GEOMORPHOLOGICAL STUDY OF PĀPŌHAKU DUNE

with recommendations for dune preservation

Prepared for the State of Hawai‘i
Office of Hawaiian Affairs

by
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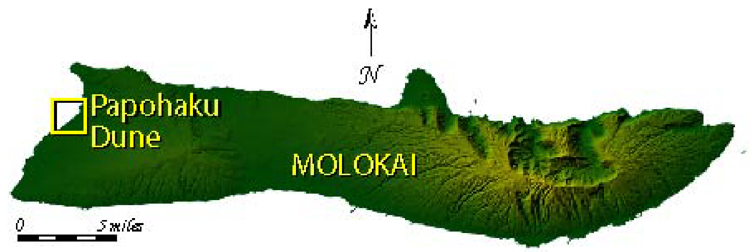
EXECUTIVE SUMMARY

A geomorphological survey of Pāpōhaku beach and dune on the west end of Moloka‘i was conducted over 4 days; November 5 and 30, 2004, and February 16 and 17, 2005. The survey was one of several different studies requested by the Office of Hawaiian Affairs to gather data regarding the existing and historical environmental and cultural conditions at Pāpōhaku dune, with the goal of improving the management of this land to better protect the unique and valuable dune resource.



The mauka and makai boundaries of the dune were surveyed using a handheld GPS, and observations were made regarding the condition of the dune. The dune had previously been divided into 9 sections to facilitate coordination of the numerous surveys being conducted as part of the project sponsored by the Office of Hawaiian Affairs. To facilitate reporting of specific observations over such a large area, the observations and recommendations provided in Part III of this report have accordingly been broken down into the 9 sections. The aerial photo maps with dune delineation and section numbers, prepared by Renee Louis, are included in Appendix A.

The southwestern portion of Pāpōhaku (Sections 2, 3 and 4) appears to be underlain by a basalt outcrop which has resulted in higher elevations of the land mauka of the beach. The homes in this area are less susceptible to future erosion and storm damage problems than homes in the northeastern portion of Pāpōhaku as they are elevated well above the beach. Significant volumes of sand have accumulated on top of the rock outcrop, particularly at the very south end of Pāpōhaku Beach, adjacent to the Pu‘u Koa‘i headland. Section 1 and the northeastern portion of Pāpōhaku (Sections 5-9) are relatively low-lying; thus the homes are more susceptible to flooding, storm damage, and erosion from long-term shoreline retreat. For these properties, a healthy dune is particularly critical to mitigate potential damage from coastal hazards.

Virtually the entire dune at Pāpōhaku has been impacted either by historic sand mining activity, by grading and development of homes and infrastructure, by long-term coastal erosion, or by other human activities. While there is still an impressive volume of sand remaining in the Pāpōhaku beach and dune system, it is clear that the system is struggling and becoming degraded under the pressure of competing uses and a sand budget deficit. Being one of the largest remaining coastal dunes in the state of Hawai‘i, the Pāpōhaku dune, beach, and coastal lands warrant a management plan that will ensure protection of this unique and valuable resource for generations to come. Long-term preservation may require the implementation of regulations that have not yet been applied elsewhere in Hawai‘i.

This report has been divided into three parts. Part 1 provides background information on coastal dunes, including how dunes are formed, how they respond to varying wind and waves conditions, the role of dunes in coastal hazard mitigation, human impacts on dunes, and dune restoration. Part 2 presents background information on Pāpōhaku dune including the origin of the Pāpōhaku sands, a brief history of the sand mining operations, and a summary of previously identified coastal hazards. Part 3 is a description of field observations and recommendations for dune repair and preservation, broken down into the nine previously identified sections. A summary of recommendations and management considerations is provided at the end of Part 3.

PART I: GENERAL DUNE INFORMATION

Introduction

Beaches and coastal dunes are natural geologic features that work together as an integrated system. They are essential components of the Hawaiian way of life, serving a great diversity of functions ranging from fishing grounds to canoe storage and launching platforms, access for swimming and surfing, gathering of limu, burial of the deceased, and imu for cooking, amongst others. They also provide a unique habitat essential to native plant and animal species, and provide birthing areas for endangered monk seals (Figure 1) and nesting areas for endangered sea turtles.

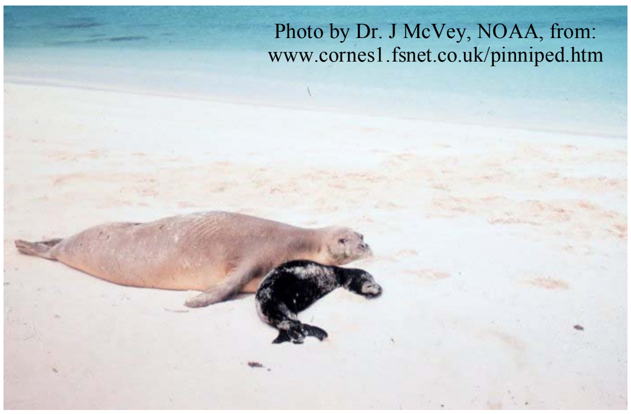


Figure 1. Beaches and dunes provide critical habitat for endangered species in Hawai'i.

A combination of natural factors such as rising sea levels, wind, waves and currents, and human impacts such as sand mining and inappropriate development, have led to the chronic retreat of many of Hawai'i's sandy beaches and dunes. Left in a natural condition, beaches and dunes tend to retreat in response to natural erosion-causing factors, while maintaining a relatively constant width. Retreating beach and dune systems often draw on inland sand reserves, located within and mauka of the dunes, to maintain their width and height while they undergo retreat. Thus it can be understood that not only are the beaches and dunes themselves worthy of protection, but sand volumes that exist *mauka* of the beaches and dunes - which will eventually become the sand source for the future beach - are also important to protect, with the long-term preservation of the beach and dune in mind.

As beaches and dunes are subject to seasonal as well as long-term influences, they are constantly in a state of dynamic flux, responding to the shaping forces of the wind and waves. As such, it is important that their mobility not be restricted. Attempts to fix the shoreline or dune in place with structures or aggressive vegetation are often, in addition to being unsuccessful, harmful to the system. Dunes need room to move; thus, buffer zones between coastal dunes and development are important, and the greater the buffer space the longer the dune is likely to be able to maintain its form and function (Figure 2).

Figure 2. (right) A migrating dune moves into a coastal home on Maui.

The role of beaches and dunes in storm damage mitigation

Coastal beach and dune systems are inherently dynamic and complex, often undergoing dramatic changes over very short time periods in response to natural variations in wind and ocean patterns. During a storm or high surf event, beaches and dunes act as buffers between the land and the ocean, absorbing the tremendous impact delivered by wave energy and providing a physical barrier to prevent the high waves from flooding inland areas. During such high energy events, the dune and beach profile undergoes physical changes. Beach sand is carried offshore by the waves and deposited in the form of a sand bar (Figure 3). The sand bar results in shallower water offshore, which causes the waves to break further offshore in the shallow water over the sand bar. As a result, the waves impacting the beach have less energy, as they have broken before they reach the beach, which thereby decreases the impact on the beach. At the same time, the dune is often gradually broken down by the wave run-up, providing sand to feed the beach as it erodes in response to the waves. Under calm weather conditions, the sand bar is gradually pushed back to the beach by the smaller waves. The wind then picks up the beach sand, which is carried up the beach to rebuild the dune.

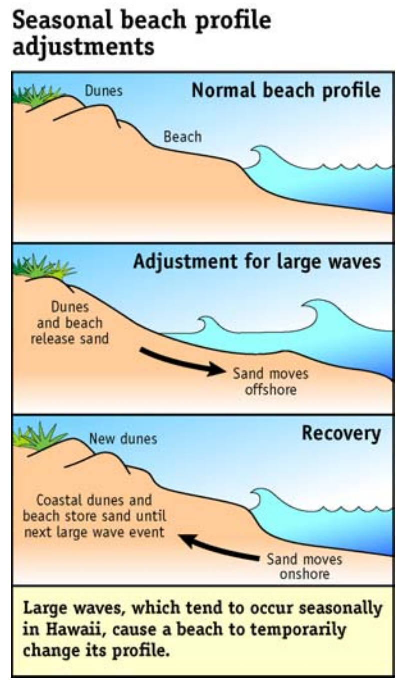


Figure 3. The response of beaches and dunes to high surf

The role of healthy dunes in tsunami mitigation

A healthy dune can contribute significantly to tsunami hazard mitigation. In the US Geological Survey monthly newsletter *Soundwaves* from February 2005, the increased tsunami hazard risk associated with the removal of coastal dunes was highlighted. Scientists found that at the Yala Safari Game Lodge in Sri Lanka, where a coastal dune had been removed to improve views to the ocean, the tsunami surged across the

Figure 4. Foreground shows intact dune that was barely overtopped by the tsunami and sustained little damage. In the background, the area where the dune had been removed prior to the tsunami to improve the ocean view from Yala Lodge, is visible.

property, destroying the resort and killing more than 175 people. Immediately adjacent to the resort, where the dunes had been left untouched, the tsunami barely crested the top of the dune, suggesting that the tragedy at the Yala Safari Game Lodge may have been avoided had the dune been left intact (Figure 4).

Dunes: A strong yet vulnerable resource

One of the important aspects to understand about beach and dune systems is that while healthy dunes display remarkable strength and resilience in their ability to provide protection to inland areas from ocean flooding during severe storms and from the pounding of high surf events, they are inherently fragile systems that are particularly vulnerable to human impacts. When weakened by erosion - often brought on by foot or vehicular traffic, by loss of protective vegetative groundcover, or by sand mining - dune systems lose their ability to defend inland areas from storms and high surf, as well as their ability to supply sand to adjoining beaches undergoing seasonal or long-term erosion.

Figure 5. Plants trap wind-blown sand, causing it to accumulate and eventually form dunes.

The creation of dunes

Natural dune building is initiated when wind picks up sand grains off the beach and carries them up the beach. Salt-tolerant coastal vegetation, that often grows seaward up to the mauka extent of the reach of the waves, traps the wind-blown sand, causing it to accumulate around the plants. As the sand volume builds up, the plants grow taller to avoid being buried; in this manner sand dunes are built up (Figure 5).

The importance of vegetation

Without plants, and in the absence of anything else that can trap the sand, the sand will continue to blow inland without accumulating in the form of a dune. This phenomenon can be observed in places where vegetation has been destroyed or removed from a dune. These damaged areas, called *blowouts,* act like funnels, as there is no interruption to the wind flow. As a result, tremendous amounts of beach sand can be lost as it blows through the damaged area and keeps going, eventually being carried out of the beach and dune system by the wind (Figure 6). Due to the continuous scouring action of the wind, these areas often become low points in the dune that are vulnerable to breaching by waves, leaving the dune and inland areas susceptible to increased storm damage potential.

Figure 6. These images are taken looking makai and mauka from the same location. This beach access path on Maui became a blowout due to the prevailing onshore winds. The funneling effect of the wind through the break in vegetation led to a low, weak area in the dune and considerable loss of sand from the beach.

Human activities that damage dunes

Virtually any activity directly on a dune, except for dune restoration activity, is potentially harmful to the dune. Due to the sensitive nature of coastal vegetation, foot traffic alone is enough to destroy dune plants. As such, beach access paths often turn into blowouts. However, even when they are not causing blowouts, footpaths through the dune inevitably lead to erosion of the path, which eventually creates a low point in the dune that is absent of vegetation, which increases the vulnerability of the dune and inland areas to breaching and storm damage during high surf events. Vehicular traffic is also extremely damaging to dunes, as are such activities as boat storage, camping and camp fires (Figure 7).

Figure 7. Vehicular traffic over dunes destroys vegetation and causes erosion of the dune.

Dune walkover structures

An alternate way to access the beach is to have elevated dune walkovers that allow access to the beach while minimizing impacts to the dune. Elevated walkovers often consist of ramps or stairways supported by pilings driven deep into the sand and are usually constructed of wood or recycled plastic (Figure 8). They eliminate the erosive action of foot traffic and allow plants to grow underneath, preserving the structural integrity of the dune. For guidelines on dune walkover construction, see Appendix B.

Figure 8. Dune walkovers allow access over the dunes while minimizing erosion and damage to plants.

Dune Restoration

While we have seen that dunes can be damaged fairly easily, they are able to recover if the factors causing the damage are removed and favorable conditions for sand accumulation are provided, as long as the damage has not been extensive. An example of extensive damage would be large-scale sand removal from sand mining activity. The type of restoration work depends on the type and extent of damage that has taken place.

In situations where an access path has damaged a dune, restoration work can involve the installation of an elevated dune walkover and planting of groundcover. Often, irrigation is required for several months in replanted areas to allow the new plants to establish roots. At the very least, if an access path is oriented in line with the prevailing wind direction but funding does not exist to build an elevated dune walkover, the pathway should be reoriented to prevent windblown sand losses through the pathway. To repair larger blowouts, often the planting of groundcover accompanied by irrigation can assist in rebuilding the dune.

Figure 9. Dune restoration often involves a combination of dune walkovers, sand fencing , planting and irrigation.

Sometimes, sand fencing is used in conjunction with planting to assist with trapping the sand while the new vegetation becomes established (Figure 9). Sand fencing comes in a variety of material from wood to plastic to fabric, is usually about 3 to 4 feet high, and consists of approximately 50% air space and 50% solid material (Figure 10). This allows the wind-borne sand to pass through, but due to the interruption of the wind flow it loses speed and the sand drops out and accumulates behind the fence. The fencing is oriented perpendicular to the prevailing wind direction, and is usually installed in staggered sections of approximately 5-10 feet in length. Once the new plants are healthy and strong, the fencing can be removed.

Figure 10. Sand fencing made of wood (left), fabric (right), or other materials can be used to trap wind-blown sand while new vegetation growth is established

In severe cases, where dunes have been removed to improve views to the coastline or where sand accumulation rates are slow due to low wind speeds and limited beach sand volumes, sand can be physically brought in and placed on the dune (or where the dune used to be), and planted with vegetation. Beach-quality sand can often be purchased in large volumes from cement companies or in smaller volumes from hardware stores, and should come from approved quarries that are located well inland and away from coastal areas. An example of such a quarry exists in central Maui, in the Maui Lani area.

When planting vegetation in the coastal area, there are several important things to keep in mind. While it may seem ideal to plant the thickest, toughest plants with the most dense root systems available for maximum stability, such as naupaka kahakai for example, these plants often lock in the sand underneath them, preventing its natural release under storm conditions as described earlier in this section. It was also pointed out that dunes need to be able to move in response to changing wind and wave conditions, as well as to retreat in response to chronic erosion. This can be best accomplished with native coastal groundcover species such as ‘aki ‘aki grass, pohuehue, ‘ākulikuli, and pōhinahina (Figure 11). These types of salt-tolerant plants have an excellent ability to spread quickly and provide effective groundcover to trap the sand and build up the dune, yet release the sand well under erosional conditions to allow the dune to respond naturally. A botanist or local expert would be able to recommend the best type of plants for dune restoration at Pāpōhaku.

Another important consideration in planting vegetation is to not try to force the vegetation seaward of the natural vegetation line with irrigation systems that go out onto the beach. The beach area belongs to the public trust, and narrowing the useable beach area is taking away from the public’s use of this resource (Figure 12). Further, vegetation that is forced out onto the beach often leads to a steepening of the beach face, which can alter the way the beach and dune respond to large waves, and potentially worsen its ability to withstand erosion and hinder its defense against flooding and storm damage.

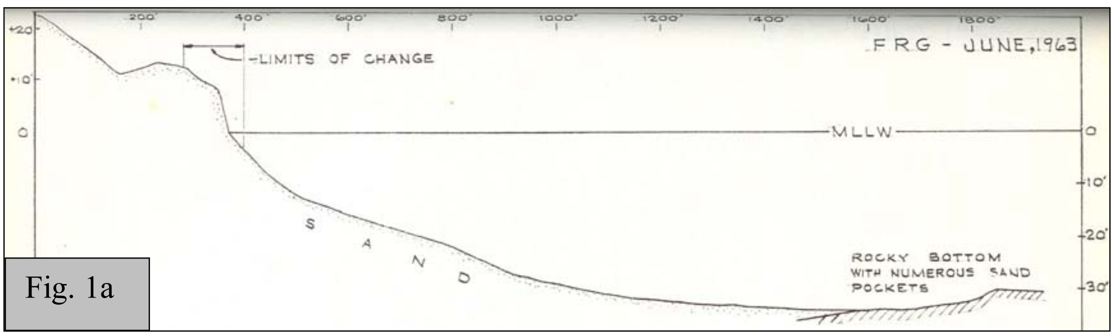
Figure 11. ‘Aki ‘aki grass (top left), pohuehue (top right), ‘ākulikuli (bottom left), and pōhinahina (bottom right) provide excellent groundcover while allowing dunes to maintain mobility. A botanist or local expert would be able to recommend the best plants for a given location at Pāpōhaku.

Figure 12. In the foreground, a dry beach exists. In the background, vegetation has been forced seaward such that no dry beach exists at high tide.

PART II: PĀPŌHAKU DUNE BACKGROUND INFORMATION

Geological Setting

Pāpōhaku beach, located on the central west coast of the island of Molokaʻi, Hawaiʻi, is a carbonate sand beach approximately 2 miles in length, bounded by a basalt (lava rock) headland on the south and a cinder cone (mainly volcanic ash) headland to the north. Pāpōhaku beach contains the largest volume of calcareous sand in the main Hawaiian Islands (Cochran, Roberts and Evans, 2002). Calcareous sand is the typically white or tan colored sand derived from marine organisms such as coral, mollusks, and other reef-associated life forms. The sand on Pāpōhaku beach consists of mainly of well-sorted, predominantly coarse and medium sized calcareous sand grains, with a small component of volcanic material (black, red, or green sand grains). The offshore area adjacent to Pāpōhaku beach consists mainly of large sand fields, with patches of coral and beach rock. According to beach profile surveys conducted in June of 1963, sand extends offshore for more than 1200 feet where it comes into contact with rock at a depth of approximately 30-35 feet (Figures 1 a, b) (Moberly et al., 1963; Moberly and Chamberlain, 1964). Coral heads and sand pockets are found on the rock surface.



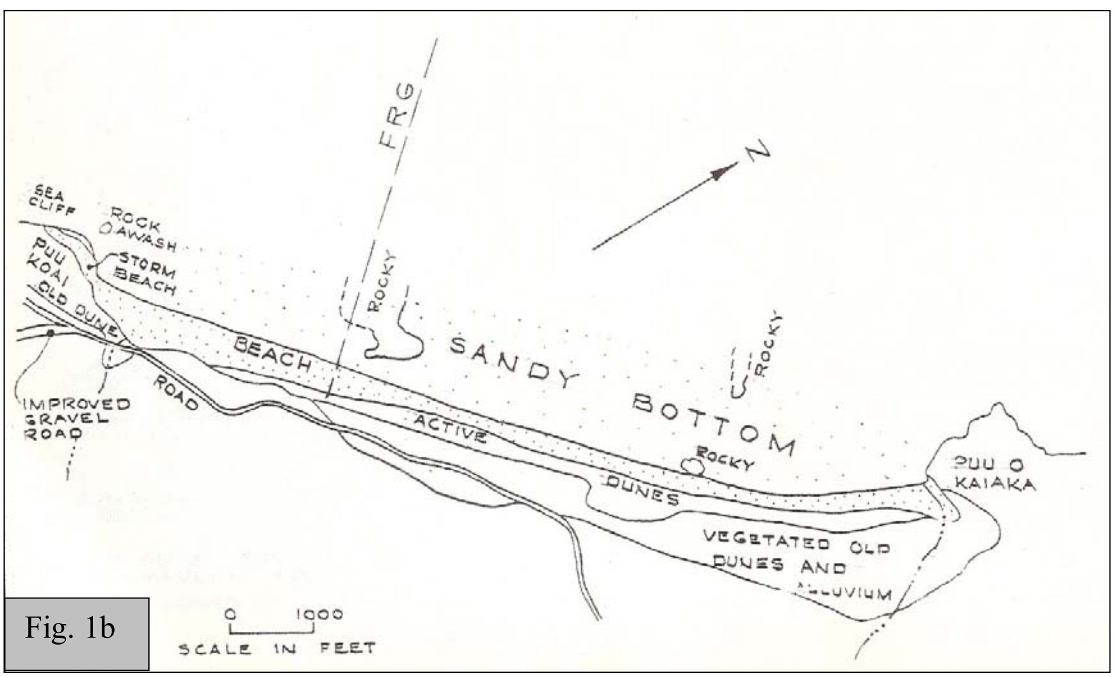


Figure 1a: Cross-sectional profile of Pāpōhaku beach. Figure 1b: This plan view of Pāpōhaku shows the location of the profile from Figure 1a ("FRG") on the beach. From Moberly and Chamberlain, 1964.

Origin of Pāpōhaku Beach and Dune

In the absence of a fringing reef offshore of Pāpōhaku beach, it is unlikely that the very large volume of sand at Pāpōhaku was produced in the adjacent offshore area. It is more likely, as proposed by Hazlett and Hyndman (1996) that the sand at Pāpōhaku originated from the Mo‘omomi dunes on the northwest coast of Moloka‘i. An exposure of eolianite (solidified or consolidated sand dune) at Pu‘u Koa‘i on the south end of Pāpōhaku is reported to be related to the Mo‘omomi dune system (Cochran, Roberts and Evans, 2002).

The Mo‘omomi area consists of several sandy beaches and large consolidated and unconsolidated sand dunes of over 60 feet in height. A large coral reef lies approximately 250 feet offshore, at a depth of approximately 15-20 feet (Moberly et al., 1963). This reef has most likely been the main source of sand production, historically, for Mo‘omomi . The dunes at Mo‘omomi were likely formed between 115,000 and 80,000 years ago, when sea levels were lower and the reef and sand fields offshore would have been exposed, allowing the sand to be blown inland (Fletcher et al., in press).

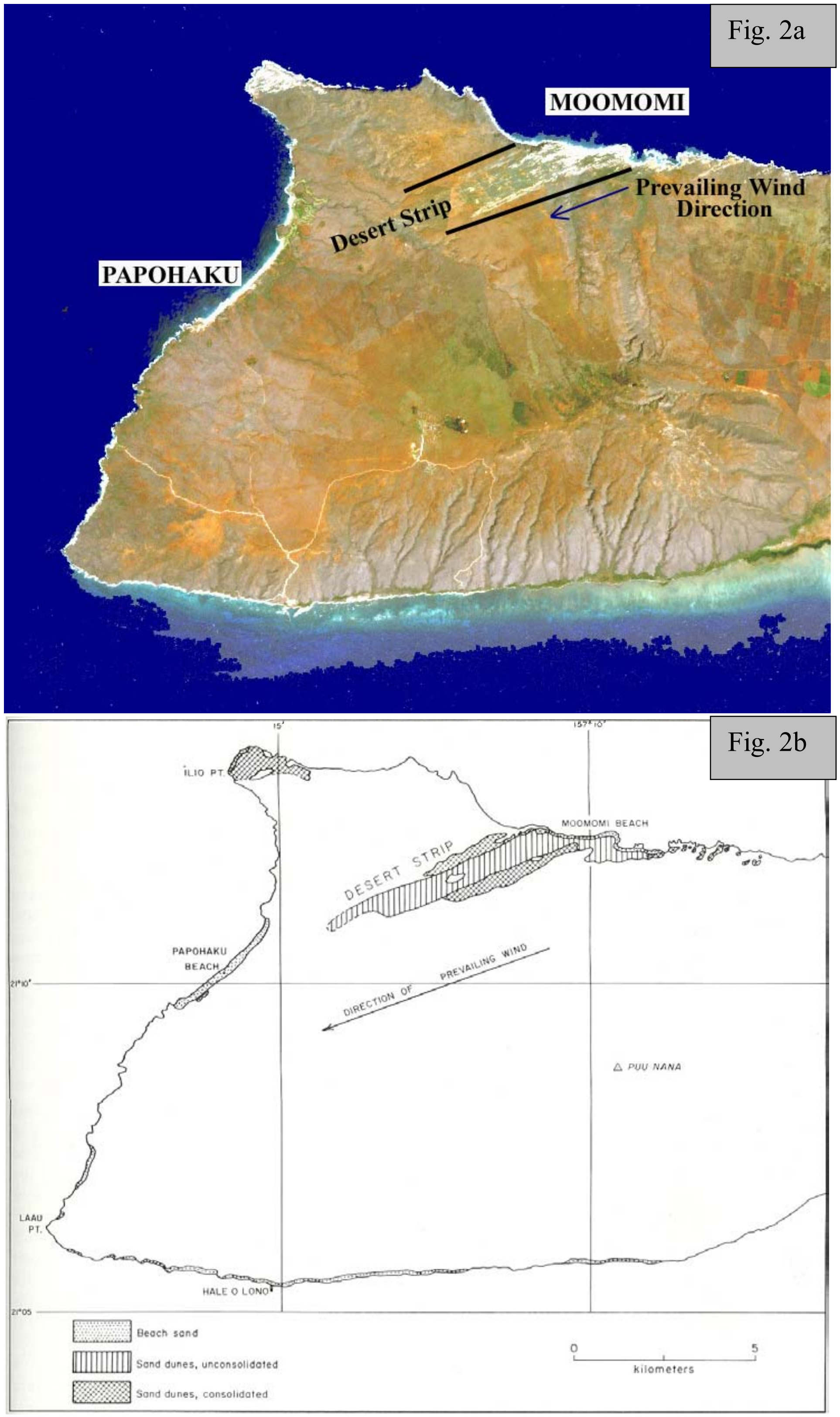
The dunes extend overland to the southwest over 5½ miles, blown by the prevailing northeast trade winds in the direction of Pāpōhaku (Figures 2 a, b). This inland dune region is known as the ‘Desert Strip’, and includes areas with cliffs of over 600 feet in elevation over which the sand has blown (Stearns, 1966). This area contains regions of actively migrating dunes, regions of consolidated dunes, and instances where consolidated dunes are eroding and contributing sand to the active dunes (Macdonald et al., 1983). The trade winds continue to blow sand through the Desert Strip, although there is no longer an active connection with Pāpōhaku.

Sand mining history

From informal discussions with local residents, information was gained about the extensive sand mining of Pāpōhaku beach and dune that took place in the 1960s and 1970s. The sand mining was conducted by Hawai‘i Construction and Dredging (HC&D), and the sand was used in the Hawaiian Islands for aggregate and construction. It is reported by Moberly et al. (1963) that due to severe southerly storms in the winter of 1962-1963, extensive erosion occurred at the south end of Pāpōhaku that heavily damaged the quarrying operation; but that the operation was thereafter rebuilt. The mining was stopped when a law suit determined that HC&D was illegally mining sand that belonged to the State of Hawai‘i. Compensation to the State for this activity was made in the form of a donation of a parcel of land adjacent to the Kaunakakai pier to the State of Hawai‘i.

Identified Coastal Hazards

Shallow fringing reefs are found adjacent to many of Hawai‘i’s beaches, and are able to protect beaches to a certain extent by absorbing and breaking up wave energy before it hits the beach. The absence of a shallow fringing reef offshore of Pāpōhaku Beach leaves the beach exposed to the full force of incoming waves. Further, the approximately northwest-facing orientaton of Pāpōhaku beach leaves it directly in line for impact by some of the largest swells in Hawai‘i that arrive from the north and northwest. It is also



Figures 2a (**LANDSAT*****) and 2b (Macdonald et al., 1983) show the dunes known as the "desert strip" extending inland from Mo'omomi. As there is no fringing reef adjacent to Pāpōhaku as a source of sand production, it has been suggested that the sand at Pāpōhaku was blown overland from Mo'omomi by the prevailing trade winds.***

susceptible to swells from the south and southwest that can wrap around the west coast of Moloka‘i by the process of diffraction. Due to its high level of exposure, the offshore slope of the beach is steep (Hazlett and Hyndman, 1996), and the shape of the beach can change dramatically over short periods of time.

Pāpōhaku beach has been identified as having a moderately high overall hazard assessment rating in the Atlas of Natural Hazards in the Hawaiian Coastal Zone (Fletcher et al., 2002) (Figure 3), which is the highest such rating on the west coast of Moloka‘i. This rating includes a high tsunami hazard, moderately high hazard from high waves and storms, high to moderately high erosion hazard, moderately high rating for increased exacerbation of hazards due to sea level rise, and a moderately high volcanic/seismic hazard.

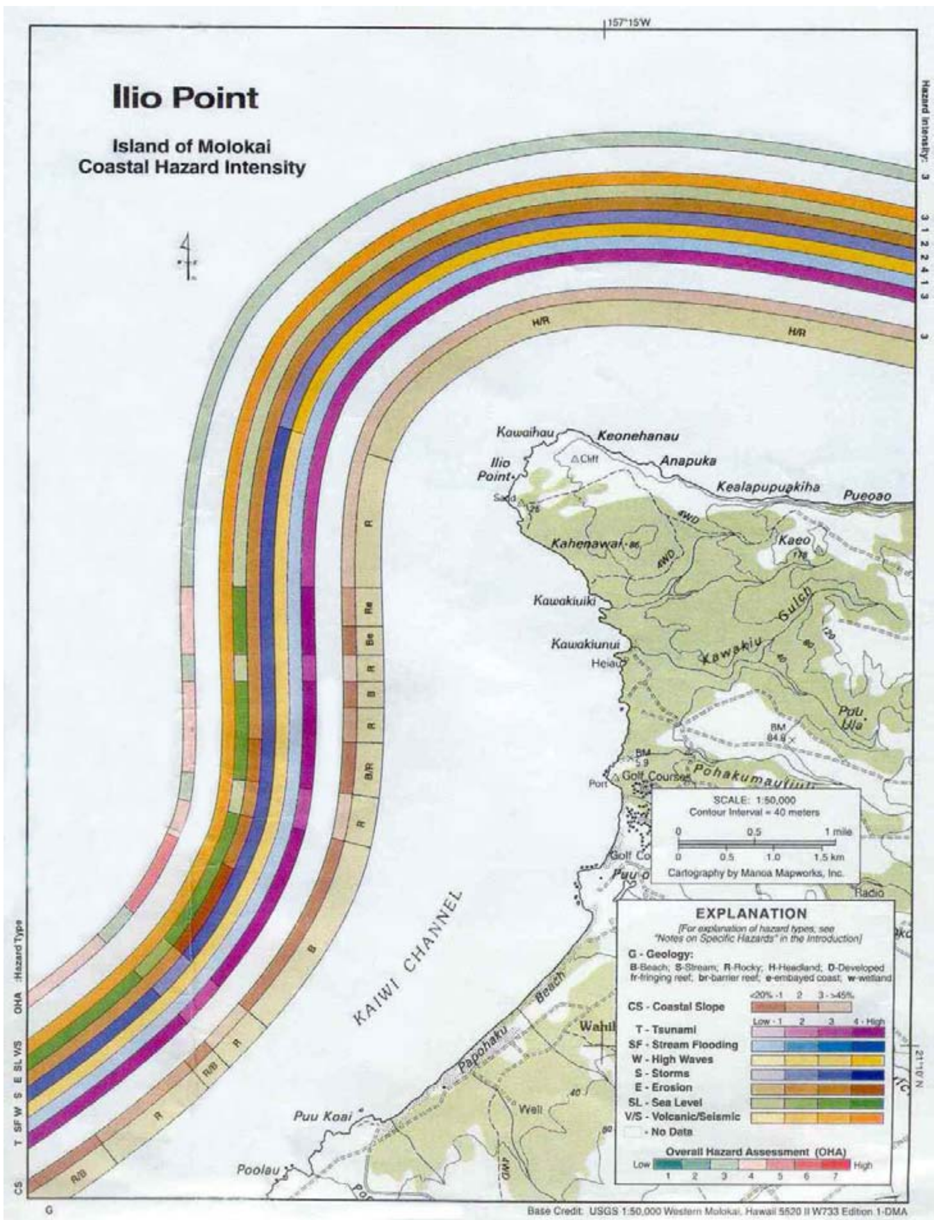


Figure 3. Coastal hazards for Pāpōhaku. From the* Atlas of Natural Hazards in the Hawaiian Coastal Zone, *Fletcher et al., 2002

The erosion hazard at Pāpōhaku has recently been analyzed more closely by the University of Hawaiʻi Coastal Geology group using historical topographic surveys and aerial photographs (Coastal Geology Group, 2005). Rates of erosion range from over 1 foot per year to over 4 feet per year, with the erosion hazard being higher toward the southwest end of the beach. Higher erosion at this end may be due to the concentrated activity of the former sand mining operation toward this end of the beach.

PART III: FIELD OBSERVATIONS AND RECOMMENDATIONS

Introduction
The delineation of the mauka boundary of the primary dune by GPS survey was challenging because of the extent of development, grading and fill that has altered the natural morphology (shape) of the dune. Because a 2002 amendment to the Maui County Code prohibits grading of the primary dune, consideration had to be given to property owners whose homes and infrastructure were in place within the dune area prior to the change in rules. As such, the mauka dune line was placed on the makai side of such homes and labeled “disturbed”.

Informal interviews with long-time residents of the area provided a helpful insight into some of the historic activity that has taken place at Pāpōhaku. Some of this information is provided within the observations below.

To view each of the nine sections described below, please refer to the aerial photo maps prepared by Renee Louis in Appendix A. A summary of the specific recommendations for each of the nine sections below can be found in Table 2b at the end of this part (Part III).

SECTION 1

Observations: Section 1 is located to the south of Pu‘u Koa‘i, but is still connected to Pāpōhaku dune. The dune line in Section 1 follows a relatively well-defined landward toe interrupted by a guest house under construction (Figure 1) and two exposed archaeological trenches (Figure 2); as such the area is categorized as disturbed. Subsequent examination of the State Conservation Land boundary at the location of the construction reveals that the Conservation Land boundary followed the dune crest at this location; thus the structure, while clearly situated within the primary dune, is not within the Conservation Land. However, the situation of this structure within the primary dune constitutes a violation of the Maui County Code which was recently amended to prevent the grading of primary coastal dunes. A misunderstanding of the permit process and a recent update to the county’s rules of which the developer was unaware led to this improper siting and construction activity which the county and the applicant are currently working to resolve.

Figure 1. Example of a misunderstanding: Partially-constructed dwelling in the primary dune. Outcome to be determined.

This example highlights the importance of working closely with county and state planners in the early stages of site development of coastal properties to ensure that all code requirements and regulations are met before any work is begun. This can prevent costly and time-consuming delays as well as damage to sensitive ecosystems.

The makai toe of the dune in this section is largely obscured under dense vegetation. The dune here is perched, separated from the ocean by a shoreline now consisting mainly of basalt rock, boulders, cobbles, and red clay.

Figure 2. Archaeological trench dug using heavy machinery left exposed in primary dune for several months

Recommendations:

1) Property developers should check with Maui County and State of Hawaiʻi planners in the earliest stages of planning the layout of structures on coastal properties to ensure that the sites chosen for structures meet all applicable regulation requirements. This can avoid costly delays in redesigning or relocating incorrectly sited structures after-the-fact.

2) Every proposed new structure in the Pāpōhaku coastal area should be checked to ensure that it does not fall within the primary dune. As the dune is actively migrating, the dune line delineated by this study will change. Thus, site visits and/or photographed submittals of the proposed structure locations are recommended to visually ensure that no structures are built within the primary dune.

3) Archaeologists should perform any digging in the primary dune by hand with shovels rather than with backhoes or other mechanical trenching equipment. Following the digs, the trenches or holes should be filled back in and restored as best as possible to the pre-dug condition.

SECTION 2

Observations: Section 2 and the southern part of Section 3 represent the terminal depositional area for the Pāpōhaku dune system. This topographically elevated area is the southwestern end of Pāpōhaku Beach, and as the prevailing trade winds blow from northeast to southwest, significant volumes of sand are deposited here, as would be expected. The sand is widely dispersed as it is blown up and over ancient lithified (solidified) sand deposits that are found on Pu'u Koa'i (Figure 3). While the natural dune line would have been much further mauka due to the broad dispersing of the sand at this location, the presence of existing houses further makai and evidence of extensive grading has led to the placement of the official dune line just makai of the houses to avoid unfair restrictions on land use for existing homeowners.

Figure 3. Pu'u Koa'i, at the southwestern (downwind) end of Pāpōhaku, consists of an active, perched sand dune overlying eolianite (solidified dunes) and basalt.

While this area has been heavily impacted, its high elevation and underlying basalt headland makes it a less likely source for a future sand supply for the beach through erosion of the dune. For the same reasons, the homes in this area are also less likely than homes in the northern sections (Sections 4-9) to be faced with coastal erosion problems in the future. However, the dune topography in Section 2 has great value due to its cultural and physical uniqueness.

Recommendation:

1) Any development between Kaluako'i road and the shoreline should be carefully reviewed to ensure that grading or excavation is kept to an absolute minimum to preserve the unique physical and cultural characteristics of this area. This is especially important as the dune line has been modified to accommodate existing development, and as such, much of the dune has been left out of the designated dune area, but still warrants careful development review.

SECTION 3

Observations: As previously mentioned in Section 2, the southwest end of Pāpōhaku dune is the receiving area for beach and dune sand carried downwind by the northeast trade winds. As such, one would expect broad, high dunes at this location. While the elevation of the dunes at this end of the beach is indeed noticeably higher than the dunes at the northeast end of the beach, this is in part due to underlying basalt rock. In addition, three dune blowouts at this location – one large blowout and two smaller blowouts – have led to significant loss of active beach and dune sand. Further, historical sand mining operations and more recent grading for housing and infrastructure have likely impacted the volume and natural morphology of the dune at this location, as the primary dune on the east side of Pu‘u Koa‘i appears to have been flattened. This was formerly the main staging area for the sand mining operations and included a tunnel through which trucks would drive to be filled with sand through a hole in the roof of the tunnel.

Two areas of large revetments, consisting mainly of large boulders and to a lesser extent concrete, exist at the south end of Pāpōhaku beach (Figure 4). The revetments may have been built as part of the sand mining operations in the 1960s and 1970s, but this has not been confirmed. At the location of the larger of the two revetments, the dune ends and the land drops steeply down approximately 25-30 feet to the beach at the face of the revetment. This morphology suggests that the revetment is protecting the land behind it from erosion, and is thus contributing to erosion of the beach by impounding the sand source that, in the absence of the revetment, would have been supplied by the dune. Adjacent to the revetments, outcrops reveal layers of coral rubble and dirt fill that represent former road beds on which the trucks and machinery for the sand mining operation were driven (Figure 5). Landward of the revetments, the dune has a broad, flattened surface, probably as a result of the sand mining. Numerous exposures of eolianite and beach rock in Section 3 are indicative of an erosional trend.

Figure 4. This image shows the main boulder revetment at the southwestern end of Pāpōhaku Beach, and the flattened area above where a sand dune likely formerly existed. This area was heavily used in the sand mining operations in the 1960's and 1970's. Eolianite exposures are visible on the beach (appearing as brown exposed rock in the photo).

Figure 5. Crushed coral and clay layers are evidence of former road bed.

At TMK 2-5-1-007:034, a drainage outlet has been diverted in order to allow a house to be built where the former drainage channel existed. This alteration of the natural drainage pattern may have impacted the morphodynamic balance of the beach, and may lead to increased sand loss during episodes of heavy rainfall and runoff. According to locals, several streams now run around the property under heavy rainfall, impacting a much larger beach area. In addition, locals described the removal of large sections of eolianite rock (solidified sand dunes) from this area to make a road for sand mining.

Seaward of TMK 2-5-1-007:048, a diagonal slash of approximately 15 feet wide has been cut through the primary dune, leading from the crest of the dune to the base (Figure 6). It appears to have been created to facilitate access to the beach. While it is not known how long ago this swath was created, it has undoubtedly damaged the dune at this location and weakened its capacity as a natural protective structure against storm and high surf damage, as well as a source of sand to the retreating beach.

Figure 6. Slash cut through the primary dune, possibly to facilitate beach access.

In the northeastern half of Section 3, basalt outcrops are occasionally distinguishable. In the case of the one undisturbed landward dune portion in this section, an elevated basalt outcrop serves as the landward dune boundary. As mentioned earlier, where preexisting developments have graded or impacted the dune and homes have been built, the landward dune boundary was placed immediately seaward of the homes or filled area to avoid unfair restrictions on land use for existing homeowners.

The existing homes at the northeasternmost end of section 3 are elevated at least 25 feet above the level of the beach, and no clear back dune boundary is distinguishable. The general elevation in topography and occasional appearance of basalt outcrops indicate that the underlying topography may consist of a larger, continuous basalt outcrop. Nevertheless, landscaping, grading, and construction of houses has obscured the landward boundary of the dune sand deposits; thus, the "disturbed" dune line was placed along the seaward edge of the houses.

Figure 7. Houses are elevated above the beach area. The right side of the eolianite exposure in foreground (rock seen at center and left) was reportedly recently removed.

According to the locals, a section of the eolianite rock in front of TMK 2-5-1-007:053 was removed around the time the house was built. This house can be seen in Figure 7, with the section where the rock has been removed on the right-hand side of the photo. While the reasons for the removal of the rock are uncertain, this has effectively exposed the property to a higher risk of erosion from which the rock offered natural protection. Removal of naturally occurring rock is not recommended.

In summary, the landward primary dune boundary for the majority of Section 3 has been impacted by grading, infrastructure placement, and houses placed within the primary dune. Partly, the reason for this is because by being situated at the downwind (receiving) end of the 3-mile-long Pāpōhaku beach, the southwest end has a naturally higher and wider dune that extends farther inland into private property boundaries, making the chances of having an existing impact greater than for the northeastern portion of Pāpōhaku where the primary dune is smaller and narrower and largely confined to the conservation district. However, the presence of elevated rock outcrops, particularly toward the northeast end of Section 3, currently provides an obstruction to a classic dune profile. In the past, when the beach and dune was farther seaward, a more typical dune may have existed makai of this outcrop, which is suggested by the presence of eolianite outcrops on the beach representing the remains of lithified sand dunes.

Recommendations:

1) Repair of the blow-outs by replanting with native dune groundcover vegetation such as ʻaki ʻaki grass or pōhinahina would help in trapping wind-blown sand, building up the dune, and keeping the sand in the active beach and dune system. This will assist in slowing down rates of dune migration and sand loss from the beach and dune.

2) As the basalt boulders are no longer protecting any structures, removal of the revetments should be considered after ensuring that no significant amount of fill or other remains from the mining operations are situated behind them. As the shoreline continues to retreat at an estimated rate of up to 4 feet per year, according to the 2005 study by the University of Hawaiʻi Coastal Geology Group, the revetments may impact the beach and dune by artificially fixing the shoreline in place and impounding sand that would otherwise be released to feed the retreating beach. Property owners on the land adjacent to the revetments may feel that this places their property at increased risk of damage due to erosion. However, as the revetments do not appear to be engineered or tied into any

solid structure, they may fail under prolonged exposure to heavy wave action. Removal of the revetments would be beneficial to the health of the beach and dune.

3) Any requests to reorient natural drainage channels should be very carefully considered, and only granted as a last resort if there are no other options available, and if it is determined that flow levels will not be increased and negative impacts will not result. In many cases, natural systems have adapted to existing conditions, and alterations in the natural patterns can lead to rapid destabilization of the affected environment. Reorientation of natural drainage outlets is not recommended.

4) Removal of naturally occurring rock is not advisable under most circumstances.

5) To avoid unnecessary damage to the dunes in the form of blowouts or sand removal for access to the beach, property buyers and building permit applicants should be provided with information on the importance of leaving coastal dunes undisturbed, as well as suitable options for shoreline access, such as elevated stairways or dune walkovers, and suitable orientation for access paths (i.e., at a 45 to 90 degree angle from the prevailing wind direction).

SECTION 4

Observations: A small blow-out exists at the southwest end of section 4, immediately to the south of a drainage outlet. North of the outlet, the mauka dune line follows the base of a clearly visible basalt outcrop, with an approximate cliff height of 40 feet. Toward the center of section 4, the basalt outcrop comes out close to the makai dune boundary (Figure 8), and the echo of the ocean can be clearly heard off the rocks. A clay layer remains from a former road bed leading from the sand quarry area immediately to the northeast of this location, to the staging area at the southwest end of the beach. The homes in this area have been built on top of the basalt cliff and thus the structures themselves have had little to no impact on the dune, and are at little risk from future erosional damage. Pathways to access the beach, however, have potential to harm the dune.

Figure 8. Basalt outcrop can be seen in upper left. In lower left, clay layer may represent a former road bed.

Toward the northeastern end of section 4, the elevation of the land mauka of the dune drops back down to a flat, floodplain-type topography, suggesting that the northeastern edge of the basalt outcrop lies in this area.

Recommendations:

1) Repair the small blow-out at the southwestern end of section 4 with native coastal groundcover plants.

2) Access paths should consist of elevated dune walkover structures or stairways built of wood or recycled plastic, so that foot traffic does not cause continuous erosion of the dune face, and so that plant growth is not disturbed.

SECTION 5

Observations: Sand mining, grading, and fill placed for houses have obscured most evidence of the former natural dune morphology in Section 5. This section represents one of the main areas where the former sand mining operations took place. The evidence exists in the form of a large trench, essentially a former sand mine, approximately 350 feet wide and over 1500 feet in length (Figure 9). The sand mining pit essentially has its southern boundary where the basalt outcrop ends. This likely represented the southernmost area where, due to the absence of the elevated basalt outcrop, significant volumes of sand were able to accumulate within and mauka of the primary dune, making it worthwhile for mining. While the face of the dune remains, it is clear that what is left of the former dune is unnaturally narrow, and where the back of the dune drops down into the mine, it is unusually steep. Due to the compromised volume and structure of the dune at this location, it is particularly vulnerable to further damage and erosion. Should a large storm, high surf event or hurricane impact this coast, this damaged section of the dune would be particularly vulnerable to breaching. Breaching occurs when waves overtop a dune or break through a low point in a dune, flooding the land behind. Once water collects behind the dune, the dune can be damaged further by the water as it flows back to the ocean.

Figure 9. Trench remaining from former sand mining operations.

It was good to see that a wooden staircase had been built from the mauka side of the dune up to the dune crest (Figure 10), which will minimize erosion due to foot traffic; however, the cement landing and rock wall at the base of the stairs does not allow for dune migration. Unfortunately, there is not much that can be done to restore the original strength of the dune fronting the sand mine, as the volume of sand necessary to replenish the dune would be prohibitive. Thus, the focus should be on minimizing further impacts.

Figure 10. Stairway on mauka side of dune

Recommendations:

1) Elevated dune walkovers are especially important in Section 5 where the former sand mine pit has left the remaining dune weak and vulnerable. Elevated ramps or stairs on both sides of the dune should be required for any beach access locations in order to eliminate the damaging effects of foot traffic which include erosion of sand, destruction of vegetation, and creation of low points and blowouts which increase the susceptibility of the dune to breaching. Concrete and/or stone landings or foundations should not be permitted.

2) Native coastal groundcover plants are also especially important in Section 5 to trap windblown sand from the beach which will help build up the volume of the dune. Any bare patches, blowouts or damaged areas should be repaired promptly.

3) Building requirements should reflect the increased risk of coastal hazards to homes which has resulted from the presence of a damaged dune. Such requirements may include increased setback distances and higher base flood elevations.

SECTION 6

Figure 11. Cleared back dune area with numerous root casts

Observations: The former sand mining pit described in Section 5 continues into the southeasternmost end of Section 6. In line with the mine pit and of a slightly narrower width is a bare sandy patch on the back of the dune that extends to the northeast about half way across Section 6 (Figure 11). This is likely an area that was cleared of trees in preparation for sand mining. While it may not be technically called a blowout as a band of Kiawe trees and grass traps beach sand from blowing through from the beach, the exposed nature of this cleared area leaves the back of the dune unstable as the sand is vulnerable to erosion and being transported by the wind. The dune line extends further mauka where the cleared area is. This is likely due to the wind having carried the sand further landward in the absence of stabilizing vegetation.

Figure 12. Root casts with pen for scale

An interesting feature of the cleared area is the great number of root casts lying on the sand (Figure 12). Root casts are hardened tubes of cemented sand with a hollow core that represents the former existence of a root which has since biodegraded. The casts are formed in a series of chemical reactions between carbon dioxide emitted from living plant roots, water from rain or the atmosphere, and the calcium carbonate of which the sand is composed. Some of the casts are up to one foot long and as large as 2 inches in diameter. As the formation of root casts is a geologic process which takes some time, the presence and large amount of root casts lying on the surface suggests that a significant amount of erosion has taken place at what was formerly a healthy dune. As root casts form below the surface of the sand, their considerable presence now on the surface suggests that a dune that took a long time to form and was at one time relatively stable, is now gone. The former dune was an established geologic environment that produced lithologic evidence of its existence in the form of the substantial number of root casts. Such a dune is not recoverable naturally on a human time scale.

It should also be noted, however, that since the area with the root casts has been cleared and is adjacent to the former sand mining location, the possibility exists that some screening of the mined sand took place and that the coarse rubble, such as the root casts, was left in this area. From historic aerial photographs, it appears that this area was originally cleared as part of a large linear swath sometime between 1968 and 1977, likely for sand mining purposes. Aerial photos from the year 2000 show that while vegetation in the rest of the cleared swath seems to have regrown, this area alone remains completely exposed, suggesting that it may have been re-cleared prior to the year 2000.

A line of boulders extends from the fence line up the back of the dune at a new house under construction (Figure 13). The purpose for the boulders is unclear, however they appear to delineate access to the beach as they extend seaward from the gate in the fence.

Figure 13. Boulders on back of dune.

In the northeastern half of Section 6, the first occurrence of a complete, unobstructed dune profile can be found. This consists of a steeper makai dune face with a gentler slope on the mauka side. It is important to note that this dune profile differs from a classic dune profile where the opposite is observed, with gentler slopes on the windward side and a steeper slope on the leeward side. The reason for this difference is likely that erosion on the makai side of the dune has led to a steepening of the makai dune face. The morphology of the dune in the northeastern half of Section 6 appears to be relatively unimpacted by recent development. Numerous access paths exist through this area, however, which can cause localized erosion of the dune and destruction of native plants.

Figure 14. Erosional scarp and exposed tree roots indicate recent erosion.

On February 16, when the final walk-through was conducted, an erosional scarp of 1-4 feet high was visible along the makai face of the dune (Figure 14). While the scarping may be indicative of either seasonal or long-term erosion, the undermining and uprooting of several trees by erosion is more likely indicative of a long-term erosional trend.

While most of the dune in Section 6 is covered with Kiawe trees and grass, the dune in front of TMK 2-5-1-006:064 has been cleared and planted with native coastal plants, primarily pōhinahina and ʻaki ʻaki grass (Figure 15). The area is irrigated and appears to be well cared for.

Recommendations:

1) The bare, exposed sand patch on the mauka side of the dune in the southwestern part of Section 6 should be replanted with native coastal vegetation.

2) Elevated dune walkovers at access points would be beneficial.

3) Boulders on the dune interfere with natural dune movement, and should be removed.

Figure 15. Native plant dune restoration on State conservation land.

SECTION 7

Observations: The dune fronting Section 7 is largely undisturbed by recent development, and remains primarily covered with Kiawe trees and grasses. The dune profile is fairly typical for this area, with a steeper makai dune face droping off in a gentler slope on the mauka side of the dune, which eventually blends into the flat, floodplain-like topography mauka of the dune. Secondary and tertiary dunes – dunes parallel to but landward of the primary coastal dune – are not currently observed along sections 4-9 of the Pāpōhaku coastline.

Figure 16. A trench mauka of the dune reveals an abundance of beach-quality sand in the floodplain area.

A trench mauka of the dune and perpendicular to the shoreline that has likely been dug for construction purposes near the middle of Section 7 reveals that below the uppermost soil/organic layer lies a significant amount of sand (Figure 16). As the trench gets further from the dune and closer to the road, the soil content visible in the walls of the trench increases, visible as a gradual reddening of the sand. The important thing to understand about the sand that exists well mauka of the primary dune is that this is the future material for Pāpōhaku beach. As the shoreline erodes at rates of up to and over 4 feet per year (University of Hawai‘i Coastal Geology Group, 2005), the entire beach and dune system will naturally shift mauka, drawing upon the sand that exists in the natural stockpiles on land to feed the eroding system. Due to the vast volumes of sand that have been stored in and mauka of the dunes at Pāpōhaku, this beach could potentially continue to exist for hundreds of years if it is allowed to have access to those stockpiles. If, however, the stockpiles are removed, such as by mining, or locked in, for instance by coastal structures, the potential lifetime of the beach and dune at Pāpōhaku will be shortened. Further, if significant amounts of dirt fill are placed on top of the sand, then should that sand ever be liberated to feed the beach system, the fill will also be liberated, and will be harmful to water quality.

A significant amount of dirt fill has been placed immediately mauka of the dune and conservation land line on three properties at the northeastern half of Section 7 that are under development (Figure 17). The northeasternmost property in Section 7 has cleared the vegetation from the dune fronting their property, and it has been nicely restored with a variety of native coastal vegetation including ‘aki ‘aki grass, pōhinahina, naupaka kahakai, and palms.

Figure 17. Dirt fill has been placed immediately mauka of the dune on three properties in this section, for construction purposes.

Recommendations:

1) Beach access paths will likely be created by property owners in the near future in Section 7 as there are a number of new construction projects underway for which access paths do not currently exist. Access paths are not necessary for each individual property as they have been created in Section 6; instead, it might be advisable to have every pair of adjacent property owners share a single access path. These access paths should be elevated wooden or recycled plastic structures to minimize damage to the dune and plants from pedestrian traffic.

2) Obervations described above in Section 7 lead to several topics that warrant discussion for future management plans for Pāpōhaku Dune and Beach. It should be understood that the following topics for consideration are mainly to protect the long-term interest of the health and preservation of Pāpōhaku dune and beach, and that such long-term visionary goals often meet with resistance from those whose short-term interests would be affected.

a) Whether or not to create a rule prohibiting shoreline protection structures, such as seawalls and rock revetments, at Pāpōhaku.
b) The possibility of implementing a planned strategy of managed retreat; such a strategy may involve a requirement that homes be built on post and pier, rather than slab on grade, so that the homes could be moved mauka as the shoreline retreats.
c) Whether or not to allow dirt fill to be used in the construction process, as this fill may end up harming water quality when the shoreline retreats.
d) Whether or not to require the properties at Pāpōhaku to be subject to the State and County rules that apply to properties that abut the shoreline, despite the fact that they are technically separated from the shoreline by State Conservation Land.

SECTION 8

Observations: As we move to the northeast through sections 1-9, the dune crest gradually becomes lower in elevation. This has to do with section 9 being the predominant "source" end of the beach due to its upwind location, while section 1, the downwind end, is primarily the depositional end of the beach where the sand tends to accumulate. Thus, in Section 8, the dune crest is noticeably lower than it was in the earlier sections. One property has had the Kiawe cleared, and ʻaki ʻaki grass covers much of the dune. However, it appears that the ʻaki ʻaki grass has been mowed (Figure 18). Not only is this unnecessary as ʻaki ʻaki is by nature a relatively short grass, but making it even shorter compromises its ability to trap windblown sand, an important ability in stabilizing the dune.

Figure 18. ʻAki ʻaki grass in the State conservation land, which has been mowed.

A small blowout exists at the southwest end of Section 8, immediately to the south of the property with the ʻaki ʻaki covered dune.

At the center of Section 8 is the public beach park, through which a drainage outlet now runs. This outlet formerly emptied into the ocean at the northeastern end of the beach, and was relocated to facilitate the construction of the golf course. This drainage outlet reportedly causes flooding of the park area under heavy runoff conditions. Large outcrops of beach rock are visible on the beach adjacent to the park, which are indicative of an erosional trend.

Recommendations:

1) The small blowout should be repaired by replanting with native coastal groundcover vegetation.

2) Property owners should be advised not to mow any native coastal plants in State Conservation Land, in particular ʻaki ʻaki grass.

3) Elevated dune walkover structures would reduce damage to dunes from foot traffic.

SECTION 9

Observations: The morphology of the natural dune at this location has been completely obliterated by the development of a golf course. No natural dune formation remains, although sand volumes do remain that will be important for future sand supply to the beach.

Recommendations:
1) No shore protection structures should be permitted to protect the golf course. If erosion threatens the golf course, the course should be relocated further mauka or to a new location.

RECOMMENDATIONS

1. Hawai‘i Coastal Hazard Mitigation Guidebook recommendations:
The newly released Hawai‘i Coastal Hazard Mitigation Guidebook (Hwang, 2005) provides recommendations for land use managers for the implementation of planning measures that address erosion concerns at the earliest stages of development. While several of the recommendations from the guidebook are provided below, a more thorough review of this guidebook in planning for the future management of Pāpōhaku Dune would be worthwhile.

Table 1: Recommendations of the Hawai‘i Coastal Hazard Mitigation Guidebook
1) 70 years should be the minimum lifetime expectancy for residential structures. This is based on a study conducted by the Federal Insurance Administration to establish reliable estimates for the life of coastal residential structures. 2) Building setbacks should be based on erosion rates. However, historical erosion rates usually do not take into account storms, hurricanes or tsunamis, thus erosion rate-based setbacks should include an additional buffer zone. A 40-foot buffer zone is suggested. In general, homes should be built as far back from the ocean as possible to protect life and property as well as beach and dune resources. 3) Deep, narrow lots are recommended for coastal subdivisions. Fortunately, the subdivision at Pāpōhaku has been designed in this way. This format allows room for homes to be built well back from the ocean, and to be relocated mauka if erosion becomes a concern. 4) Dune restoration with planting of native coastal groundcover is recommended to assist in mitigating coastal hazards and protecting the health of the beach system. 5) Coastal structures on retreating shorelines should be built with the understanding that over time they will be at increased risk to flooding, and should thus be built according to the next higher level of flood-protection standards provided by the Federal Emergency Management Agency (FEMA). In other words, if a house is planned to be built immediately outside the high flood hazard zone, chances are that it will eventually be situated within the high hazard zone as the shoreline retreats; thus, it should be designed according to the high flood hazard standards. Houses built of post and pier construction can be relatively easily relocated if threatened by erosion in the future. For more information, refer to the FEMA Coastal Construction Manual (2000)

2. Short-term recommendations
The following were observed during the field surveys as issues that ought to be addressed relatively soon to prevent further damage and repair some of the existing damage to Pāpōhaku dune. These recommendations have placed in two tables; Table 2a addresses issues that apply to all of Pāpōhaku dune, and Table 2b summarizes the section-specific recommendations provided above in Part III.

Table 2a: Immediate Recommendations for Pāpōhaku Dune Management
1) Access paths over the dune should minimize damage to the dune in any or all of the following manners: a) Use elevated dune walkover structures for beach access over the dune; b) Avoid orienting access paths parallel to the prevailing wind direction; and c) Minimize the number of access paths to one for every two properties. 2) Areas of the dune that are bare of vegetation, such as blowouts, should be replanted with native coastal groundcover. 3) If clearing of kiawe from the dune is desired, clearcutting of the trees should not take place, and roots should be left in the sand. Gradual, selective removal of trees in conjunction with replanting, rather than removal of all trees all at once, will avoid sudden exposure of the sand surface to wind action, which could otherwise contribute to significant sand loss and vulnerability of the dune. Immediate replanting with native coastal vegetation as the kiawe trees are selectively removed is critical to avoid sand loss. 4) If grading takes place on coastal properties, sand should not be removed from the property. The sand on these properties will potentially be a future sand source for the beach and dune. 5) Natural drainage outlets should not be relocated. Relocation of these outlets can lead to dramatic destabilization of the beach and dune and significantly alter natural sand transport patterns. 6) Homes in the sections with lower elevations (Sections 1 and 5-9 in particular) should have increased setback distances and be constructed with higher base flood elevations, to reflect the increased risk of coastal hazards and flooding in these areas. 7) Provide homeowners with educational material on coastal dunes, and have this material be made available to renters. 8) No rocks, concrete, or permanent structures should be placed in the dune area or on State conservation land. 8) Address the section-specific recommendations for dune repair and protection listed in Table 2b.

2. Short-term recommendations (continued)

The following section-specific recommendations were provided above in Part III, and should be addressed relatively soon to prevent further degradation of Pāpōhaku dune.

Table 2b: Summary of Immediate Section-specific Recommendations	
Location	**Recommendations**
Section 1	1) Every proposed new structure in the Pāpōhaku coastal area should be checked to ensure that it does not fall within the primary dune. As the dune is actively migrating, the dune line delineated by this study will change. Thus, site visits and/or photographed submittals of the proposed structure locations are recommended to visually ensure that no structures are built within the primary dune. 2) Archaeologists should perform any digging in the primary dune by hand with shovels rather than with backhoes or other trenching equipment. Following the digs, the trenches or holes should be filled back in and restored as best as possible to the pre-dug condition.
Section 2	1) Any development between Kaluakoʻi road and the shoreline should be carefully reviewed to ensure that grading or excavation is kept to an absolute minimum to preserve the unique physical and cultural characteristics of this area. This is especially important as the dune line has been modified to accommodate existing development, and as such, much of the dune has been left out of the designated dune area, but still warrants careful development review.
Section 3	1) Repair of the blow-outs by replanting with native dune groundcover vegetation such as ʻaki ʻaki grass or pōhinahina would help in trapping wind-blown sand, building up the dune, and keeping the sand in the active beach and dune system. This will assist in slowing down rates of dune migration and sand loss from the beach and dune. 2) As the basalt boulders are no longer protecting any structures, removal of the revetments should be considered after ensuring that no significant amount of fill or other remains from the mining operations are situated behind them. As the shoreline continues to retreat at an estimated rate of up to 4 feet per year, according to the 2005 study by the University of Hawaiʻi Coastal Geology Group, the revetments may impact the beach and dune by artificially fixing the shoreline in place and impounding sand that would otherwise be released to feed the retreating beach. Property owners on the land adjacent to the revetments may feel that this places their property at increased risk of damage due to erosion. However, as the revetments do not appear to be engineered or tied into any solid structure, they may fail under prolonged exposure to heavy wave action. Removal of the revetments would be beneficial to the health of the beach and dune.

	3) Any requests to reorient natural drainage channels should be very carefully considered, and only granted as a last resort if there are no other options available, and if it is determined that flow levels will not be increased and negative impacts will not result. In many cases, natural systems have adapted to existing conditions, and alterations in the natural patterns can lead to rapid destabilization of the affected environment. Reorientation of natural drainage outlets is not recommended. 4) Removal of naturally occurring rock is not advisable under most circumstances. 5) To avoid unnecessary damage to the dunes in the form of blowouts or sand removal for access to the beach, property buyers and building permit applicants should be provided with information on the importance of leaving coastal dunes undisturbed, as well as suitable options for shoreline access, such as elevated stairways or dune walkovers, and suitable orientation for access paths (i.e., at a 45 to 90 degree angle from the prevailing wind direction).
Section 4	1) Repair the small blow-out at the southwestern end of Section 4 with native coastal groundcover plants. 2) Access paths should consist of elevated dune walkover structures or stairways built of wood or recycled plastic, so that foot traffic does not cause continuous erosion of the dune face, and so that plant growth is not disturbed.
Section 5	1) Elevated dune walkovers are especially important in Section 5 where the former sand mine pit has left the remaining dune weak and vulnerable. Elevated ramps or stairs on both sides of the dune should be required for any beach access locations in order to eliminate the damaging effects of foot traffic which include erosion of sand, destruction of vegetation, and creation of low points and blow-outs which increase the susceptibility of the dune to breaching. Concrete and/or stone landings or foundations should not be permitted. 2) Native coastal groundcover plants are also especially important in Section 5 to trap windblown sand from the beach, which will help build up the volume of the dune. Any bare patches, blowouts or damaged areas should be repaired promptly. 3) Building requirements should reflect the increased risk of coastal hazards to homes that has resulted from the presence of a damaged dune. Such requirements may include increased setback distances and higher base flood elevations.

Section 6	1) The bare sand patch on the mauka side of the dune in the southwestern part of Section 6 should be replanted with native coastal vegetation. 2) Elevated dune walkovers at access points would be beneficial. 3) Boulders on the dune interfere with natural dune movement, and should be removed.
Section 7	1) Beach access paths will likely be created by property owners in the near future in Section 7 as there are a number of new construction projects underway for which access paths do not currently exist. Access paths are not necessary for each individual property as they have been created in Section 6; instead, it might be advisable to have every pair of adjacent property owners share a single access path. These access paths should be elevated wooden or recycled plastic structures to minimize damage to the dune and plants from pedestrian traffic. 2) Obervations described above in Section 7 lead to several topics that warrant discussion for future management plans for Pāpōhaku Dune. It should be understood that the following topics for consideration are mainly to protect the long-term interest of the health and preservation of Pāpōhaku dune and beach, and that such long-term visionary goals often meet with resistance from those whose short-term interests would be affected. a) Whether or not to create a rule prohibiting shoreline protection structures, such as seawalls and rock revetments, at Pāpōhaku. b) The possibility of implementing a planned strategy of managed retreat; such a strategy may involve a requirement that homes be built on post and pier, rather than slab on grade, so that the homes could be moved mauka as the shoreline retreats. c) Whether or not to allow dirt fill to be used in the construction process, as this fill may end up harming water quality when the shoreline retreats. d) Whether or not to require the properties at Pāpōhaku to be subject to the State and County rules that apply to properties that abut the shoreline, despite the fact that they are technically separated from the shoreline by State Conservation Land.
Section 8	1) The small blowout should be repaired by replanting with native coastal groundcover vegetation. 2) Property owners should be advised not to mow any native coastal plants in State Conservation Land, in particular ʻaki ʻaki grass. 3) Elevated walkovers would reduce damage to dunes from foot traffic.
Section 9	1) No shore protection structures should be permitted to protect the golf course. If erosion threatens the golf course, the course should be relocated further mauka or to a new location.

3. Long-term recommendations

The following topics may be controversial but warrant careful consideration and discussion. These are the issues that will make a difference in the long-term preservation of Pāpōhaku beach and dune, but will require a commitment by the people of Molokaʻi to a vision of protection of this resource for many generations to come.

Table 3: Future Planning Considerations for Pāpōhaku
1) Consider implementing, by amendments to the shoreline setback rule or by policy, a prohibition on shoreline hardening for new structures that runs with the land and requires disclosure to future homeowners 2) Consider implementing a plan for managed retreat. If homes should become threatened by erosion, the homes could be relocated mauka on the property. 3) Consider disallowing dirt fill over sand deposits, even if outside the shoreline area. When the shoreline retreats to a point where these sand deposits become the source of sand for the beach, the dirt fill will be harmful to water quality. 4) Consider requiring homes to be built of post-and-pier construction. Not only does this protect homes from coastal flooding, but it makes them easier to pick up and relocate. 5) Consider adopting erosion rate-based building setbacks. Consider basing these setbacks on the 70 or 100 year erosion hazard. 6) Consider adopting language that requires that properties be subject to State and County coastal zone management rules as though they were abutting the shoreline. (Currently the privately owned parcels are separated from the shoreline by a parcel of conservation land, and thus may claim they are not subject to rules such as the setback rules as their parcel does not technically abut the shoreline.)

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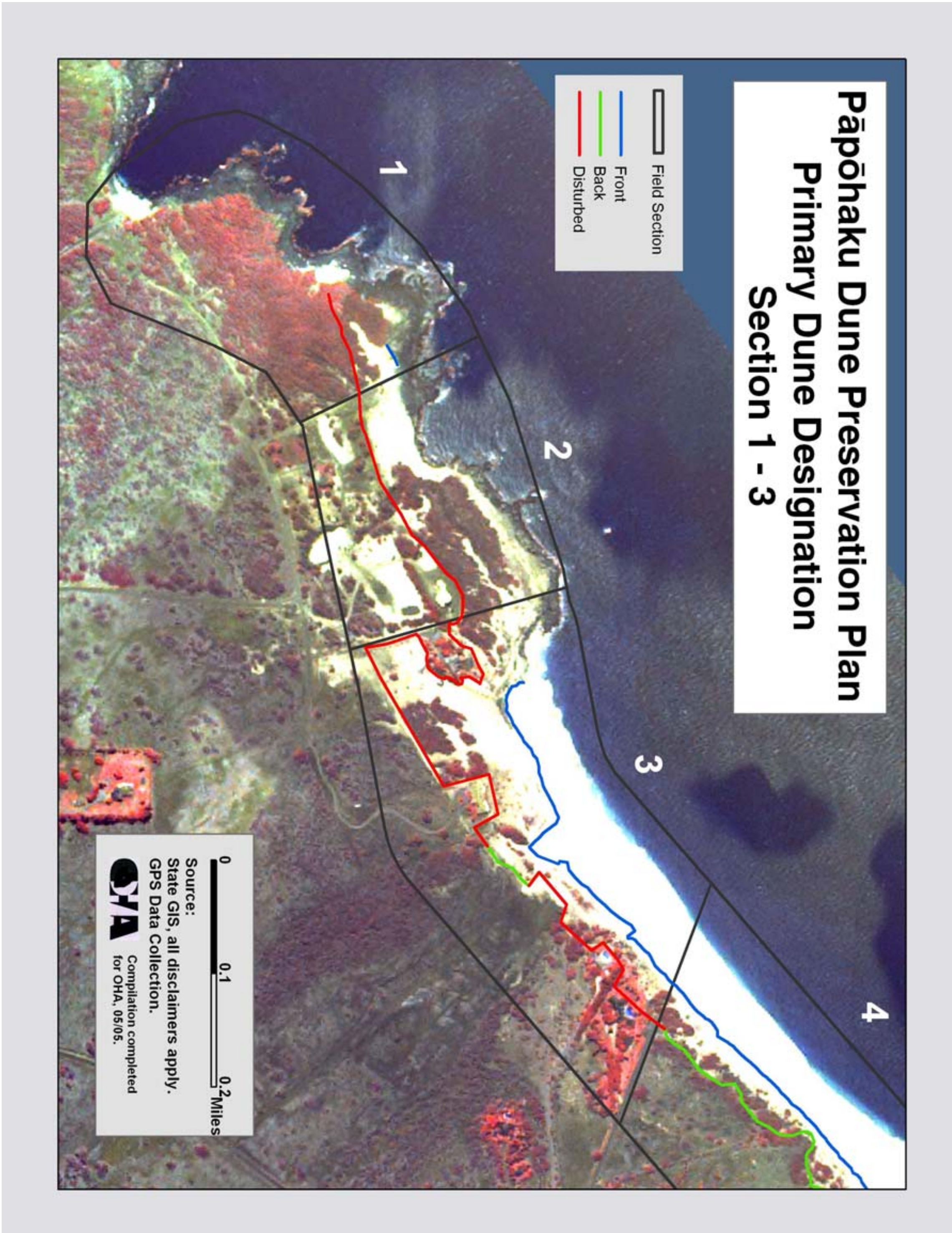
APPENDIX A

Dune Delineation

Maps prepared by Renee Louis for the Office of Hawaiian Affairs, 2005


Pāpōhaku Dune Preservation Plan
Primary Dune Designation
Section 1 - 3
Field Section
Front
Back
Disturbed
1
2
3
4
0
0.1
0.2 Miles
Source:
State GIS, all disclaimers apply.
GPS Data Collection.
Compilation completed
for OHA, 05/05.


Pāpōhaku Dune Preservation Plan
Primary Dune Designation
Section 4 - 6
Field Section
Front
Back
Disturbed
4
5
6
0
0.1
0.2
Miles
Source:
State GIS, all disclaimers apply.
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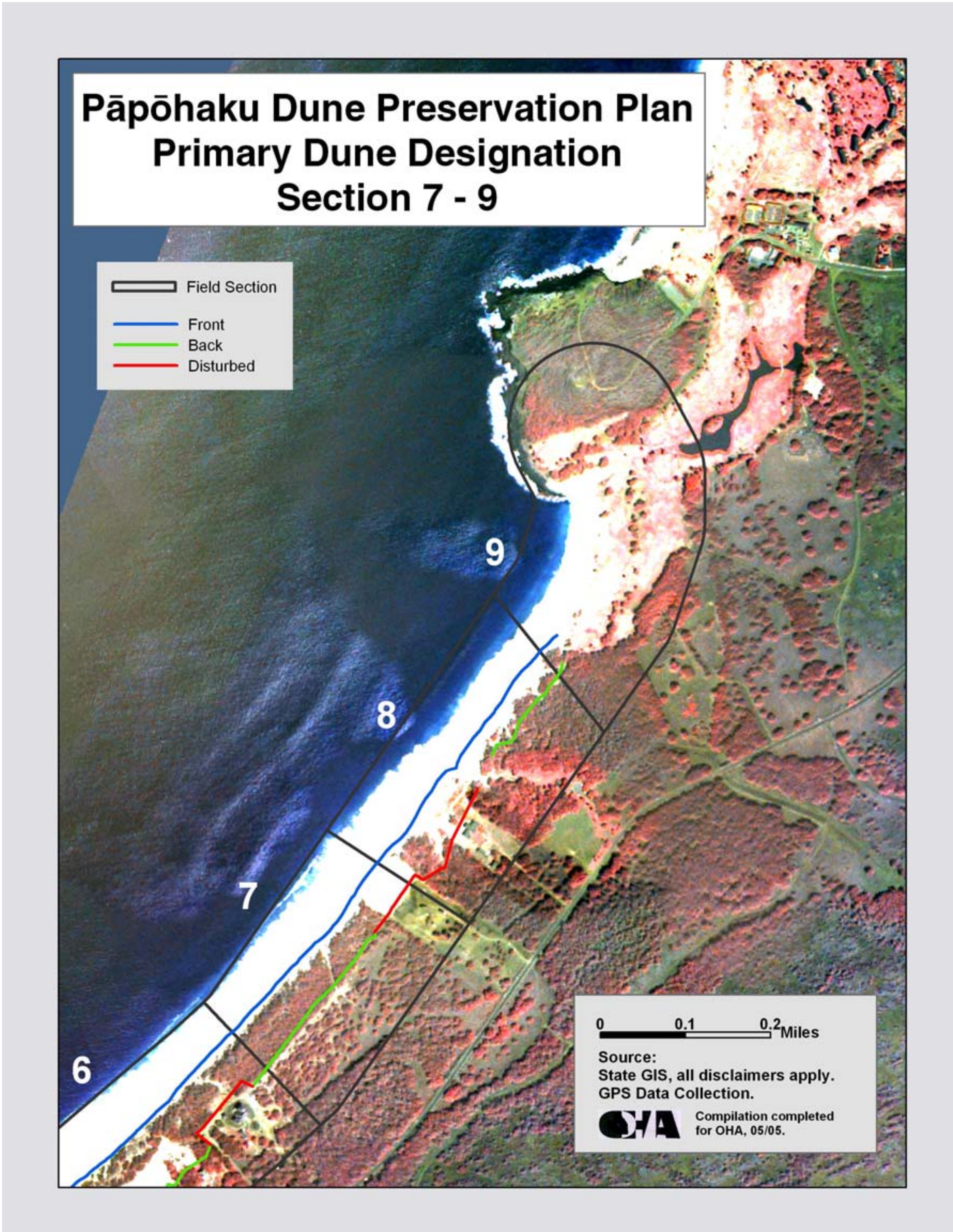
for OHA, 05/05.



Pāpōhaku Dune Preservation Plan
Primary Dune Designation
Section 7 - 9
Field Section
Front
Back
Disturbed
9
8
7
6
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Miles
Source:
State GIS, all disclaimers apply.
GPS Data Collection.
Compilation completed
for OHA, 05/05.

APPENDIX B

Dune Walkover Guidelines

From the Federal Emergency Management Agency Coastal Construction Manual, 2002

This appendix contains copies of the following two publications, which provide design criteria for beach walkover structures:

***Beach/Dune Walkover Guidelines*, by the Florida Bureau of Beaches and Coastal Systems, Florida Department of Environmental Protection, Revised January 1998**

***Beach Dune Walkover Structures,* SUSF-SG-76, by Todd L. Walton, Jr., and Thomas C. Skinner. Published by the Marine Advisory Program of the Florida Cooperative Extension Service and Florida Sea Grant, March 1983.**

BUREARU OF BEACHES AND COASTAL SYSTEMS
BEACH/DUNE WALKOVER GUIDELINES

INTRODUCTION

In many areas of the State, sand dunes provide a significant amount of protection to the upland property, to upland development, and to adjacent beach areas. The Department, therefore, encourages the construction of elevated walkover structures which are designed to protect the dune topography and dune vegetation from pedestrian traffic and which allow for the natural reconstruction and revegetation of damaged or eroded dunes.

PERMIT REQUIREMENTS

A permit from the Florida Department of Environmental Protection is required for construction of walkovers on most sandy beaches fronting on the open waters of the Atlantic Ocean or Gulf of Mexico. In areas where a coastal construction control line has been established pursuant to provisions of Section 161.053, Florida Statutes, a permit is required for all excavation, construction, or other activities with the potential to cause beach erosion or damage coastal vegetation. Permits for walkovers contain standard conditions which require construction to be conducted in a manner that minimizes short term disturbance to the dune system and existing vegetation. Replacement of vegetation destroyed during construction with similar plants suitable for beach and dune stabilization is required. Only limited excavation for the placement of support posts is authorized for construction of walkovers. The construction of walkovers may not occur during the marine turtle nesting season, typically May 1 through October 31, except for Brevard through Dade counties (March l through October 31).

GENERAL DESIGN

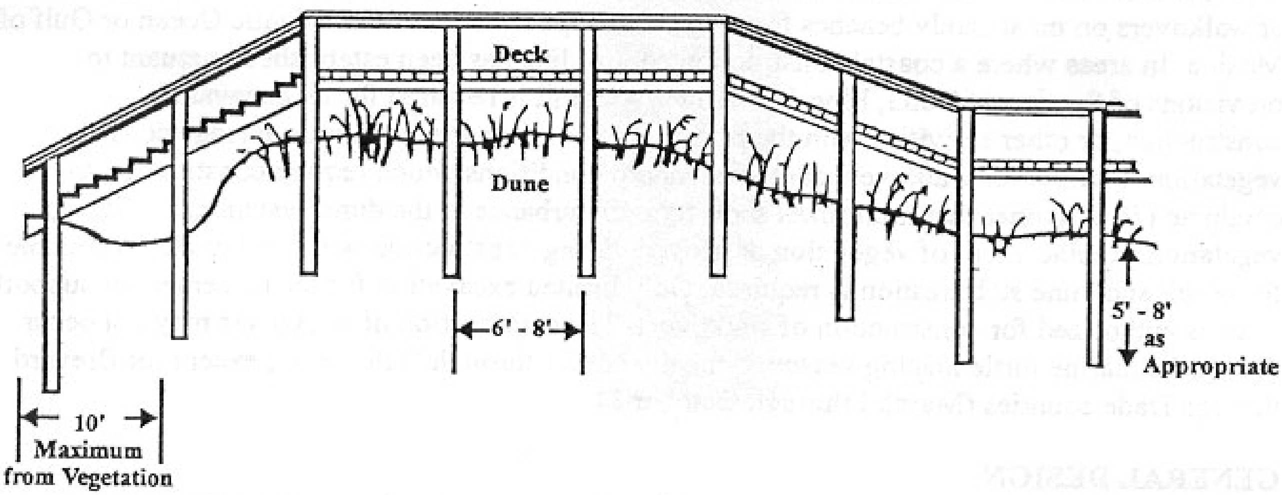
Walkovers to be constructed across vegetated dunes or across heavily vegetated beach berms should be post-supported and elevated a sufficient distance above the existing or proposed vegetation to allow for sand build-up and clearance above the vegetation (this may be several feet depending on the type of vegetation). Walkovers should generally be constructed perpendicular to the shoreline and extend at least to the seaward toe of the frontal dune or the existing line of vegetation but not farther than 10 feet seaward of the vegetation. Support posts should not be installed into dune slopes which are steeper than approximately 30 degrees. Whenever possible, stairways leading from the top or crest of a dune down to the beach should be designed to completely span the seaward slope of the dune.

DESIGN CRITERIA FOR SINGLE FAMILY DEVELOPMENTS

Walkovers should be designed as minor structures and need not meet specific structural requirements to resist wind and wave forces, but should be designed to produce minimum scour of the beach and dune topography during a storm event and to reduce the potential for damage to upland structures as airborne or waterborne debris. The width of the walkover structure should not exceed 4 feet. The railing should be limited to a handrail and one center guard rail. The posts for the walkover structure should be 4-inch by 4-inch (although 6-inch posts may be allowed), should be embedded deep enough to support typical live and dead loads (minimum of 5 feet.), and should not be encased in concrete. Typical spacing between post bents is 6 to 8 feet. Supporting beams, bents, and stair stringers should not be greater than 2-inch by 12-inch pressure treated lumber. Connections may be fastened with bolts or nails hotdipped galvanized or stainless steel. All lumber should be pressure treated.

DESIGN CRITERIA FOR MULTI FAMILY DEVELOPMENTS

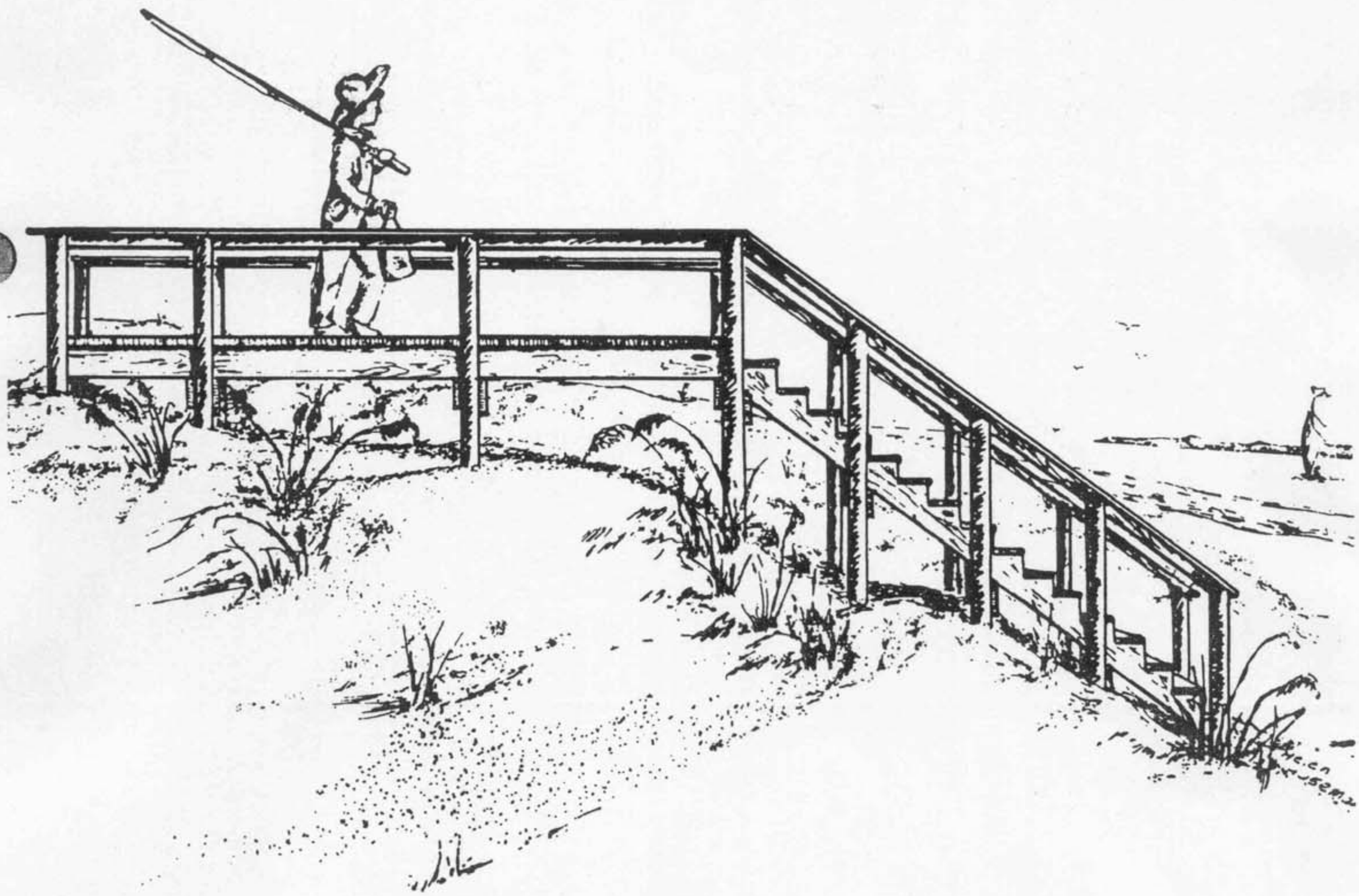
The number of walkovers within the development depends on the expected volume and type of traffic; however, the width of each walkover allowed should not exceed 6-feet. Where more than one walkover is authorized within the development, a minimum 150-foot spacing should be provided between authorized walkovers. The piles for the typical walkover are 6-inch in diameter and should be embedded approximately 8 feet to account for both structural stability and possible dune deflation losses. <u>Since the structural design guidelines provided herein may not apply to many of these structures, designers of such structures are encouraged to consult the Bureau staff.</u>



MAP-18

Beach Dune Walkover Structures

Todd L. Walton, Jr. and Thomas C. Skinner



Florida Cooperative Extension
Marine Advisory Bulletin

MARCH 1983*

The State University System of Florida Sea Grant College is supported by award of the Office of Sea Grant, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, grant number NA80AA-D-00038, under provisions of the National Sea Grant Collge and Programs Act of 1966. This information is published by the Marine Advisory Program which functions as a component of the Florida Cooperative Extension Service, John T. Woeste, dean, in conducting Cooperative Extension work in Agriculture, Home Economics, and Marine Sciences, State of Florida, U. S. Department of Agriculture, U. S. Department of Commerce, and Boards of County Commissioners, cooperating. Printed and distributed in furtherance of the Acts of Congress of May 8 and June 14, 1914. The Florida Sea Grant College is an Equal Employment Opportunity-Affirmative Action employer authorized to provide research, educational information and other services only to individuals and institutions that function without regard to race, color, sex, or national origin.

This public document was promulgated at a cost of $166.25 or 11 cents per copy, to provide information on construction of beach dune walkover structures. Cost does not include postage and handling.

12/3M/76
11/1M/81
3/1.5M/83

*This publication is a reprint with revisions of Marine Advisory Bulletin SUSF-SG-76-006 originally published in 1976. The number has been changed to MAP-18.

BEACH DUNE WALKOVER STRUCTURES

by

Todd L. Walton, Jr.[1] and Thomas C. Skinner[2]

INTRODUCTION

The idea behind this publication originally came from the Bureau of Beaches and Shores, Department of Natural Resources, State of Florida. It was recognized that numerous dune systems within our state were undergoing destruction due to the loss of vegetation caused by unrestricted access to the beach over the dune systems. As the vegetation was lost, the wind became capable of eroding the dune and caused a progressive deterioration of the entire dune system.

In areas of high human traffic, a beach walkover structure is needed to save this vegetation. Two structure designs are presented in this publication. Figures 1 through 7 give details of a structure for use in areas of heavy foot traffic. A good example of such use might be for a condominium or a community public access ramp. The depths of pilings account for both depth necessary for structure stability and added depth to account for possible dune deflation losses.

Figures 8 and 9 give details of a smaller structure more suitable for the typical coastal land owner where only light foot traffic is expected. The depth of pilings in sand is correspondingly less which should minimize interference with the dune system in construction of the walkway. It should be noted that any construction seaward of the State Coastal Construction

[1] Coastal Engineering Advisory Specialist, Marine Advisory Program, with the Coastal and Oceanographic Engineering Laboratory, University of Florida.

[2] Extension Agricultural Engineer, Florida Cooperative Extension Service, IFAS University of Florida.

Setback Line (Reference 1) must be permitted by the Bureau of Beaches and Shores, Department of Natural Resources.

The designs are basic enough such that various alternatives can be added to the designs without altering the structures to a great degree. One such alteration would be a transverse extension of the deck section with benches for people to sit on overlooking the beach area. The addition of properly spaced skid resistant materials to the decking of the ramp section of the large walkover structure would make the deck and the deck extension accessible to handicapped people in wheelchairs. Additional features which could also be added are limited only by the planner's imagination.

The authors would like to thank both Mr. Gill Hill and Mr. William Sensabaugh of the Bureau of Beaches and Shores, Department of Natural Resources, for the ideas and suggestions used in these plans. The authors hope that this publication will lead to the building of more walkover structures in areas where dune systems are threatened by human traffic. The authors also hope to hear any suggestions, comments, or criticism which might be included in a future revision of this publication.

MATERIALS SPECIFICATION SHEET

(1) Wood

All wood to be pressure treated in accordance with American Wood Preservers Association Standard C-2. The preservative used should be a waterborne preservative such as Type B or C or equivalent as covered in Federal Specification TT-W-535 and AWPA Standards P5, C2, and C-14. The type wood to be used depends on the quality of the construction desired. A suitable inexpensive wood for construction would be southern pine. Higher grade and more expensive woods would be the heartwood of Bald Cypress, Redwood, or Eastern Red Cedar. Very expensive but extremely durable and decay resistant woods would be Greenheart or Basra Locus. "Rough cut" lumber can be used on all lumber in the substructure while "dressed" (i.e. surfaced) lumber should be used on the flooring and handrails. Further information on the specifications for buying lumber can be found in Reference 2.

(2) Hardware

All bolts and other hardware to be hot dipped galvanized.

(3) Nails

All nails to be galvanized.

GENERAL NOTES

(1) Bolts in handrails shall have nut end toward post. Countersink so that bolt does not project beyond post. Trim excess of projecting bolts after fastening.

(2) Use bolts for all connections to posts.

(3) Do not encase bottoms of pilings in concrete. This would be termed objectionable construction in obtaining a permit from the Bureau of Beaches and Shores.

(4) Some may find the pitch of the steps (8 on 10) too steep; likewise the ramp slope (20%) is too steep for handicap access (8.33% recommended). The design may be modified accordingly.

(5) Check with local building officials to make sure the design contained herein, or as modified, conforms to local codes and ordinances.

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1. Coastal Construction Setback Line by J. A. Purpura and W.M. Sensabaugh, Marine Advisory Bulletin, SUSF-SG-74-002, Florida Cooperative Extension Service, 1974. (Out-of-Print).

2. Wood Handbook: Wood as an Engineering Material, U.S.D.A., Forest Products Laboratory, 1974.

3. Timber Design and Construction Handbook, McGraw Hill Publishing Co., 1956.

4. Wood Engineering, G. Gurfinkel, Southern Forest Products Association, 1973.

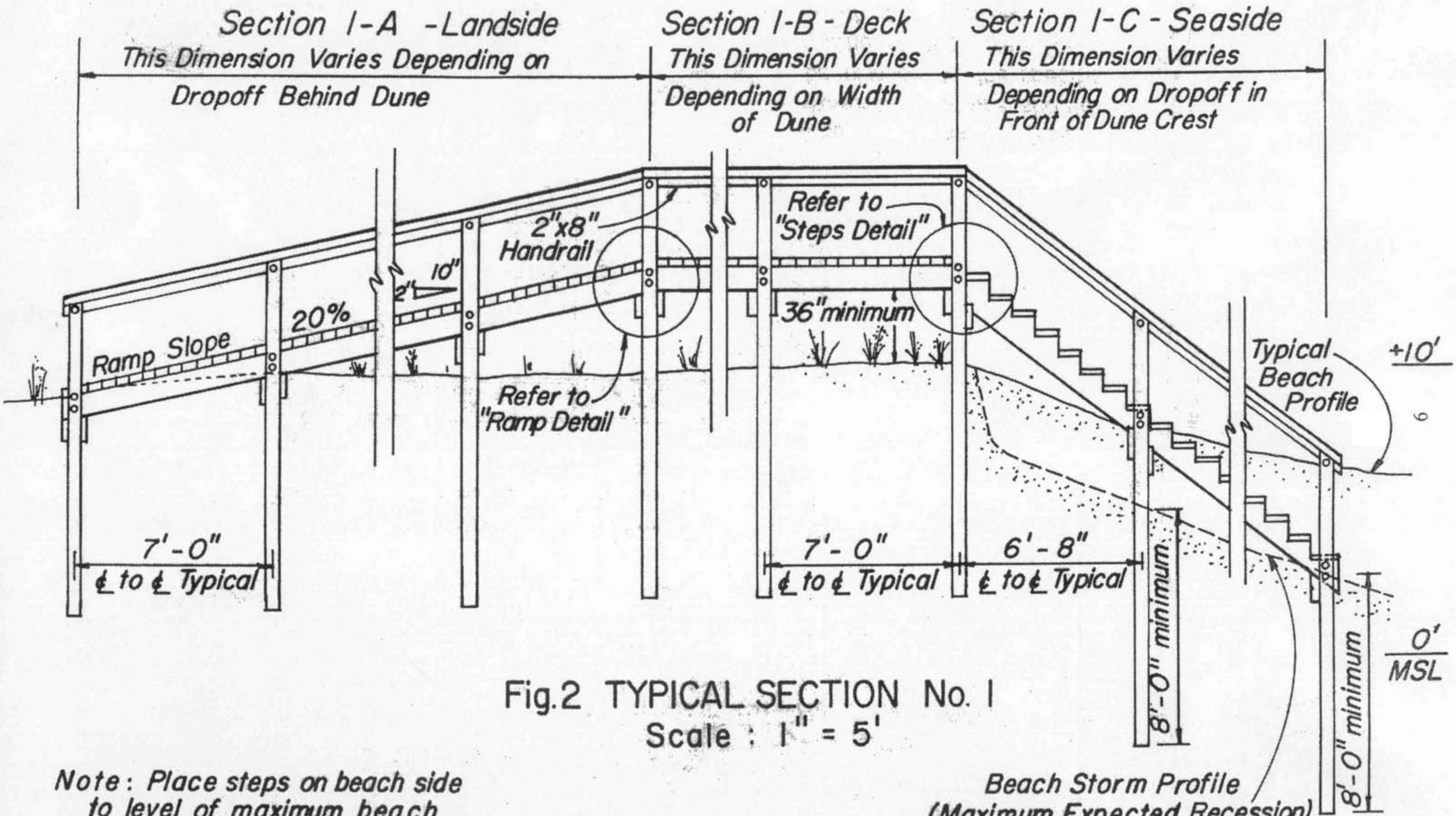


Fig.2 TYPICAL SECTION No. 1
Scale : 1" = 5'

Note: Place steps on beach side to level of maximum beach recession during a severe storm or tropical hurricane

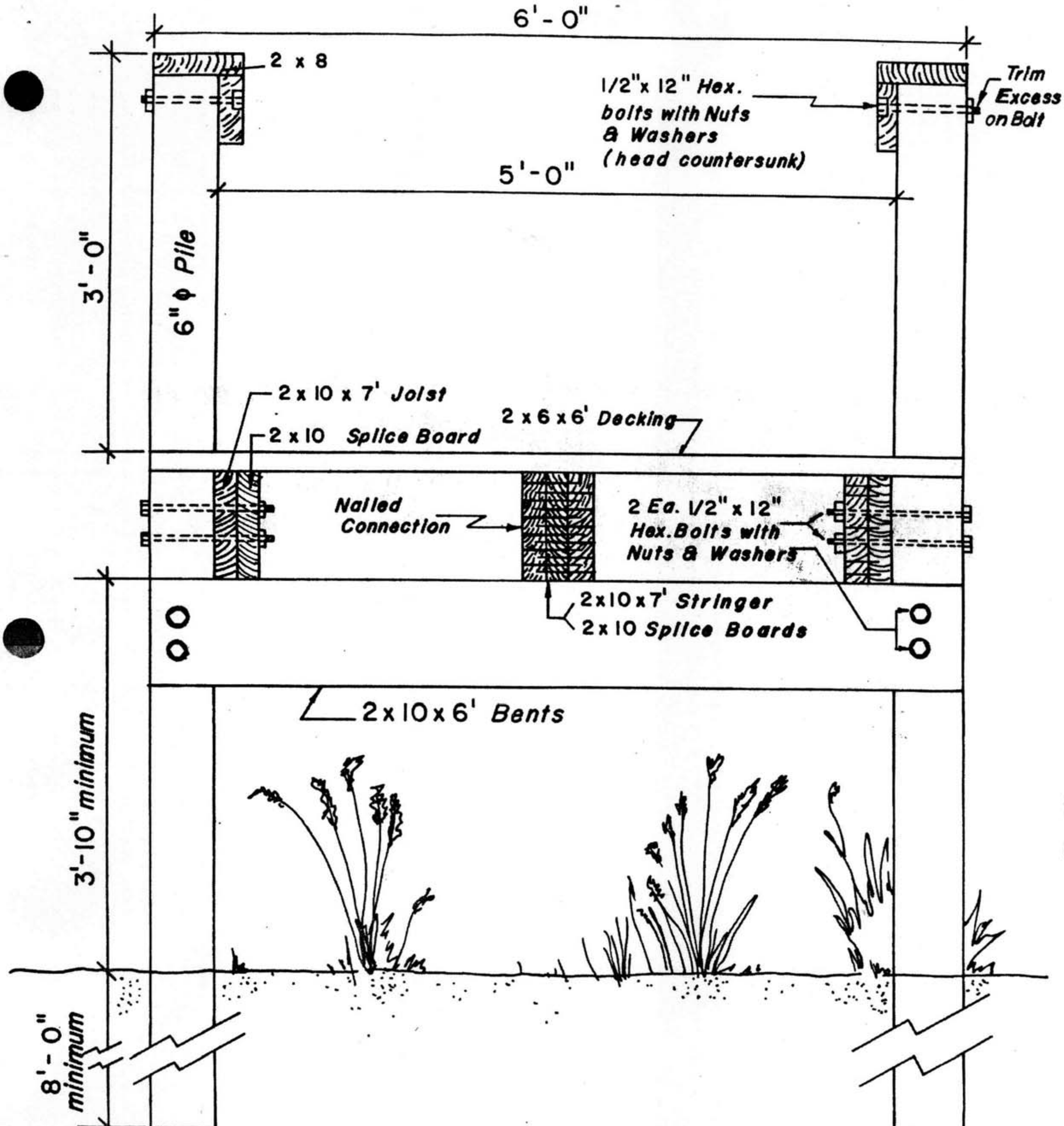


Fig. 3 TYPICAL SECTION I-B DECK
Scale: 1" = 1'-0"

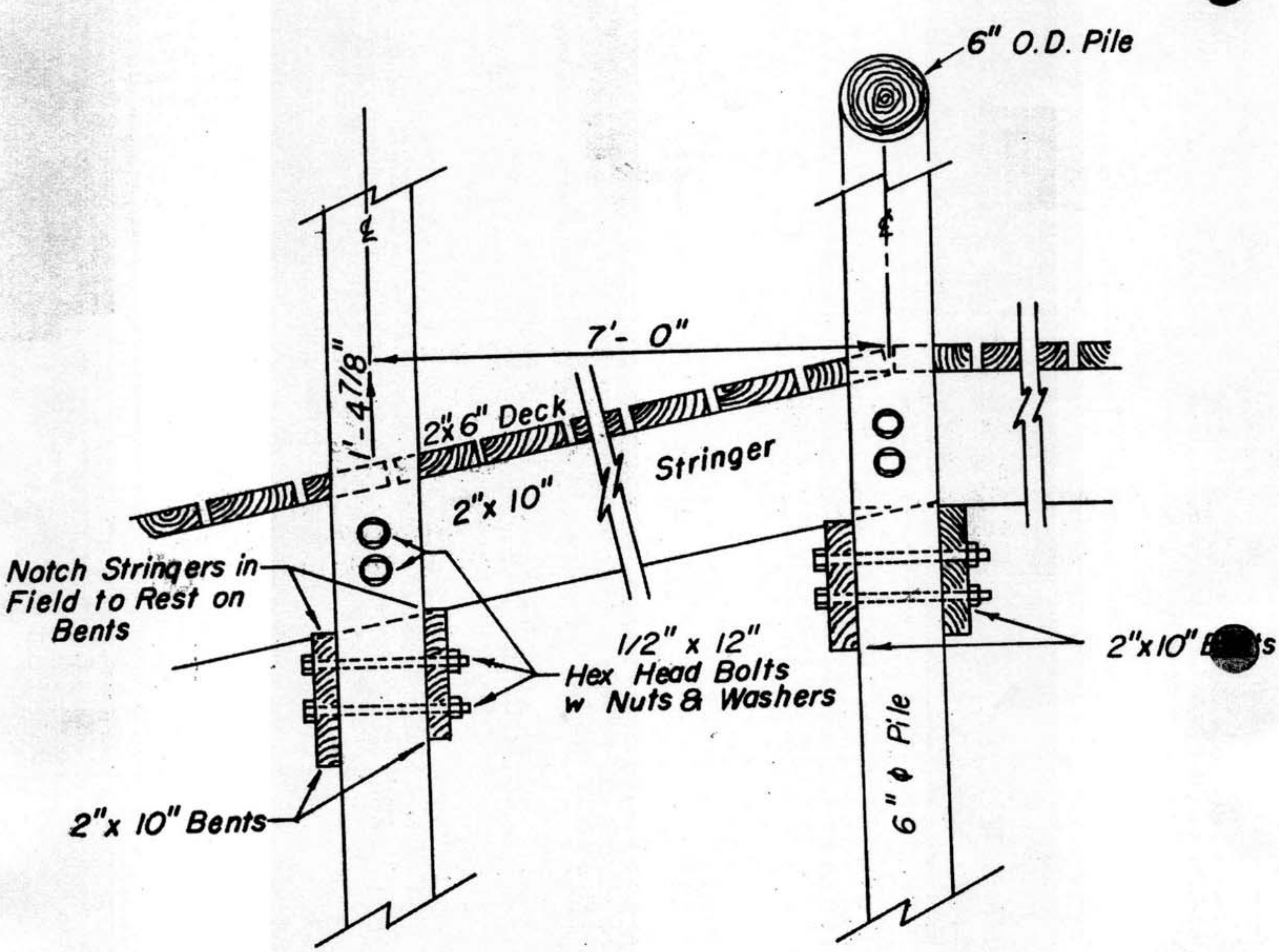


Fig. 4 TYPICAL RAMP DETAIL

Scale: 1" = 1'- 0"

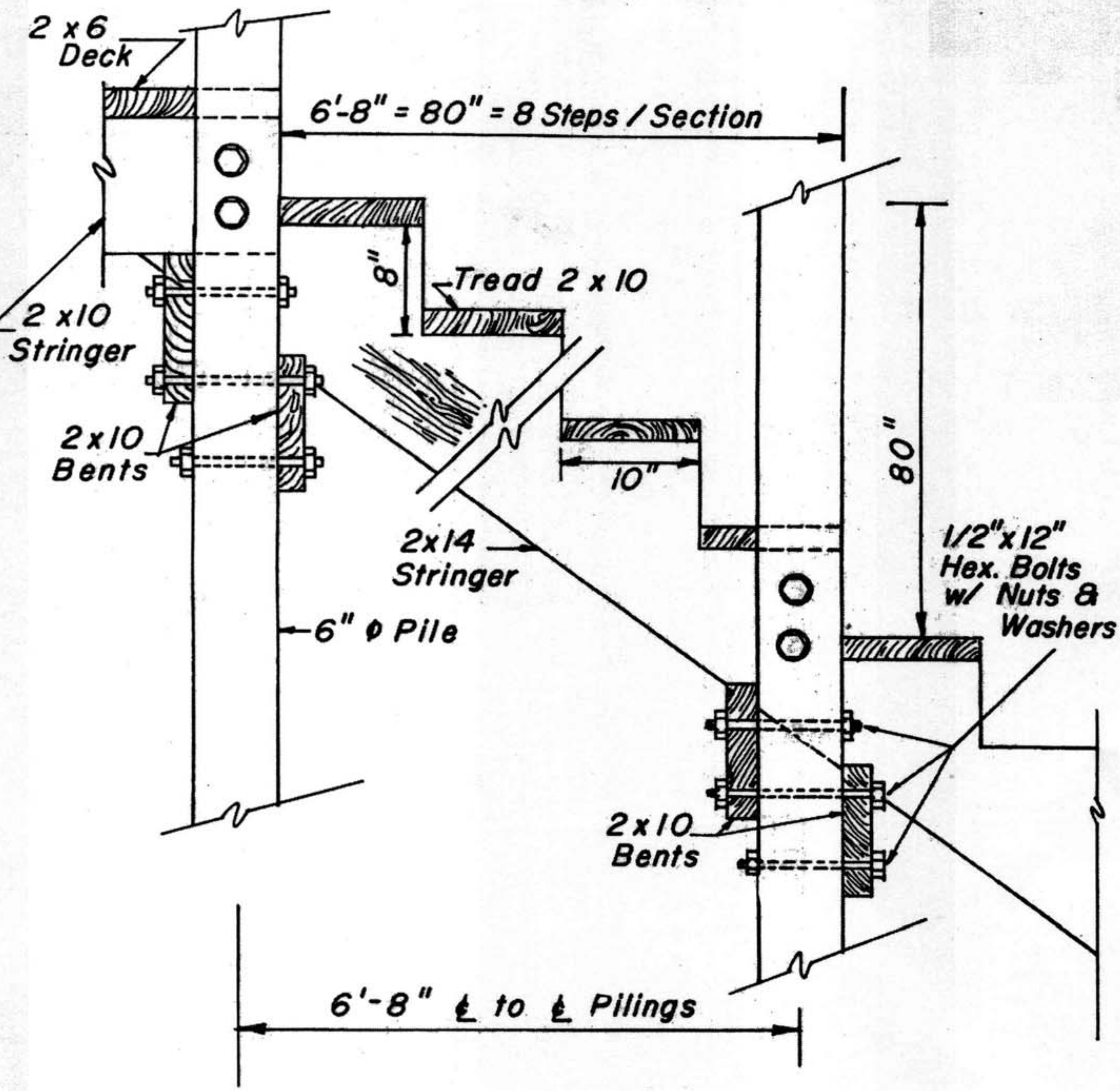


Fig. 5 TYPICAL STEPS DETAIL
Scale : 1" = 1'-0"

Include as many step sections as necessary to grade from top of dune + 3 feet to base of rear dune.

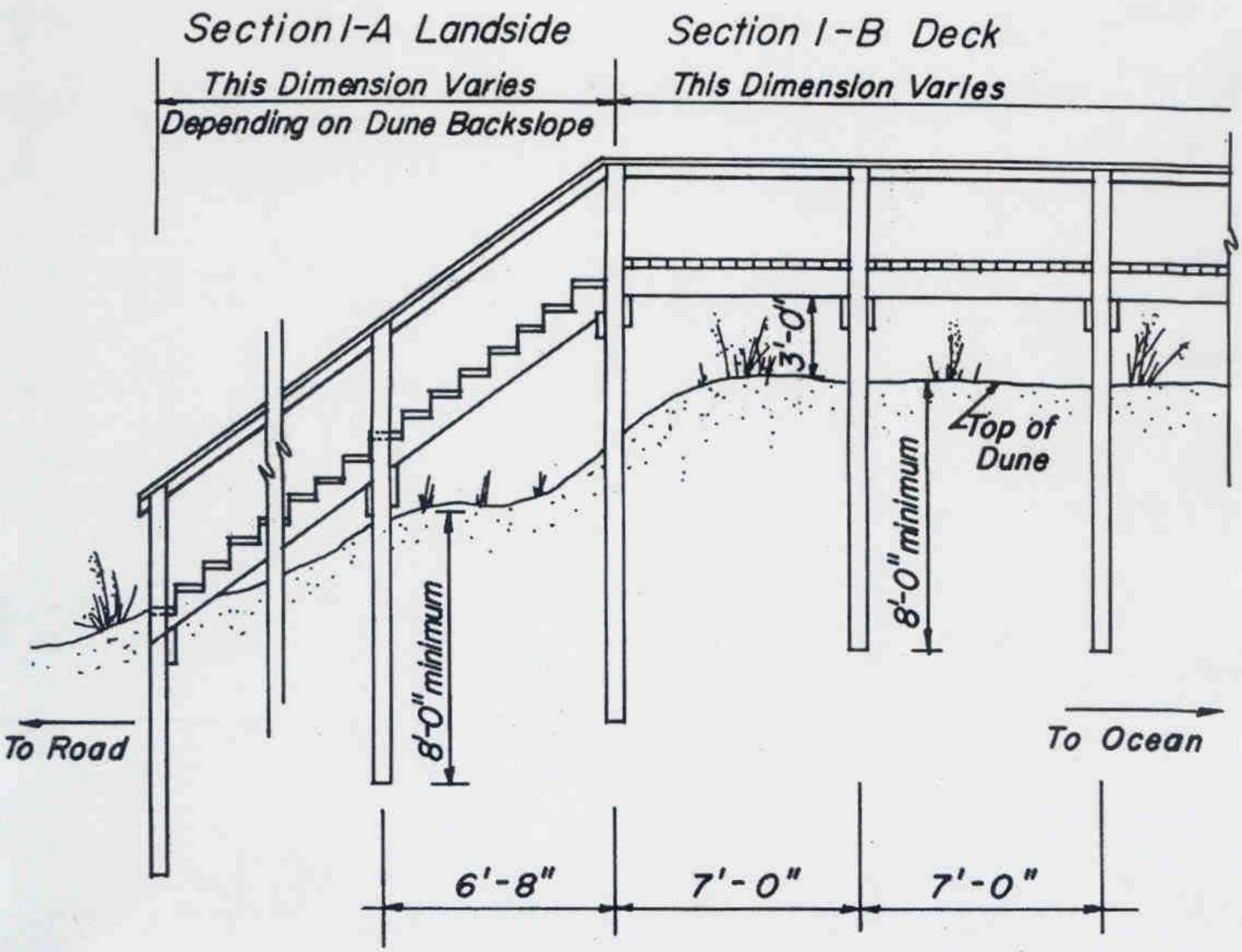


Fig. 7 ALTERNATE SECTION No. I
Scale : 1" = 5'-0"
(Refer to details as per Figure 2)

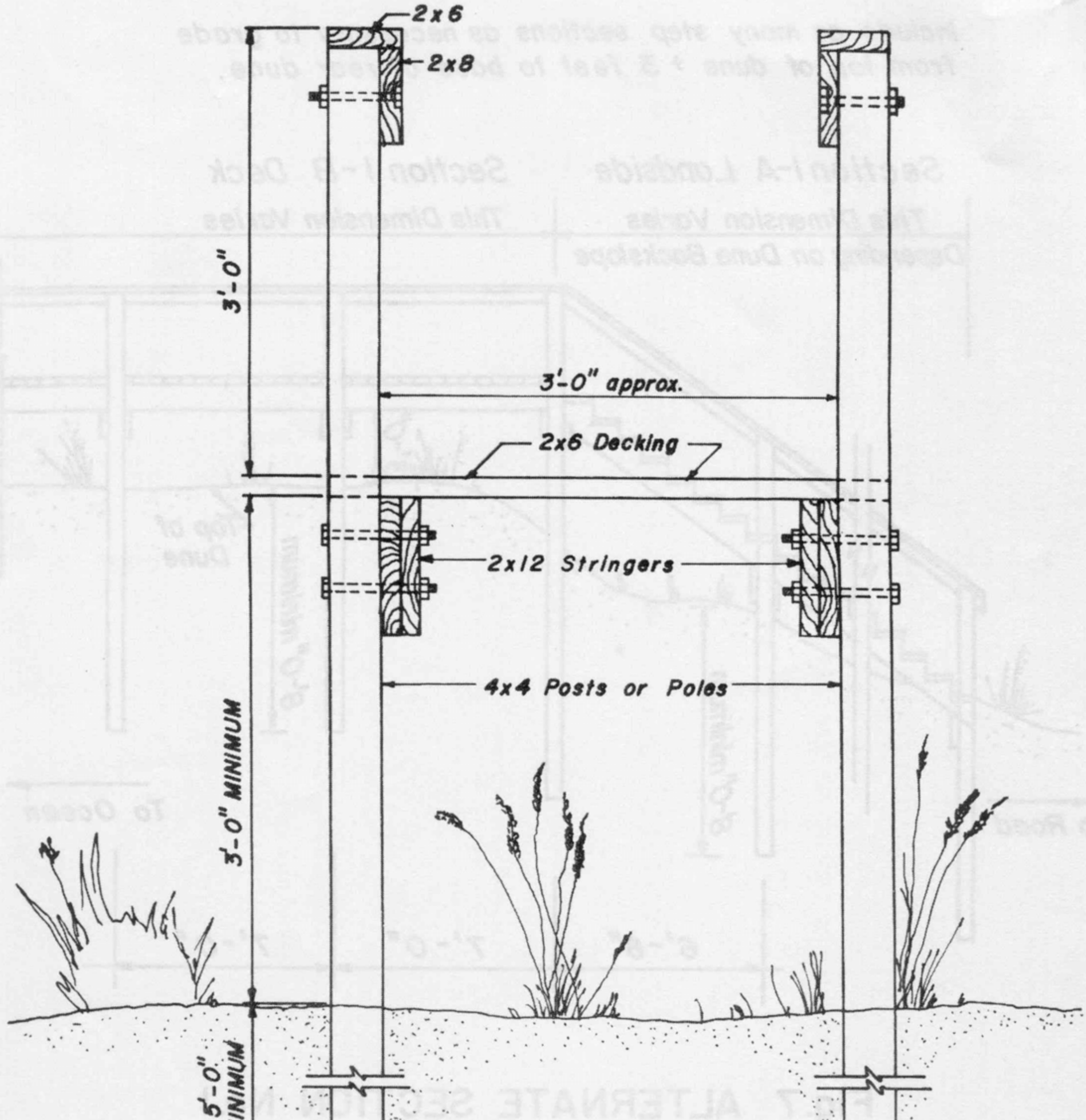
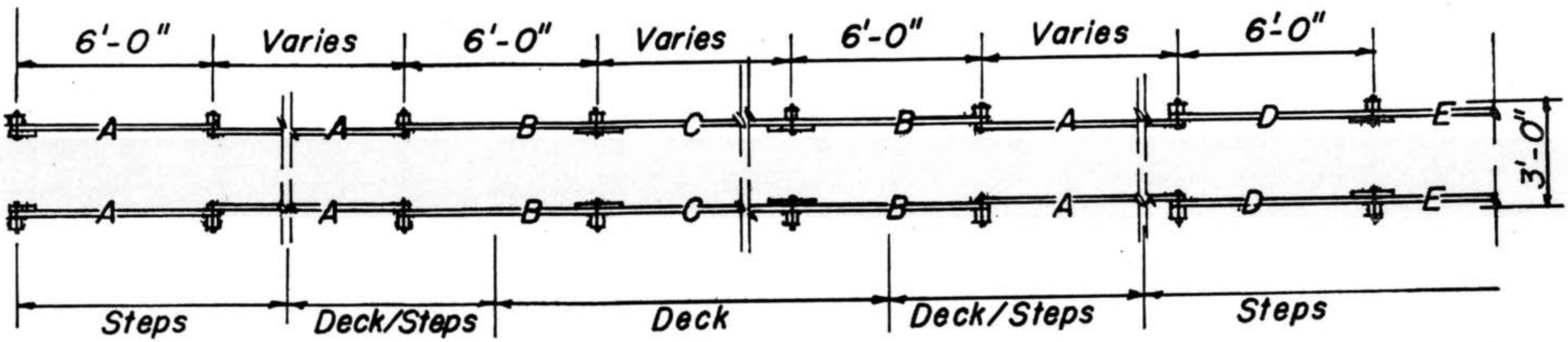


FIG. 8 TYPICAL SECTION scale: 1"=1'-0"



STRINGER DIMENSION	
A	2 x 12 x 8' notched for steps
B	2 x 12 x 7'-9"
C	2 x 12 x 6'
D	2 x 12 x 7'-8" notched for steps
E	2 x 12 x 7'-6 notched for steps
SPLICE BLOCK DIMENSION	
F	2 x 12 x 1'-6"

BILL OF MATERIALS	
QUANT.	ITEM DESCRIPTION
108'	2x12 Stringers & Splice blocks
16	4"x4" Posts or Poles
66	1/2"x 12" Hex bolt w/ nut and washers
36	2x6x 20' dressed
28	2x8x 20' dressed
4	2x10x 20' dressed

Note: *All splice blocks to be nailed to stringers to provide both lateral and bearing support at joints. All pile bolted connections to be 1/2"x 12" hex bolt with nut and washers.*

Bill of Materials based on 24' deck and step lengths, 6' and 12'.

FIG. 9 TYPICAL STRINGER LAYOUT
scale: 1" = 5'