of the problem at Shishmaref. The second major problem is that a considerable part of the island, nearly one-third, is considered off the table for development because of a snow fence emplaced in the 1980s in order to collect (mostly) wash water for the town. Locating another water source would serve a critical need and open the most commodious part of the island for development.

The nature of bluff erosion at Shishmaref remains contentious. On the one hand, repeated anecdotal accounts by residents suggest that erosion has proceeded rapidly, as documented in the Anchorage *Daily News*, APRN, and *Arctic Sounder* press releases and news accounts. A different perception arises from inspecting aerial photographs from 1948, 1986, and the present; these seem to indicate that erosion was not quite so severe until the present. What is different and what explains the difference? Storm frequency? Ice extent? Certainly the amount of engineering has increased significantly since 1983; first, a concrete block revetment that failed quickly and only fostered erosion until the placement of rocks onto the Shishmaref shore in 2002 seems to have sent the system into increased erosion. Another possibility is that as people restored the 1983 revetment each successive storm eroded the reconstructed land surface, and erosion likely occurred as a series of divots into different lateral portions of the island.

About 10 years ago, the State of Alaska sent me to Shishmaref to examine various alternative relocation sites, all on the mainland. In addition to this task, I considered the means available to remain on the barrier island chain. With some flexible engineering such as moveable structures and dune trapping devices (plants, fences, matting, etc.), I suggested that Shishmaref residents could remain in sync with the barrier or groom a nearby island for future settlement. The approach favored in the last 10 years has been the opposite: increasing hard stabilization, with the rocks larger and the lateral distance subject to seawalls longer. Further, the height of the wall is still far below the maximum storm surge limit, for reasons that I do not understand. In any case, it seems that Shishmaref is heading toward a fortress mentality, and I predict that in 10 years the community will be a bastion surrounded by rock. After all, this "solution" will be cheaper than relocation. The consequences for the remaining barriers and the inlet may be dire.

At the next site, **Wales**, a community on low dunes, faces little or no threat due to the extensive low gradient beach that damps wave energy. No serious engineering efforts are recorded at Wales, despite occasional storm surge flooding since 1960. Wales, of course, has a steep bedrock hillside just to its south. This firm ground lends a sense of security to the community on the low dunes.

Teller was the scene of a classic attempt at folk engineering. I haven not returned to witness the fate of the phone truck revetment; any observations would be welcome.

Finally, this last summer, I encountered a community living nearly in harmony with a gravel barrier island. Of course, infrastructure is at a minimum at the summer camp of King Islanders at Woolley Lagoon, maintained since the 1970s. Remembering that the island is nearly 1 m below the highest storm surges, people have had to adjust by shoveling out the gravel that accumulates during storms, as that of 2004. Some structures are atop posts, now only slightly above storm levels. On the negative side, several cabins were carried landward with the big storm of 2004. Any electricity on the island derives from generators, and residents do maintain houses in Nome. Nonetheless, no need should arise for hard stabilization as King Islanders refine their means of securing and caching supplies away from the waves and in constructing cabins that can be moved readily as the island moves.

Founded as a tent camp on the most vulnerable location imaginable, a sand spit at the mouth of the Snake River, **Nome** has continued in its century-long battle against the sea, repeatedly facing down the threat of storms and erosion. Nome miners soon realized, as early as 1900 (and repeatedly until 1913), that the Bering Sea was immensely powerful. Mason et al. (1997) studied Nome newspapers that showed the 1920s and early 1930s were reasonably pacific, with fewer and smaller storms. This respite likely bred complacency. The extensive development adjacent to the coast could have been relocated inland following the great fire of 1936. Commercial interests prevented that cautionary course of action; instead when several furious storms hit Nome in the mid-1940s, the town sought out the Corps of Engineers. The U.S. Congress was supportive: Nome was still basking in its war-time importance as an air transport location. Although a bulkhead or two was placed in the 1920s and the inlet was maintained by two small jetties, Nome still had a beach in the 1940s. By 1951, however, the Nome seawall was constructed at the cost of $1.8 million, the first use of Cape Nome granite. There is now no beach at Nome, of course, and the seawall has had to be extended by a revetment. The latest engineering efforts at Nome are truly gargantuan—a pair of causeways around a newly cut inlet across the sand spit. Although I am sure the engineers are confident in its design parameters, at least superficially and to some of the harbor users, the due south orientation of the causeway more resembles a bowling alley capable of feeding storm waters directly into the airport. Here's hoping for the best. Although Nome did not retreat from the sea, development has finally taken hold inland up into "Icyview"; hopefully, fear of the sea has some role in real estate calculus.

Figure 3. In Nome, Alaska, the beach present in 1948 (in this photo) is gone today.

The ongoing engineering travesty in the Nome vicinity involves the overlaying of sizable boulders as a revetment to buttress an unpaved road on the Safety spit; the rock is only too easily transported from the seemingly inexhaustible Cape Nome. Orrin and I observed the first efforts at road stabilization in 1993 and the story is recounted in the book. Since the mid 1990s, the rocks have grown in size and an area just east of the safety bridge has been reveted. These efforts border on idiocy, a truly golden-fleecing. First, the road is unpaved and eminently rebuilt after any storm surge. Further, the revetments are fostering erosion; already beaches adjacent to the rocks are narrowing and steeper. In addition, the few subsistence cabins out on the spit are unprotected by the revetment and are actually more threatened from the efforts.

Unalakleet serves as a major air hub for PenAir and houses nearly 1,000 people, including a lodge that caters to sportsmen. The relatively low-lying village extends along a sandy spit and has met several storm surges during the last 30 years. Nonetheless, the beaches remain healthy and flat, dissipating waves; the town should be able to cope with future storms, if hard structures are avoided. At present, only an 8 foot stepped wall of gabions has been placed along the inlet margin. The town has extensive high ground inland for an orderly retreat if storms are too powerful. Re-engineering structures should be a priority for Unalakleet.

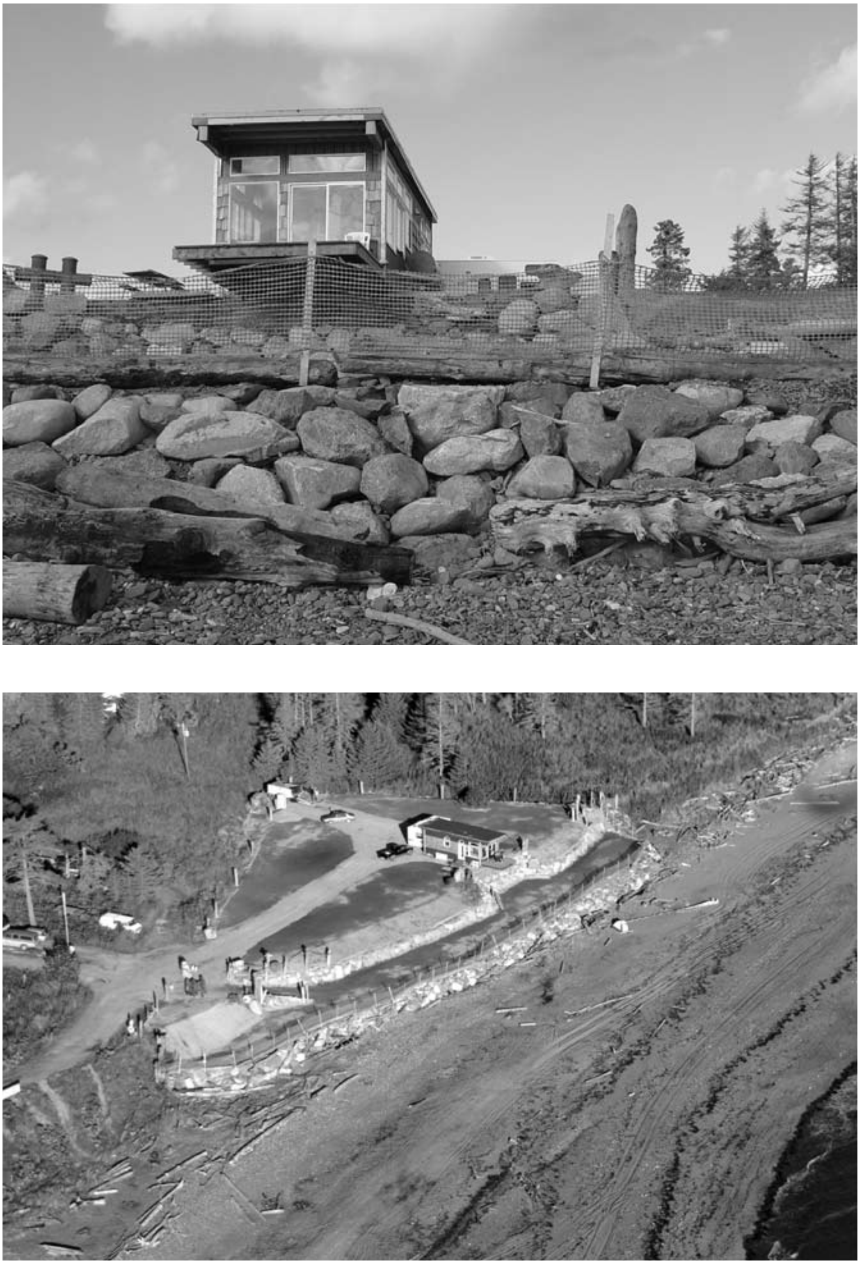
Erosion of considerable proportion, certainly hundreds of yards, threatens **Newtok** within the Yukon Delta; the community has more urgency and shows the initiative of moving to a bedrock island around the bay. Erosion is no stranger to many Yukon-Kuskokwim Delta villages, including Bethel; fortunately, a junk-car seawall has been replaced with a serviceable bulkhead. Bethel certainly has much area for an orderly retreat from its erosion problem.

Dillingham deserves special mention for the ill-advised location of a sewage pool within striking distance of an eroding bluff. The protection of sludge should not threaten other facilities and the town itself.

The section on the **Kenai Peninsula** would require the most extensive revision in this revisit to Alaska's coast. The peninsula is saddled with a burgeoning population and the usual anti-government, pro-development elements, many of whom control the planning process (or what passes for planning on the peninsula). The phrase "re-inventing the wheel" is not strong enough; Kenai residents are re-inventing folly and teasing the gods. Some folks place subdivisions within the oxbows of the Kenai River floodplain, just below the outlet of the lake. Others build homes at the seaward base of high, soft unvegetated bluffs, tempting the fates to strike either from the sea or from above as a cascade of water-saturated silt. Insult to injury is added when property owners place bulkheads around their homestead and foster erosion at the margins of the bluff just beyond their property. More Kenai Peninsula residents need to follow the news reports about slope failures in California, Honduras, Colombia, Italy, etc., and think about their own house lots. My particular favorite concerns the poor scoundrels who develop property at the toe of debris fans in the Homer area. Hopefully, the banks aren't insuring these properties.

Visiting **Kenai** last year with some local officials as part of an erosion meeting in Homer, we were told about the Wally Hickel (or Don Young) approach to erosion that doubles for public policy in Kenai: "Build it and They will come," they being the developers who will follow the seawall and bank stabilization at the old town site of Kenai, largely unoccupied and comfortably far from its eroding margin. The effects of a seawall on the Kenai River are largely unknown as yet and should caution any reasonable public executive from writing the 25 or 35 million dollar check.

Homer, famed for its eclectic mix of progressive and survivalist politics, has its share of half-baked and harmful coastal erosion control efforts, as well as a number of profound hazards—tsunami from Mt. St. Augustine, tephra, earthquakes, etc. As I mentioned, a host of slope-related problems are present in the Homer region, including those foolhardy souls who live at the toes of debris fans (above the town). Orrin and I observed, in 1993, that one property owner on the east side of Homer had placed a breakwater seaward of their



BOB SHAVELSON

BOB SHAVELSON

Figure 4. Revetment at Bishop's Beach, Homer, Alaska.

Figure 5. Bulkhead at Oceanic Bluff, Homer, Alaska.

bluffs, and others continue to tempt fate by living too close to the edge of the eroding bluffs (I haven't seen this area since). The hazards on the Homer spit are severe, especially in summer when thousands of day tourists are present. Rumor has it that a major condo project is altering this calculus, increasing the full-time residents and probably heightening the desire for hard stabilization.

The situation on the eroding bluffs west of town, at Bishop's Beach, has shifted to critical as one resident "cowboyed" an ill-considered revetment. This property owner, simply to protect a small trailer-sized cabin, removed all vegetation from the bluff and placed small boulders at the base of the bluff, just below the limit of storm waves as marked by driftwood. The fill landward of this revetment is small gravel and seems likely to be eroded at the next large storm. Similarly, the small rocks above this stepped revetment are likely to be undercut. So far, I have heard that this landowner has met with no sanctions to cease from his misguided efforts.

A more esthetically pleasing but just as useless bulkhead was placed along the Oceanview Bluff, to the south. Designed and emplaced for only $1 million, this bulkhead was overtopped by storm waves soon after its construction and the bluffs above continue to erode. One imagines in the near future the bulkhead will stand bold and alone seaward of a lowering bluff.

The good news for Homer is that a significant part of the community is energized by erosion issues and benefits from the presence of researchers at the Kachemak Bay Science Center. The meeting in 2004 proved a cathartic experience for some of us—such events, and this one, are clearly needed on a larger scale.

As a parting observation, I would like to encourage all of you to contact the press and our public servants with concerns about coastal policy. However, I have learned that it is not an easy task, especially in speaking with the press, who also feel the emotive and financial pressures of the same groups. One must measure one's words and coin the appropriate sound bite that will be used on the air.

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Global Sea Level Rise and Relative Sea Level Change in Alaska

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An understanding of both global sea level rise (GSLR) and relative sea level (RSL) change is required to understand the changes in shoreline position in coastal Alaska. GSLR, also known as eustatic sea level rise, pertains to worldwide changes of sea level that affect all oceans. RSL pertains to crustal and gravitational adjustments that can affect sea level position on a local and regional scale.

Global sea level rise (GSLR) is affecting coastal regions throughout the world. Tide gauge measurements of mean sea level show global sea level has been rising at a rate of 1.8 ± 0.1 mm yr^{-1} for most of the past century (Douglas 1997). Topex/Poseidon and Jason satellite altimetry radar measurements indicate that the rate has accelerated to 3.2 ± 0.4 mm yr^{-1} during the past decade (Nerem 2005; www.sealevel.colorado.edu). Contributions to GSLR come primarily from melting of the polar ice sheets and mountain glaciers (Table 1) and from heating of the ocean. The current thermosteric contribution is estimated at 1.2 to 1.6 mm yr^{-1} (Nerem 2005). Contributions from the Greenland Ice Sheet (GRIS) to GSLR have risen from 0.14 mm yr^{-1} during the 1990s (Krabill et al. 2000) to its current rate of about 0.4 mm yr^{-1} (Rignot 2005, Velicogna and Wahr 2005). This acceleration has been attributed to the collapse of a number of outlet glaciers draining GRIS in southern Greenland. The meltwater contribution from Antarctica has also accelerated during the same time period, from 0.3 mm yr^{-1} to 0.5 mm yr^{-1} (Rignot 2005, I. Velicogna and J. Wahr submitted) as a result of the collapse of major ice shelves there. The melting of Alaska glaciers is a primary contributor to sea level rise (0.3 mm yr^{-1}) (Arendt et al. 2002, Tamisiea 2005) and accounts for nearly half of the amount attributed to the melting of mountain glaciers worldwide (Dyurgerov and Meier 2005), with the reminder coming from Patagonian glaciers and other mountain glaciers. GSLR is projected to rise an additional 30-85 cm through the twenty-first century as a result of climate warming (IPCC 2001). However, these forecasts do

Table 1. Contributions to sea level rise from the world's glaciers.

Region	Sea level rise equivalent (mm yr^{-1})	Years	Reference
Alaska/NW Canada	0.14 ± 0.04	1950s-1990s	Arendt et al. (2002)
Alaska/NW Canada	0.27 ± 0.10	1990s-2000/01	Arendt et al. (2002)
Alaska/NW Canada	0.31 ± 0.09	2002-2004	Tamisiea (2005)
Canadian Arctic Archipelago	0.064	1995-2000	Abdalati et al. (2004)
Patagonia	0.042 ± 0.002	1968/75-2000	Rignot et al. (2003)
Patagonia	0.105 ± 0.011	1995-2000	Rignot et al. (2003)
West Antarctica	0.12 ± 0.03	Late 1990s	Rignot and Thomas (2002)
West Antarctica	0.2	2002-2003	Thomas et al. (2004)
East Antarctica	0.05 ± 0.06	Late 1990s	Rignot and Thomas (2002)
Greenland	0.14	Late 1990s	Krabill et al. (2000)
Greenland	0.20 ± 0.07	2002-2004	Velicogna and Wahr (2005)
Greenland	0.23 to 0.55	2002-2005	Rignot (2005)

not take into account the accelerated glaciodynamic response that tidewater glaciers and polar outlet glaciers are now experiencing.

Relative sea level (RSL) change along coastal Alaska is a function of GSLR and also the local and regional rates of crustal adjustments to isostatic rebound from melting glaciers, tectonic processes, and the effects of gravity due to changing ice masses. In the latter case, while ice melting adds water to the oceans globally, reduced gravitational attraction exerted by the shrinking ice masses can cause a drop in RSL locally. Estimates of this effect in regions where glacier melting in Alaska is strong and ongoing, range from –2.3 mm yr^{-1} (Tamisiea et al. 2003), to –0.4 mm yr^{-1} (Larsen et al. 2004), where negative indicates a falling relative sea level. The loss of glacier ice is also driving strong glacial isostatic rebound along much of southern coastal Alaska. The effects of this rebound are clearly seen in tide gauge records and in GPS measurements. The post–Little Ice Age collapse of the Glacier Bay ice field (Motyka and Larsen 2005) and ongoing rapid melting of mountain glaciers throughout the region (C.F. Larsen et al. submitted) has resulted in rebound rates of as much as 32 mm yr^{-1} in Glacier Bay, with RSL falling as much as 5.7 m near Glacier Bay since 1770 AD (Motyka 2003; Larsen et al. 2004, 2005). This broad dome of uplift extends as far south as Sitka and as far north as Cape Yakataga, where the ~20 mm yr^{-1} average uplift rate has also been attributed to glacier rebound (Sauber and Molnia 2004).

Tectonically, the strike-slip margin along southeast Alaska contrasts sharply with the collision of the Pacific Plate with the North American Plate

(NAP) along the Aleutian megathrust. Great earthquakes there can rapidly and dramatically affect broad regions of coastline, e.g., the Good Friday earthquake. Co-seismic uplift of several meters in Prince William Sound (PWS) accompanied the Good Friday earthquake of 1964, while subsidence of up to 1 to 2 m occurred along Turnagain Arm near Anchorage (Eckel 1970). The overriding NAP has since been slowly deforming as part of the ongoing subduction of the Pacific Plate. These effects are reflected in the tide gauge and GPS records for PWS and Kenai area with Cordova now very slowly subsiding (ΔRSL = 5 mm yr^{-1}), and Kodiak (ΔRSL = –15.1 mm yr^{-1}) and Seldovia (ΔRSL = –8.6 mm yr^{-1}) slowly rising (Larsen et al. 2003 and unpublished GPS data). Regions in PWS and the Kenai Peninsula are also likely being affected by glacier isostatic adjustment. Both the Harding Icefield on the Kenai Peninsula and the Western Chugach Mountains south of Anchorage have been experiencing dramatic loss of ice (Arendt et al. 2002, and submitted), which will likely lead to isostatic uplift in these areas.

RSL changes are much less likely to affect regions distant from glaciers and plate boundaries, such as western and northern Alaska. Continued GSLR threatens the erosion of these lowland coasts. Shorelines composed of unconsolidated sediments are particularly susceptible. A 50 cm rise in sea level will typically cause a shoreward retreat of coastline of 50 m if the land is relatively flat (like most coastal plains) (ACIA 2005).

Acknowledgments

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Ice, Wind, Waves, and Storminess Trends along the Alaska Coast

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Introduction

Alaska has emerged as the canary in the mine for manifestation of climate change. We are not discussing hypothetical situations but instead are dealing with emerging, serious problems on a variety of fronts. The coastal zone has been among the hardest hit. This paper briefly reviews trends in major environmental forcing parameters that affect the coast, and focuses on likely trajectories for these trends, so that state planners and agencies have a better idea where to commit resources.

Sea ice

Sea ice is one of the most important moderating/driving agents in the arctic coastal zone. Its effects are manifested in a variety of ways: land-fast ice significantly dampens wave energy incident upon the coast. Open water distance to the ice edge controls wind fetch which in turn governs wave and surge height. Ice floes driven ashore by the wind can exert significant geomorphological impact at the local scale. Sea ice trends of interest to coastal managers center around the first two factors. In general, trends over the last two decades have been toward later land-fast ice formation and greater open water distances. There are three important factors to bear in mind, however, when working with sea ice trends and projections. The first is that there are long-term, multidecadal cycles in sea ice occurrence that are imperfectly understood at the present time. Some researchers feel that, despite the recent trend, there will be a return to heavier ice conditions, such as were observed along the north shore in the mid-late 1970s. Second is the inherent year-to-year variability in sea ice cover. This stems from a broader issue, that trends in natural phenomena are rarely the smoothed, gradual slope that statistical assessments reduce them to, but instead represent averages that in some cases encompass significant swings about the average point. Computer model simulations of arctic

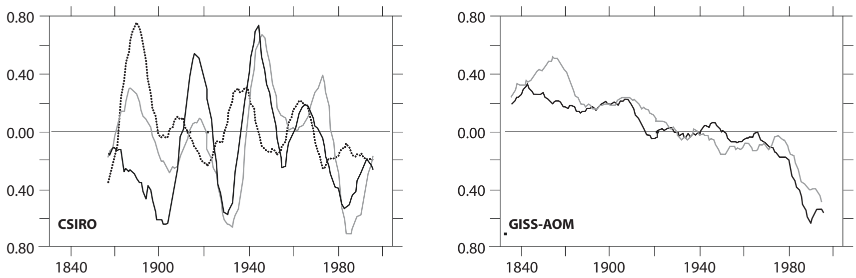

Figure 1. An example of two model-simulated runs showing circum-arctic sea-ice concentration. Note the large discrepancies and the large swings in sea ice concentration exhibited between the model outputs. This is typical of the other model results for hemispheric sea ice (Figure provided by Xiandong Zhang, IARC/UAF).

sea-ice variability reflect both points, that sea-ice understanding is far from complete and that large year-to-year swings are possible (Fig. 1). Third, current models are unable to capture land-fast ice at the shore, which is one of the most important elements for coastal managers.

Winds

Wind is an important environmental parameter from a management perspective, via its capacity to transfer momentum (ocean waves), remove energy (cooling) and moisture (drying), reduce the severity of inversions (mixing), and cause problems during forest fire situations. In the coastal zone, interest centers around strong winds. Wind speed patterns and trends for the three broad coastal regions in the state (i.e., North Slope, Bering/Chukchi, Gulf of Alaska) reveal distinct windy regions with trends in relative occurrences of different speed ranges. On the north coast strong winds (>22 mph) are observed 10-20% of the time, with the eastern region (Barter) seeing higher winds on average than farther west (Barrow). This is due to the proximity of the Brooks Range and the channeling effect it has on the wind. Trends on this coast range from more frequently observed high speed winds in the Barter/Deadhorse area, to less frequent in the vicinity of Barrow. Such trends can be the result of a slight change in average storm tracks. The west coast is the windiest region in Alaska, with average high speed wind occurrences ranging from ~9% at Nome to ~40% at Tin City. A recent, small increase in high wind frequency was exhibited at Nome. The south coast has a lower frequency of high speed winds, ranging from 1% to 5%, although it should be emphasized that these results were taken from stations with more sheltered locations than those on the west coast.

Ocean waves

The essential reason for interest in the wind regime stems from its capacity to drive other systems that directly impact the coast. Waves, sea level changes (surges), and ice movement are of primary concern here. A preliminary examination of seasonal wave energy totals for the circumpolar region underscored the importance of sea ice in moderating ocean waves. Specifically, it showed that (a) heavy ice will reduce seasonal wave energy totals, and (b) trends in sea ice conditions are as important as trends in strong wind (and storm) frequency. This was shown by wave energy trend results for the southern Beaufort Sea coast, where trends from wind alone suggested a slight decrease in wave energy; but the addition of sea ice trends, which are decreasing at a faster rate, indicated a net increase of wave energy.

Storms

Trends in storm activity, with "storm" being objectively defined by an algorithm working with wind-speed, were instructive by the lack of strong trends spanning many decades. Instead, the more important point here is that the time series are characterized by periods of higher and lower activity. The length of cycles differed: Barrow has moved through one cycle, while Bethel seems to exhibit higher-frequency of cycling (Fig. 2). Another interesting observation from the Barrow time series is that, in the last 20 years, the number of events occurring in the "open water" season (July-December) has increased with respect to the number of events in the "freeze-up" season (January-June). This represents a departure from the first 30 years of record, during which the two had been roughly equal.

Conclusions

The three main points to take away regarding sea ice are (a) its reduction opens up the coast to greater erosion threat from storms, (b) its inherent variability means that a return to heavier ice conditions, at least temporarily, is likely, and (c) model predictions of future patterns at the local scale are not immediately forthcoming, especially for land-fast ice. Regarding wind patterns, some trends are noted, but large differences are noted as a result of station location. Exposed coastal sites can be far windier than relatively sheltered sites only a few miles away. Seasonal totals of coastal wave energies are very dependent on sea ice conditions, both concentrations during a given season as well as trends. Storm event counts showed no long-period trends, but instead exhibit cycles of activity with periods lasting several years to several decades.

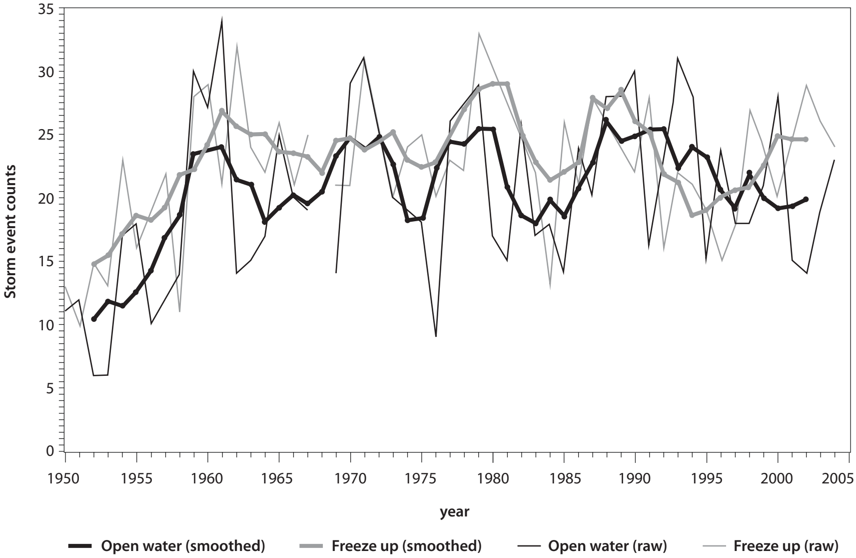

Figure 2. High speed wind events (storms) at Bethel, 1950-2004. Lines are 5-year running means of events during a roughly defined "open water" season (July-December), and during a roughly defined "freeze-up" season (January-June).

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Management Responses to Erosion

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The National Flood Insurance Program (NFIP) is a Federal program enabling property owners in participating cities and boroughs to purchase flood insurance as a protection against flood and flood-related erosion losses in exchange for state and community floodplain management regulations that reduce future flood damages.

Communities incorporate NFIP requirements into their zoning and subdivision ordinances and building codes or adopt special-purpose floodplain management ordinances. The NFIP requirements apply to areas mapped as Special Flood Hazard Areas (SFHA) on Flood Insurance Rate Maps issued by the Federal Emergency Management Agency (FEMA).

The NFIP does not map erosion hazard areas and therefore is unable to inform homeowners of the risk to their property from erosion. Moreover, FEMA's flood insurance rate maps do not inform current and prospective property owners of erosion risks. Although FEMA has not identified **Erosion Hazard Areas** in implementing the NFIP, the code of federal regulations governing the NFIP include a flood related erosion setback standard (CFR 60.5).

A flood, as defined by the National Flood Insurance Program is

> "A general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties (at least one of which is your property) from:
>
> Overflow of inland or tidal waters,
>
> Unusual and rapid accumulation or runoff of surface waters from any source, or a mudflow.
>
> **[The] collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels that result in a flood."**

A few flood insurance facts:

- Flood insurance costs vary according to flood zone, but consider that the owner of a residence in a community and an area at medium or low risk of flooding can buy a Preferred Risk Policy (PRP) with basic building and contents coverage for an annual premium as little as $111.
- A typical residential building in an area at high risk of flooding is six times more likely to be damaged by flood than by fire. An erosion loss is much more likely to be a total loss than a percent of structure damage due to typical flooding.
- Federal disaster assistance might pay for some flood damage—but there's a costly catch. Disaster assistance, when authorized, usually takes the form of loans, which must be repaid with interest. The annual interest on an average federal disaster loan is greater than the annual premium for an average NFIP policy.
- The NFIP appears to pay for most erosion-related damage claims. From the banks of the Matanuska River, to the Cook Inlet bluffs, to Shishmaref, flood insurance has paid for erosion losses. Unfortunately few at risk properties are properly insured.

Congress directed the General Accounting Office to study Alaska Native villages affected by flooding and erosion and to identify federal and state flooding and erosion programs. In their December 2003 report to Congress, GAO announced that "to some extend flooding and erosion affects 184 out of 213, or 86 percent of Alaska Native villages."

Thirty-two (32) or 17 percent of these "villages" are cities that participate in the NFIP and thus have flood insurance available and are regulating flood and to some extent erosion risks. The limits of flood insurance in rural Alaska is an example of the unique circumstances of Alaska Native villages and their inability to qualify for assistance under a variety of federal flooding and erosion programs. The GAO suggested several alternatives for Congress to consider "that could help mitigate the barriers that villages face in obtaining federal services: (1) expanding the role of the Denali Commission to include responsibilities for managing a flooding and erosion assistance program, (2) directing the Corps and Natural Resources Conservation Services to include social and environmental factors in their cost/benefit analyses for projects requested by Alaska Native villages, and (3) waiving the federal cost-sharing requirement for flooding and erosion projects for Alaska Native villages."

Senator Stevens held a full Senate Appropriations Hearing in Anchorage in June 2004 to take testimony on the erosion problem. Senator Murkowski participated, calling for a statewide erosion assessment. This was funded with a $2 million appropriation in the Omnibus bill and the project is currently under way.

In January 2005, Senator Stevens introduced S. 49 Floodplain and Erosion Mitigation Task Force, which would establish a multi-agency Federal-State commission to evaluate and direct actions on the erosion problem.

This forum and others like it need to continue to define when effects of coastal erosion are a State issue:

- When the erosion occurs during an event that elevates to a level of a State disaster.
- When state-funded and maintained structures and infrastructure are impacted.
- When the Alaska Legislature directs named Legislative Grant.

Alaska needs to continue to limit additional or redevelopment in high hazard areas; and continue to develop community plans and funding mechanisms that

- Provide for relocation of structures out of high hazard areas,
- Restrict erosion control devices, such as seawalls, revetments, and groins.

Instituting mechanisms to **control development** in coastal communities, to help prevent significant increases in buildings and infrastructure relocation, abandonment, and loss is a most difficult challenge. The engineering community has a significant role to assist with the challenges faced by our natural setting.

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Appendix

State of Alaska
Office of the Governor
Juneau
Administrative Order No. 175
Alaska Erosion Management Policy

Introduction

Erosion threatens individual structures, roads, airports, utility infrastructure and in some locales, entire communities (city, village, subdivision) can be at risk. This policy concerns state-funded and state pass-through funded construction. Other entities in Alaska who construct erosion control structures, or propose development near coastal waters or rivers, are encouraged to consider the following siting, design, and construction policies.

Special Appropriations by the Legislature have been the primary method of funding most (nonfederally funded) erosion control structures (bulkheads, sea walls, rock revetments, etc.). No State of Alaska departments have authority to build erosion control structures, or to maintain already constructed erosion control structures, intended to protect privately owned facilities, roads or land.

This is intended as general policy. State agencies are encouraged to develop their own more detailed guidance related to state actions adjacent to water bodies.

Alaska erosion policies

1. Before constructing erosion control measures, state agencies should analyze nonstructural alternatives, such as relocating threatened structures, and if consistent with law, proceed with the option that has the greatest benefit for the least cost.
2. State funded projects should not cause adverse erosion effects to adjacent (unprotected) properties or habitat.
3. Erosion control structures should not be built to protect minimally used or vacant land.
4. New structures should be located so that erosion control is not likely to be needed within the structure's design life. If such structures are

at risk of erosion loss/damage, the cost of erosion safeguards should be considered.

5. The cause of the erosion problem (water, ice, wind, current, waves, thermal degradation, precipitation, seepage), and factors that increase or accelerate erosion (such as gravel removal, boat wakes, shoreline vegetation removal) should be identified before alternative solutions are proposed.
6. Erosion control projects should be sited and designed using appropriate engineering principles. Consideration should include, but are not limited to:
   - Design life of a specified project, or survivability to a specified level or event (e.g. 1 percent flood, base flood elevation, 30-year, 60-year project design life, piling depth necessary to withstand scour).
   - Performing an analysis to determine rate of erosion, then avoid building in area that would erode in life of building.
   - Provide erosion control protection as part of the project development.
7. A state-funded erosion control project shall include stamped drawings designed by a registered engineer in Alaska. The completed structure must conform to these design drawings.
8. Communities with structural erosion control measures, or erosion-prone areas, should be encouraged to incorporate appropriate flood risk and erosion mitigation planning considerations into local comprehensive plans, ordinances, and subdivision approvals.
9. Communities which receive state funds for erosion protection should be encouraged to prepare an erosion (and if appropriate, flood) mitigation plan, and land use regulation(s) to prevent losses and to guide development in high-risk erosion and flood-prone areas.
10. To the extent practical, and consistent with state law, priority for state funds for erosion hazards should be given to communities which have an erosion (and if appropriate, flood) mitigation plan, or land use regulation(s) indicating measures are being taken locally to prevent future losses and development in high risk erosion areas.
11. If the state finds building, platting, and land use regulations within the affected jurisdiction(s) are inadequate and therefore have added substantially to the magnitude of a state declared disaster, public recovery assistance should be limited to a disaster loan until essential changes in such regulations are adopted.

Erosion assessment

An erosion assessment should be performed if major state-funded development is proposed on property adjacent to a body of water. Examples of acceptable erosion assessments include:

- Existing reports that include an erosion rate estimate.
- Site evaluation by a registered engineer, or water resources specialist.
- Long period, low altitude aerial photography can be compared to ascertain shoreline movement. However, long-period adequate scale aerial photography is often not available. Many river shore and coastal shoreline areas are subject to dramatic short-term changes, often measuring several hundred feet in major storms or during a high water season. Modeling to depict impact on recession rates has not been developed.

In determining how large a setback to adopt, or how stringent building design and construction standards should be, or whether structural erosion control measures are needed, accurate hazard delineation is needed. Erosion hazards data should meet three tests: 1) Data should be realistic (tested against academic models and/or past experience); 2) Data should be available for use (not too costly to secure or too time-consuming to generate or use); 3) Data should be legally defensible. This standard does not require perfection, but it does require reasonable accuracy.

State and Coastal District Plan and Policy Influence on Coastal Hazards: Background and History of the Alaska Coastal Management Program (ACMP)

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The state of Alaska's coastline consists of approximately 44,500 miles which, measured either on the tide line or measured around an average perimeter that parallels the mainland limits of the Territorial Sea, exceeds that of the entire continental United States (*The Alaska Coastal Management Program*, as amended June 2, 2005). The Alaska coastal area has national and international significance for its vast, healthy ecosystems and is a generous source of renewable and non-renewable resources, including proven and potential energy resources. Three-quarters of Alaska's people live on or near the coast. Many earn their living from direct use of coastal resources and many more from indirect uses, such as Alaska's growing tourist industry. The Native people of Alaska maintain a cultural and economic intimacy with the coast that dates back thousands of years.

Alaska began considering comprehensive coastal management in the mid-1970s, after passage of the federal Coastal Zone Management Act of 1972. At the time, state and local interest in participating in coastal zone management resulted in part from ambitious plans for federal oil and gas leasing off Alaska's coasts. Several federal agencies managed large portions of Alaska (over 60%) and Alaska's offshore areas, affecting the economies and lifestyles of local communities. Coastal communities also argued strongly for a voice in decisions that might affect their livelihood and way of life. Increasing demands for the use and enjoyment of Alaska's rich and diverse coastal resources (such as timber production, tourism, mining, fisheries, recreation, and oil and gas development) created a need for an effective forum for responsible development and resolving local issues. From its inception in 1972, the CZMA provided the various stakeholders and Alaska's coastal communities with that forum.

The Alaska Legislature enacted the Alaska Coastal Management Act (ACMA) on June 4, 1977 (ch. 84 SLA 1977), which established the ACMP. In passing the ACMP, the Alaska Legislature noted several issues: waterfront space scarcity, energy resource development impacts, maintaining the fisheries, managing the forest resources, transportation needs and impacts, impacts of mining, impacts of Western culture on Native cultures, providing for the Alaska subsistence lifestyle, geological hazards, changing land ownership patterns, bottomfish, and governmental regulation. To address these issues, the legislature made the following findings about the state's coastal area, which apply as much today as they did in 1977:

1. The coastal area of the state is a distinct and valuable natural resource of concern to all the people of the state;
2. the demands upon the resources of the coastal area are significant and will increase in the future;
3. the protection of the natural and scenic resources and the fostering of wise development of the coastal area are of concern to present and future citizens of the state;
4. the capacity of the coastal area to withstand the demands upon it is limited;
5. the degree of planning and resource allocation which has occurred in the coastal area has often been motivated by short-term considerations, unrelated to sound planning principles; and
6. in order to promote the public health and welfare, there is a critical need to engage in comprehensive land and water use planning in coastal areas and to establish the means by which a planning process and management program involving the several governments and areas of the unorganized borough having an interest in the coastal area may be effectively implemented.

In 1979, the Coastal Policy Council guided the ACMP to final federal approval. The ACMP has evolved significantly since 1979. Each district coastal management plan, statutory or regulatory revision, or other program amendment that gains state and federal approval is incorporated into the ACMP. Today, two chapters of statutes, three chapters of regulations, 33 coastal district plans, and 33 areas meriting special attention and special area management plans are part of the ACMP.

Objectives, intent, and approach of the ACMP

The legislature set forth in AS 46.40.020 the following objectives for the ACMP, which remain unchanged over its nearly thirty-year life:

1. the use, management, restoration, and enhancement of the overall quality of the coastal environment;
2. the development of industrial or commercial enterprises that are consistent with the social, cultural, historic, economic, and environmental interests of the people of the state;
3. the orderly, balanced utilization and protection of the resources of the coastal area consistent with sound conservation and sustained yield principles;
4. the management of coastal land and water uses in such a manner that, generally, those uses which are economically or physically dependent on a coastal location are given higher priority when compared to uses which do not economically or physically require a coastal location;
5. the protection and management of significant historic, cultural, natural, and aesthetic values and natural systems or processes within the coastal area;
6. the prevention of damage to or degradation of land and water reserved for their natural values as a result of inconsistent land or water usages adjacent to that land;
7. the recognition of the need for a continuing supply of energy to meet the requirements of the state and the contribution of a share of the state's resources to meet national energy needs; and
8. the full and fair evaluation of all demands on the land and water in the coastal area.

When the legislature addressed the coastal issues it identified in 1978, it developed a comprehensive management program to satisfy the requirements of the CZMA and as the general solution to managing important coastal resources, and set forth basic program policy in Section 2 of the Alaska Coastal Management Act:

1. preserve, protect, develop, use, and where necessary, restore or enhance the coastal resources of the state for this and succeeding generations;
2. encourage coordinated planning and decision making in the coastal area among levels of government and citizens engaging in or affected by activities involving the coastal resources of the state;
3. develop a management program which sets out policies, objectives, standards and procedures to guide and resolve conflicts among public

and private activities involving the use of resources which have a direct and significant impact upon the coastal land and water of the state;

4. assure the participation of the public, local governments, and agencies of the state and federal governments in the development and implementation of a coastal management program;
5. utilize existing governmental structures and authorities, to the maximum extent feasible, to achieve the policies set out in this section; and
6. authorize and require state agencies to carry out their planning duties, powers and responsibilities and take actions authorized by law with respect to the programs affecting the use of the resources of the coastal area in accordance with the policies set out in this section and the guidelines and standards adopted by the Alaska Coastal Policy Council under AS 46.40.

The articulation of the Program's objectives from 1978 carries through to today. So does the explanation that, while the ACMP is a program of government, the private sector is viewed as a partner in coastal management. This partnership applies to the business community, public interest groups, environmental organizations, and rural interests as well as the public at large. Certainly, the ACMP has environmental goals, but these goals are part of a spectrum of management goals set forth as policies for the program by the legislature. Continued development of Alaska's coastal resources is vital to both the state and local economies and to national interests. Local governments, aside from being closest to coastal issues, are also most familiar with local conditions and have the traditional political right and responsibility to govern local land use on city owned land within their municipal boundaries. Alaska is little different from other states in this respect. Thus, the reader will note an emphasis on state management and use of coastal resources, with local input on matters of local knowledge and concern. Through this management philosophy, state, local, national, and private sector goals and aspirations that depend on the use of coastal resources can be met through an open planning and management process where interested parties can be brought together to resolve their differences and eliminate potential conflicts before more serious problems occur.

With this in mind, the legislature called on local governments to prepare plans to govern the use of coastal resources in their areas. At the same time, a state level element was established by the formation of the Alaska CPC. The CPC, made up of appointed state agency and elected local government officials, provided overall leadership for the program and established the basic guidelines and standards to be used by the local governments in the development of their coastal plans and by state agencies in making coastal permitting and management decisions. While the CPC no longer exists, the ACMP was designed, and continues to operate, as a "networked" program. Rather than establishing its own comprehensive coastal permitting structure, Alaska instead coordinates existing agencies' authorization and permitting authorities and processes to determine whether a given use is consistent with the standards and objectives of the ACMP.

Alaska's program is voluntary at the local level, but the networking process encourages local land use planning which, coupled with statewide policies, provide coordinated, intergovernmental evaluation of a proposed coastal project. The process involves a partnership between the project review team, the applicant, the coastal districts, state/federal agencies, and the public. The ACMP thus places emphasis upon coordination between state, local, national, and private sector interests in the management and use of coastal resources. The networking approach demonstrates Alaska's commitment to properly manage the competing demands upon, preservation of, and sustainable use of, its precious coastal resources.

ACMP Application to Coastal Natural Hazards

The ACMP consistency review process at 11 AAC 110 is the primary means by which proposed coastal uses and resources are evaluated for compliance and consistency with the ACMP enforceable policies. As such, the consistency review process is the keystone component of the ACMP that coordinates the application of the state's enforceable policies, brings all relevant ACMP participants to the table, and establishes the authorities, responsibilities, and opportunities for participation in the review of proposed coastal projects. An ACMP consistency review is required for:

- Any federal agency that proposes an activity within or affecting the state's coastal zone uses or resources.
- Any proposed coastal project that requires a federal consistency certification and that is located within the area identified under AS 46.40.096(l).
- Any proposed coastal project that requires an authorization listed on the "C List" (as authorized under 11 AAC 110.750) and that is located within the state's coastal zone or defined geographic location description.

All activities that are subject to the ACMP consistency review process, as described above, must comply with the relevant and applicable Statewide Standards of the ACMP at 11 AAC 112, as well as any coastal district enforceable policies approved under 11 AAC 114. Specific to coastal natural hazards, activities must comply with the following statewide standard at 11 AAC 112.210:

(a) In addition to those identified in 11 AAC 112.990, the department, or a district in a district plan, may designate other natural processes or adverse conditions that present a threat to life or property in the coastal area as natural hazards. Such designations must provide the scientific basis for designating the natural process or adverse condition as a natural hazard in the coastal area, along with supporting scientific evidence for the designation.

(b) Areas likely to be affected by the occurrence of a natural hazard may be designated as natural hazard areas by a state agency or, under 11 AAC 114.250(b), by a district.

(c) Development in a natural hazard area may not be found consistent unless the applicant has taken appropriate measures in the siting, design, construction, and operation of the proposed activity to protect public safety, services, and the environment from potential damage caused by known natural hazards.

(d) For purposes of (c) of this section, "appropriate measures in the siting, design, construction, and operation of the proposed activity" means those measures that, in the judgment of the coordinating agency, in consultation with the department's division of geological and geophysical surveys, the Department of Commerce, Community and Economic Development as state coordinating agency for the National Flood Insurance Program under 44 C.F.R. 60.25, and other local and state agencies with expertise,

(1) satisfy relevant codes and safety standards; or

(2) in the absence of such codes and standards,

(A) the project plans are approved by an engineer who is registered in the state and has engineering experience concerning the specific natural hazard; or

(B) the level of risk presented by the design of the project is low and appropriately addressed by the project plans.

As described, the department (defined in 11 AAC 112.990 as the Department of Natural Resources) ". . . may designate other natural processes or adverse conditions that present a threat to life or property in the coastal area as natural hazards." The department may designate such natural hazards in a departmental planning effort or within the context of a consistency review under 11 AAC 110. In either case, the designations must provide the scientific basis for designating the natural process or adverse condition as a natural hazard in the coastal area, along with the supporting scientific evidence for the designation. In addition, as authorized under 11 AAC 114.250(b), the coastal district ". . . shall consider the likelihood of occurrence of natural hazards in the coastal area and may designate natural hazard areas."

Conclusion

The ACMP provides an important tool and forum to consider the location and impacts of projects that may be located in natural hazard areas. Potential project impacts, and the loss of life and property, can be avoided, minimized, or mitigated through efficient and effective application of the statewide standards and coastal district enforceable policies. However, in order to apply the natural hazard statewide standards and coastal district enforceable policies, the natural hazards must be scientifically documented and formally designated in the ACMP as a "natural hazard area." Unfortunately, development and compilation of natural hazard information, while important, has proven difficult. Developing and compiling natural hazard information, synthesizing it in a form prescribed in the ACMP planning process or consistency review process, and using that information through the application of land/water use rules such as the ACMP, is critical to reducing impacts and eliminating conflicts with proposed uses that may occur within those natural hazard areas.

Understanding Shoreline Change

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Shoreline change occurs both episodically and gradually over long time scales. Movement of the shoreline can result in coastal land loss, habitat destruction, and damage to infrastructure and property. Where the change in shoreline position causes beach loss the impacts can include (a) lost valuable recreational and economic resources, (b) reduced coastal land protection by limiting the natural buffer zone that beaches provide, (c) reduction of sandy intertidal habitat, and (d) damage to culturally significant lands. Where shoreline change includes coastal cliff erosion there is an irreversible retreat of the coast. Fragile coastal habitats that are impacted by shoreline retreat include mangrove forests, salt marshes, coastal dunes, estuaries, lagoons, permafrost, and tundra shorelines. The documentation of the rates and magnitudes of shoreline change is an important tool in coastal management and planning programs. Two main components of shoreline change analysis include documenting historical change and monitoring shoreline response to forcing parameters.

Historical shoreline analysis

There is no single standard methodology for historical shoreline change analysis, but the technique commonly involves the comparison of shoreline positions derived from maps, charts, aerial photography, aerial lidar surveys, and satellite imagery. The procedure includes identifying past shoreline positions and projecting all shoreline information into a common reference frame. For each data source it is important to identify all sources of error so a reasonable accuracy assessment can be made (Thieler and Danforth 1994).

Aerial photography

Vertical aerial photography is a common data source for determining past shoreline positions. A "typical" analysis will incorporate numerous photographs ideally taken from the same time of year to reduce errors associated with seasonal fluctuations. Smaller-scale photography, such as 1:20,000 or less, provides better detail for the shoreline reference feature that is used as a proxy for shoreline position. Depending on coastal location, data source, and scientific preference, different proxies for shoreline position are used to document coastal change, including the high water line, wet-dry line, vegetation line, dune toe or crest, toe of the beach, cliff base or top, and the line of mean high water (MHW).

Aerial photography has several types of inherent distortions and displacements associated with the geometry of the camera system, the change in the position of the aircraft from one photo to another, and the relief of the terrain being mapped. Digital photogrammetry is the current preferred method used to remove these displacements using digital imagery (usually scanned diapositives of vertial stereopair photographs). GPS ground control points are used to relate the imagery to true ground space so that the images can be georeferenced. The processing provides a fully orthorectified, or corrected, image that can be used as a base map. The orthorectification process requires the generation of a digital terrain model (DTM), which involves taking user-input measurements (ground control points and tie-points) and deriving the DTM from a stereo model through interpolation (Ackermann 1996). The DTM itself is a network of grid points containing XYZ information. Additionally, breaklines can be added to areas between grid points where the topography changes abruptly, such as the top edge or base of a sea cliff. Breaklines, which allow for more accurate definition of topographic changes, can only be added to the DTM while viewing in stereo, in order to see the elevation changes in 3 dimensions. Once the imagery is orthorectified, orthophotographs and mosaics can be created that provide distortion-free, georeferenced base maps. The rectified stereo model can also be displayed on a stereo-viewing monitor, and accurate, georeferenced measurements can be acquired directly from the model.

Airborne lidar

Airborne lidar surveys ground elevation using an elliptically rotating blue-green laser. GPS (global positioning system) positions and inertial navigation systems are used to correct for aircraft pitch, roll, and heading, providing ground elevations with accuracies of about ±15 cm (Sallenger et al. 2003). To compare lidar-derived datum-based shorelines with historical shorelines, a comparable shoreline reference feature must be used. In a study by Morton et al. (2004) comparing historical NOAA T-sheet shorelines with a modern lidar-derived shoreline the MHW shoreline was the reference feature. The lidar shoreline was determined from densely spaced airborne lidar data, using a method developed in 2002 by Stockdon et al., where shorelines were extracted from cross-shore profiles which consist of bands of lidar data 10 m wide in the alongshore direction and spaced every 20 m along the coast. Repeating this procedure at successive profiles 20 m apart generates points that can be connected to create a continuous shoreline. An example of a historical analysis utilizing historical T-sheet derived shorelines compared with a modern lidar-derived shoreline is shown in Fig. 1.

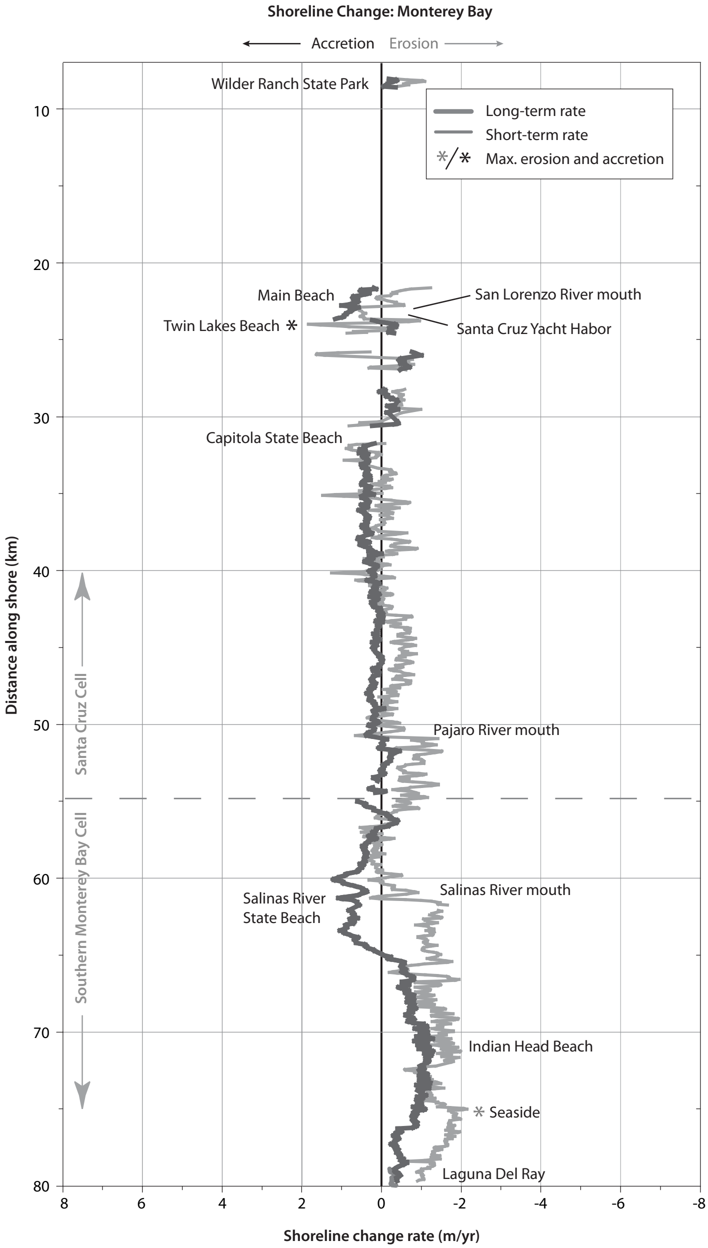

Figure 1. Results of long-term (1850-1890s to present) and short-term (1970s to present) shoreline change for Monterey Bay area, California. The older data are from scanned, digitized, and georeferenced historical T-sheets. The modern shoreline represents an MHW elevation derived from lidar data. Draft figure from USGS Report in preparation.

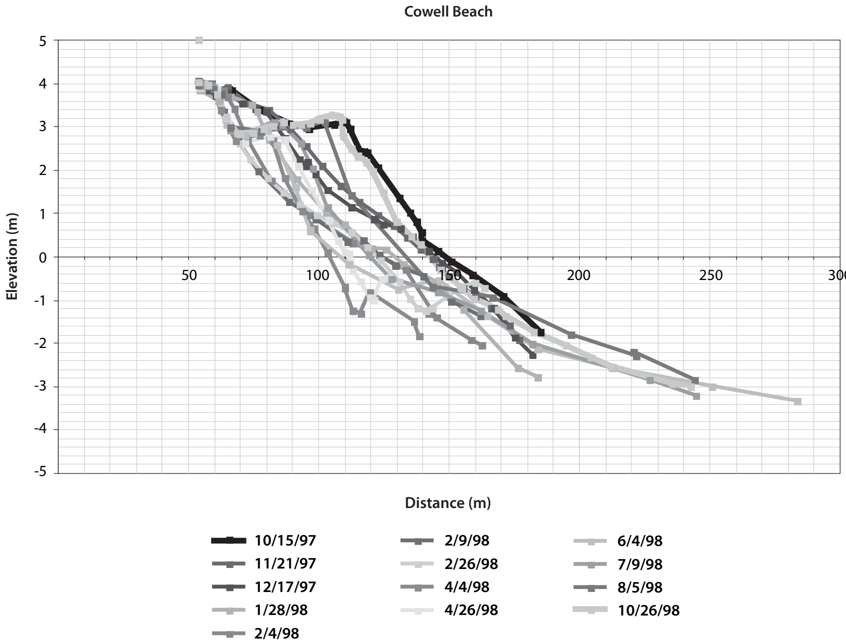

Figure 2. Cross-shore profiles from Cowell Beach, Santa Cruz, California, showing the seasonal erosion and accretion trends during 1997-98 El Niño event. Minimum beach width occurred in February and is coincident with the maximum storm waves. The net result was little change over the course of a year.

Monitoring shoreline changes

The most common and widespread method of monitoring shoreline change is repeated profiling of the foreshore in an effort to capture seasonal and long-term changes in shoreline position. Methodology varies from traditional shore-normal survey lines to 3-dimensional survey arrays that incorporate land-based and offshore survey techniques. Generally, a yearlong record of repeated surveys is needed to identify gross seasonal changes. Multiyear monitoring is needed to track longer-term changes. The time between successive surveys can range from days to months and is determined by desired outcomes of the study. High rates of coastal change typically require more frequent surveys, whereas slow-changing coasts need fewer surveys to capture the rate of change. Figure 2 is an example of shore-normal beach profiles taken to document beach erosion and recovery during the 1997-98 El Niño in central California.

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Coastal Sediment Budgets

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Introduction

The concept of the sediment budget has proven to be a very useful approach for evaluating the relative importance of various sediment sources and losses in the nearshore zone. Sediment budgets can aid in accounting for regions of deposition or erosion and in evaluating the impacts of humans on coastal systems. This abstract will examine the basic principles of a sediment budget and discuss the relative importance of various sediment sources and sinks.

Basic principles

A sand budget employs the conservation of volume concept, and can be as simple as a bookkeeping of sand entering, leaving, or contained within a study area, often a littoral cell. Dean and Dalrymple (2001) compute sand accumulation in an area, ΔVs, by

$$\Delta Vs = Vx1 - Vx2 + Vy1 - Vy2 + S$$

$Vx1$ = volume of sand carried into the study area alongshore
$Vx2$ = volume of sand leaving the study area alongshore
$Vy1$ = volume of sand transported into the area from the landward side
$Vy2$ = volume of sand going offshore out of the area
S = volume added artificially within this study area

Change in total sand volume is related to the difference in sand transported into and out of the storage area alongshore, the difference in sand transported to the area from landward sources, such as river discharge and seacliff erosion, and sand transported offshore, as well as sand added artificially to the area, such as beach fill or nourishment (Figs. 1 and 2).

Sediment sources and sinks

The main challenge in developing a sand budget for a littoral cell is quantitatively assessing all the sources and sinks to a reasonable degree of accuracy (Komar 1996). Table 1 summarizes the possible sources and sinks of sand for a sediment budget.

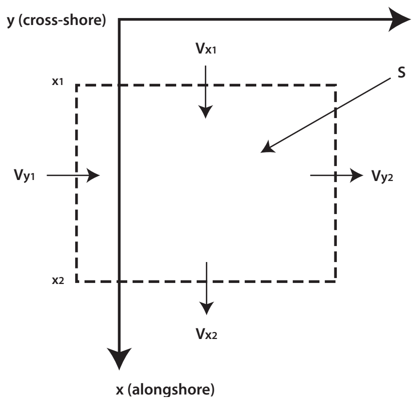

Figure 1. Conceptual model of sediment budget (after Dean and Dalrymple 2001).

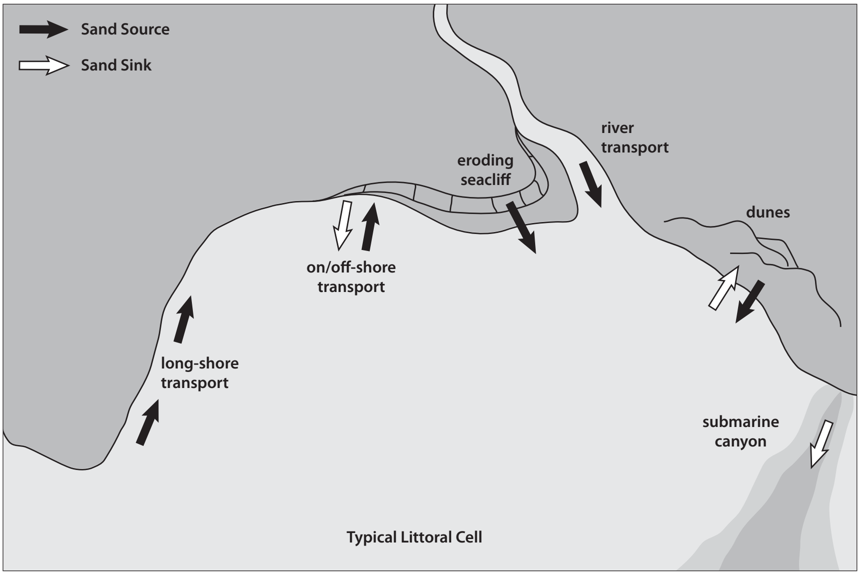

Figure 2. Conceptual model of sediment budget (modified after Komar 1996).

Table 1. The budget of littoral sediments (after Bowen and Inman 1966, and Komar 1996).

Credit	Debit	Balance
Longshore transport into area	Longshore transport out of area	Beach deposition or erosion
River transport	Wind transport out	
Sea cliff erosion	Offshore transport	
Onshore transport	Deposition in submarine canyons	
Biogenous deposition	Solution and abrasion	
Hydrogenous deposition	Mining	
Wind transport onto beach		
Beach nourishment		

Figure 3. Primary sources (rivers and sea cliff erosion) and sinks (submarine canyons and human activity) to a sediment budget.

Typically rivers and longshore transport from updrift beaches provide the majority of inputs to sedimentary systems. Longshore transport out of an area, submarine canyons, and human interference are the primary sediment sinks. Net cross-shore sediment transport is often one of the most difficult values to quantify in a sediment budget and can be either a source or a sink. However, due to a typical paucity of data, cross-shore transport is usually assumed to be balanced in a net sense.

Summary

While the concepts of sediment budgets should aid in understanding and ultimately predicting coastal change along Alaska's shorelines, there are several challenges associated with applying these concepts in Alaska. These include

- Megatidal environments
- Mixed sediment beaches
- Permafrost shorelines and bluffs
- Sea ice
- Large rivers and high but unquantified sediment discharge
- Active vertical tectonics (co-seismic and glacial rebound)
- Data paucity

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Alaska District Coastal Engineering Policy and Planning Issues

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Significant new authorities and funding mechanisms have been created by Congress to address the ongoing erosion issues in Alaska. The focus of this presentation will be the various issues, changes, and new programs the Corps are working on as this complex problem is addressed. Whereas the presentation contains significant information in itself, it does not provide the multiple legislative citations often referred to. By examining the following legislative excerpts, one can gain better understanding of the foundational elements of the Corps' work. The presentation by Mr. Sexauer will address the various issues surrounding coastal erosion planning and polices within the Corps of Engineers.

The Tribal Partnership Program (TPP) was authorized as Section 203, WRDA 2000, Public Law 106-51, which reads as follows:

SEC. 203. TRIBAL PARTNERSHIP PROGRAM

a. Definition of Indian Tribe. In this section, the term "Indian tribe" has the meaning given the term in section 4 of the Indian Self-Determination and Education Assistance Act (25 U.S.C. 450b).

b. Program

   1. In general. In cooperation with Indian tribes and the heads of other Federal agencies, the Secretary may study and determine the feasibility of carrying out water resources development projects that

      A. will substantially benefit Indian tribes; and

      B. are located primarily within Indian country (as defined in section 1151 of title 18, United States Code) or in proximity to Alaska Native villages.

2. Matters to be studied.—A study conducted under paragraph (1) may address
   - A. projects for flood damage reduction, environmental restoration and protection, and preservation of cultural and natural resources; and
   - B. such other projects as the Secretary, in cooperation with Indian tribes and the heads of other Federal agencies, determines to be appropriate.

c. Consultation and coordination with Secretary of the Interior.

1. In general. In recognition of the unique role of the Secretary of the Interior concerning trust responsibilities with Indian tribes and in recognition of mutual trust responsibilities, the Secretary shall consult with the Secretary of the Interior concerning studies conducted under subsection (b).
2. Integration of activities. The Secretary shall
   - A. integrate civil works activities of the Department of the Army with activities of the Department of the Interior to avoid conflicts, duplications of effort, or unanticipated adverse effects on Indian tribes; and
   - B. consider the authorities and programs of the Department of the Interior and other Federal agencies in any recommendations concerning carrying out projects studied under subsection (b).

The funding authority for the tribal partnership effort was the Consolidated Appropriations Resolution, 2003 PL 108-7, Division D, Energy and Water Development Appropriations, 2003, Conference Report (H.R. 108-10, page 807) and Senate Report (S.R. 107-220, page 23), which reads as follows:

> "The Committee acknowledges the serious impacts of coastal erosion due to continued climate change and other factors in the following communities in Alaska: Bethel, Dillingham, Shishmaref, Kakatovik, Kivalina, Unalakleet, and Newtok. The Committee directs the Corps to perform an analysis of the costs associated with continued erosion of these communities, potential costs associated with moving the affected communities to new locations (including collocation with existing communities), and to identify the expected time line for a complete failure of the useable land associated with each community.
> An additional $2,000,000 above the President's request has been provided for this work, of which $1,000,000 is for Shishmaref, AK. Due

to rapid erosion occurring at Shishmaref, AK, the Committee directs the Corps to expedite all necessary environmental studies to document the impacts of this severe and continuing erosion."

The additional funding for the Tribal Partnership and the funding for the Baseline Erosion Study were identified in the Consolidated Appropriations Act of 2005, PL 108-447, Division C, Energy and Water Development Appropriations Act, 2005.

> "Tribal Partnership Program.—The conferees acknowledge the serious impacts of coastal erosion and flooding due to continued climate change in Alaska. The conference expects the Corps to continue its work in this area and has included a total of $4,000,000, of which $2,000,000 is to combat erosion in Alaska. A field hearing was held in Anchorage, Alaska on June 29 and 30, 2004, on the impacts of severe erosion and flooding on Alaska Native villages. There is no Federal or State agency to coordinate and assist these communities in the relocation or in the interim provide preventative measures to slow the effects of the erosion and flooding. The conference finds there is a need for an Alaska erosion baseline study to coordinate and plan the appropriate responses and assistance for Alaska villages in the most need and to provide an overall assessment on the priority of which villages should receive assistance. Therefore, the conference has provided the $2,000,000 for this study."

In addition to more study authority and funding, the new authority was added for construction of projects at full Federal expense: Consolidated Appropriations Act of 2005, PL 108-447, Division C, Energy and Water Development Appropriations Act, 2005, which states as follows:

> "SEC. 117. Notwithstanding any other provision of law, the Secretary of the Army is authorized to carry out, at full Federal expense, structural and non-structural projects for storm damage prevention and reduction, coastal erosion, and ice and glacial damage in Alaska, including relocation of affected communities and construction of replacement facilities."

Funding for the new construction authority was made available in the Energy and Water Appropriations Bill, 2006, Senate Report 109-84, page 41 which states "The Committee has provided $2,400,000 for Alaska Coastal Erosion. The following communities are eligible recipients of these funds: Kivalina, Newtok, Shishmaref, Koyukuk, Barrow, Kaktovik, Point Hope, Unalakleet, and Bethel. Section 117 of Public Law 108-447 will apply to this project."

Navigation

- Homer Small Boat Harbor
- Flood Damage Reduction
- Chena River Lakes and Tanana River Levee
- Hurricane and Storm Damage Reduction
- Shishmaref Emergency Bank Protection (Fig. 1)

Non-Traditional Benefits

- Cultural Significance
- Subsistence
- Environmental

High Construction Costs

- Limited Construction Season
- Equipment and Labor Availability
- Difficult Logistics

Inability to Provide Funds

- Agrarian and/or Subsistence Economies
- Transitory Workforce
- No Tax Base
- Competing Resources

Comparative per capita income

National	$37,800
Anchorage	$25,287
Nome	$23,402
Shishmaref	$10,487
Newtok	$9,514

Tribal Partnership

- Seven communities (study only)
  - Bethel, Dillingham, Kaktovik, Kivilina, Newtok, Shishmaref, Unalakleet
- Three questions
  - What is the cost of the ongoing erosion?
  - What does it cost to relocate the community?
  - How long does the community have left?
- Provide technical assistance

- Funding
    - $2 million FY03, $2 million FY05

Baseline erosion assessment

- Coordination
    - Technical committee
    - Boroughs and regional corporations
    - Villages
- Plan
    - Approximately 165 communities
    - What is the problem, what is being damaged, what can be done?
- Prioritize
    - How long until significant damages occurs
- Funding
    - $2 Million FY05

Section 117—Alaska Coastal Erosion

- Full federal expense
- Can be used for structural and relocation activities
- Nine communities
    - Barrow, Bethel, Kaktovik, Kivilina, Koyukuk, Newtok, Point Hope, Shishmaref, Unalakleet
- Actions to be taken
    - Plan, design, and construct
- Funding
    - $2.4 million FY06
    - Future funding likely through congressional add only

Conclusion

- Policy and planning issues
- Issues related to cost sharing and benefit categories
- High construction cost always a factor
- New programs show promise
- Increased awareness key for momentum
- Who should lead

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Figure 1. Shishmaref emergency bank protection. Top photo October 2004, bottom photo October 2005.

Proven Constructed Works

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Shoreline erosion caused by natural physical processes was generally not an engineering issue in the United States until the early 1900s when development of the coastal shorelines began in earnest. As more and more investment in buildings and supporting infrastructure occurred at the water's edge, engineers were asked to develop techniques to counter the natural short-term and long-term shoreline changes.

Shores erode in response to storms, sea level rise, and man-induced changes to the littoral system brought about by construction of ports and harbors, stabilization of inlets, and even placement of adjacent shoreline protection measures. The rate of erosion depends on a number of factors including wave exposure, coastal geology, composition and size of beach material, shoreline orientation, and sheltering by headlands, bays, or offshore bathymetry. The wide variety of shoreline types, combined with the vast range of hydrodynamic forcing conditions, negates the possibility of a single engineering solution for all coastal erosion problems. Consequently, several viable engineering solutions have evolved, each with its particular application and set of caveats.

Shore protection methods are used (1) to reduce storm damage to the shore caused by coastal flooding or large waves; (2) to mitigate erosion caused by adjacent projects or by chronic long-term shoreline recession; and (3) to restore coastal ecosystems that are damaged by storms or by man's activities. The five general categories of engineering response to shoreline erosion problems are listed below:

- Armoring ("draw the line")
- Moderation ("slow the loss")
- Restoration ("fill it up")
- Adaptation ("live with it")
- Abstention ("do nothing" or "abandon")

Implementation of the above response strategies is usually in the form of the following shore protection alternatives.

- Non-structural alternatives
  - Beach nourishment
  - Adaptation
  - Retreat
- Structural alternatives
  - Armoring
  - Shore stabilization
- Combined alternatives
- Do nothing

Non-structural alternatives

Beach nourishment is the most common and popular shore protection solution on coasts with sandy beaches. The technique simply consists of placing beach quality sand or gravel on the shore to replace material lost due to erosion processes. Material placement can be on the dune as protection against storms with high surge levels, on the subaerial beach to provide a recreational asset, or along the entire beach profile through the surf zone.

Some beach nourishment projects rely on natural littoral processes to assist the nourishment. Sand can be placed as offshore mounds or on updrift "feeder beaches" with the expectation that nearshore currents will move the sand to the project site. Beach nourishment is referred to as a "soft structure" because of its dynamic nature. Many shore protection projects feature hard structures to help retain the placed beach sand so project life is extended. This is a combined alternative.

Adaptation is a shoreline erosion response that recognizes long-term erosion consequences, and then accommodates the projection either by restrictions, physical modifications, or warning/evacuation procedures. Restrictions include coastal zone management options such as construction setback lines and development limitations. Physical modifications typically are elevating and/or flood-proofing existing structures.

The decision to retreat from an eroding shoreline is based largely on comparing the cost of providing adequate protection to the expense of relocating existing structures and infrastructure landward to an area outside the long-term expected shoreline recession. Some cases may even justify abandonment of structures that will be eventually destroyed by the encroaching sea. Abandonment is the "do nothing" alternative, and the costs associated with doing nothing can serve as the basis for comparing and judging the value of other proactive shore protection alternatives.

Structural alternatives

"Hard structure" shore protection alternatives consist of "armoring" solutions and "shore stabilization" solutions. Both have been employed successfully for a wide range of project sites and environmental conditions.

Armoring alternatives

Armoring alternatives are used at locations where the shoreline must be held at its present position. Hard structures, often substantial and expensive, are constructed with expectation of withstanding projected severe waves and water level conditions. Costs for shoreline armoring alternatives are justified when substantial human investment is threatened by shoreline erosion. Seawalls, bulkhead, and revetments are the primary armoring structure types.

Seawalls are vertical structures constructed parallel to the shoreline, separating the land and water areas. Their primary purpose is preventing erosion and other damage due to wave action. Some seawalls may be constructed well above normal water level fluctuations, only serving their function during high storm surges.

Bulkheads are also vertical front structures similar to seawalls with the main difference being that bulkheads are designed primarily to retain the soil landward of the wall. A secondary purpose is to protect upland areas from wave damage. Bulkheads are common in more protected areas such as inside bays or harbors.

Seawalls and bulkheads can be constructed of timber, sheet metal, vinyl, or concrete. Some of the pertinent design considerations include wave reflection and overtopping, toe scour, drainage of the retained soil, tie-backs and pile depths, and impacts to the fronting beach and adjacent shorelines.

Revetments are shoreline structures constructed parallel to the shore and generally sloped to mimic the natural slope of the shore profile. Waves are dissipated more effectively on these sloping front structures. Revetments are usually constructed of stone or riprap overlaying bedding stone or geotextile filter fabric. Other construction materials include concrete, gravel, geotextile tubes, and marine mattresses. The primary design considerations for revetments are wave reflection, runup, and overtopping; stone stability; toe scour; drainage; foundation; and habitat and adjacent shorelines impacts.

Dikes and levees are mounded structures made of natural or man-made materials. Their primary function is to prevent flooding of low-lying areas.

Shore stabilization alternatives

Shore stabilization alternatives attempt to slow shoreline erosion by moderating the local sediment transport processes. These alternatives are deployed where local erosion rates are high and/or diminished sediment supply contributes to chronic erosion. The purpose of shoreline stabilization is to slow material loss without trapping too much littoral sediment. The protection methods usually involve hard structures, often combined with beach nourishment to reduce downdrift effects caused by the project.

Groins are man-made structures constructed perpendicular to the shoreline. They help create or widen beaches by capturing alongshore moving sand and holding it in place. Groins should always be combined with beach nourishment to avoid adverse erosion effects downdrift. Groins can be constructed of stone, concrete, timber, sheetpile, or geotextile tubes. Primary design considerations include crest elevation, groin length and spacing, groin orientation, stone stability, toe scour, flanking, foundation, and impacts to nearshore habitat and downdrift shoreline.

Breakwaters are large-scale structures constructed seaward of, and usually parallel to, the shoreline. Their function is to reduce incoming wave energy before it reaches the shoreline. Breakwaters can be deployed either as singular structures or as a series of segmented breakwaters with gaps between adjacent structures. Littoral sediment is trapped in the lee of the breakwaters, building up the shoreline. However, once equilibrium is reached, littoral sediment will move through the project to the downdrift shores. Breakwaters are primarily constructed of stone, but sometimes concrete or geotextile tubes are used. Design considerations include crest elevation, gap width between breakwaters, distance offshore, orientation, stone stability, foundation, habitat, and adjacent shorelines.

Reef breakwaters are smaller submerged breakwaters constructed seaward of, and usually parallel to, the shoreline. They provide less protection than emergent structures, but they do not obstruct the view. Sills are placed at the seaward toe of a "perched beach" to retain placed sand and prevent it from moving farther offshore.

Shore protection project planning

The design considerations listed for the various shore protection alternatives discussed above are chiefly engineering aspects of the project. Additional design constraints arise due to shortcomings in understanding natural processes, economics associated with a particular project, local and national environmental policies, and aesthetics. Perhaps even more difficult are dealing with the institutional, political, social, and legal constraints that may face a proposed shore protection project.

The total life-cycle cost of a shore protection project consists of initial design and construction cost, periodic maintenance cost, and any alteration or removal costs over the expected lifetime of the project. Federally allowed benefits for estimating benefit/cost ratios are storm damage reduction, coastal erosion mitigation, and ecosystem restoration. Other benefits include recreation, tourism, and increase in property valuation (i.e., higher tax revenue).

Project maintenance

Ongoing project maintenance at some level is necessary for most shore protection projects to assure continued acceptable project performance. Periodical inspection and maintenance is particularly crucial for beach nourishment projects and shore stabilization projects incorporating nourishment. Methods exist for estimating renourishment intervals with reasonable competence. Of course natural storm variability may negate the most careful planning, so don't be surprised if some projects fail to survive the expected time.

Conclusions

Shore protection projects are justified at some locations, and many options are available ranging from hard to soft structures. Whereas much has been learned about successful shore protection techniques, each project is unique. Some solutions are only temporary, and all projects should be monitored for performance and deterioration. Maintenance is an essential component of all shore protection projects.

Arctic and Low-Cost Erosion Control: Designs for Alaska

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Arctic designs

Shore protection in Alaska often requires the consideration of design modifications for arctic conditions. According to the United States Arctic Research Commission (USARC) Permafrost Task Force Report "Climate Change, Permafrost, and Impacts on Civil Infrastructure," more than three-quarters of Alaska's highways are underlain by continuous (90-100%) or discontinuous (50-90%) permafrost, making them susceptible to damage. Sixty percent of Alaska's communities rest on permafrost soils, and of the remainder most are coastal. While some coastal communities are large (Anchorage, Kenai, Juneau), most are small villages that cannot afford or justify costly shore protection measures. Low-cost shore protection techniques are often considered out of desperation to do anything rather than nothing.

Arctic design modifications are necessary due to the interaction of coastal structures with ice; freeze-up formations and ice accretions, impacts from moving ice, problems arising from freeze-thaw mechanisms, and permafrost. Additional problems related to logistics and remote coastal village locations (short construction season, limited materials and equipment, unskilled local labor) combine to increase the cost of typical coastal designs.

Freeze-up accumulations and ice accretions on structures (pilings, seawalls, riprap) can increase the weight acting on the structure as well as increase the drag of the structure to flowing water, either by current or wave action. Ice accumulations can increase buoyancy on individual rocks or shore protection elements, reducing their resistance to movement by wave action. Ice accretion on surfaces can also be a safety concern for port facilities. Impacts from moving ice sheets or accumulations can result in damage or failure of docks, seawalls, or shorelines. Areas with high tidal ranges (Cook Inlet) can experience the development of large grounded bergs that float free and move during high tides.

Damage due to ice movement and impact is dependent on many variables, including the velocity of the moving ice as well as the characteristics of the ice sheet or accumulation. Velocity can be slow in the case of thermal expansion, or rapid if induced by wind or current forces. The forces exerted on the structure will depend on the ice strength, mode of ice failure (crushing, bending, and buckling), ice thickness, contact area, and ice/structure interface (coefficient of friction, slope angle). For shore protection structures and natural coastlines, the slope of the bank is important in determining the interaction of the moving ice with the shore and whether the ice will ride-up or pile-up. Generally, thin ice sheets on shallow slopes result in ride-up with the sheet experiencing bending failure near the water line and being pushed up the slope. At greater ice thicknesses and steeper slopes, the pieces being pushed up the slope incur greater frictional resistance and often begin to pile-up. The ice piles are much more resistant to movement and additional ice will build the pile at the sheet/pile interface.

Sodhi et al. (1996) conducted a series of scaled physical model experiments to investigate ice action on a riprap slope. He used three slope angles (18, 27, and 34 degrees), three stone sizes, and a range of ice thickness, and pushed the ice sheet into the riprap slope. He found pure ice ride-up in only two cases of the shallowest slope with limited stone movement or bank damage. The maximum damage occurred when the ice sheet bulldozed into the riprap slope under a developing ice pile-up, moving individual stones as well as the filter material and sub-grade.

The process of freeze-thaw can affect structures by damaging concrete or rock, sometimes splitting larger rocks into smaller pieces that are less resistant to wave or current forces. Freezing of water within a structure can also cause expansion, lifting, or moving individual shore protection elements or buckling seawalls or sheet pile structures. Permafrost thawing often results in considerable settlement and loss of internal strength. Coastal soils at Shishmaref are very fine-grained sand permafrost, which washes or blows away when thawed.

Low-cost options

Low-cost options typically involve materials more affordable than large quarried rock, concrete, or steel sheetpile. Most low cost options have high risk of structural failure. They may perform well for a time, but become damaged or destroyed by a severe storm. Low-cost options also have higher risk of performance failure and may not live up to erosion control expectations. No money is saved if the shore protection works require rebuilding or expensive repairs to remain functional. Organic materials or "bioengineering" products that have appeal in low energy environments are not durable enough for coastal conditions of waves, tides, and salt water. Plantings, woven mats, and similar devices may have value as secondary measures at the inner margin of more durable primary works, however.

Low cost options should always be compared to proven conventional alternatives in terms of life-cycle cost-effectiveness. Estimates of construction and maintenance costs and the cost of property damages prevented (i.e., benefits) should be objectively compared before a decision is made. Competent coastal engineers can design conventional as well as non-conventional alternatives. A promoter of a single low cost alternative as the only answer to a problem should be questioned in this context.

The outline below notes positive and negative aspects ("pros" and "cons") of functional performance and structural integrity of some common low-cost options for coastal erosion control.

Wire-mesh gabions (wire baskets filled with cobbles or sandbags)

Pros

- Transportable.
- An alternative to larger rock or concrete elements.
- Requires modest construction skill.
- No specialized equipment required.
- Can be wired together as an interlocked retaining wall.

Cons

- Salt water corrodes wire, even if anodized or coated.
- Ice distorts shape and causes wires to fail.
- Sunlight degrades sandbag fabric, eventually spilling contents.
- Wave forces distort baskets, eventually spilling contents.
- Wire from failed gabions is hazardous.

Wooden bulkheads and groins

Pros

- Can use Alaska timber.
- Requires modest construction skill.
- No specialized equipment required.
- Repairable with readily available materials, supplies, and equipment.
- Wood of failed structures is not particularly hazardous and can provide habitat.

Cons

- Planks must be buried rather than driven (supporting piles can be driven).
- Salt water corrodes metal connecting hardware.
- Fine material can escape between planks.
- Limited resistance to ice abrasion and pressure.
- Metal hardware of failed wooden structures can be hazardous.
- Failed steel or concrete structures are more unsightly.

Sandbags and similar filled fabric construction

Pros

- Transportable.
- An alternative to larger rock or concrete elements.
- Requires minimal construction skill.
- No specialized equipment required.
- Common emergency measure.

Cons

- Sunlight degrades fabric, eventually spilling contents.
- Limited resistance to wave and ice forces.
- Synthetic (plastic) material of failed bags is hazardous to birds.

Small prefabricated concrete units

Pros

- Transportable by barge.
- An alternative to larger rock or concrete elements.
- Requires modest construction skill.
- Conventional construction equipment is sufficient.
- Can be interlocked to form a smooth retaining wall or revetment.
- Moderately resistant to ice abrasion and pressure.

Cons

- Salt water corrodes interlocking wire and hardware.
- Fine material can escape through gaps between modules (without a gravel or geotechnical fabric filter below).
- Once interlocking fails, the entire matrix comes apart.
- Impermeability causes wave reflection.
- Smooth surface allows maximum run-up.

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Coastal Erosion Books/DVD Published by Sea Grant Programs Nationwide

Drowning the North Carolina Coast, by Stanley R. Riggs and Dorothea V. Ames, provides in-depth information about erosion rates along North Carolina's estuarine shoreline. The authors look at sea level rise and its effect on shoreline change, as well as the dynamics of the estuarine system. It has full-color photos and maps along with comprehensive text, figures, and tables. Published by North Carolina Sea Grant, 152 pp., $25.00, www.ncseagrant.org/index.cfm?fuseaction=page&filename=Drowning_Coast.html.

Shoreline Management in Chesapeake Bay, by C. Scott Hardaway and R.J. Byrne, discusses management strategies to reduce shoreline erosion with cost-effective and environmentally acceptable methods. Published by Virginia Sea Grant, 54 pp., $10.00, www.web.virginia.edu/seagrant/pubs.asp.

California's Coastal Natural Hazards, edited by Lesley Ewing and Douglas Sherman, includes chapters on coastal processes, human-altered coastal systems, coastal erosion, and beach nourishment and coastal protection. It is the proceedings from a conference hosted by the California Shore and Beach Preservation Association and USC Sea Grant. Published by University of Southern California Sea Grant,162 pp., $10.00, www.usc.edu/org/seagrant. Order from seagrant@usc.edu.

Living on the Coast: Protecting Investments in Shore Property on the Great Lakes, edited by Philip Keillor and Elizabeth White, describes how natural processes affect the coast as well as how to protect coastal investments by adapting to natural processes, restoring a natural shoreline, moderating coastal erosion, armoring the shore, stabilizing bluffs and banks, controlling surface water and groundwater, and working with engineers and contractors. Published by University of Wisconsin Sea Grant Institute and the U.S. Army Corps of Engineers-Detroit District, 49 pp., $4.00 or a free download, aqua.wisc.edu/publications/ProductDetails.aspx?productID=439.

Improving Natural Hazards Management on the Oregon Coast: Recommendations of the Coastal Natural Hazards Policy Working Group describes natural forces, some cataclysmic and some gradual and relentless, that have shaped the Oregon coast over millions of years, and continue to reshape it. Published by Oregon Sea Grant, 128 pp. $6.00 plus $4.00 shipping, or free download, seagrant.oregonstate.edu/sgpubs/onlinepubs.html (free download). Order from https://admtn.ucsadm.oregonstate.edu/ustores/web/index.jsp.

Coastal Natural Hazards: Science, Engineering, and Public Policy, edited by James W. Good and Sandra S. Ridlington, lays out the risks of building on the shifting sands and eroding sea cliffs that typify the U.S. Pacific coast. It also looks at ways people have tried to stop the changing coastline from doing what comes naturally. Written mainly for lay readers, the book grew out of a 1990 Oregon conference of coastal geologists, oceanographers, engineers, planners, and resource managers. Published by Oregon Sea Grant,162 pp., $6.00 plus $5.50 shipping, https://admtn.ucsadm.oregonstate.edu/ustores/web/index.jsp.

Living on the Edge: Buying and Building Property on the Oregon Coast (DVD) provides an overview of coastal property issues. It is intended for developers, realtors, lenders, and coastal officials as well as builders, buyers, and homeowners. Vivid footage portrays the natural processes that create challenges in shoreline development. Knowledgeable Oregon scientists, engineers, planners, and realtors offer insights and recommendations to address the challenges. Produced by Oregon Sea Grant, 35 min, $9.95 plus $2.00 shipping, https://admtn.ucsadm.oregonstate.edu/ustores/web/index.jsp.

Hawaii Coastal Hazard Mitigation Guidebook, by Dennis J. Hwang, can help planners, architects, homeowners, etc., reduce coastal development risk for natural hazards such as erosion, flooding, tsunamis, and hurricanes. Published by Hawaii Sea Grant, 240 pp., $25.00, www.soest.hawaii.edu/SEAGRANT/communication/HCHMG/hchmg.htm.

Coping with Beach Erosion, by Gillian Cambers, is a guide for beach users, builders, and homeowners about factors to consider when buying property and constructing houses, hotels, and other infrastructure near erosion-prone beaches in Caribbean islands. Published by UNESCO Publishing, (sponsored by University of Puerto Rico Sea Grant), available at www.unesco.org/csi/pub/source/ero1.htm.