BANK FAILURE ASSESSMENT
16 Sea Watch Court, Florence, OR

March 18, 2011

Prepared for:
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EXECUTIVE SUMMARY

A catastrophic bank failure occurred on the east bank of the Siuslaw River below 16 Sea Watch Court in Florence on December 26, 2010. In an area approximately 80 feet wide (N-S) and up to 70 feet long (up- and down-slope) sand and imported fill slid downslope along several compound, head-ward progressive failure surfaces. Since that time, movement has occurred sporadically, resulting in further exposure of the lower portion of a sheet pile sea wall retaining the sand on which the western portion of the house is constructed. After a similar failure in 1997, a sheet-pile seawall had been constructed near the house and a rip rap revetment and two-tiered gabion-basket buttress had been placed at the toe of the bank. The gabion buttress had been pushed into the river by the recent movement along with a portion of the rip rap revetment. At the time of this writing, the exposure of the seawall is at or slightly beyond the maximum for which the sea wall is designed.

In this area, the east bank of the Siuslaw River is underlain in the shallow subsurface by recent dune sand, consisting of fine, poorly graded sand. Albeit stabilized at the surface by vegetation, the sand in these recent dunes is non-cohesive. The most recent dune sand overlies several generations of older dune deposits on which paleo-sol formed at the time they were located at the surface. The paleo-sol consist of dune sand which has been cemented by clay and iron hydroxide compounds derived from weathering of feldspar and ferro-magnesian minerals contained within the sand. These older dune deposits and paleo-sol are grouped together in a unit which is designated as Marine Terrace Deposits (MTDs).

Several mechanisms of erosion/slope movement contribute to the eastward recession of the bank. The MTDs exposed at and near the water level of the Siuslaw River are eroded by the current, wave action (exacerbated by the wakes of water craft) and water dripping and running over the steep edges. Erosion of the uncemented recent dune sand mostly occurs as a result of development of groundwater pore pressures near the base of the unit and resulting mobilization of the sand grains by flowing water or liquefaction of the sand by the pore pressure. The groundwater discharge occurs as a result of precipitation falling on a large area east of the bank, with the groundwater perched on the impermeable, cemented paleo-sol in the subsurface and running off westward following the buried topography. The removal of the sand at the base of the slope results in loss of lateral support at the toe, which, in turn results in sporadic catastrophic sliding movements of larger blocks of sand higher on the slope. Another mechanism of sand removal higher on the slope is the headward progression of minor scarps by flow of the sand during the drier summer months.

Due to the high risk to the house at 16 Sea Watch Court, it is recommended to mitigate the recent catastrophic bank failure as soon as possible. The proposed mitigation involves installation of a sand-retention system at the top of the cliff-forming MTD paleo-sol, reconstruction of the buttress using rip rap instead of gabions and re-construction of the rip rap revetment at the toe of the slope utilizing appropriate filter geotextile. As part of this work, it is proposed to remove additional gabion baskets present to the north of the currently active failure and those gabions currently in the river, which can be reached with the equipment.

INTRODUCTION AND SUMMARY OF SITE HISTORY

This report presents the findings of an assessment of the bank failure which occurred on December 26, 2010, below the residence at 16 Sea Watch Court in Florence (Figures 1 and 2), following significantprecipitation. The failure has continued to be active and has progressed head-ward since that time. The house, which was constructed in 1992, is the oldest structure in the Sea Watch Estates subdivision, which is located on the east bank of the SiuslawRiver immediately south of the Coast Guard Station. Failures have occurred at the site previously, in 1997 resulting in mitigation using a sheet pile seawall near the top of the slope and rip rap placement along the lower bank. When failures of the slope continued below and adjacent to the seawall, a two-tiered gabion basket system was installed above the rip-rap revetment to retainthe sand. The slope was then restored by importing sand containing organics ("root mat"). This assessment was conducted and the report prepared in its entirety by Dr. Gunnar Schlieder, an Oregon Certified Engineering Geologist.

GEOLOGY AND SOILS (Published Information)

Geologic History

The site is located on the east bank of the Siuslaw River, in an area indicated to be "Sand Dunes" on the geologic map accompanying USGS Water Supply Paper 1539-K *Ground Water in the Coastal Dune Area Near Florence, Oregon* (Hampton, E.R., 1963). The water resources paper indicates that the dune sand is located over a "planed-off" surface of underlying Tertiary *Tyee Formation* (sandstone). Cooper (1958) includes the area in the Coos Bay dune sheet, North Siuslaw Region. Lately, investigators (e.g. Beckstrand, 2001, Peterson, 2002) have described the area as part of the "Florence Dune Sheet". Whereas earlier researchers assumed that the dunes were formed in response to *Holocene* (younger than approx. 10,000 years BP) sea level rise, more recent thermoluminescence and radio-carbon dating has shown that portions of the dunes are up to 37,000 years old or older. Published thermoluminescence and radio-carbon dates (Beckstrand, 2001, Peterson, 2002) on dune deposits and vegetation covered by the Florence Dune Sheet just north of the subject area indicate ages ranging from 6,100 to 24,600 years BP.

Of importance in this context are eustatic (global) sea level fluctuations which are related to the amount of water stored in ice sheets during glacial periods in the *Pleistocene* (appr. 1.64 Million to 10,000 yrs BP). As water is stored on land as ice, sea level drops. The maximum reported drop in the last 80,000 years occurred around 18,000 years ago, at the time of the last glacial maximum. At that time, global sea level is thought to have been approximately 400 feet lower than today (Shackleton, 1986, 1987) and the mouth of the Siuslaw would have been located up to 25 miles farther westward than today. With the *late Pleistocene* and *Holocene* deglaciation, sea level has once again risen and this rise is continuing today. During the previous interglacial high stand, which occurred approximately 135,000 years before present (yBP), sea level was approximately 15 feet higher than today.

Name: MERCER LAKE
Date: 3/1/2011
Scale: 1 inch equals 2000 feet

Location: 043° 59' 32.4" N 124° 07' 19.1" W
Caption: Figure 1: Location Map

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Figure 2: Site Vicinity Map, Tax Lot Map, and 1997 Contour Map

Not to Scale. Base from Google Earth, Lane Co. Tax Map, and Ward Northwest.

Based on the age dates obtained in the vicinity in recent years, a significant portion of the dune sand at the site was likely deposited during the period from approximately 24,000 to 6,000 yBP, including the period of the last glacial maximum. At that time, sea level was around 400 feet lower than today and the mouth of the Siuslaw River would have been several miles to more than 20 miles west of its current location. It is probable that soil horizons formed at that time on several paleo-land surfaces which were subsequently buried by additional advancing dunes. This process of soil formation and subsequent burial was likely repeated several times during the period of deposition, resulting in the presence of several buried soil horizons within the dune sand deposits. The soil horizons are characterized by the presence of organics, buried tree stumps in growing position, and decomposition of some of the mineral grains contained in the sand. Partial or complete decomposition of some silicate minerals other than quartz (e.g. feldspars, pyroxenes, hornblende) has produced both clay minerals and iron-oxides which tend to cement the sand. These cemented sands and paleo-sols have been designated as part of a larger group of sediments known as Marine Terrace Deposits or MTDs.

The Siuslaw River is currently located immediately west of the subject site, although older channels, now buried by dunes, are probably present both to the west and south, and possibly east of the site. Since the early 1900s, the current location of the channel and mouth of the river has been artificially maintained by the US Army Corps of Engineers. Maintenance of the location of the channel is achieved by several means, including construction (and later extension) of the Siuslaw Jetty, dredging of the channel, and construction of several groins along the west side of the channel approximately one half mile downstream from the subject site. The latter measures are designed to prevent the river from shifting its mouth southward by breaking through the fore-dune area of the sand spit which extends northward west of the river for 3.5 miles from the area west of downtown Florence to the current mouth of the river.

Soils

The *Soil Survey of Lane County Area, Oregon* (USDA Soil Conservation Service, 1987) indicates that the site is underlain by *Waldport fine sand, 0 - 12 percent slopes*. The soil is developed on stabilized sand dunes. The typical soil stratigraphy is described as:

> "Typically, the surface is covered with a mat of leaves, needles, and twigs about 3 inches thick. The surface layer is very dark gray and very dark grayish brown fine sand about 5 inches thick. The substratum to a depth of 60 inches or more is yellowish brown fine sand".

The Unified Soil Classification System (USCS) group names are: 0-5": SM; and 5 - 60": SM.

Physical Setting

The residence is located on hummocky ground resulting from its origin as sand dunes. This dune topography terminates against the east bank of the Siuslaw River immediately west of the residence. The bank is approximately 50 feet high and sloped at an overall angle of approximately 1.25H : 1V.

SITE OBSERVATIONS

Methods

The site was visited on several occasions in late January and early February, 2011. On January 19 and 20, three topographic sections were measured in the fall line in the northern, central, and southern portion of the failure, respectively. The sections were measured using a clinometer and 300-ft fiberglass tape measure. Also, two Williamson Relative Density Drive Probes were installed. The method uses a 12-lb slide hammer with a 40-inch drop to drive nominal ½-inch steel pipe with smooth couplings into the ground. Blow counts are obtained for 6-inch intervals and reported as blows per foot (BPF) per six inches. The locations of the sections and drive probes are shown on Figure 3.

Results

The currently active failure is approximately 80 feet wide (Figure 3) and, for the most part, extends from the steel sheetpile sea wall beyond the low water mark of the bank of the Siuslaw River. At the southern end, the failure extends eastward beyond the edge of the sheetpile wall and is encroaching north toward the house behind the seawall (see site photos, Appendix A). Figures 4, 5, and 6 show the three field-developed geologic cross sections measured at the site. The failure area is underlain by imported organic-rich sand ("root mat") overlying native clean, cross-bedded dune sand, which in turn overlies several older dune forms with variably well-developed paleosol horizons. The lowermost two (exposed) paleo-sol appear to be horizontal to very gently sloping. Another, higher paleosol has significant relief, rising towards the east at angles ranging from approximately 10 degrees to 36 degrees. The lower two paleo-sol form both a "ledge" (lowermost paleosol, designated SU-1, and exposed only at low tide) and a "cliff band" (second-lowest exposed paleosol, designated SU-3, mostly exposed even at ordinary high tide) which ranges in height from approximately 4 feet to as much as 8 feet or more south of the immediate failure area. All paleo-sol consist of former dune sand which is cemented by clay, derived from weathering of feldspar sand grains and, in places, by iron hydroxides (rust), derived from weathering of ferro-magnesian sand grains. Even the better-cemented portions of the material can be easily cut and craved with a pocket knife.

SU-1 and SU-3, the two lowermost exposed paleo-sol are separated by a layer of less cemented dune sand which is cross-bedded, and appears to range in thickness from 1 to 2 feet. This unit, which was designated SU-2, forms a "groove" at the base of the cliff-forming SU-3. Erosion of SU-2 proceeds until the overlying SU-2 is sufficiently undermined to fail by toppling of blocks of the better-cemented material. Numerous of these blocks lie on the ledge formed by SU-1,and most of these blocks are covered with barnacles.

SU-4, the uppermost paleosol is exposed only in the center of the failure area, where it is characterized by rust-brown staining. This unit appears the least cemented of three exposed paleo-sol. Nonetheless, groundwater is discharging on top of SU-4 from the overlying un-cemented dune sand.

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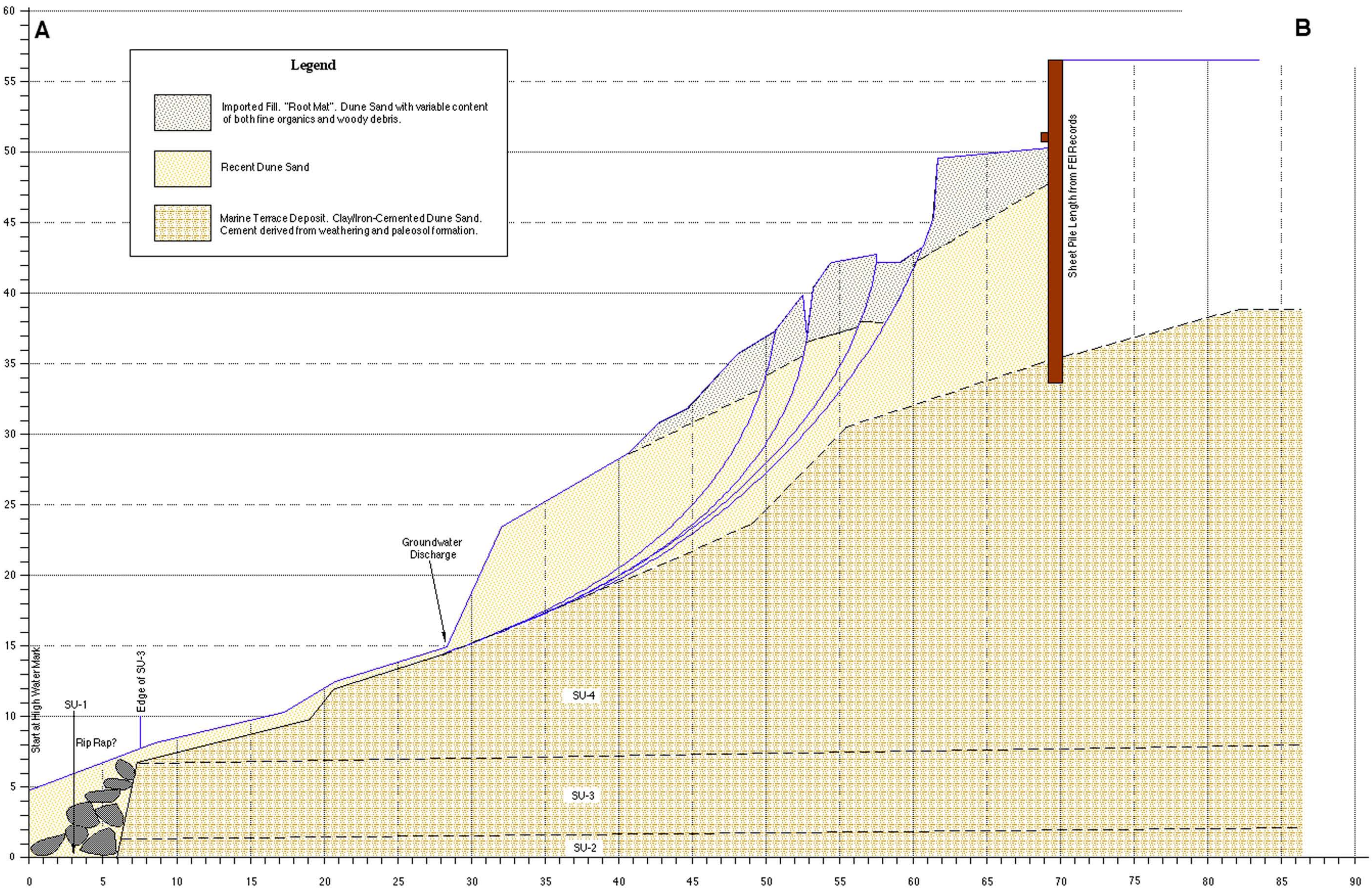
Figure 3: Failure, Field-developed Cross Section and WRDP Locations

Not to Scale. Base from Google Earth, Lane Co. Tax Map, and Ward Northwest.



Note: Section measured using clinometer and 300-ft fiberglass tape. This represents only one of numerous possible interpretations of the data. It is based on very limited subsurface information and is subject to change as additional data is developed.

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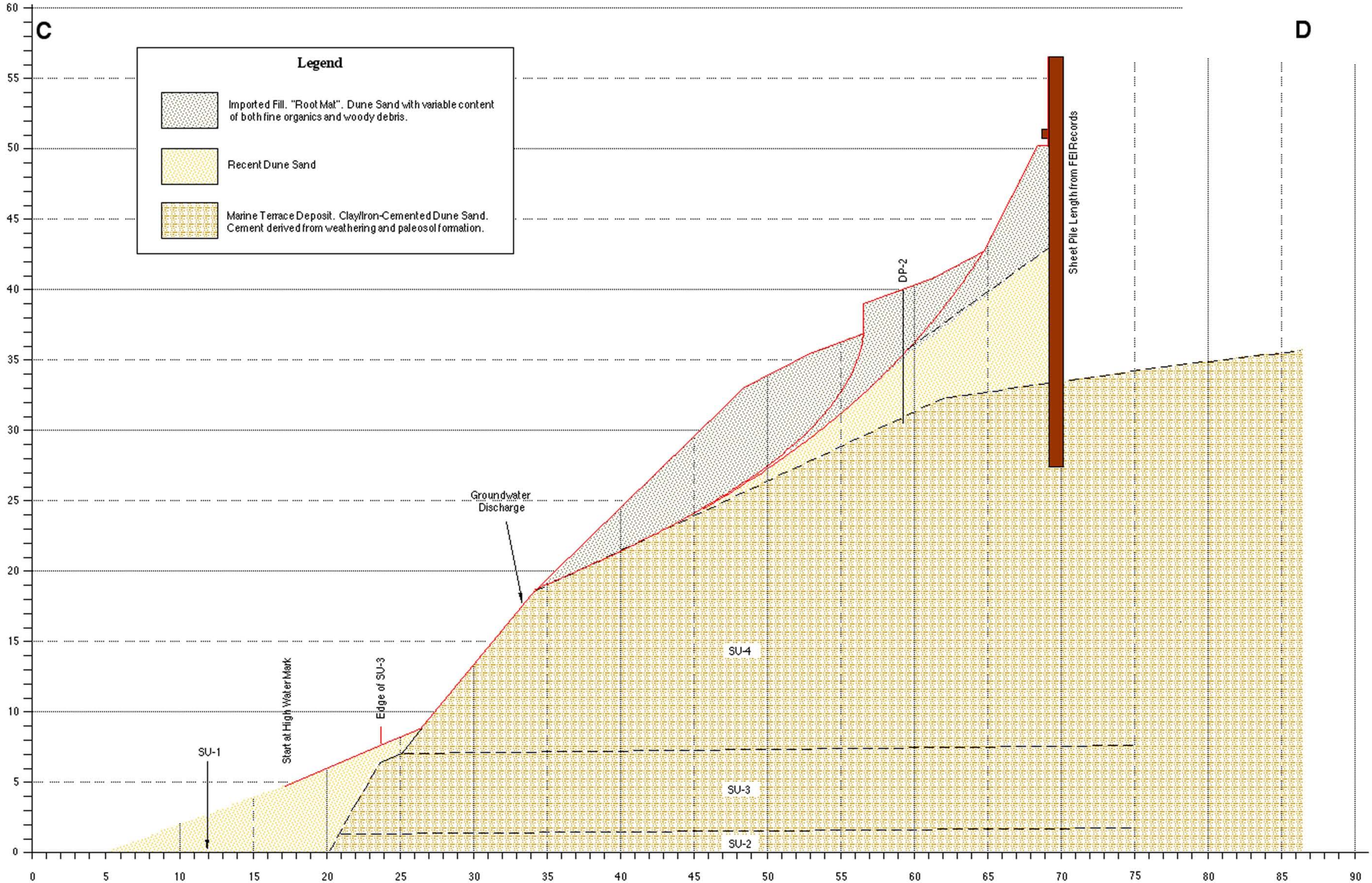
Figure 4: Field-Developed Cross Section A-B

Scale as Shown (1" = 5')



Note: Section measured using clinometer and 300-ft fiberglass tape. This represents only one of numerous possible interpretations of the data. It is based on very limited subsurface information and is subject to change as additional data is developed.

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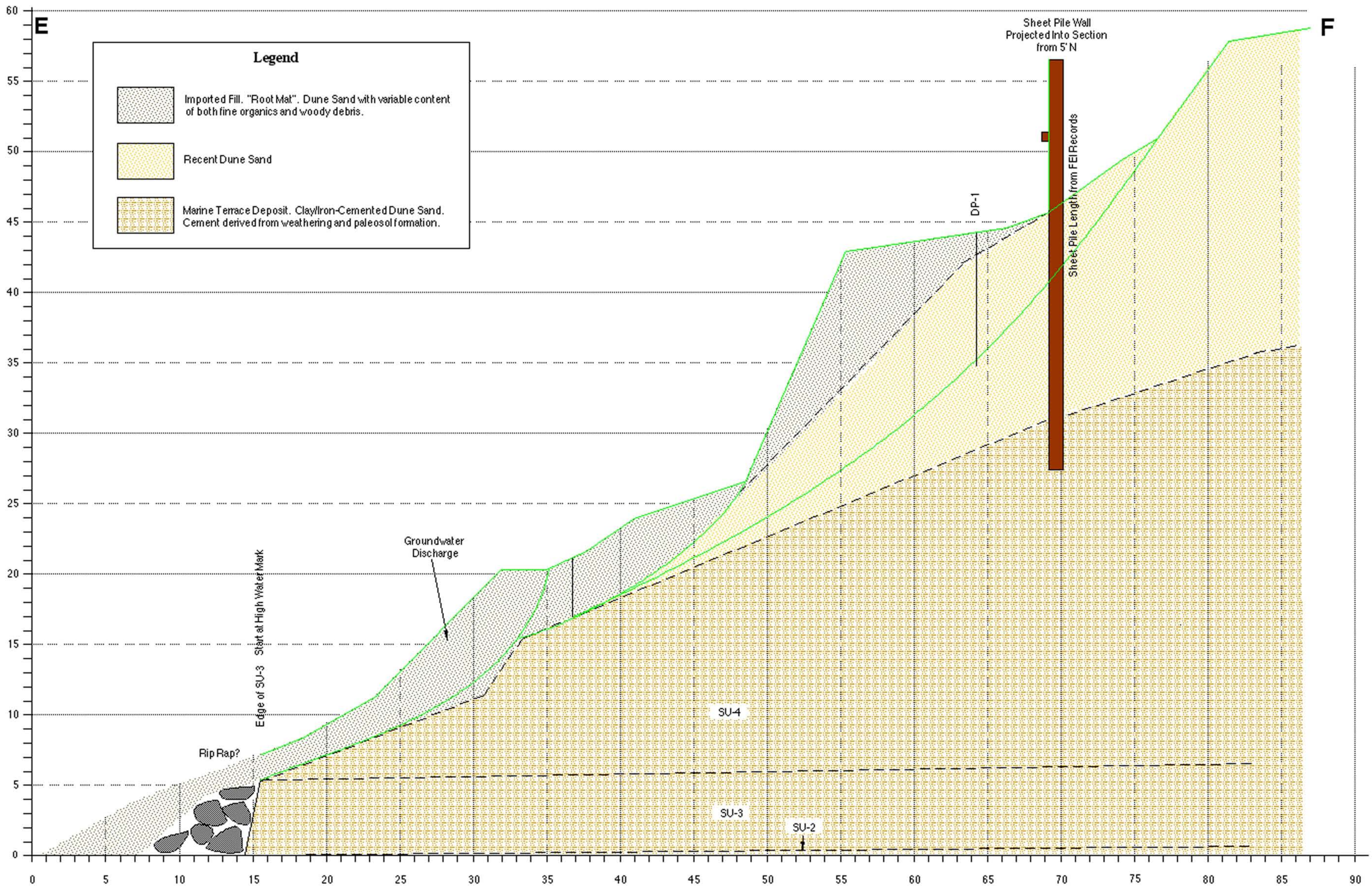
Figure 5: Field-Developed Cross Section C-D

Scale as Shown (1" = 5')



Note: Section measured using clinometer and 300-ft fiberglass tape. This represents only one of numerous possible interpretations of the data. It is based on very limited subsurface information and is subject to change as additional data is developed.

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	Figure 6: Field-Developed Cross Section E-F
	Scale as Shown (1" = 5')

Significant groundwater discharge is occurring at three distinct locations within the failure area. These locations are near the northern and southern limits of the recent failure and in the central portion. At all three locations, groundwater is discharging sufficiently rapidly to mobilize the un-cemented dune sand on top of SU-3 or -4, which then flows slowly toward the west. At the western edge of the top of SU-3 the sand is deposited, as the water drains downward. However, this area of deposition is located within the tidal inundation zone and, therefore, the sand is removed by the river at high tide. As a result, the failure has not reachedequilibrium, and is progressing headward at all times, accelerating during and following periods with heavier precipitation.

A steel probe was utilized to ascertain that SU-4 extends across the entire lower- to mid-slope from the center to the northern and southern limits of the current failure. The unit was found at different depths, with the maximum depth around 6 feet located about 23 feet north of the central exposure of the unit. Low areas found in SU-4 in this manner correlate well with concentrations of groundwater discharge from the slope.

In addition to the three sand liquefaction areas within the failure area itself, significant amounts of sand were observed in transport off the edge of SU-3 both to the north and south of the boundaries of the current failure. A smaller, recent parasitic failure area is present within the larger older failure extending south across the slope of the adjacent lot. Below the smaller failure, significant amounts of sand were observed in transport over the cliff of SU-3. Similarly, sand was observed in transport over the top of SU-3 in the vicinity of the gabions remaining above high tide level immediately adjacent to the failure area to the north.

Portions of the gabion baskets were observed partially buried under the northern edge of the failure. These gabions appear to have been pushed westward and toppled off the cliff-forming SU-3. It is likelythat the rest of the gabions have been pushed into deeper water below the low tide level near the center of the failure, where they have been buried by the slope failure deposit. Similarly, portions of the older rip rap revetment appear to remain in place both at the northern and southern edge of the failure, but in a portion of the center of the failure, estimated at 15 to 20 feet wide, the revetment appears to have been pushed into the river.

DISCUSSION

The house at 16 Sea Watch Court in Florence was constructed in 1992, prior to development of a clearer understanding of the mechanisms contributing to the eastward retreat of the river bank along the stretch of the Siuslaw River from it's northward turn near downtown Florence to the north jetty at its mouth. Based on observations at this site, at Marine Manor, located approximately 1/4 mile to the south, at Shelter Cove, located approximately ½ mile to the north, and at other sites in between, several mechanisms are active in the recession of the river bank, not all of which are directly related to erosion by the current or waves.

Erosion of Uncemented Dune Sand as a Result of Groundwater Discharge

The primary factor contributing to the erosion of the completely uncemented sand of the most recent generation of dunes along this stretch is piping and liquefaction of the sand by groundwater discharging to the river which is perched on the much less permeable clay- and iron hydroxide-cemented dune sands of the Marine Terrace Deposits (MTDs). The upper surface of these older dune sands appears to be sloping generally to the west for a significant distance (a couple of miles?) eastward. Precipitation falling onto the dune sheet to the east of the subject site percolates downward through the recent dune sand until it reaches the impermeable MTD's and then moves westward through the base of the dune sand until it reaches the bank of the Siuslaw. There, the volume of water discharging during and following times of significant precipitation produces pore pressures of sufficient magnitude to mobilize the uncemented dune sand either as slow-moving flows or within small creeks/rivulets discharging from the base of the dune sand. Based on Hjulström's diagram and Shield's diagram, fine sand is the material which is most easily mobilized by the shear stress imparted by flowing water. The mobilized sand is then transported to the edge of the MTDs either as a flow of liquefied sand or at the base of the small creeks/rivulets. From there the sand is then removed by the current of the river. Because this mechanism is active only directly above the MTDs, in many cases located at the toe of the bank, sand is preferentially removed from there, resulting in removal of lateral support at the toe of the bank. Subsequently, the sand located on the bank above fails in one of several modes. During the winter, while the sand is moist and has apparent cohesion (due to the surface tension of the water), the failure occurs either by toppling of blocks of sand, or by sliding failure along straight or curved surfaces within the sand. Due to the depth at which these failure surfaces occur and due to the mass of material involved in larger blocks, these failures cannot be addressed by vegetation and root strength. During the summer, when the near-surface sand layer dries out and loses the apparent cohesion, failure occurs by dry flow of sand grains, which results in a "knick point" migrating up the slope. Based on observations and testing at the site of the Three Rivers Casino, GeoScience determined that the stable angle of dry Florence dune sand is on the order of 27 to 28 degrees, or very close to 2H : 1V (50% slope). Of course, even if this angle is maintained, wind erosion can still be a factor. However the latter issue can be effectively dealt with by planting vegetation.

In this case, an initial failure of this kind was mitigated in 1997, by installation of the sheet-pile wall and rip rap and gabion baskets on the MTDs at the toe of the slope. However, due to a lack of