THESIS APPROVAL

The abstract and thesis of Sunny Blake Simpkins for the Master of Science in Geology were presented April 22, 2008, and accepted by the thesis committee and the department.

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ABSTRACT

An abstract of the thesis of Sunny Blake Simpkins for the Master of Science in Geology presented April 22, 2008.

Title: Surficial Mapping of Lincoln City and Newport Dune Sheets of the Oregon Coast.

At the onset of development resurgence, the central Oregon Coast counties are positioned at a pivotal time to create sustainable growth. The central Oregon coastal plain is primarily comprised of active or stabilized sand dunes that extend 0.5-3.0 miles inland and range in age from present to 111,000 years old. Engineering and hydrologic site assessments are complicated due to the paleodunes' various layers of interbedded soils, cemented sand, iron oxides and deflation zones; previous studies have not differentiated the paleodune strata from alluvium or beach strata that locally overlie the marine terraces. The surficial GIS database created in this project integrates geologic analysis of the paleodunes with thematic data such as digital elevation models (DEM), surface hydrology, roads, and jurisdictional boundaries. The geospatial relations established in the geodatabase will enable the end user to better predict development impacts on slope stability, surface water drainage, dune aquifer contamination, and dune pond habitat. Through GIS analysis this project has established that development is primarily occurring in the coastal plain in Lincoln County rather than the foothills of the Coast Range. Compilation of relative dune

sheet cementation data indicate that where excessive groundwater flow occurs at dune-bedrock contact, there is cement leaching. This leaching is also confirmed by field observations of slope failures initiated in the weakest basal dune strata. Rapid, deep seasonal dune sheet drainage is established through analysis of redox conditions interpreted from dune strata logs. These conditions cause a reducing environment, limiting the natural biodegration of bacterial and/or other contaminants in the dune aquifer. GIS spatial analysis of the dune aquifer and the basal aquitard confirm that public beaches, creeks and ponds are directly connected through the groundwater to non-point source contamination. The geospatial relationships established in this project are the first land-use targeted application of recent surficial mapping within a complete Oregon Coast dune system.

SURFICIAL MAPPING OF LINCOLN CITY AND NEWPORT DUNESHEETS OF THE OREGON COAST

by

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A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
GEOLOGY

Portland State University
2008

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Introduction

The Oregon Coast presents unique challenges for providing safe and sustainable development as the area's population significantly expands. Active or stabilized sand dunes comprise approximately 62% of the Oregon ocean-facing coastline (Reckendorf, 1998). For the central Oregon coast covered by the Lincoln and Newport dune sheets this value exceeds 80% (Figure 1). Considerable residential and commercial development occurs on the sand dune cover within the coastal plain (Clough, 2005). The stabilized dunes referred to as paleodunes contain interbedded soils, cemented sand, iron oxides, and deflation layers that pose unusual geotechnical and hydrologic properties (Clough, 2005).

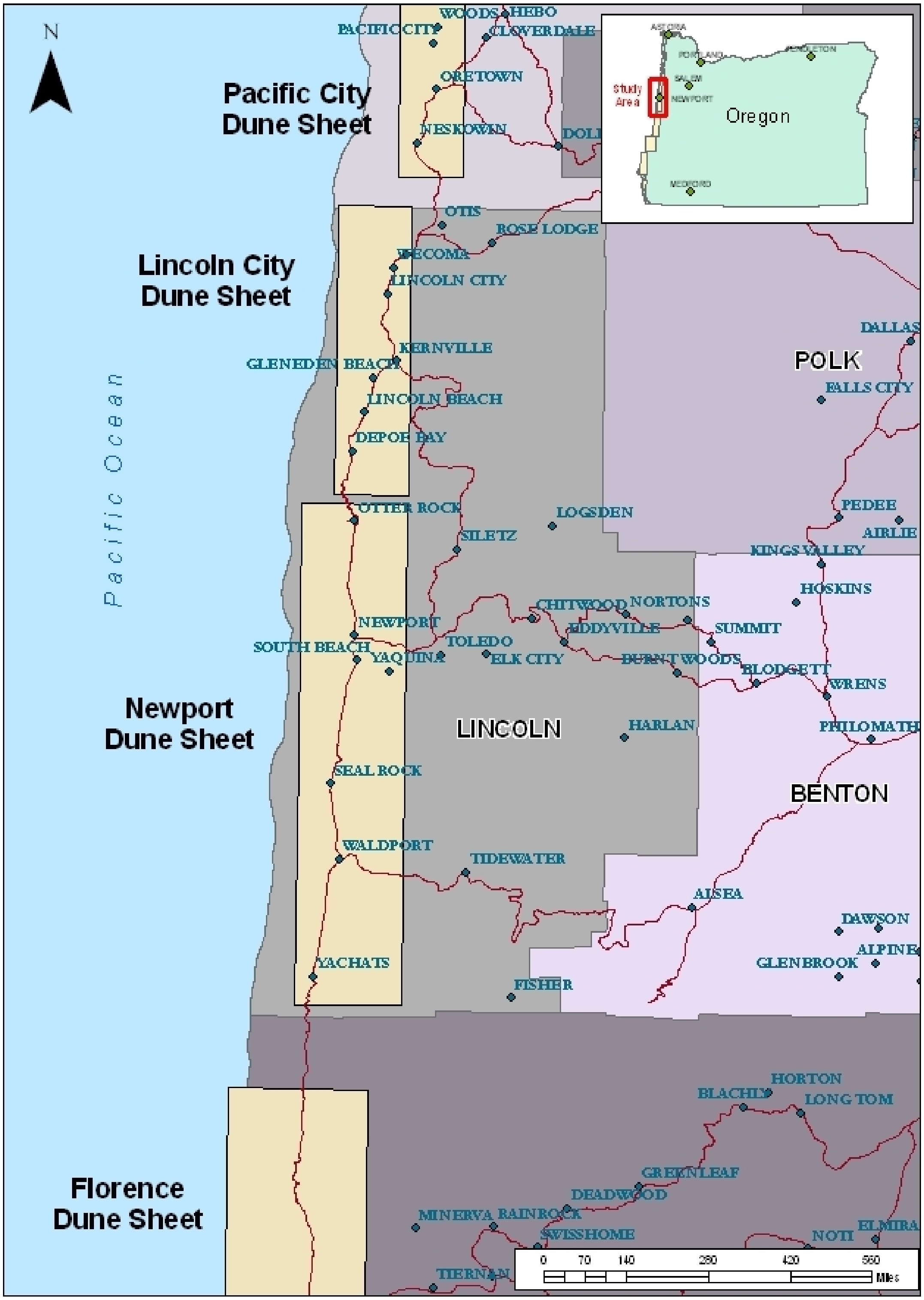

Figure 1: Oregon's Central Coast showing the location of the Newport and Lincoln City Dune Sheets.

In 2005 Charles M. Clough's thesis posed the question: "Do the paleodune deposits require special geotechnical consideration for site planning, development and construction?" His results show that the dune sheets do require special consideration for development of the areas because of their unusual geotechnical properties resulting from the alternating sequences of dune paleosols, dune cemented sand layers, dune peat layers, loess layers, and uncemented dune sand layers (Figure 2).

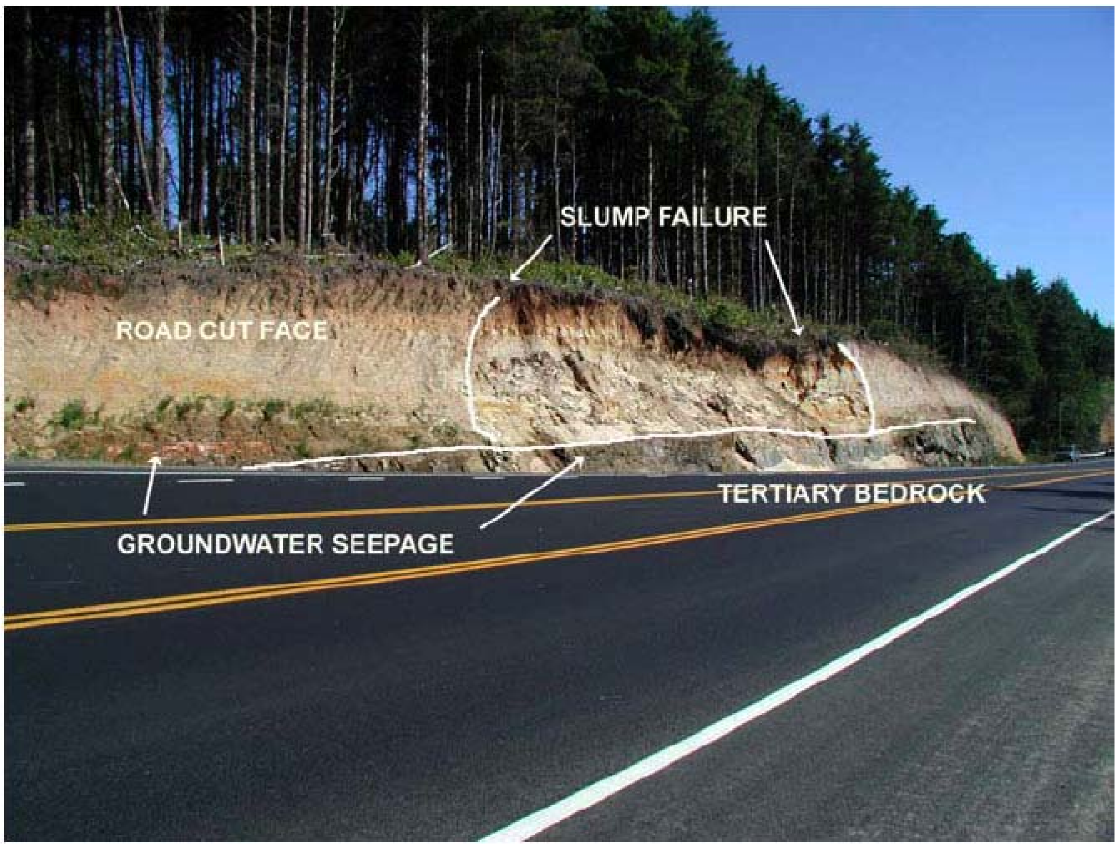

Figure 2: A roadcut failure along Highway 101 south of the Newport Airport. There is groundwater seepage at the contact between paleodune and bedrock causing loss of cement and loss of shear strength in the paleodune strata (Clough, 2005).

Hydrologic issues within the paleodunes also complicate development in the coastal plain. Nutrient input into interdunal lakes from ground water seepage has been identified as one of the possible causes of eutrophication in the lakes increasing algal and macrophyte growth (Nielson, 2005). The growth in residential development and associated use of fertilizers around interdunal lakes could lead to greater nitrogen and phosphorus input, causing the lake to become trophic. Another hydrologic issue is the presence of paleosol aquitards in the Pleistocene dunes that lead to perched water tables, and locally problematic drainage for septic systems. An additional issue is *E. coli* contamination of public beaches which are linked to leasking sewer drainage into the Pleistocene dune aquifer (Peterson et al., 2003).

Prior geological investigations (Schlicker et al., 1973) indicate that Oregon's central coastal plain is overlain with undifferentiated marine terrace deposits including dunes, beach sand and lenses of pebble and cobbles. The maps produced from these previous studies do not illustrate the full extent of the paleodune deposits and their complex stratification of sand and buried soil horizons. In addition, there continues to be a lack of understanding of the dune deposits among engineers, geologists, planners and consultants (Figure 3). Development problems such as slope failure, drainage, coseismic liquefaction, and sea cliff erosion are persistent in the central Oregon coastal plain. These issues seem to be related to incomplete field reconnaissance compounded by misinterpretation of the site geologic data. It is imperative for land use interests to understand the complexity of the paleodune's geotechnical and hydrologic characteristics in order to make safe and sustainable decisions for development along the coastal plain. The ultimate goal of this project is to provide accessible geospatial data that will relate key properties of the dune deposits to the natural resources, infrastructure, and future development in the coastal plain.

Figure 3: Parking lot behind Newport Middle School. This slope was cut to extend parking and road access. It contains paleodune deposits overlying weathered mudstone. The initial grades were too steep, resulting in gullying and small slumps in the paleodune deposits after winter rains. The paleosol near the middle of the slope reduced drainage and lead to excess surface runoff causing gullying of the weakly cemented paleodune sand. The slope has been mitigated by installation of geotextile nets and grass seeding, and a lateral drainage system. Photo from Peterson et al. (2003).

To accomplish this goal the following objectives are addressed in this study:

1) Gain insight from the Lincoln County, Lincoln City and Newport City officials, Geotechnical consultants, and other land use interests, as to what will make the GIS dataset useful in their decision making process for planning and permitting of developments in the Lincoln and Newport Dune sheets.

2) Create a GIS dataset of existing dune sheet properties including minimum dune sand thickness, dune soil relative strength, depth to groundwater influence and dune emplacement age.

3) Incorporate other GIS datasets such as jurisdictional boundaries, infrastructures, digital elevation models (DEM), surface hydrology, cadastral and known cultural sites to the surficial maps.

4) Analyze the overlapping coverages to highlight areas of potential risk from geotechnical, hydrological or sensitive habitat conditions, and provide the potential risk coverages in GIS and hard copy format to the County and City planners and engineers.

Beckstrand (2001) and Peterson et al (2002) hypothesized that the older paleodune deposits along the Oregon Coast are remnants of extensive dune sheets that were formed during the late-Pleistocene low stand sea levels. The Pleistocene dune sheets extend 0.5-3 miles inland from the present shoreline. The paleodunes mantle the preserved marine terraces. Dr. Curt Peterson, Dr. Trevor Smith and Dr. Georg Grathoff, of Portland State University along with Dr. John Baham from Oregon State University began an Oregon Sea Grant study in 2002 to examine the paleodune geohydrology, groundwater geochemistry and geotechnical processes. The information gathered from their study provided a strong foundation for my thesis project.

This thesis expands upon previous dune sheet studies by creating surficial maps of the Lincoln and Newport dune sheets (Figure 4) which show the paleodune boundaries from the Pleistocene and Holocene time periods. Cross-sections illustrate the individual dune soil layers as well as alteration proxies of redox conditions from vertical profiles that will indicate depth to groundwater influenced aquifers. The maps produced in this thesis indicate areas with potential slope stability problems, septic drainage, groundwater flow directions and sensitive dune/wetlands habitats. These geospatial relationships are the first application of recent surficial mapping within a complete coastal dune system on the Oregon Coast.

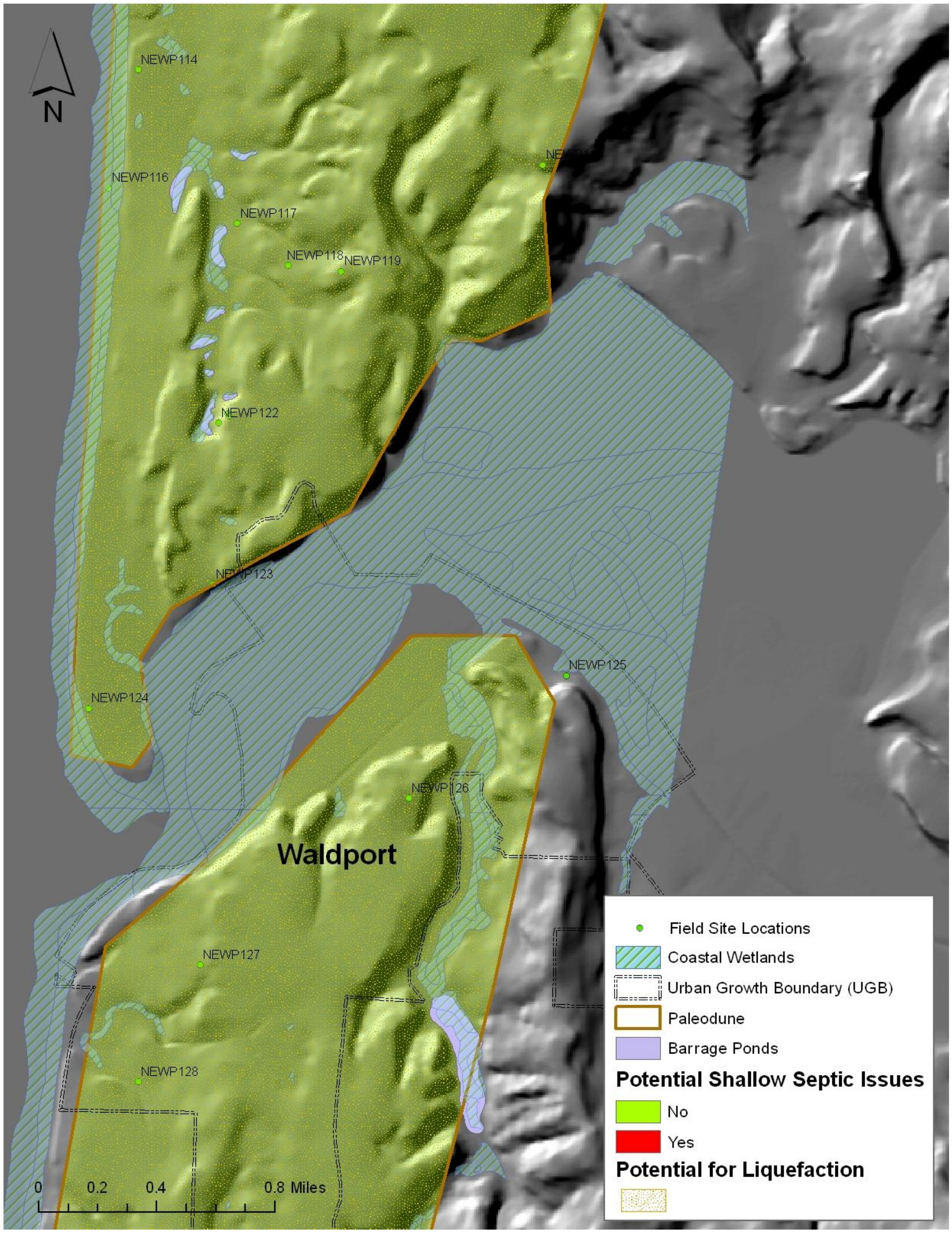

Figure 4: Surficial map example of the Waldport area. This map contains the layers: field site locations, coastal wetlands, UGB, paleodune boundaries, barrage ponds, potential septic issues and potential for liquefaction that can be produced from a GIS dataset.

Background

Study Area (Geography, Geology, Climate)

The study area is located in the Central Oregon Coastal Plain, which contains the informally named Newport and Lincoln dune sheets (Cooper, 1958; Reckendorf, 1985). These sheets are two of the nine dune sheets that were mapped on the Oregon Coast by the 2005 Oregon Sea Grant Study. They are bounded by Cascade Head to the north, Cape Perpetua to the south and the Coast Range to the east. The Coast Range rocks consist of basalts at the higher elevations and siltstones and sandstones along the coastal foothills (Snavely et al., 1976). The remnants of flood basalt flows make up resistant headlands along the coast (Peterson et al., 1991). The central coastal climate is distinguished by wet, stormy winters and dry, mild summers. Typical temperature ranges for the winters are 7°C to 9°C and for the summers are 11°C to 15°C. Most the precipitation falls from November to March with an annual average of 177 cm for 1971 to 2000. Modern wind directions are not relevant to this study as the dune sheets are largely of Pleistocene age.

The geomorphic features of the area's coastal plain began forming in the Pliocene and later through the Pleistocene and Holocene. During the last million years episodic continental glaciation caused global sea level fluctuations (Orr and Baldwin, 1992); these fluctuations caused rapid erosion of the Tertiary deposits of sandstones and siltstones along the Oregon Coast (Reckendorf, 1998). Multiple eustatic high-stands of sea level during the Pleistocene produced successive wave-cut platforms.

These platforms were then tectonically uplifted producing stacks of several coastal terrace levels along the Oregon coast (Cooper, 1958). Tectonic deformation has deformed the marine terraces since at least the Oxygen isotope stage 5e sequence (100-125 ka) (Peterson et al., 2006).

With the lowered sea levels on the inner shelf during Pleistocene glacial periods, the exposed inner-continental shelf was exposed to the subaerial environment (Peterson et al., 2002). During low-stand periods of the late Pleistocene the dune sheets were fed by across-shelf sand supply from low-stand shoreline deposits (Figure 5) (Peterson et al., 2002; Peterson et al., 2006). During periods of enhanced across-shelf sand supply, onshore wind forcing, and diminished vegetative stabilization, the Pleistocene dunes were able to migrate inland. A marine transgression during the Holocene led to the formation of thin dune caps on top of the sea cliffs in this study area (Reckendorf, 1996). Much more extensive Holocene dune deposits occur in the south-central Oregon coast, including the Florence and Coos Bay dune sheets (Peterson et al., 2006).

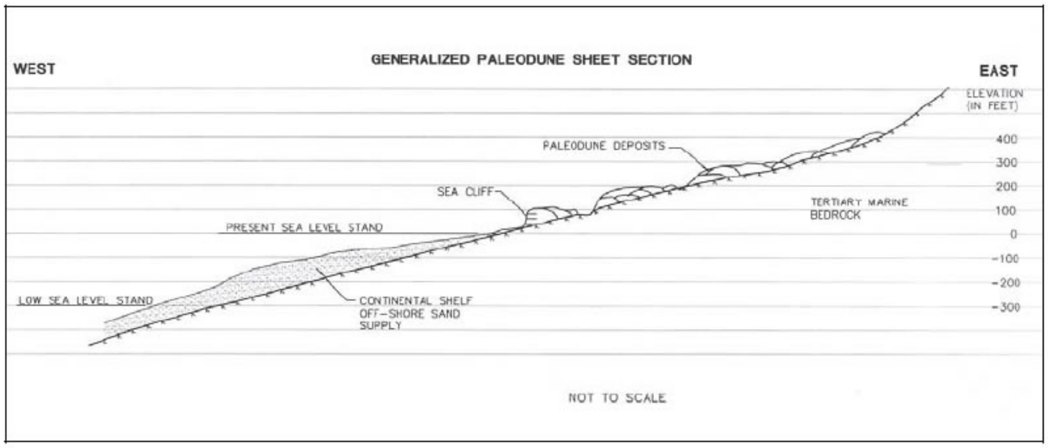

Figure 5: Low stand emplacement model, modified from Beckstrand (2001).

The paleodunes deposits in Lincoln County are largely limited to the low-stand Pleistocene dunes in the central Oregon coastal area. The Pleistocene dune sheets decrease in landward width from 3 km in the Newport dune sheet to about 1 km in width in the Lincoln dune sheet. The dune sheets mantle the preserved marine terraces.

Dunes (History, Geotechnical, Hydrologic)

Recent studies by Clough (2005) and Peterson el al. (2006) illustrate the importance of paleodune geological model to help facilitate sustainable development in the coastal plain. Both studies demonstrate the unique geotechnical and hydrologic properties of the dune deposits that need to be accounted for when developing on these deposits. The unique characteristics of the paleodune deposits are attributed to: 1) the process of formation that occurs during alternating periods of deposition and stabilization, and 2) post-depositional diagenesis of cementation that occurred during the late Pleistocene. The episodic accretion in the parent dune material leads to interbeds that contain variable states of permeability and compaction (Peterson et al., 2006). Previous studies and maps existing of the paleodune sheets do not differentiate between the beach deposits and Pleistocene stratified dune deposits. In addition, soil survey maps only address the upper 1.5m of the parent deposits (Clough, 2005). Considering these limitations of existing soil and geologic maps it is important to develop comprehensive surficial maps of the dune sheet deposits. The availability of such maps will enable land use interests to make informed decisions regarding foundation soils, cut slope stabilities and subsurface drainage.

Clough (2005) identified several unusual geotechnical and hydrologic properties in the paleodune deposits. Conclusions from Clough's study include: 1) some natural angles of repose are significantly larger in the field than laboratory tests would predict, 2) several older deposits contain very weak or no significant cementation, 3) there is lower permeability in several paleodunes than would be expected in recent dune deposits, and 3) substantially higher negative pore water pressure was found in various deposits under triaxial tests. These anomalies are attributed to widely varying cementation in the paleodune deposits.

Sea cliffs and road cuts in the paleodunes are frequently meta-stable at angles 50-70 degrees, which is in contrast to laboratory tests that yield angles of repose between 27-37 degrees for the tested dune sands. Clough hypothesizes that the higher slope angles are provisionary stabilized by hydrous cements under field conditions that dehydrate during sampling and testing (Figure 6). Hydraulic conductivity tests support the hypothesis of weak cementation within the paleodunes. X-ray diffraction

(XRD), Energy-dispersive X-ray spectroscopy (EDX), and Scanning Electron Microscope (SEM) analysis confirm that several paleodune deposits contain poorly crystalline to amorphous cementing minerals of allophone-imogolite, ferrihydrite, gibbsite and vermiculite. The presence of hydrous cements complicates modeling predictions of drainage, slope stability and susceptibility to coseismic liquefaction. Such hydrous cements are at risk for failure when leaching occurs thereby reducing the strength of critical layers.

Figure 6: Photo of steep faces of paleodune sea cliffs illustrating the alternating sequences of erosion resistant cemented layers and un-cemented weak layers at Ona Beach in the Newport dune sheet.

Another distinctive characteristic of the paleodune deposits is that permeability varies greatly between interbedded strata. The lower values ($k=10^{-3}-10^{-4}$) are attributed to: 1) tight packing of particles or filling of the pore space with loess materials, 2) filling of pore spaces with hydrous cement minerals, and 3) densification from coseismic liquefaction. The semibrittle cements temporarily increase the internal angle of friction during stress-strain triaxial testing. Sample dilation in triaxial conditions result in unusually high negative pore water pressure or negative volume strain. Clough interpreted the sample dilation during shearing to the effect of weak cementation of the particles. High permeability of the cemented dune strata leads to high flow rates for groundwater and any contaminants carried by the groundwater.

GIS

Geographic Information Systems (GIS) is a database of spatially referenced features and tools used to store, analyze and present geographic data (Shamsi, 2002). It is a powerful tool for land-use planning because of its ability to produce new information by integrating existing varied datasets (Dai et al., 2001). One of the main objectives of this project is to create a tool for planners and engineers that will help them to make appropriate and sustainable development decisions in the coastal plain. To achieve this goal ArcGIS by ESRI is used because it is the prevailing software used in city, county and private land use decisions (see Results). The data will be packaged in both ESRI's Geodatabase format as well as Microsoft Access. Providing both formats will provide future users the ability to manipulate the data with ease in order to fit their specific needs.

Field data from previous studies of the dune sheets exist in the form of morpho-stratigraphic logs, but these are difficult to interpret by planners and engineers. The surficial GIS models created from this project integrate geologic analysis of the paleodunes with thematic data such as surface hydrology, roads and jurisdictional boundaries. The geospatial relations of these data will enable the user to better understand the unique geologic issues of the coastal plain. The GIS format provides flexibility, allowing users to update the dataset quickly and to incorporate new thematic layers as they become available (Longhorn, 2003). This integrated approach should make geotechnical and hydrologic data more accessible to policy makers thereby improving sustainable development efforts in the coastal plain.

Survey

An important goal of this project is to gain insight from potential users regarding which data types will make the GIS dataset useful in their decision making. Traditionally, scientific research focuses on problem identification. Because of the practical aspects of this study it is important to take into consideration the identified needs of the end users (Robson, 1993). In order to achieve this goal the potential users were surveyed about data, format, scale, and attribute preferences for the potential GIS products.

The use of social surveys in geologic projects is unusual. There is currently a strong push among the scientific community to produce more policy-relevant scientific information. A recent article by Lisa Dilling et al. (2007) calls for more "applied" or "solutions-orientated" research in conjunction with traditional scientific research to make the study results more relevant to decision-making. The survey in this project engages the potential end user in the development process of the data set. Their involvement early in the project should encourage the end-users to employ the surficial maps into their coastal plain planning efforts.

Methods

Introduction

There are four distinct parts to this thesis project. The methods are divided into four sections to describe each component of the project. The first section covers the representative user survey, describing survey design, the sampling method and questionnaire distribution. The next subject is the project database. Its design and implementation are detailed in this section. GIS analysis is the third topic. This section describes how the GIS technology can aid in determining the relationships between coastal plain geology and sustainable development. The last topic covered in the methods section outlines procedures used to field check the GIS-based dune sheet surficial map.

Survey

For the end-user survey an anonymous questionnaire was created from closed, multiple choice questions (Robson, 1993). This type of questionnaire is considered reliable because the form provides consistent data; that is all participants reply in terms of the same option, i.e. least, moderately or most (Fink, 2005). The questionnaire contained six subjects, each with topics to which the participants addressed their level of interest. Before the survey was administered the Human Subjects Research Review Committee (HSRRC) at Portland State University reviewed the project to ensure the security of the participants. The questionnaire is contained in Figure 7.

Technical Expertise: Planner, Engineer, Technician, Administration
Please circle all that apply or fill in other
Other Staff Expertise: GIS Programs, Surveyor, Geotechnical Engineer,
Please circle all that apply or fill in other
Primary User(s) of your GIS Data: In-house, Consultants, General Public,
Other users

1: Preferred GIS Format:

	1 Least	2 Moderately	3 Most
ArcInfo			
ArcView			
ArcMap			
CAD			
Open Source			

2: Coverage Area(s)

	1 Least	2 Moderately	3 Most
Region			
County			
City			
CAD			
Drainage Basin			

3: Level of Map Detail (Base Map Scale)

	1 Least	2 Moderately	3 Most
1:5,000			
1:12,000			
1:24,000			
1:100,000			

4: What attributes are you interested in?

	1 Least	2 Moderately	3 Most
Geological			
Topographical			
Geotechnical			
Hydrological			
Environmental			
Jurisdictional			
Infrastructure			

5: What risks are you interested in?

	1 Least	2 Moderately	3 Most
Unstable Slopes			
Liquefaction			
Drainage			
Contaminant Flow Path			
Drainage Basin			
Habitat Impacts			

6: Product Delivery

	1 Least	2 Moderately	3 Most
CD			
FTP			
Hardcopy			

7: What GIS data can you supply for incorporation into this Data Set?
8: Suggestions or comments for this project?

Figure 7: Questionnaire used to survey potential end users of the surficial map of the dune sheets.

The survey combined purposive and snowballing sampling methods (Robson, 1993). The survey employed purposive sampling to specifically target participants that influence or directly impact land use decisions. The survey also utilized the snowballing sampling method to increase the sample size by asking respondents to refer to other potential participants (Robson, 1993).

The questionnaires were given directly to the respondent by mail or in person and filled out at a later time. Once the questionnaires were returned the answers were normalized because respondents did not answer every question. To normalize the results the numbers of respondents were calculated for each topic, the responses were then divided by the number of respondents for that topic to provide a percentage. The percentages were then added up for least, moderately and most and this number was used to normalize the topic percentage.

Database

To provide flexibility for the end user the data is stored in both MS Access and ESRI ArcMap geodatabase. The survey results provided the framework for both databases. The basic data process is illustrated below in Figure 8.

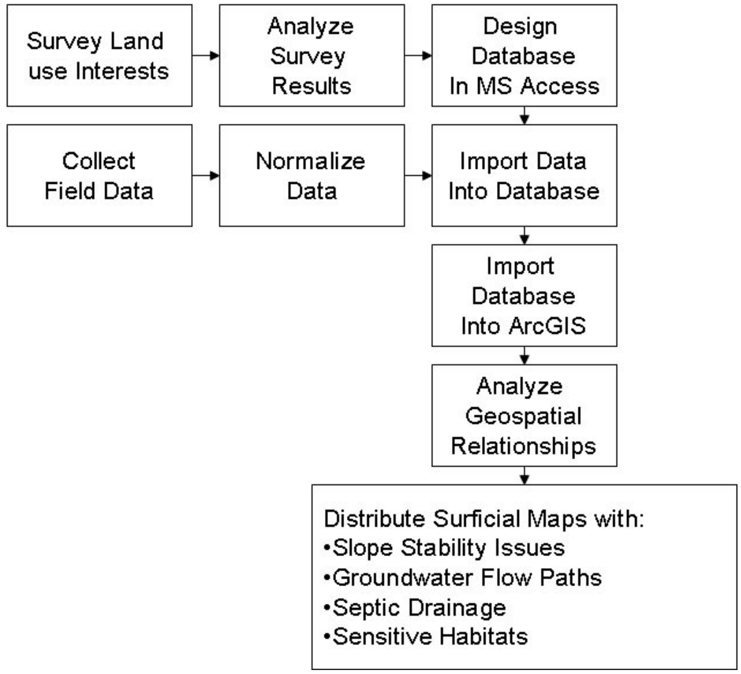

Figure 8: Data process for developing the surficial map.

The first step was to design an Access database that both functions with ArcMap and is efficient for queries and data analysis. The database was built from two main tables (Figure 9), including a location table that contained coordinates of each field site and a horizon table that broke down each soil horizon interval with a starting and ending depth. The location table is linked to site notes, images, and exposure in a one-to-many relationship. The soil horizons are also related by a one-to-many relationship with the following field attributes: bedding, relative age, parent material, grain size, strength, horizon type, structures and diagenesis.

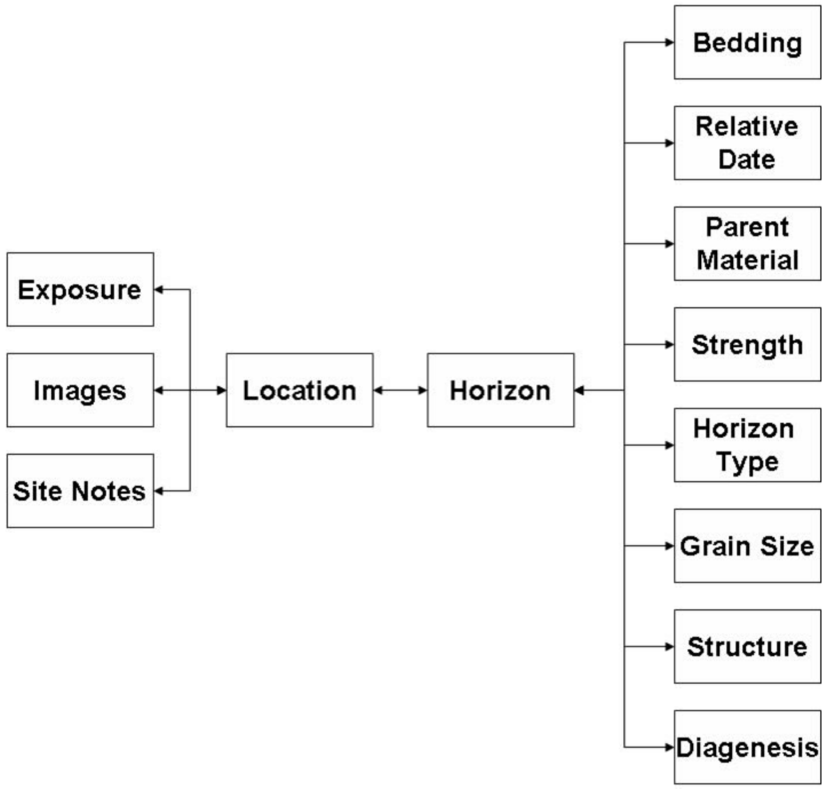

Figure 9: The basic design of the dune sheet database.

A linking table was also created for each attribute, this table aids queries and reports to be processed more efficiently in Access. An example of the relationship between the soil horizon, linking table and attribute is illustrated below (Figure 10).

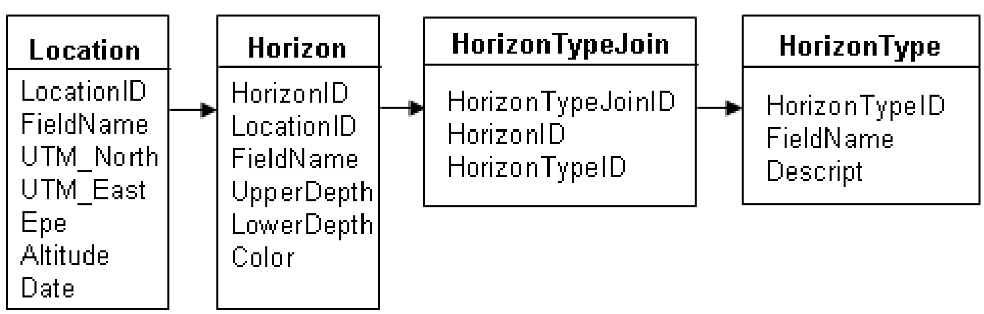

Figure 10: An example of how the database relationships work for soil horizons.

After the design phase was completed the field data was imported into the Access database. The original data was collected from 1997-2000 through an Oregon Sea Grant Project (Peterson et al., 2006). The field data was contained in MS Excel spreadsheet which needed to be normalized to import into Access. After normalization and importation, the relationships were built. This Access database was then registered into an ArcCatalog geodatabase where the data relationships were rebuilt.

GIS Analysis

The first step in creating the surficial map was to gather existing GIS datasets that was developed to analyze the paleodunes. Lincoln County provided the county specific datasets and the rest were downloaded from Oregon Geospatial Data Clearinghouse (www.oregon.gov/DAS/EISP/GEO) and Seamless Data Distribution from the U.S. Geological Survey (http://seamless.usgs.gov). Table 1 contains the external datasets, their scale and source of the data.

Table 1: External GIS datasets used in the surficial map.

Dataset	Scale	Source
Digital Elevation Model	10 meter	
Geology	1:62,000	Digitized from Schlicker 1973
Imagery	1 meter	USGS DOQQs
Lincoln County Roads	1:24,000	Lincoln County
Lincoln County Taxlots	1:24,000	Lincoln County
Lincoln County Zoning	1:24,000	Lincoln County
Soils	1:24,000	NRCS
Urban Growth Boundaries	1:24,000	Oregon Department of Transportation
Water Bodies	1:2,000,000	US Geological Survey
Zoning	1:100,000	Department of Land Conservation and Development

After collecting the datasets the GIS analysis was undertaken. The first step was to delineate the landward extent of the dune sheets. The back edge of the dune sheet was primarily mapped from field observations. Where field observations were not accessible the boundary was interpolated from a combination of topography and proximate bedrock outcrops. The dune sheet boundaries were then compared to the marine terraces mapped by Schlicker et. Al. in 1973. Schlicker describes the marine terrace deposits as "flat-lying marine terrace deposits, overlain in places by semi-consolidated dune sand, form a discontinuous series of coastal exposures along the entire length of Lincoln County. The deposits mantle wave-cut benches on tilted Tertiary strata. The marine terrace deposits are predominately massive, fine- to medium-grained, friable sandstone of beach origin with thin interbeds of siltstone."

An important aspect of this study is to map the depth of groundwater influence and characterize its effects on the stability and contamination issues in the paleodunes. To do this the geodatabase for Bg and Bw soil horizons was queried. The Bg layers were selected and then compared to their depth of first occurrence in the sea cliffs and the inland ridges. The depths were statistically analyzed with F and T tests to determine whether the horizon's first occurrence was statistically distinguishable in the two topographic settings. Also, the quantity of Bg horizons were evaluated for both settings.

With the dune database it is possible to construct hypothetical cross-sections. These cross-sections provide a conceptual model of the depth to bedrock. To create the cross sections, the topographic profile was exported from the DEM to Excel. The field sites were plotted on the topographic data with the depth of the bedrock that can be tested by future subsurface investigations. The cross sections were examined in an attempt to identify potential relationships between bedrock, topography and paleodune characteristics (Figure 11).

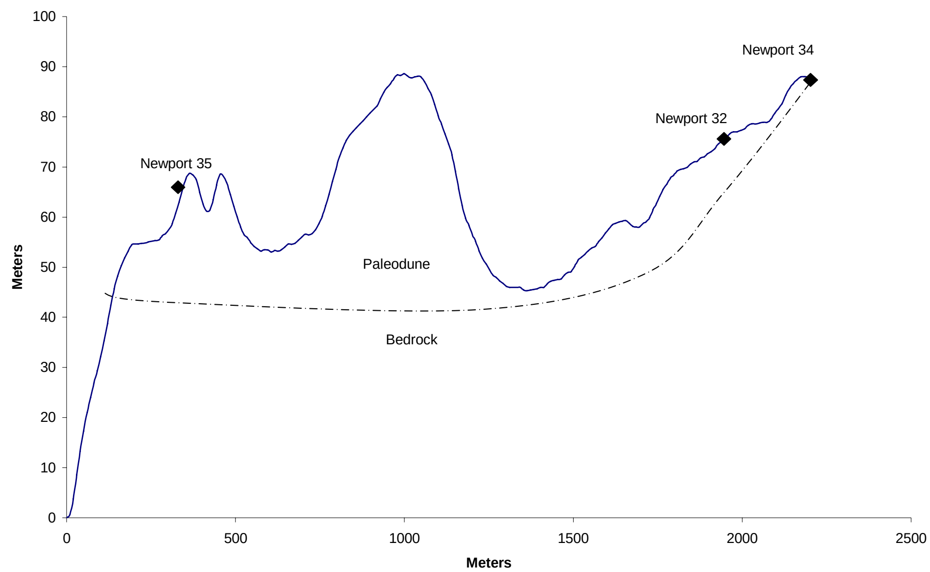

Figure 11: An example of potential depth to bedrock analysis for the dune sheets. The solid line is the topography of the surface. The dashed line is a representation of potential depth to bedrock. Newport 35, 32 and 34 are field sites located north of the city of Newport. The profile was orientated at N9E.

Both surface and groundwater flow has a significant impact on the stability of the paleodunes. Groundwater flow, most concentrated at the contact between the dunes and bedrock, leaches the cement internally. To highlight areas with possible stability issues due to cement leaching the likely flow paths derived from the DEM were drawn from slope gradients (Figure 12).

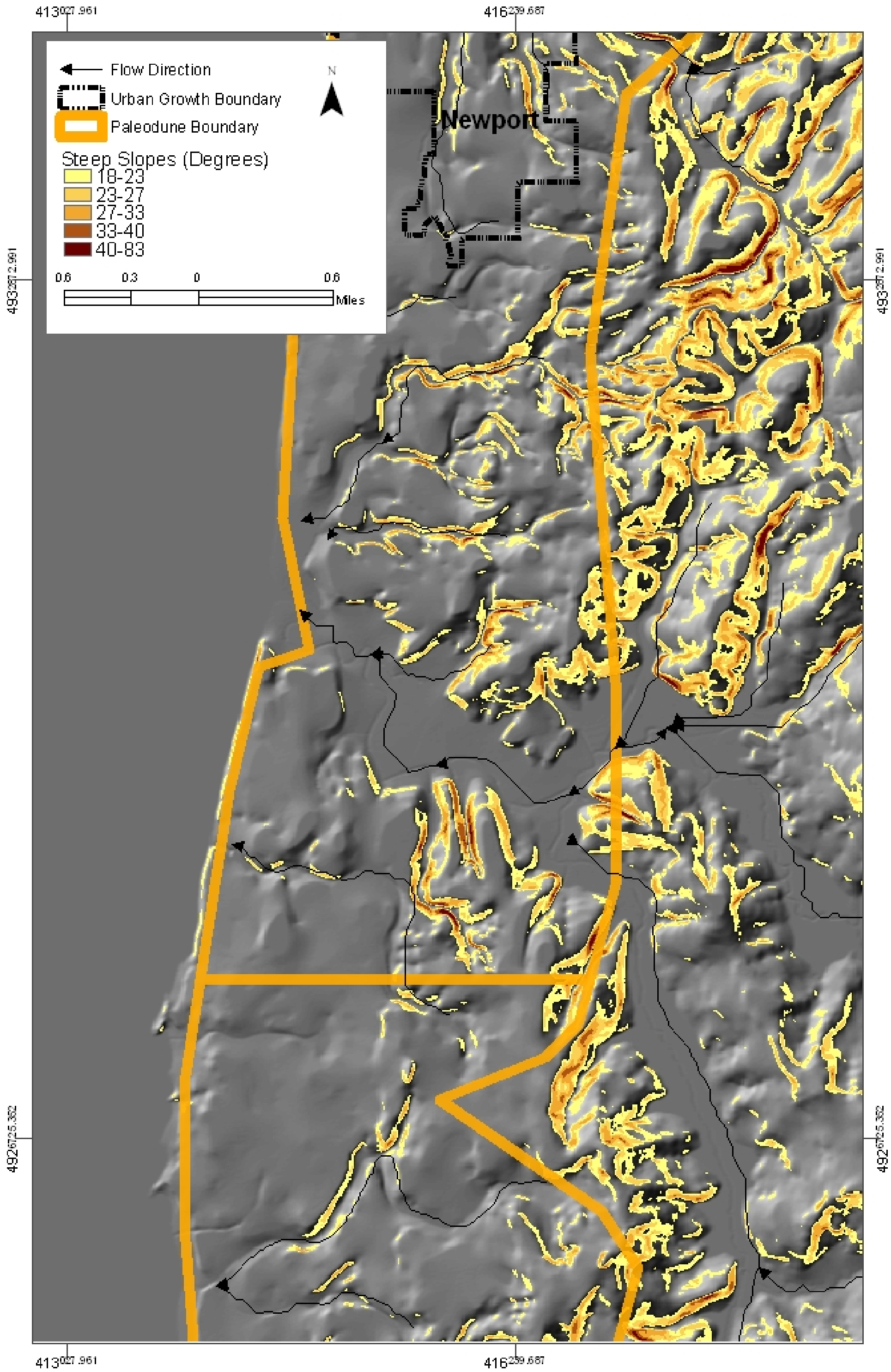

Figure 12: An example map of Ona Beach area showing the direction of groundwater flow with the steep slopes layer.

Cement leaching has a potentially significant impact on the stability of slopes cut into the paleodune deposits. To test this relationship the relative cementation in the upper and lower sections of the sea cliffs, valleys and ridges was addressed. To compare these all the field sites that had pocket penetrometer data was queried. Contours, slope maps, aerial photography, and hillshades were used to classify the topography of field site e.g. sea cliff, valley or ridge. The sea cliff pocket penetrometer data was separated out into the upper, middle and lower sections of the sea cliffs. The pocket penetrometer data for the upper and lower sections were compared using T tests to establish whether the relative cementation was distinguishable between the upper and lower sections of the sea cliffs. The relative cementation between valleys and ridges was similarly tested.

Field Verification

Following the completion of the GIS analysis I went into the field in December of 2007 to verify several aspects of the surficial map and geospatial relationships. The first priority of the field work was to fill in data gaps for the landward extent of the paleodunes. Before heading to the field the areas with dune limit data gaps was identified from the preliminary GIS maps. The landward extent of the paleodune sheets was verified by following road cuts to where the dune deposits terminated. GPS points were collected for the termination points. In addition to the paleodune boundaries verification, more relative cementation data for the sea cliffs was collected with a pocket penetrometer (Figure 13).

Figure 13: Confirming relative cementation of paleodune deposits exposed in Cove Beach in Lincoln City.

Results

Survey

The survey conducted in this study provides insight as to what potential users of the dataset expect too find useful in addressing land use decisions. It is important to recognize that these results should be interpreted with caution because of the limited sample size (Figure 14). Although the sample size is small, this initial study provides a foundation for future projects involving land use planning based on surficial geology of the Central Oregon Coast.

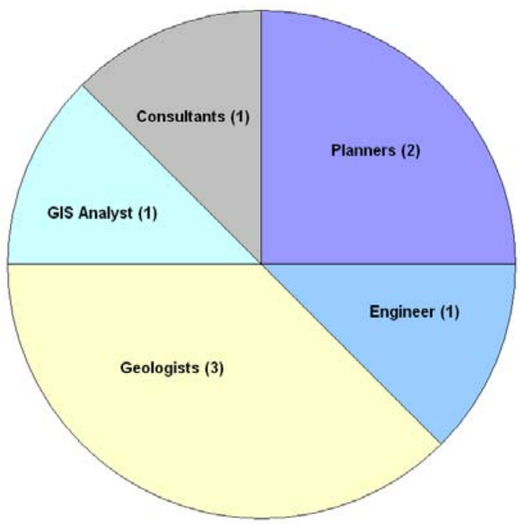

Figure 14: Pie Chart illustrating the occupations of the sample population. There were 8 participants in the survey for the Lincoln County Area.

The questionnaire covered six topics including preferred GIS format, coverage area, base map scale, attributes, risks and product delivery. The number of respondents varied for each subject within the topics. Because of the inconsistent participation for each question, it was necessary to normalize the percentages of the responses. The tables below contain summarized data from the survey; for complete survey results see Appendix A.

The first topic was preferred GIS format. It was included in the survey because it is important to 1) gauge how familiar respondents were with ESRI products, and 2) establish whether they were using the most up to date software package. The results are contained in Table 2, with CAD the preferred GIS format at 30%, closely followed by ArcView at 22%.

Table 2: Results for preferred GIS format topic in the questionnaire.

Preferred GIS Format	Least	Moderately	Most	Number of Respondents	Normalized Least	Normalized Moderately	Normalized Most
ArcInfo	3	3	1	7	27%	37%	6%
ArcView	3	1	4	8	23%	11%	22%
ArcMap	1	3	3	7	9%	37%	19%
CAD	1	1	4	6	10%	15%	30%
Open Source	1	0	1	2	31%	0%	22%

The next topic in the survey was the coverage area (Table 3). This is an important aspect of the survey because it will determine the coverage area of the GIS dataset. Fifty one percent of the respondents preferred the county as the coverage area, closely followed by city coverage at 39%. The drainage basin was the least preferred at 0%. Because of the strong response from the respondents the extent of the coverage area in this study will be Lincoln County.

Table 3: Normalized results for coverage area topic in the questionnaire.

Coverage Area	Least	Moderately	Most	Number of Respondents	Normalized Least	Normalized Moderately	Normalized Most
Region	2	3	1	7	31%	30%	10%
County	0	3	6	8	0%	26%	51%
City	1	2	4	7	15%	20%	39%
Drainage Basin	3	2	0	6	54%	23%	0%

The scale of the base map was the third topic covered in the questionnaire. It was anticipated that the respondents would want the best resolution possible. It was also important to obtain indications of the scales of other datasets in use. The participants clearly prefer the largest scale possible with 55% favoring 1:5000, and 36% choosing 1:12,000 (Table 4). The high preference for the 1:12,000 scale, coupled with it not being the highest resolution choice, indicates that the users are familiar with this scale and that it will be compatible with their other datasets.

Table 4: Normalized results of the base map scale topic in the questionnaire.

Base Map Scale	Least	Moderately	Most	Number of Respondents	Normalized Least	Normalized Moderately	Normalized Most
1:5,000	0	1	6	7	0%	11%	55%
1:12,000	0	3	4	7	0%	33%	36%
1:24,000	1	5	1	7	13%	56%	9%
1:100,000	6	0	0	6	88%	0%	0%

The attribute list for the dataset was the fourth subject covered in the questionnaire (Table 5). This topic is one of the most important in the survey because it specifies what attributes the end user requires to make appropriate land use decisions. Seven attributes are presented in the survey. Of those seven attributes there is a group of four that the participants preferred, including geological 29%, topographical 24%, geotechnical 17% and hydrologic 19%. Environmental, jurisdictional, and infrastructure received low ratings, possibly due to the limited sample population, or to the availability of these coverages from other existing sources. Table 5: Normalized results for attributes topic in the questionnaire.

Attributes	Least	Moderately	Most	Number of Respondents	Normalized Least	Normalized Moderately	Normalized Most
Geological	1	1	6	8	6%	5%	29%
Topographical	1	2	5	8	6%	10%	24%
Geotechnical	1	3	3	7	7%	18%	17%
Hydrological	0	4	4	8	0%	21%	19%
Environmental	2	4	0	6	17%	28%	0%
Jurisdictional	6	0	1	7	43%	0%	6%
Infrastructure	3	3	1	7	21%	18%	6%

Risk is another important aspect of the survey. The results from this question influenced the type of risk analysis that was performed for this project (Table 6). The respondents overwhelming chose unstable slopes as their greatest concern at 43%. Contaminant flow path, drainage basin and habitat impacts received little interest at 8%, 9%, and 0%, respectively. It is expected that the relative importance of risks will vary over time and with different planning issues. Basic data in this GIS project database can be formatted to address different risk factors.

Table 6: Normalized results for the risks topic in the questionnaire.

Risks	Least	Moderately	Most	Number of Respondents	Normalized Least	Normalized Moderately	Normalized Most
Unstable Slopes	0	1	7	8	0%	5%	46%
Liquefaction	0	4	3	7	0%	25%	23%
Drainage	0	5	2	7	0%	31%	15%
Contaminant Flow Path	4	2	1	7	32%	12%	8%
Drainage Basin	3	2	1	6	28%	14%	9%
Habitat Impacts	5	2	0	7	40%	12%	0%

The final question on the survey is how the end user would like the surficial geologic data to be delivered. It is important to find out what format is most accessible for the user. CD is the preferred method at 55%, hardcopy maps follows at 27% and the last choice of FTP received 18%.

Table 7: Normalized results for the product delivery topic in the questionnaire.

Product Delivery	Least	Moderately	Most	Number of Respondents	Normalized Least	Normalized Moderately	Normalized Most
CD	0	1	7	8	0%	23%	55%
FTP	3	2	2	7	50%	52%	18%
Hardcopy	3	1	3	7	50%	26%	27%

Dune Database

The last published geologic map of the surficial deposits in the coastal plain of Lincoln County is from 1973 by H.G. Schlicker et al. (1973). With the significant development expansion in the area it is imperative that planners have an updated dataset to make decisions for safe and sustainable development. In addition, the previous mapping is only available in hard copy format. A GIS dataset will provide the ability for land use interests to not only view the data but also query and analyze it with digital overlays, enabling better informed development decisions.

The mapped Lincoln City dune sheet begins at NW 57th Street in Lincoln City. The dune sheet extends east to Devil Lake, approximately 0.86 miles inland (Figure 15, Figure 16). The paleodune boundary follows the lake's west border to the south. South of the lake the dune sheet's landward extent decreases to between 0.3 to 0.5 miles (0.5 to 0.8 km) inland to Siletz Bay. South of Siletz Bay to Depoe Bay the dune sheet's extent continues to be narrow generally extending 0.3 miles inland (Figure 17,

Figure 18). The Lincoln City dune sheet's southern boundary is located south of Depoe Bay (Figure 19, Figure 20). In the area around Lincoln City the dune sheet's maximum elevation is generally, between 25 and 50 feet (7.6 and 15.2 meters).

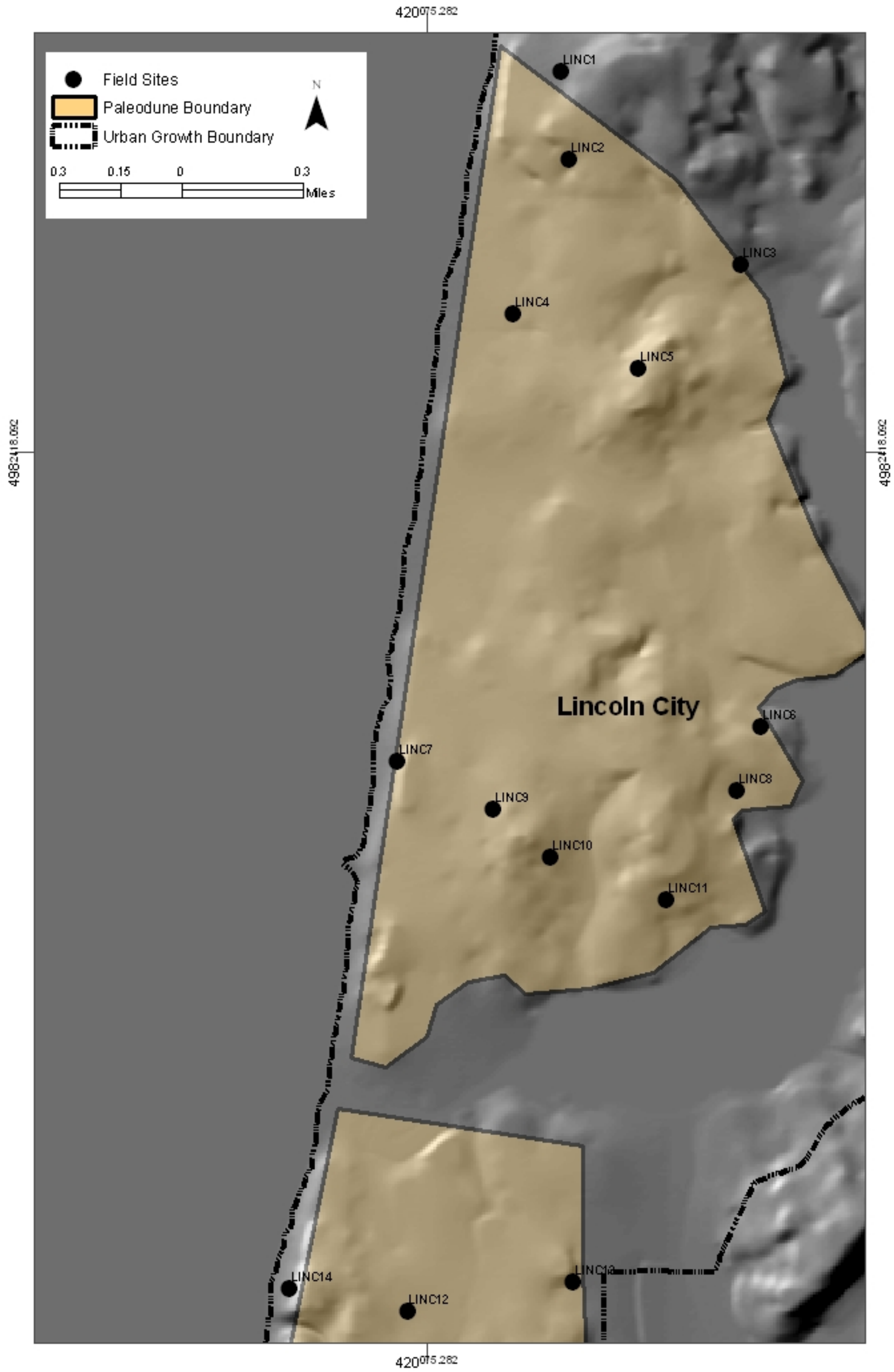

Figure 15: The Lincoln City dune sheet extent in the Lincoln City area.

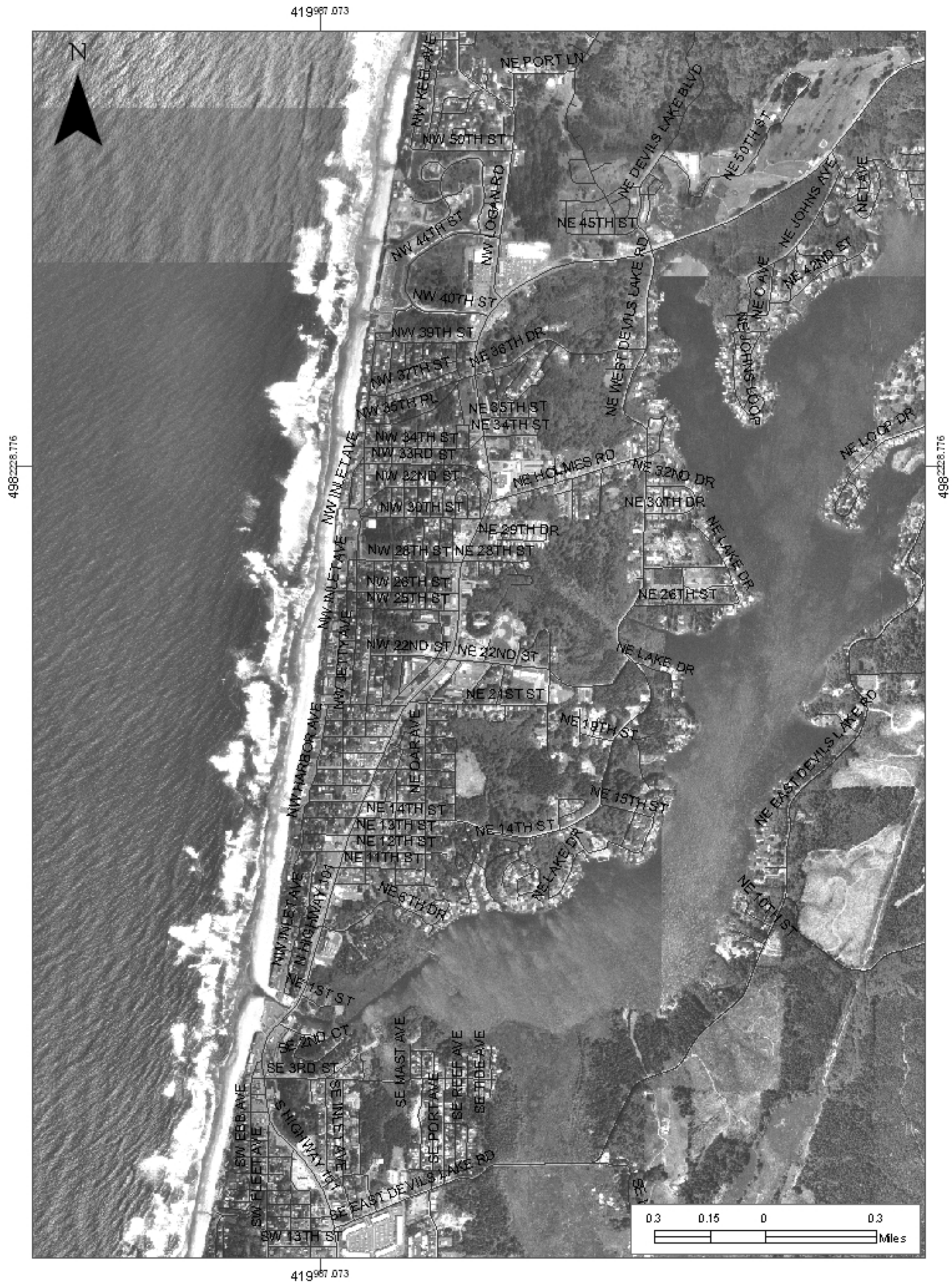

Figure 16: Aerial photo and streets in the extent of Figure 15.

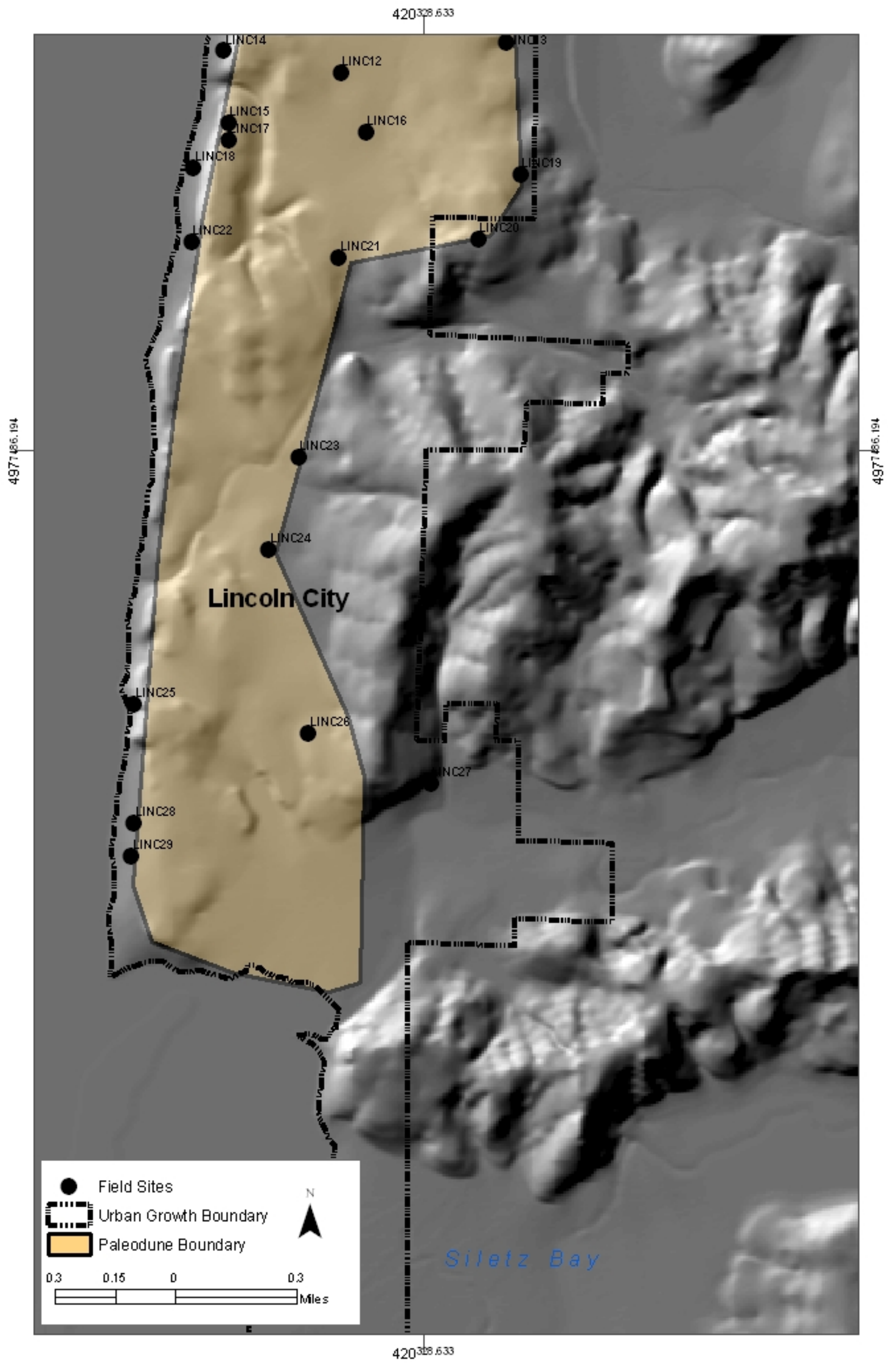

Figure 17: The Lincoln City dune sheet extent near Siletz Bay.

Figure 18: Aerial photo and streets in the extent of Figure 17.

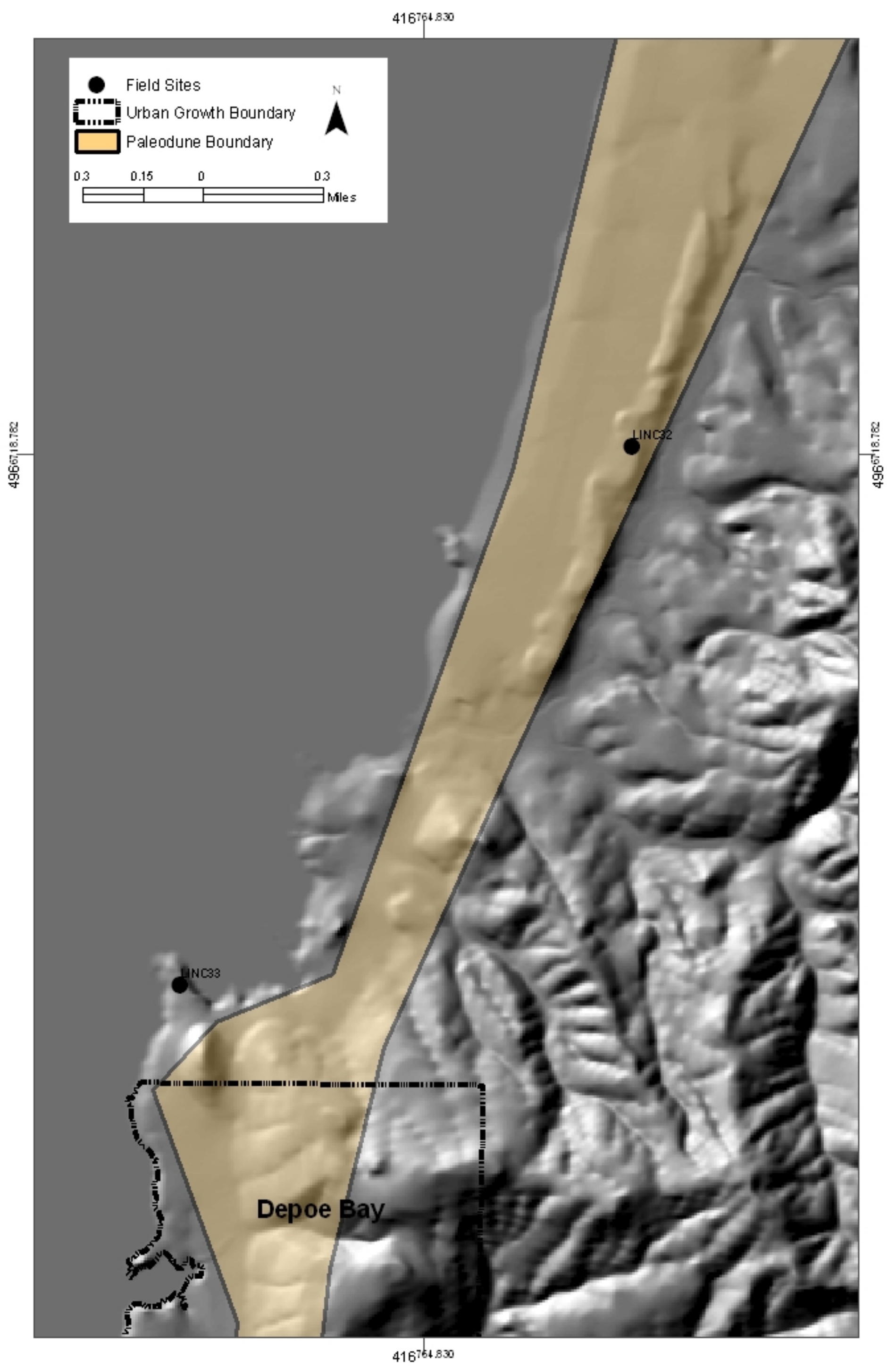

Figure 19: The Lincoln City dune sheet near its southern boundary at Depoe Bay.

Figure 20: Aerial photo and streets in the extent of Figure 19.

The Newport dune sheet begins approximately 3 miles (4.8 km) south of Depoe Bay (Figure 21, Figure 22). It extends 3.5 miles (5.6 km) north of the urban growth boundary for Newport. The dune sheet's landward extent varies from 0.5 miles to 1.0 miles (0.8 to 1.6 km) from the ocean shoreline. The greatest width occurs just north of Yaquina Bay (Figure 23, Figure 24). The paleodunes in this section reach elevations of 280 to 320 feet (85 to 97 meters). South of Yaquina Bay the dune sheet extends even further inland, to 2.0 miles (3.2 km) beyond the shoreline (Figure 25, Figure 26). Just south of SE 98th Street, around Holiday Beach, the dune sheet narrows to 1.5 miles (2.4 m) in width (Figure 29, Figure 30). The maximum elevation of the paleodunes in this section is approximately 415 feet (126 m). At 1.5 miles (2.4 km) south of the urban growth boundary of Waldport the extent of the dune sheet narrows to 0.5 miles (0.8 km) inland (Figure 31, Figure 32), while the maximum paleodune elevation decreases to approximately 85 feet (26 m). The dune sheet remains narrow in Yachats, to the southern border of the dune sheet (Figure 33). However the maximum elevation of these southern deposits increases to 305 feet (93 m).

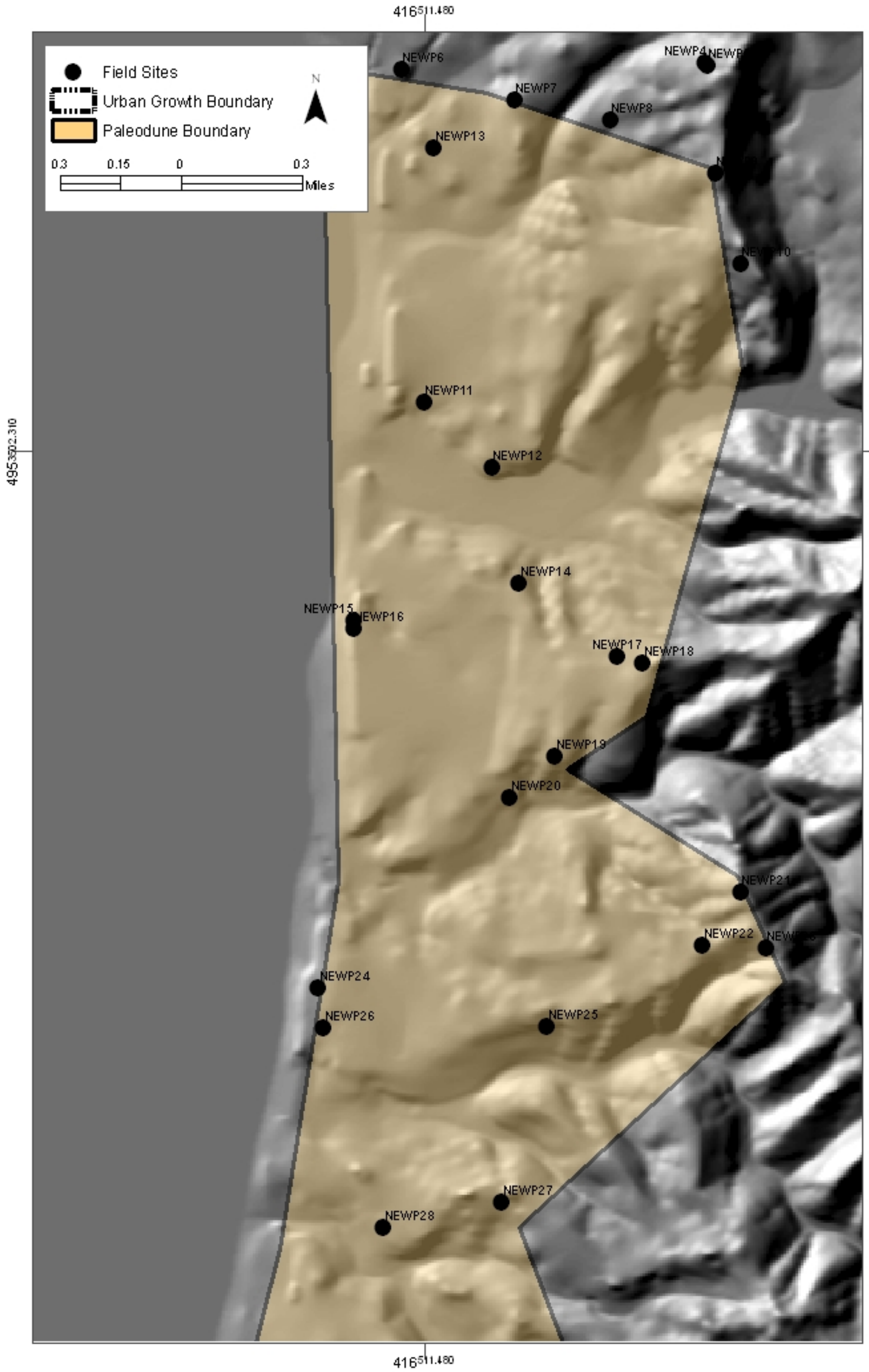

Figure 21: The beginning of the Newport dune sheet, south of Depoe Bay and north of the Newport.

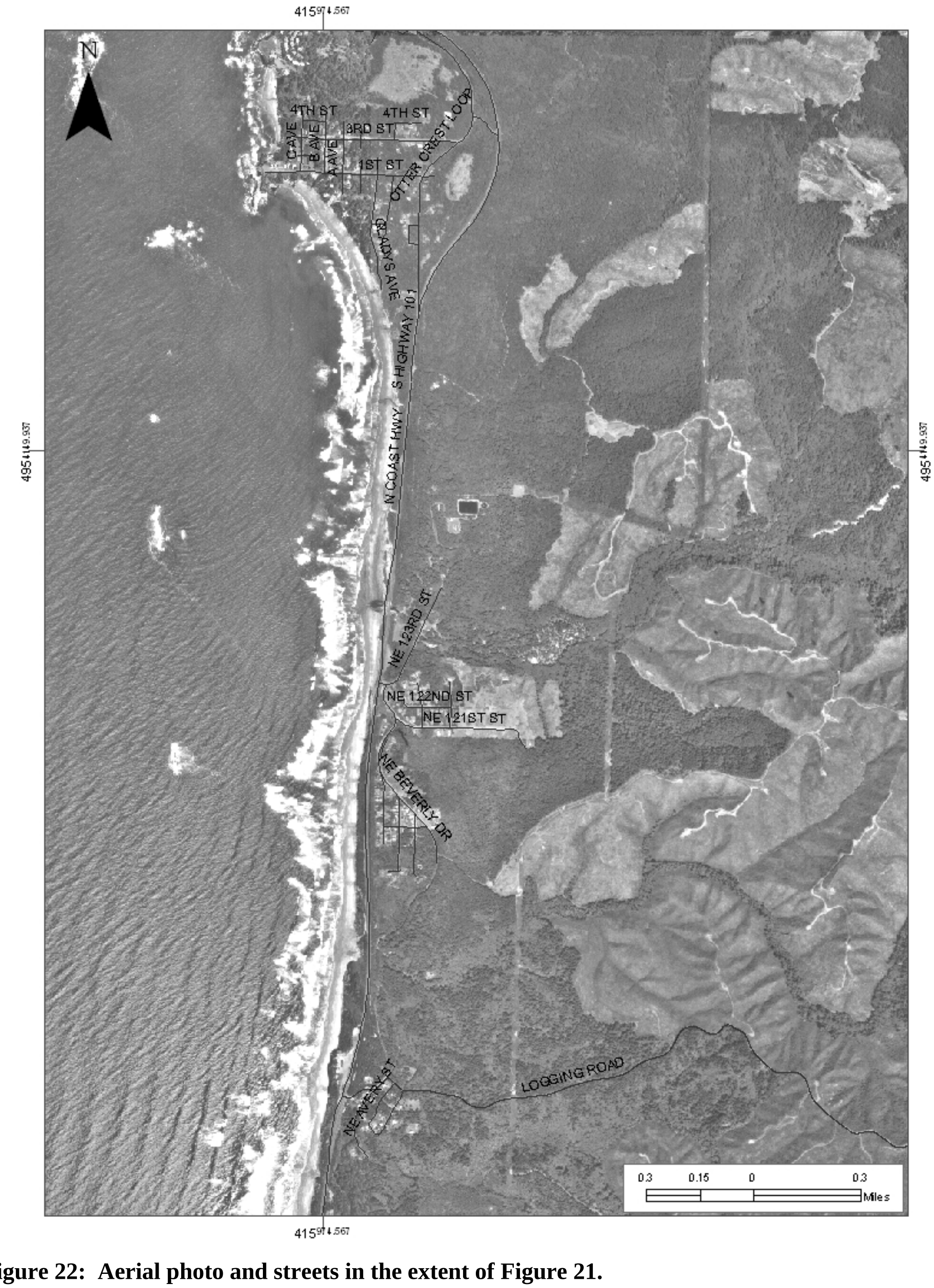

Figure 22: Aerial photo and streets in the extent of Figure 21.

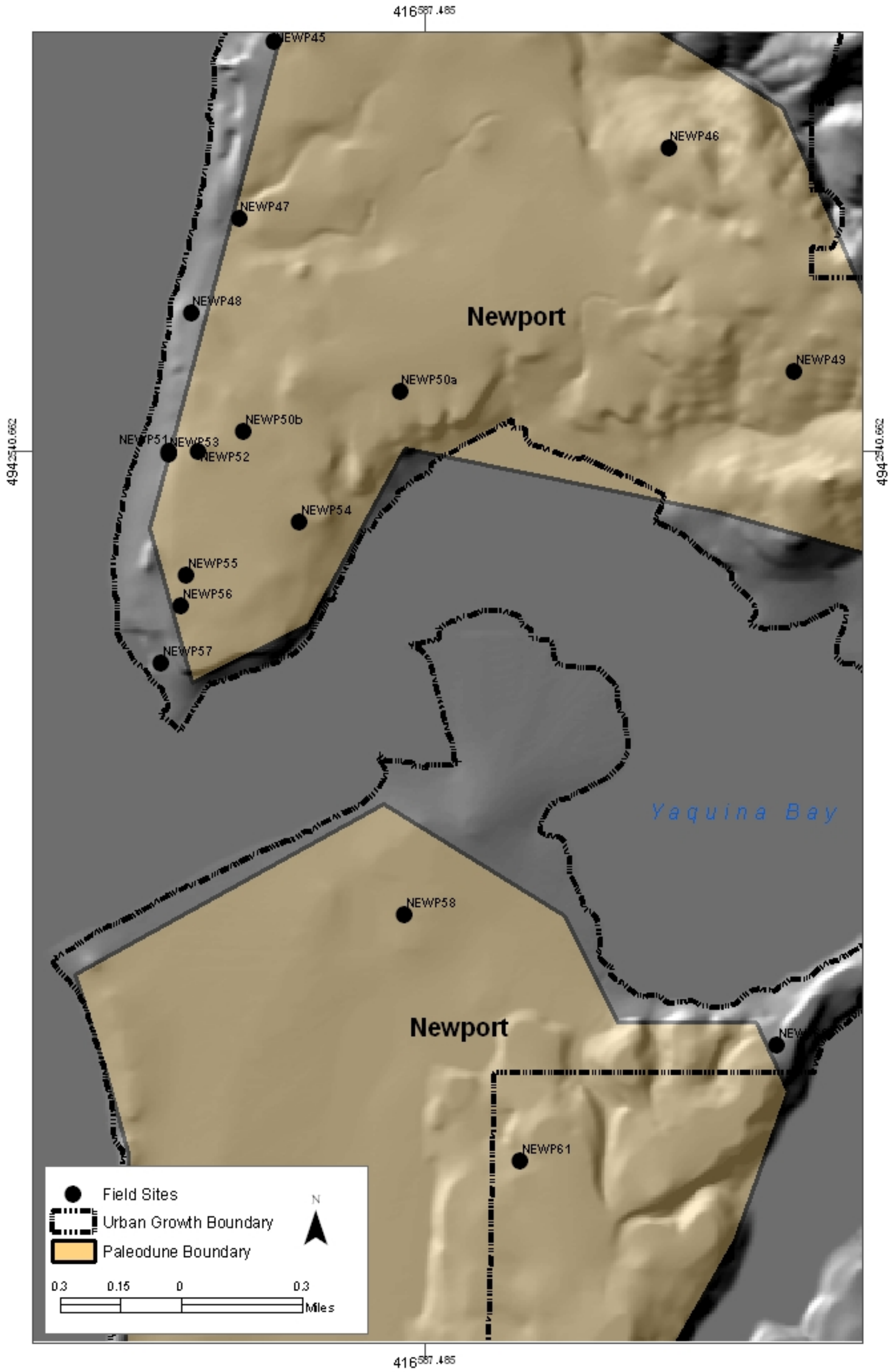

Figure 23: The Newport dune sheet in Newport around Yaquina Bay.

Figure 24: Aerial photo and streets in the extent of Figure 23.

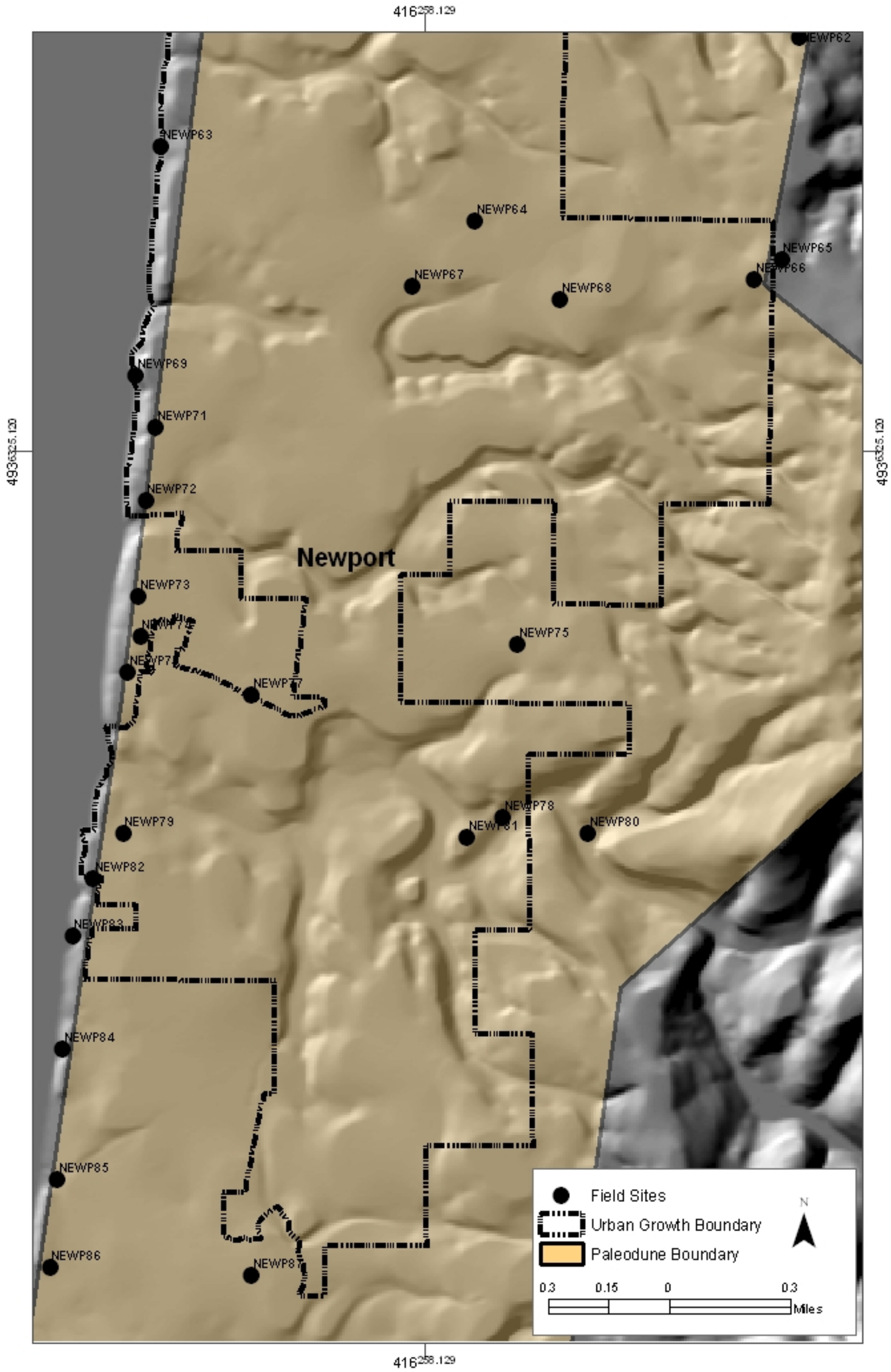

Figure 25: The Newport dune sheet south of Yaquina Bay, the dune sheet extends inland approximately 2 miles beyond the shoreline.

Figure 26: Aerial photo and streets in the extent of Figure 25.

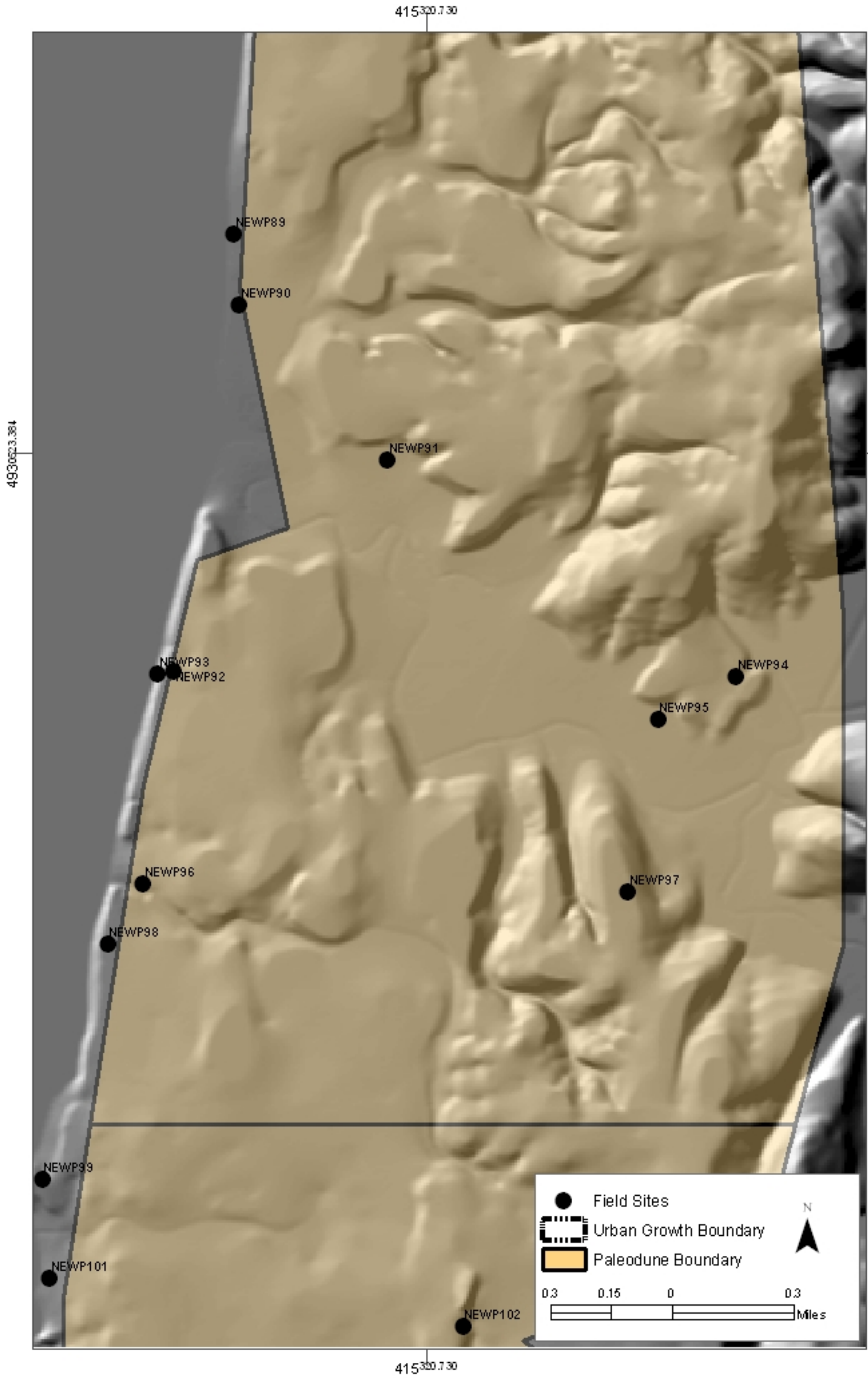

Figure 27: The Newport dune sheet south of Newport. Just north of field site NEWP99 where the line splits the dune sheet the Holocene dune caps begin.

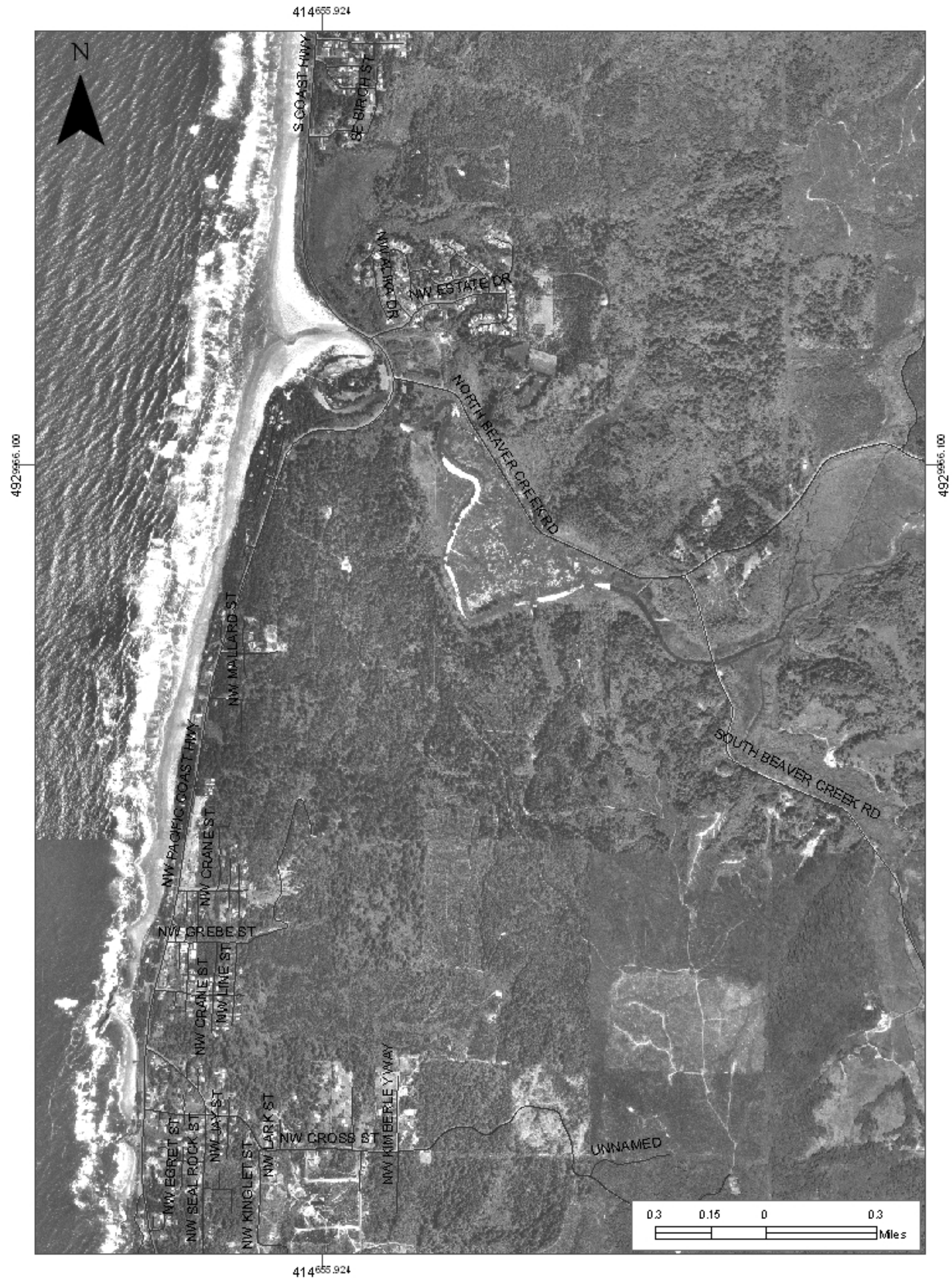

Figure 28: Aerial photo and streets in the extent of Figure 27.

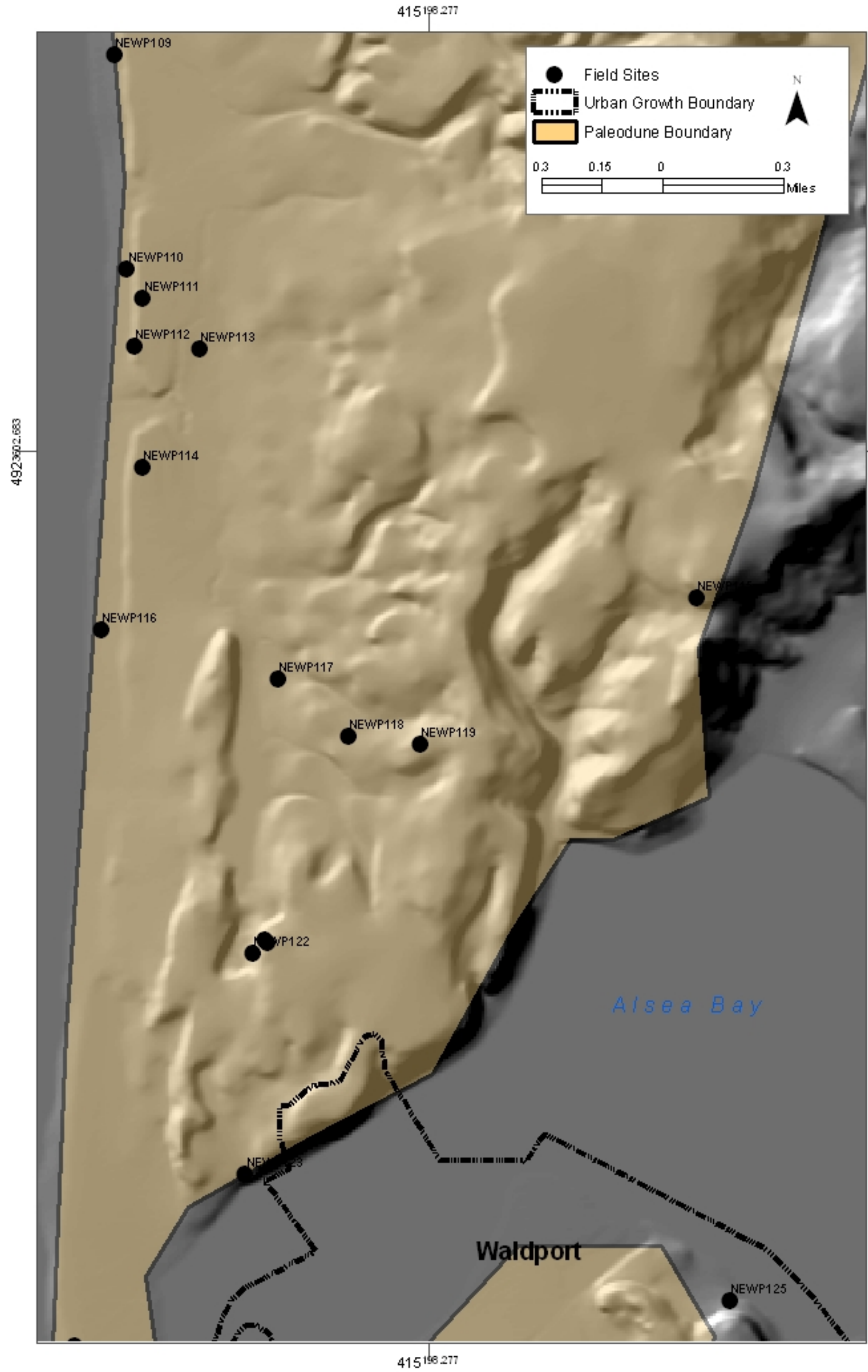

Figure 29: The Newport dune sheet in the Waldport Area. The dune sheet begins to thin around Holiday Beach.

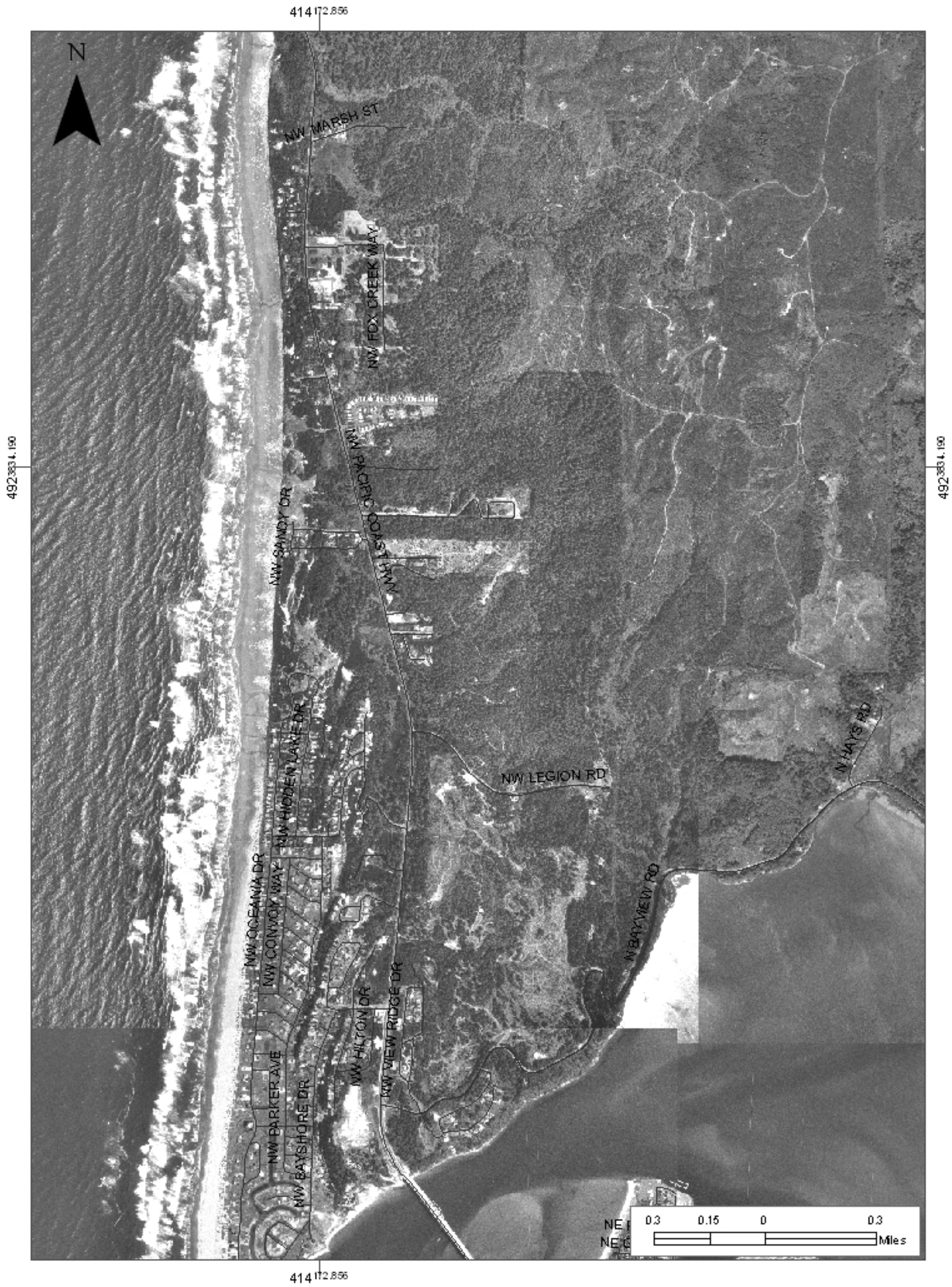

Figure 30: Aerial photo and streets in the extent of Figure 29.

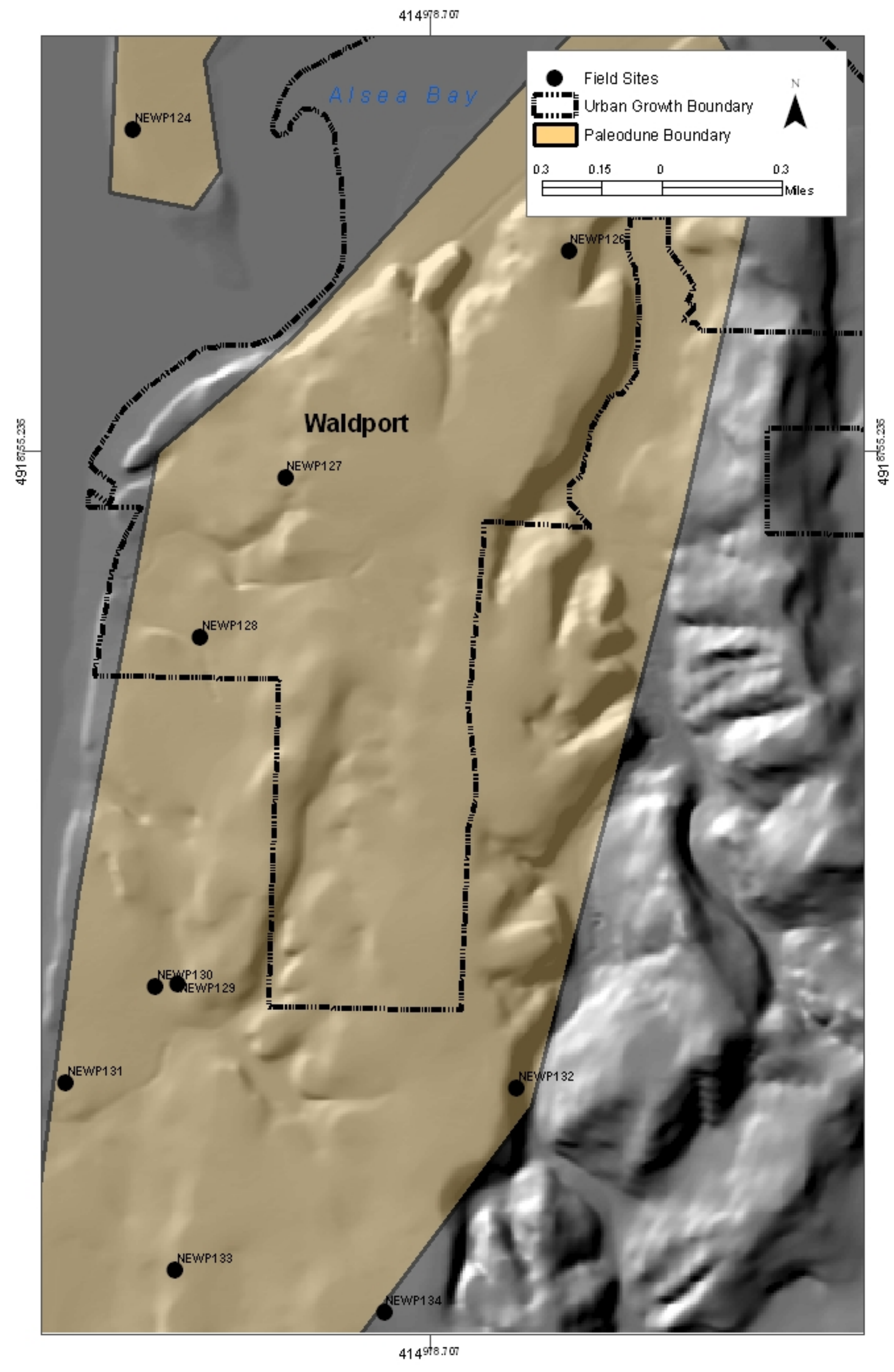

Figure 31: The Newport dune sheet south of Alsea Bay at Waldport. The dune sheet continues to thin.

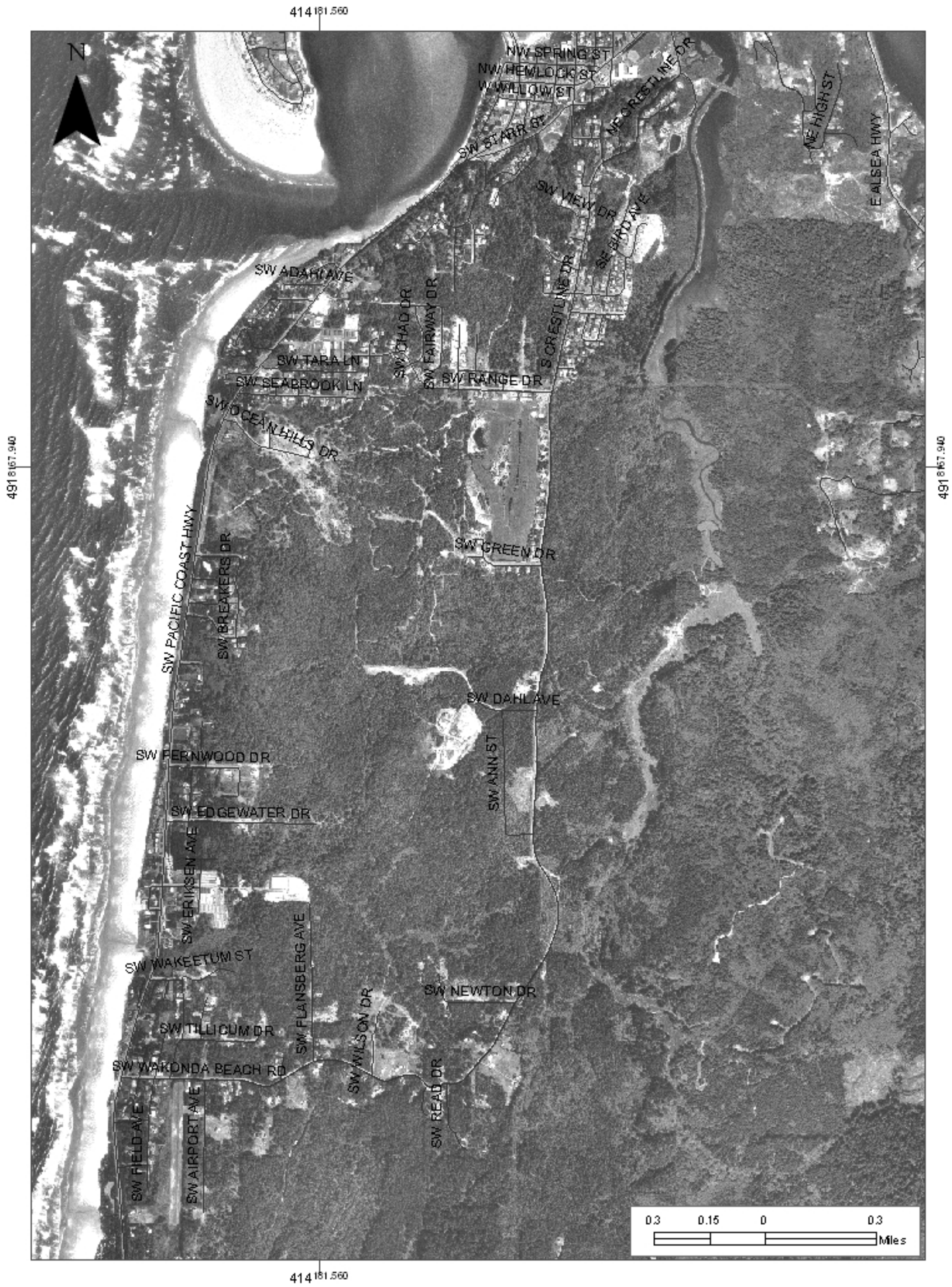

Figure 32: Aerial photo and streets in the extent of Figure 31.

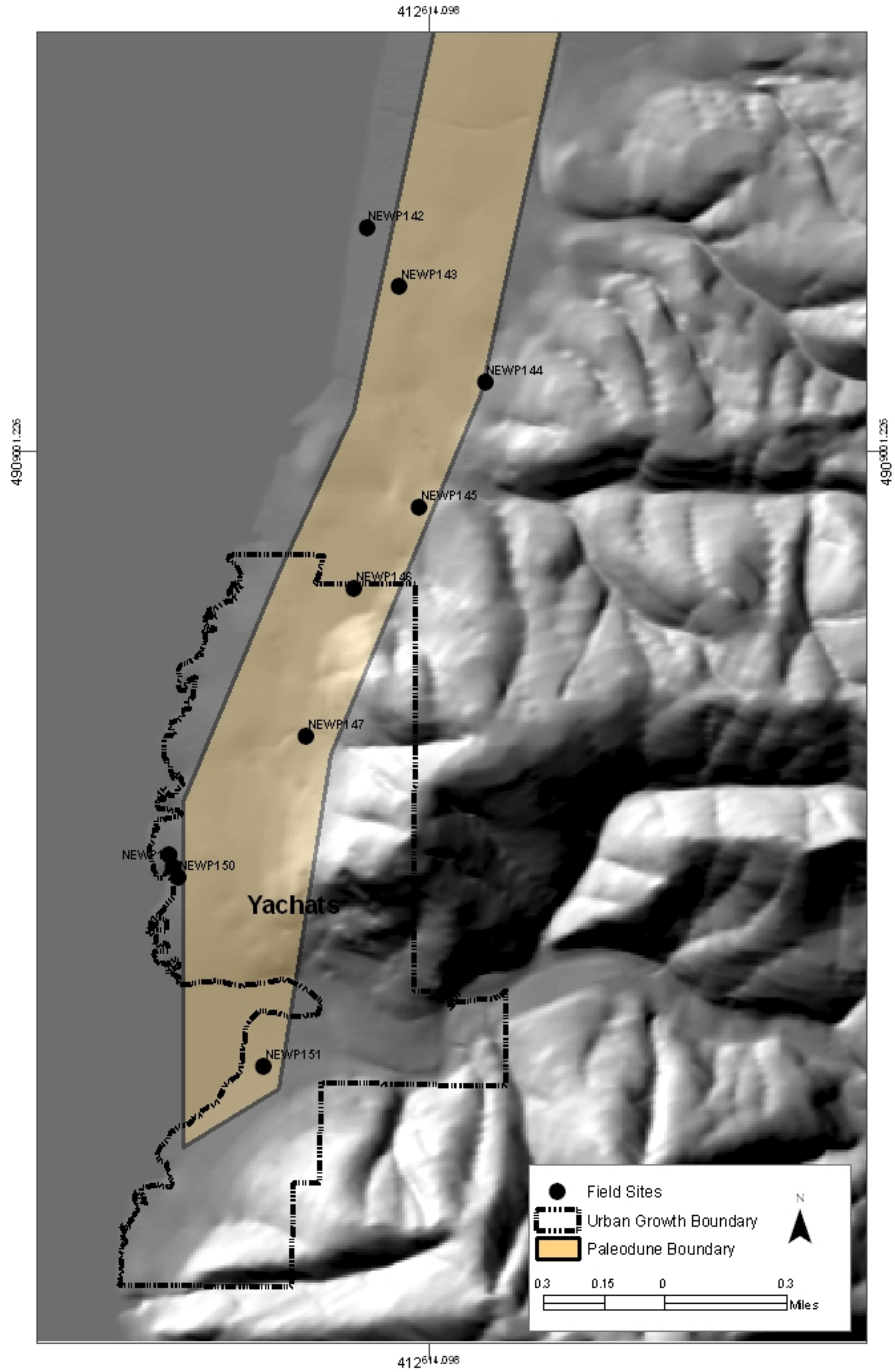

Figure 33: The southern boundary of the Newport dune sheet in the Yachats area.

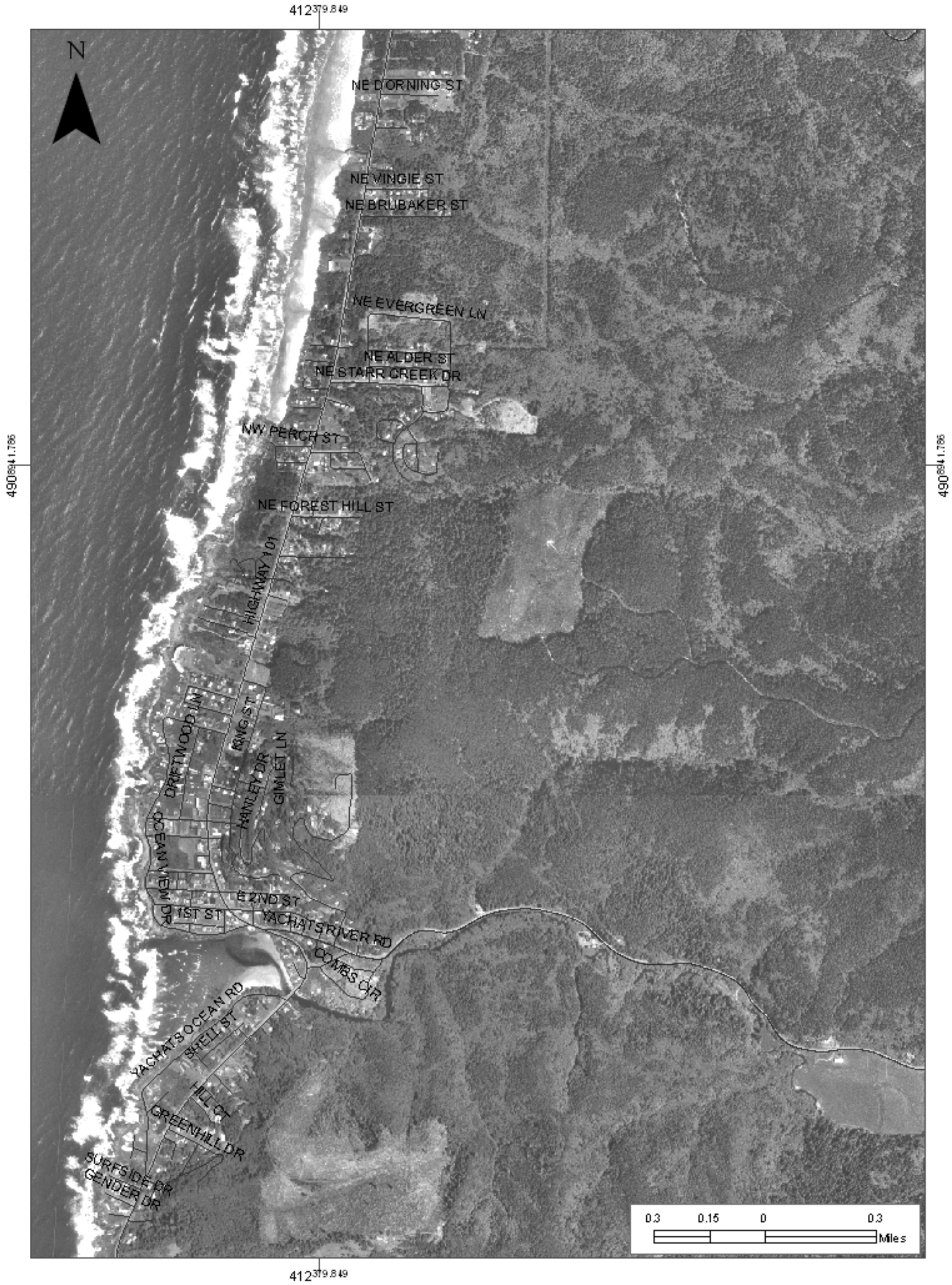

Figure 34: Aerial photo and streets in the extent of Figure 33.

Pleistocene age dunes dominate most of the Lincoln City and Newport dune sheets. However, approximately 1.5 miles south of Ona Beach State Park the

Holocene age dunes cap the Pleistocene dunes (Figure 27, Figure 28). The Holocene dune caps are consistently present until just north of Waldport, and then the Holocene dunes become intermittent to the southern dune sheet border.

With the advancement of new mapping, dating and geotechnical analyses of surficial coastal deposits (see Background) the extent and discrimination of the coastal plain geologic units in Lincoln County have increased greatly. It is important to integrate the data generated from these new studies with the older established geologic units. The newer and older datasets are compared by overlaying the dune sheet database with a digitized version of Schlicker's marine terraces (Figure 35).

Figure 35: Comparison between marine terraces mapped by Schlicker (1973) and paleodune boundary in the Waldport area.

The total area of the marine terraces mapped by Schlicker (1973) in Lincoln County is 65 square miles (168 square km), whereas the area of the mapped paleodune deposits is 38 square miles (98 square km). The relative overlap of these mapped units is discussed by regions below. As mapped in much of the Lincoln City area, the dune sheet and marine terrace extents generally agree with each other in size and shape. The only area where there is significant difference is south of Siletz Bay where the marine terrace extends inland approximately 0.5 miles (0.8 km) past the dune sheet (Figure 36). In the area north of Yaquina Bay the paleodune deposits are continuous, and they generally extend inland between 0.8 to 1.0 miles (1.3 to 1.6 km). The terraces are not continuously mapped in this northern section and their inland extent is approximately 0.3 miles (0.5 km) (Figure 37). South of Yaquina Bay to the Lincoln County line, the boundaries of the marine terraces and the paleodunes are very similar with the main exception that the paleodune deposit is again more continuous than the marine terraces in this area.

Figure 36: Comparison between marine terraces mapped by Schlicker (1973) and paleodune boundary south of Siletz Bay. The marine terraces extend approximately 0.5 mile inland past the paleodunes.

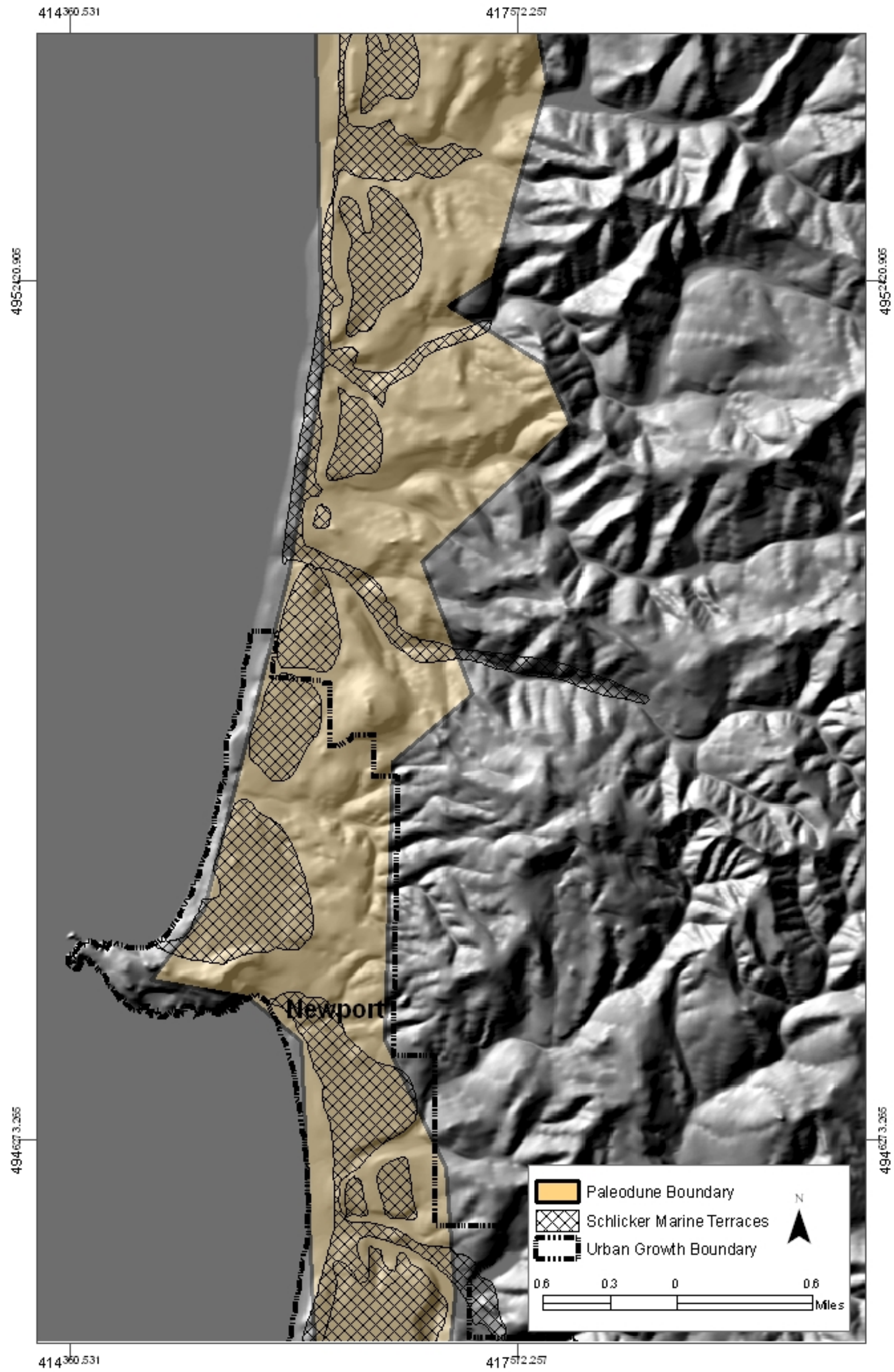

Figure 37: The area north of Yaquina Bay in the city of Newport. In this area the marine terraces are not continuously mapped and only extend approximately 0.3 miles inland.

For this comparative analysis published soils maps for Lincoln County are also compared with the mapped paleodune coverage (Figure 38). The Pleistocene, Holocene, and loess soils digitized from the United States Department of Agricultures (USDA) (1997) are not adequate proxies for the paleodune deposits in the project area (Figure 38). Generally, the USDA Pleistocene and loess soils are discontinuous within the paleodunes (Figure 38). The USDA soils confirm the presence of Pleistocene, Holocene and loess soils in the paleodunes but they do not reflect the size or shape of the paleodune boundary. The discrimination between Holocene and Pleistocene dunes is important in terms of cementation, loess interbeds, permeability and stability which are generally higher in Pleistocene relative to Holocene dunes (Table 10, Table 11, Table 12, Table 13, Table 14, and Table 15). The Holocene dominated soils in the south of Lincoln County do accurately signify the change from Pleistocene to Holocene age paleodunes. These relations between preexisting geologic soils maps and newly mapped dunes are further examined within the Discussion section.

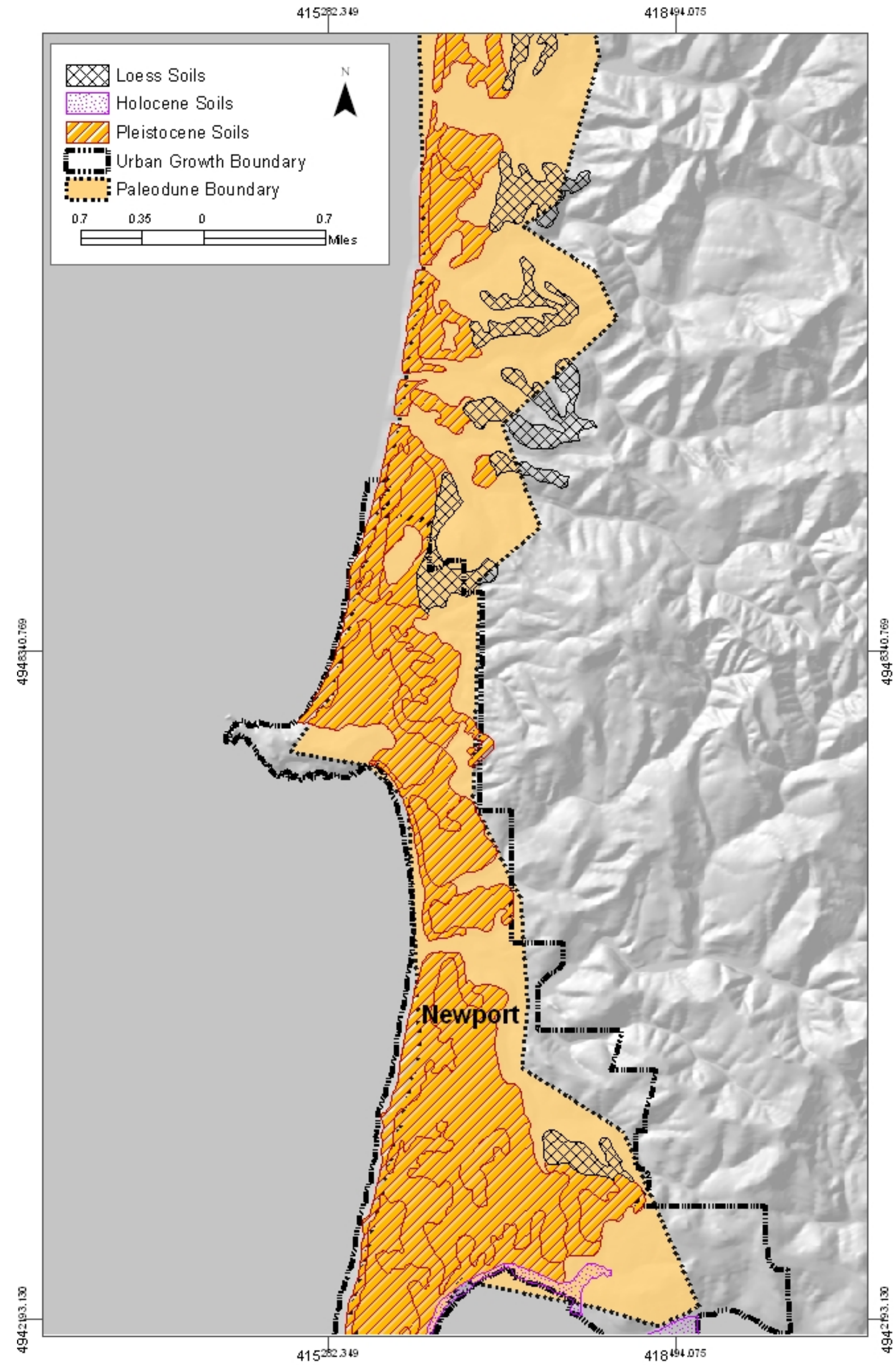

Figure 38: Comparison between the USDA mapped soils in Lincoln County and the paleodunes.

Data Parametrics

The database developed for this GIS analysis was designed to: 1) capture the most information about each sample site, 2) be efficient in exporting data through queries and reports, and 3) accommodate future needs through additional tables. It was originally designed in MS Access to provide flexibility for the end user. The Access database and ESRI geodatabase is contained on a CD accompanying the thesis.

The Access database and ERSI geodatabase contain the same files. The Access database includes shapefiles and the ERSI geodatabase contains data tables with relationships. Both are included in this project to optimize the data updates and data extraction through either Access or ArcMap, depending on the user's needs. The tables (Table 8, Table 9) below describe both the Access database and ESRI geodatabase.

Table 8: Data tables included in the Access database and ESRI geodatabase and the number of features contained in each table.

Tables	Number of Attributed Features
Elevation	1177
Exposure	182
Grain Size	362
Horizons	1177
Horizon Type	985
Images	132
Locations	132
Parent Material	1099
Relative Dates	1038
Site Notes	114
Strength	382
Structure	381

Table 9: Layers included in the Access database and ESRI geodatabase, the number of features contained in each and the approximate area of the coverage.

Layer	Number of Attributed Features	Square Miles
City Limits	7	24
Holocene Soils	689	42
Lake	1	1
Lincoln County	1	988
Loess Soils	338	15
Marine Terraces	269	18
Pleistocene Soils	1536	62
Streets	5548	1188
Urban Growth Boundary	5	25
Waterbodies	761	22
Wetlands	665	30
Zoning	547	988

Geospatial Relationships

With the dune sheet database it is possible to query the attributes and identify important geospatial paleodune relationships. Some of the relationships evaluated here are the ratios, frequencies, and locations of the Bw and Bg horizons relative to groundwater conditions in the paleodune aquifer. The B horizon underlies topsoil and shows evidence of redox conditions during soil formation. The Bg horizon designation indicates constant saturation and a reducing environment. The Bw horizon reflects oxidative and non-saturated conditions (Birkeland, 1999). With those considerations, the B horizon type is used as an indicator of seasonal groundwater levels. Clough (2005) hypothesized that Bw horizons are primarily found in the top section of the sea cliffs, while Bg horizons are more frequent at the bottom (Figure 45). This distribution of the horizons is attributed to the redox state of the unsaturated dune tops and saturated (low redox) of the dune bottoms. To test this hypothesis the occurrence and relative depth of Bw and Bg horizons in the sea cliffs are compared. The results are presented in the table below. The ratio of Bw to Bg horizons in the upper sea cliffs is 27% Bw and 73% Bg, while the ratio of the lower sea cliffs is 82% Bw and 18% Bg. The Bg horizon dominates the upper section of the sea cliffs and the Bw horizon dominates in the lower section of the sea cliffs. The predominance of Bg horizons in the sea cliff sections probably reflects low preservation potential of Bw horizons in the seaward deflation plain setting exposed in the sea cliffs. Nevertheless, these results indicate: 1) a wide vertical range of seasonal wetting and 2) an importance of oxygenated groundwater underflow in some dune deposits (see Discussion) (Figure 46).

Soil morpho-stratigraphic logs of the dune sheet deposits are included to illustrate the complex interbedding of soils, cemented sand, silt, iron oxides and deflation layers. These logs include traverses that oriented in north-south and east-west direction. Figure 39 is located in Lincoln City at the 21st public beach, the log traverses south for 3 miles (5 km) capturing the sea cliff exposures. Figure 40 is a 25 mile (45 km) south traverse showing the major sea cliff exposures in the Newport dune sheet. Figure 41 is 1.5 miles (2.5 km) east traverse starting at Nye Beach and ending at the foothills of the coast range. Figure 42 is 1.8 miles (3 km) east traverse starting at Ona Beach and ending at the foothills of the coast range. Figure 43 is 0.9 miles (1.5 km) east traverse starting at the sea cliff exposure at Spencer Creek and ending at the foothills. Figure 44 is a 0.6 mile (1 km) east traverse starting at the sea cliffs in Yachats.

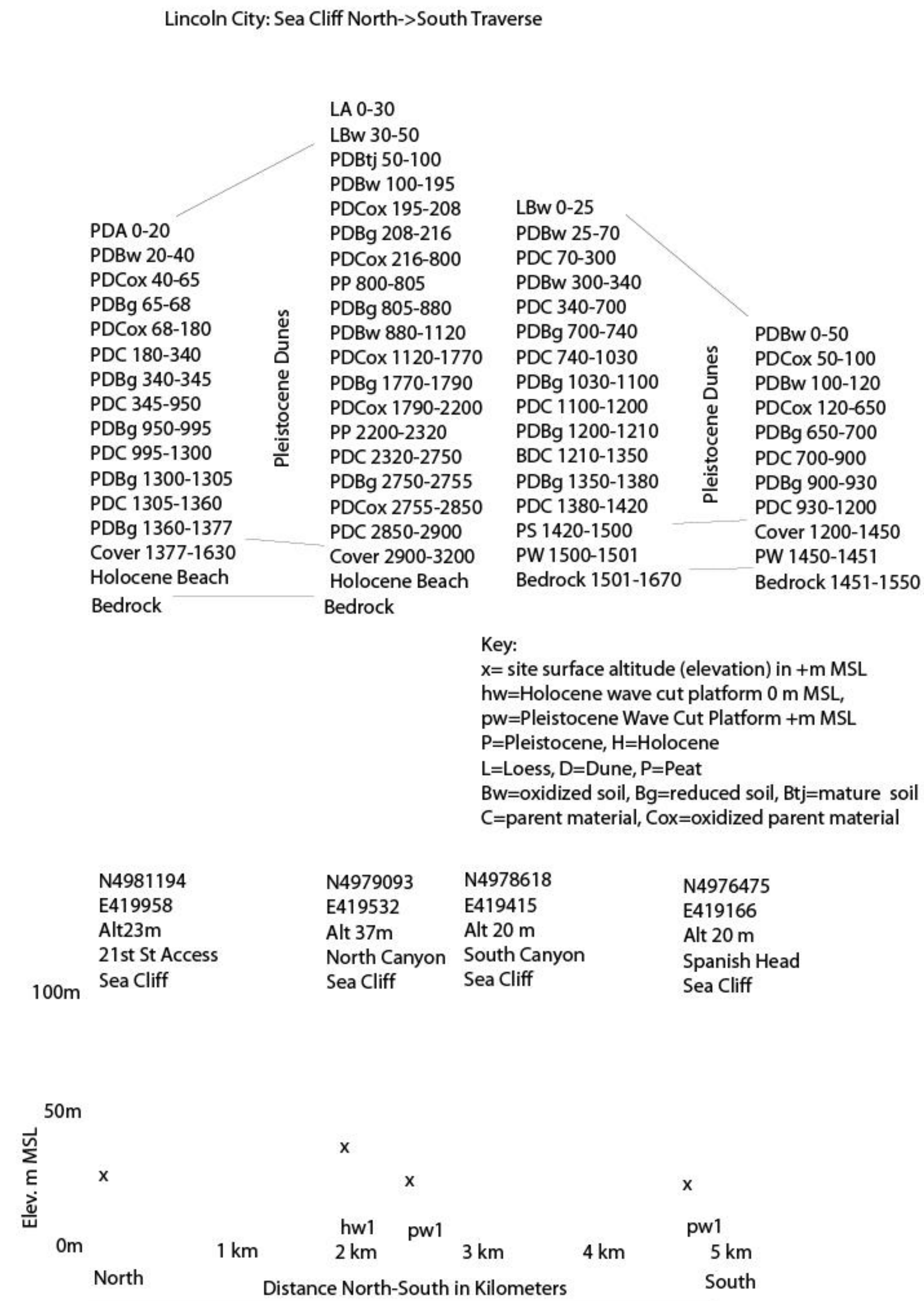

Figure 39: Morpho-stratagraphic log of Lincoln City sea cliff exposure illustrating the complex interbeds of the paleodune deposits. From Clough (2005).

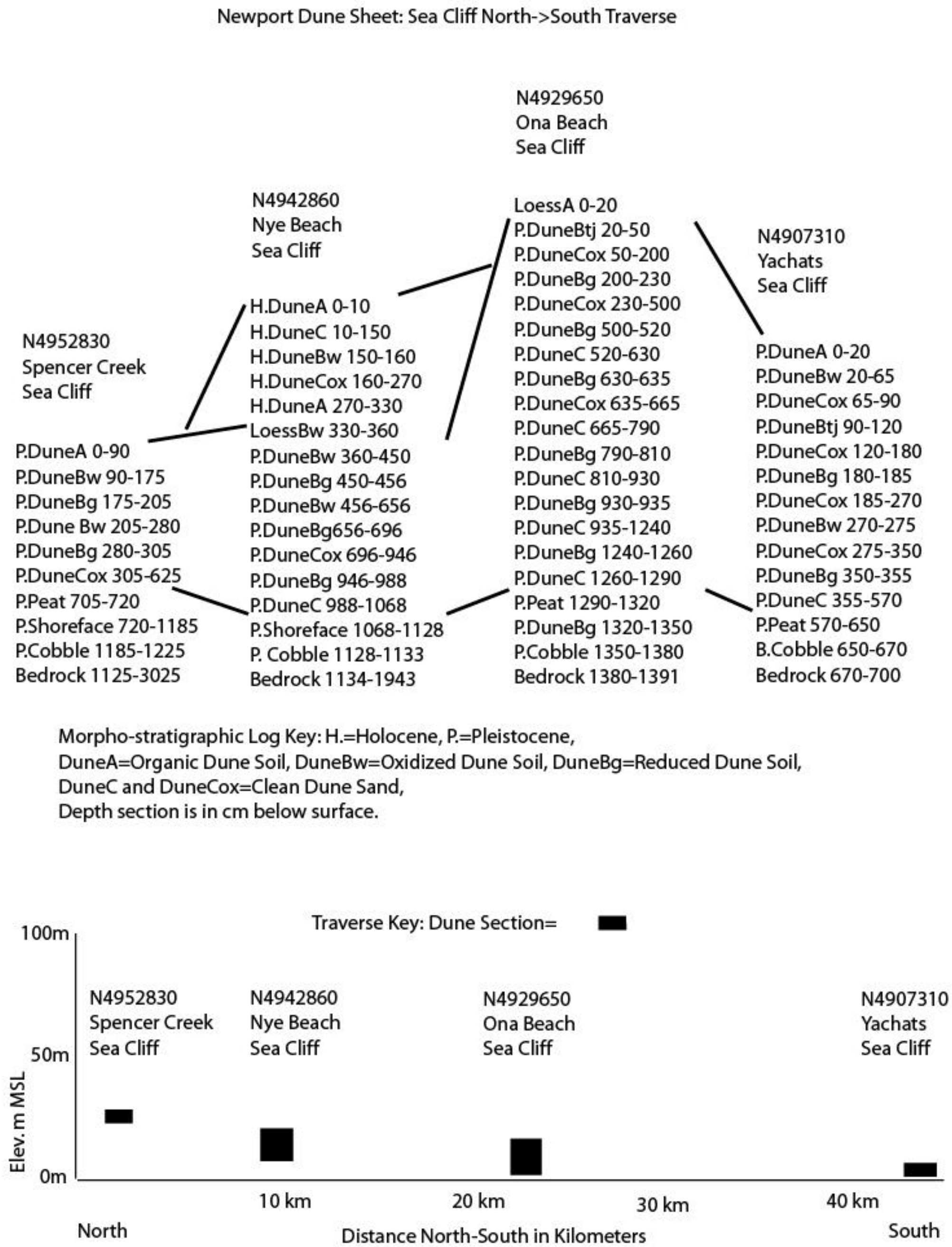

Figure 40: Morpho-stratagraphic log of Newport dune sheet sea cliff exposure illustrating the complex interbeds of the paleodune deposits. From Clough (2005).

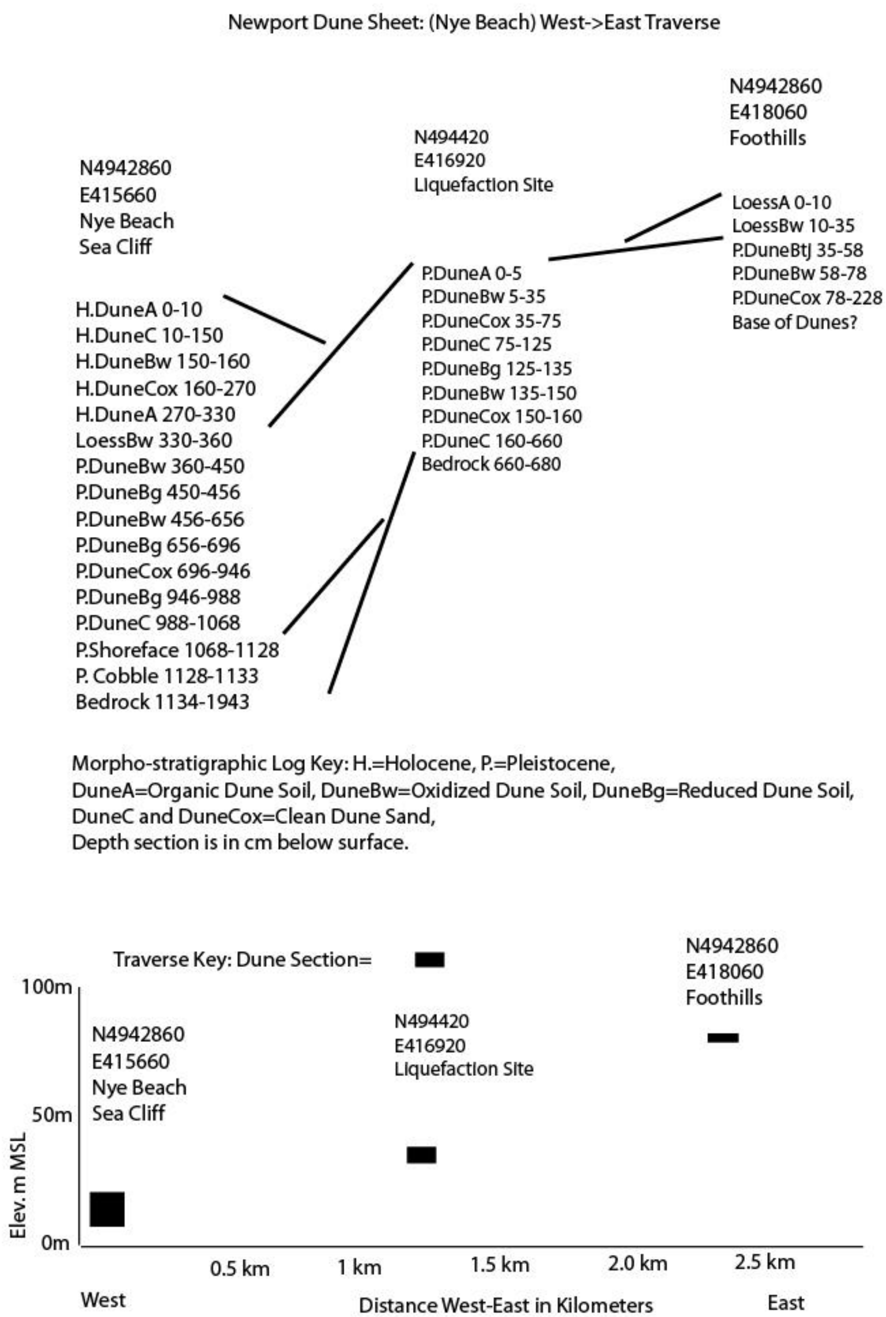

Figure 41: Morpho-stratagraphic log of Newport dune sheet sea cliff exposure at Nye Beach illustrating the complex interbeds of the paleodune deposits. From Clough (2005).

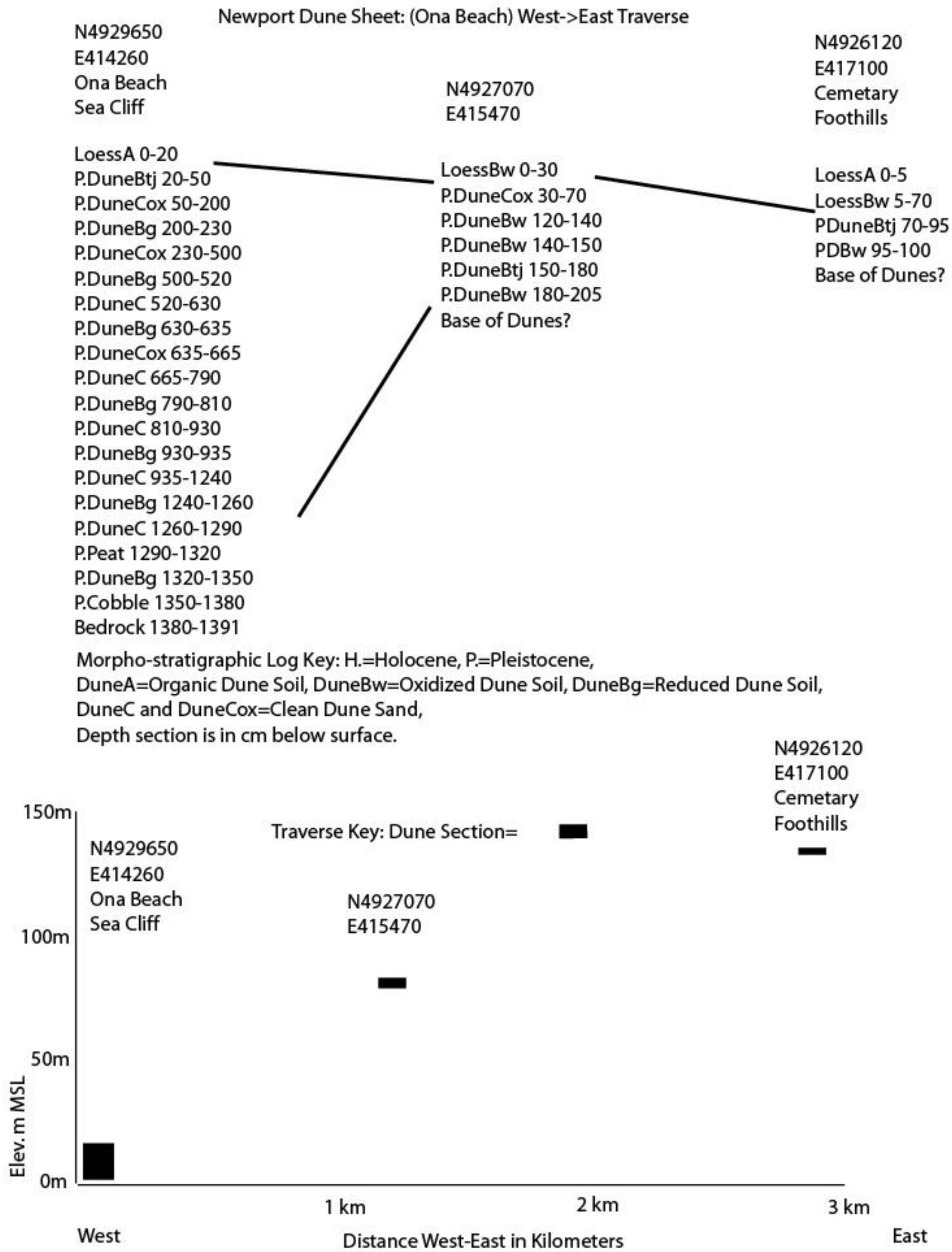

Figure 42: Morpho-stratagraphic log of Newport dune sheet sea cliff exposure at Ona Beach illustrating the complex interbeds of the paleodune deposits. From Clough (2005).

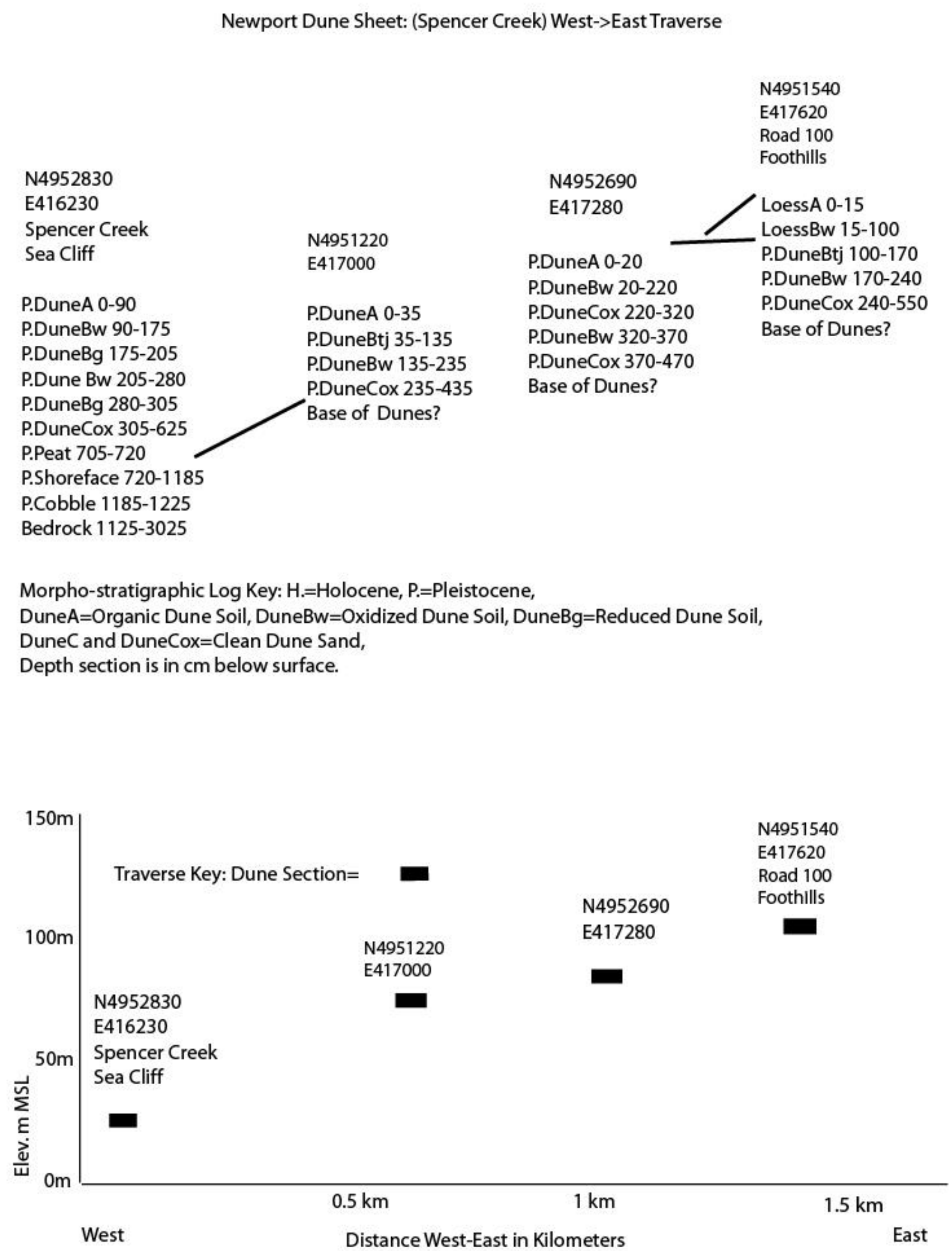

Figure 43: Morpho-stratagraphic log of Newport dune sheet exposure at Spencer Creek illustrating the complex interbeds of the paleodune deposits. From Clough (2005).

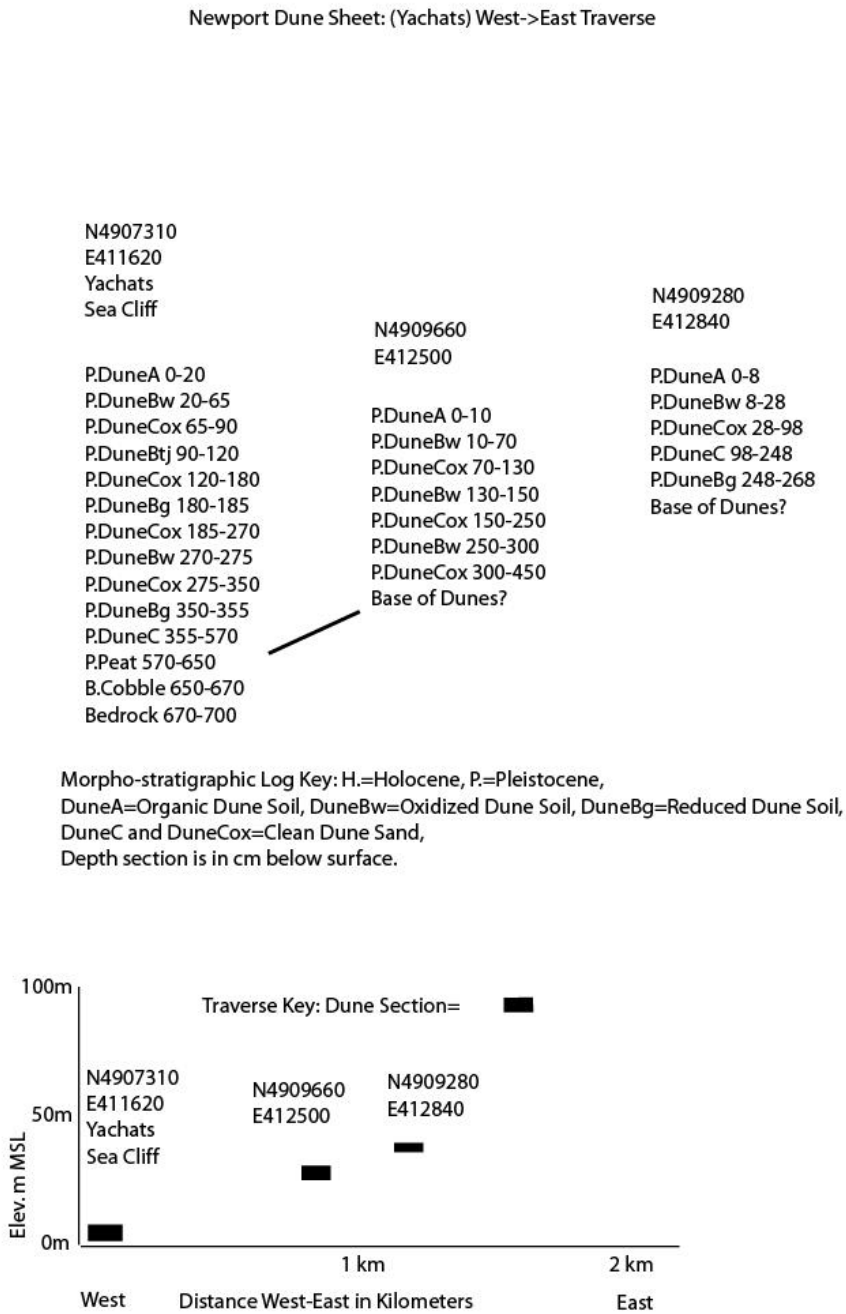

Figure 44: Morpho-stratagraphic log of Newport dune sheet exposure at Yachats illustrating the complex interbeds of the paleodune deposits. From Clough (2005).

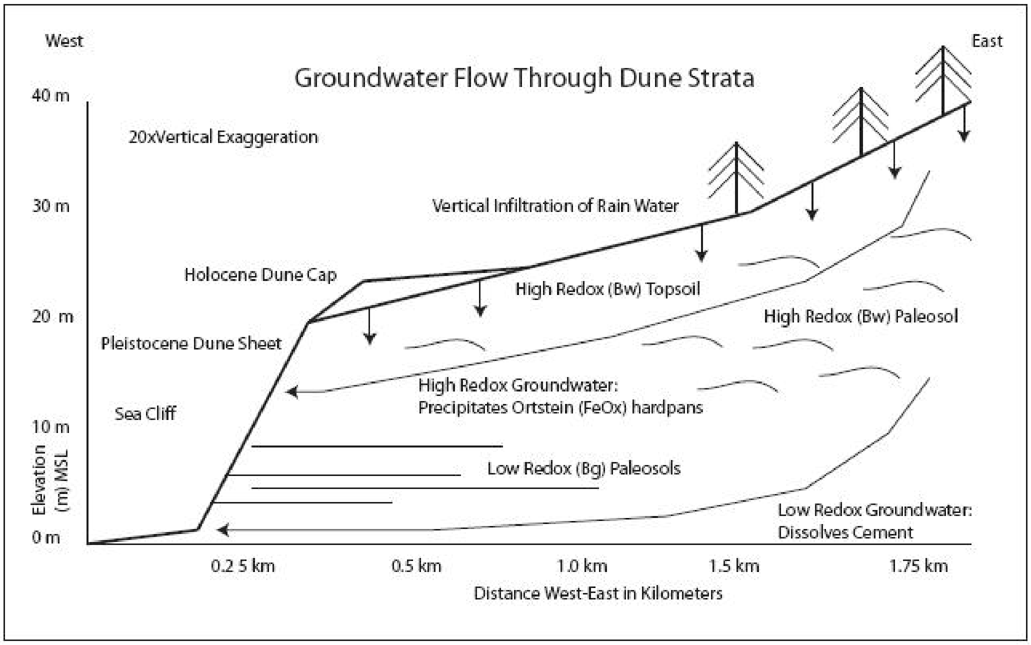

Figure 45: Clough's (2005) conceptual model of ground water flow with redox conditions.

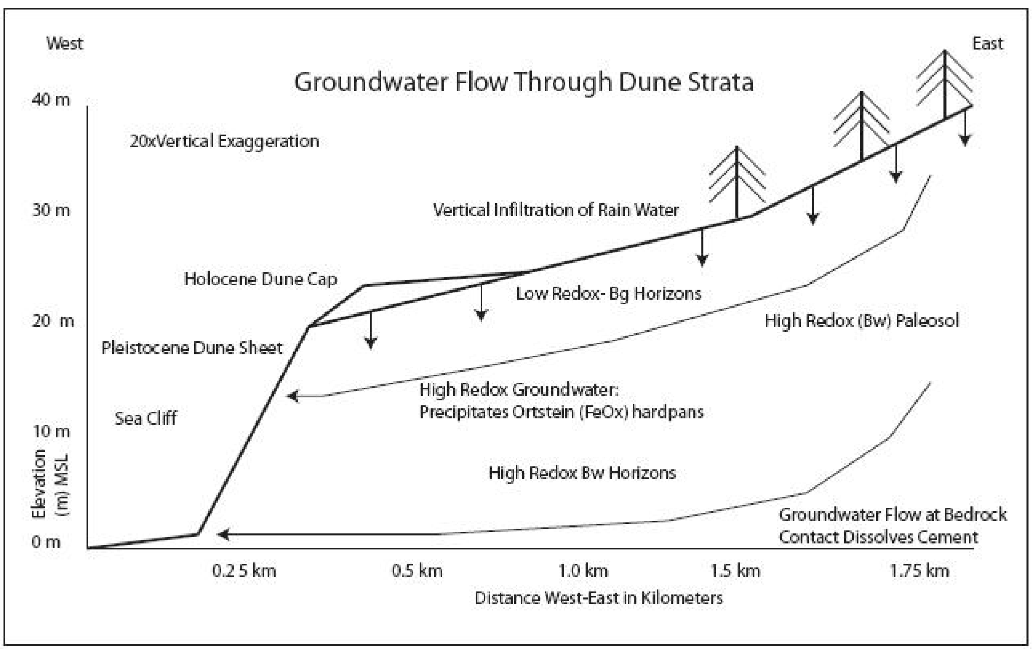

Figure 46: Updated conceptual ground water flow model with redox conditions.

Table 10: Ratio of Bw and Bg horizon in the sea cliffs.

	Percent of Bw	Percent of Bg
Upper Section Of Sea cliffs	27%	73%
Lower Section Of Sea cliffs	82%	18%

I also wanted to confirm if the groundwater redox trends extended inland for the paleodunes. The ratio and relative depth of occurrence of the Bw and Bg horizons are compared. These results are presented in Table 11. The ratios of the Bw and Bg horizons in the ridges are 95% Bw and 5% Bg. The ratios for the valleys are 94% Bw and 6% Bg. The Bw horizon dominated in the shallow sections exposed in road cuts, and in river cuts examined by the mappers, and in both the topographic highs and lows inland of the sea cliffs. The dominance of Bw horizons in the dune sheets at the foot of the coast range hills suggest high preservation potential for oxidized soils in areas of vertical aggredation. However, these results also confirm seasonal lowering of the groundwater surfaces in the landward dunes, thus permitting subsurface oxidation in the upper sections of the sea word dune deposits (see Discussion).

Table 11: Ratio of Bw and Bg horizons inland.

	Percent of Bw	Percent of Bg
Ridges	95%	5%
Valleys	94%	6%

Another important relationship that can be examined from the paleodune database is the relative cementation based on the pocket penetrometer values of unconfined shear strength in kg/cm^2. Comparisons are made between the Pleistocene and Holocene age dunes. Comparisons of relative cementation are also made between Pleistocene dune sections in the valley floors and in the ridge tops. Based on the statistical T Test against the sample means the relative cementation of the Holocene and Pleistocene age dunes are distinguishable from each other (Table 12). The mean pocket penetrometer value for the Holocene Age dunes is 1.26 kg/cm^2 with one standard deviation of ±0.91, whereas the mean value for the Pleistocene age dunes is 3.49 kg/cm^2 with one standard deviation of ±0.87. The relative cementation between the valley and the ridges are also distinguishable from each other based on the T-test for sample means (Table 13). The mean pocket penetrometer value for the valleys is 3.50 kg/cm^2 with one standard deviation of ±1.05, whereas the mean for the ridges is 2.78 kg/cm^2 with one standard deviation of ±1.07. In addition, the relative cementation between the lower sections of the sea cliffs and the upper sections of the sea cliffs is distinguishable (Table 14). The mean pocket penetrometer value for the upper section is 2.87 kg/cm^2 with one standard deviation of ±1.24, whereas the mean for the lower section is 3.57 kg/cm^2 with one standard deviation of ±1.09.

Table 12: Comparison of relative cementation between Holocene and Pleistocene Dunes.

	Mean Cementation kg/cm^2	Standard Deviation	T test statistic	Table Statistic $\alpha = 0.025$
Holocene Age	1.26	0.91	2.54	2.25
Pleistocene Age	3.49	0.87		

Table 13: Comparison of relative cementation between valley and ridges.

	Mean Cementation kg/cm^2	Standard Deviation	T test Statistic	Table Statistic $\alpha = 0.025$
Valley	3.50	1.05	3.24	2.27
Ridges	2.78	1.07		

Table 14: Comparison of relative cementation between the upper sections of the sea cliffs and the lower section of the sea cliffs.

	Mean Cementation kg/cm^2	Standard Deviation	T test Statistic	Table Statistic $\alpha = 0.025$
Upper Sections of Sea cliff	2.87	1.24	2.91	2.27
Lower Sections of Sea cliff	3.57	1.09		

After review of the previously collected cementation data from the sea cliffs (Table 14), I questioned whether the middle sections of the sea cliffs were consistent with the expected groundwater hydrology of the dune sheets (Easterly, 2005). The local groundwater hydrology in the dunes impacts aluminum, silica and iron cementation. The Seagrant Publication (2006) hypothesizes that cementation is diminished at contact between the dunes and bedrock because of excess concentrated groundwater flow. In order to test the statistics and the groundwater hydrology model, additional cementation data was gathered from the sea cliffs. The ground truthing was conducted in December of 2007. The mean pocket penetrometer value for the upper section is 4.63 kg/cm^2 with one standard deviation of ±0.61, whereas the mean for the lower section is 1.18 kg/cm^2 with one standard deviation of ±0.86. The new data in Table 15 indicates the Seagrant hydrology model is correct and that the cementation in the middle sections is significantly higher than of the basal contact layers. These results confirm that there are particularly weak dune sand layers at the base of the dune sheets (see Discussion).

Table 15: Updated cementation data for comparison of relative cementation between the upper sections of the sea cliffs and the lower section of the sea cliffs.

	Mean Cementation kg/cm^2	Standard Deviation	T test Statistic	Table Statistic $\alpha = 0.025$
Upper Sections of Sea cliff	4.63	0.61	6.91	2.63
Lower Sections of Sea cliff	1.18	0.86		

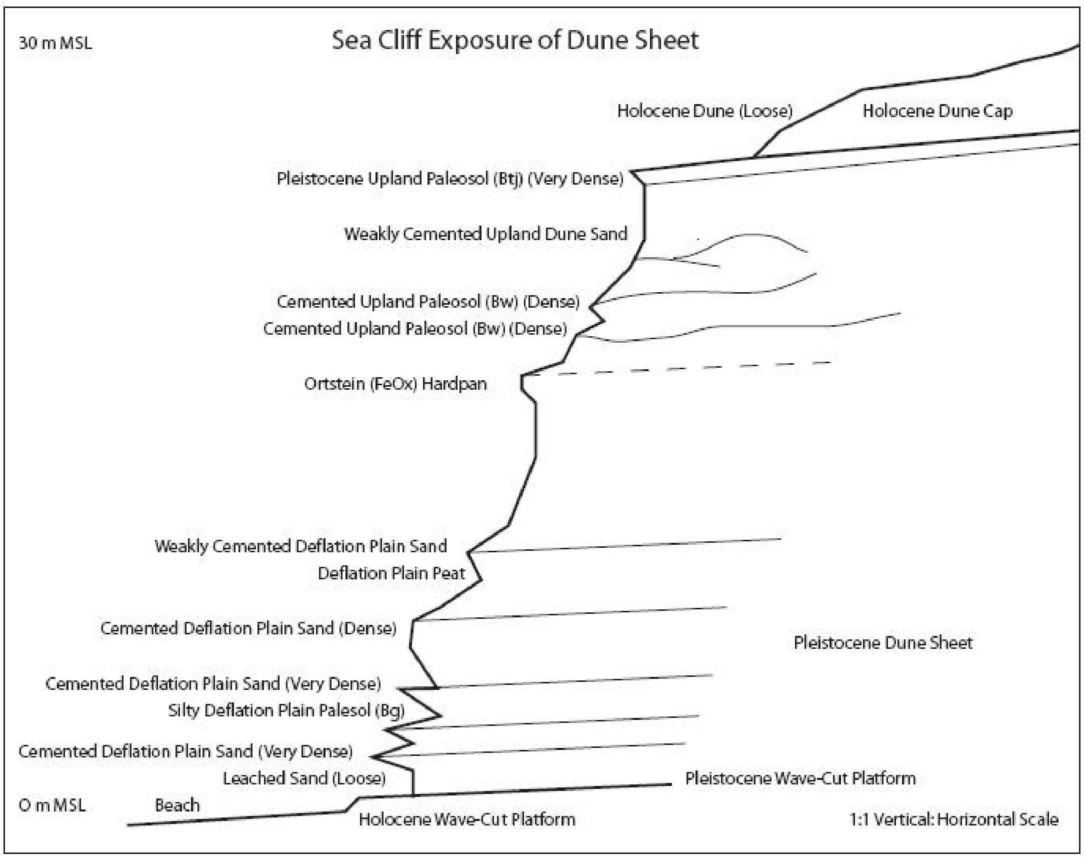

Figure 47: Sea cliff exposure conceptual model. The basal wave-cut marine terraces act as aquitards, the concentrated ground water flow leaches the cement from the lower section of the paleodunes. Modified from Clough (2005).

A key issue of development in the paleodunes is slope instability. There are several factors that contribute to slope failures, but as mentioned above the instability frequently occurs at the contact between the paleodune deposits and bedrock because of the diminished cementation. Construction in the paleodunes can minimize instability uncertainty by knowing the soils shear strength and depth to bedrock. The depth to bedrock is important in foundation design that requires constraints excavation, (2) weight of overburden, and (3) certainty of adequate drainage below grade walls. At the present there is little to no regional GIS coverages of paleodune thickness. To show the importance of this data gap representative cross-sectional models of the paleodunes and bedrock are created where sample sites extended inland.

Nine bedrock profiles are portrayed within the Lincoln and Newport dune sheets that are presented in the following figures. Figure 50 shows the cross section located in Lincoln City at SW Bard Street, the cross section is oriented east west. The depth to bedrock is highly variable in this area, at the sea cliff it is 40 meters deep and then outcrops 600 meters in land from the sea cliff. Figure 51 is the cross section orientated S30E at NW 40th Street in Lincoln City. The bedrock is relatively shallow and the paleodune deposits thin in this cross section. Figure 52 is the cross section orientated S15E, located approximately 2 miles north of the UGB for Newport. The paleodune deposits are thick in the sea cliff outcrop and thin moving inland. Figure 53 is the cross section orientated N15E, located approximately 1 mile north of the UGB for Newport. Again this cross section shows the dune sheet thinning landward, the bedrock outcrops at 2000 meters in land. Figure 55 is the cross section orientated N9E, located at NW Lighthouse Drive in Newport. The bedrock elevation is relatively consistent at approximately 45 meters above sea level while the dune sheet thickness varies with topography. is the cross section orientated N30E at NE 40th Street in Newport. The dune sheet thickness is around 10 meters thick for the majority of the cross section and then abruptly thins with steep rise in topography. Figure 56 is the cross section orientated east west at SW 97th Court in Newport. The paleodune thickness mimics the topography and is approximately 25 meters thick. Figure 57 is the cross section orientated at N5E at US Forest Service Road 1045 south of Waldport. Figure 58 is the cross section orientated S70E at W 7th Street in Yachats. The paleodune deposit thickness follows the topographic surface trend.

The hypothetical cross-sections outlined above are based on the currently available data regarding depth to bedrock under the mapped dune sheets. In all cases there is a seaward dipping gradient of the dune-beach to bedrock (mudstone) contact. However, the limited dune thickness data suggest substantial changes in the slope of the contact along the cross-sections. It is expected that the dune bedrock contacts will also dip towards paleo-river valleys filled in by the paleodune deposits. No detailed profile cross-sections are attempted in this study due to insufficient depth to bedrock data in the study area (see Discussion).

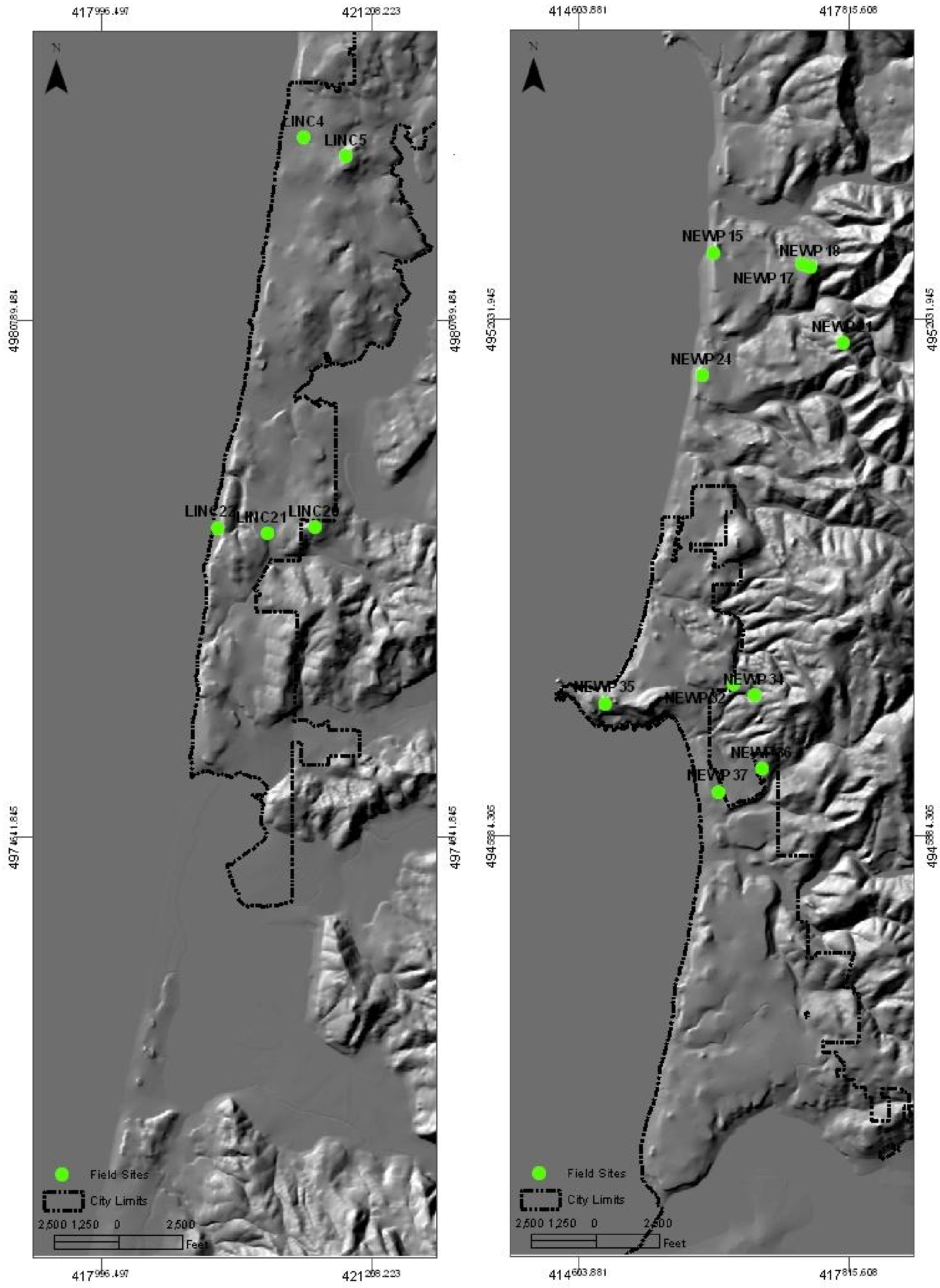

Figure 48: Locations of bedrock profiles from Figure 50, Figure 51, Figure 52, and Figure 53.

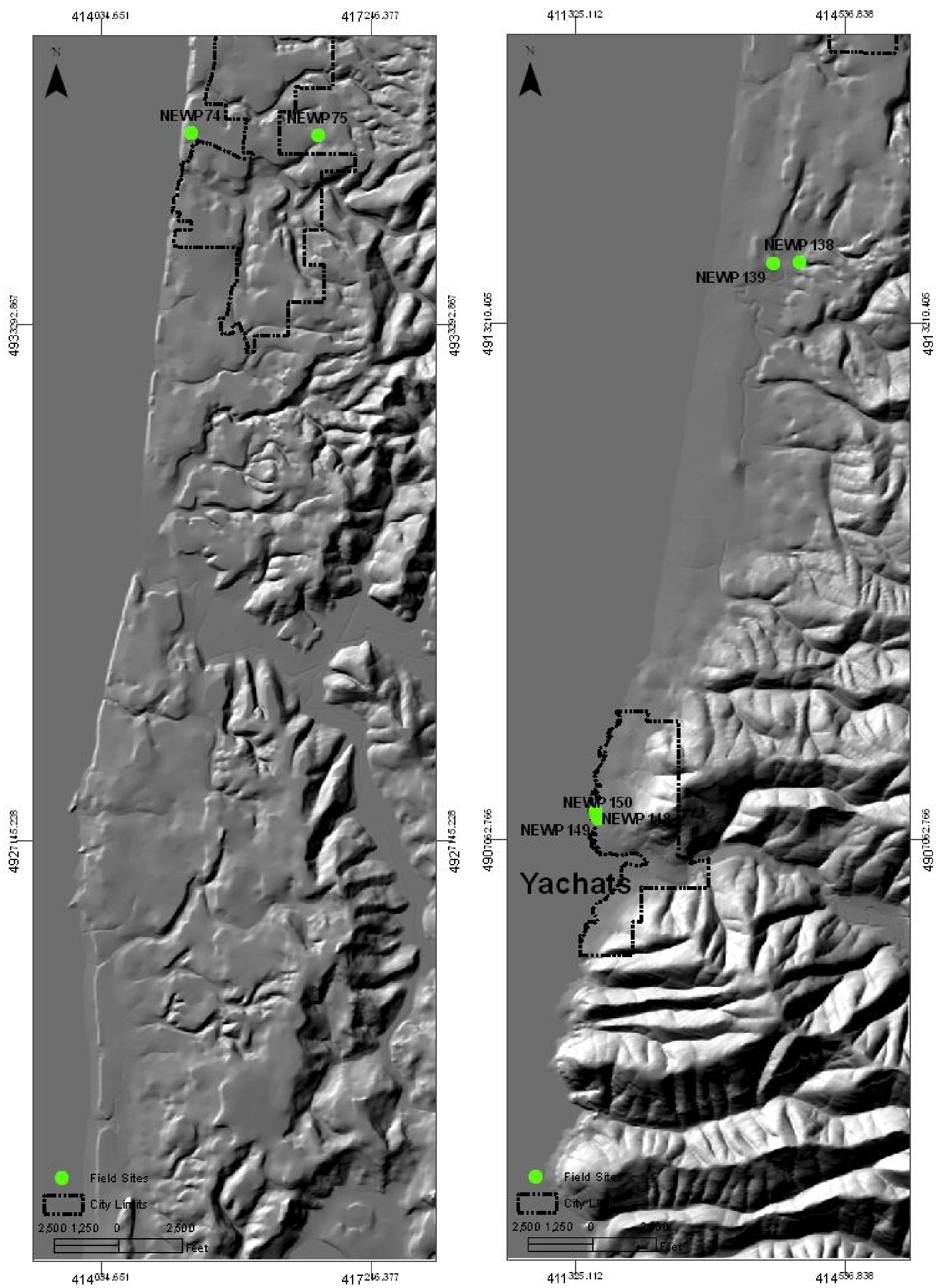

Figure 49: Locations of bedrock profiles from Figure 55, Figure 56, Figure 57, and Figure 58.

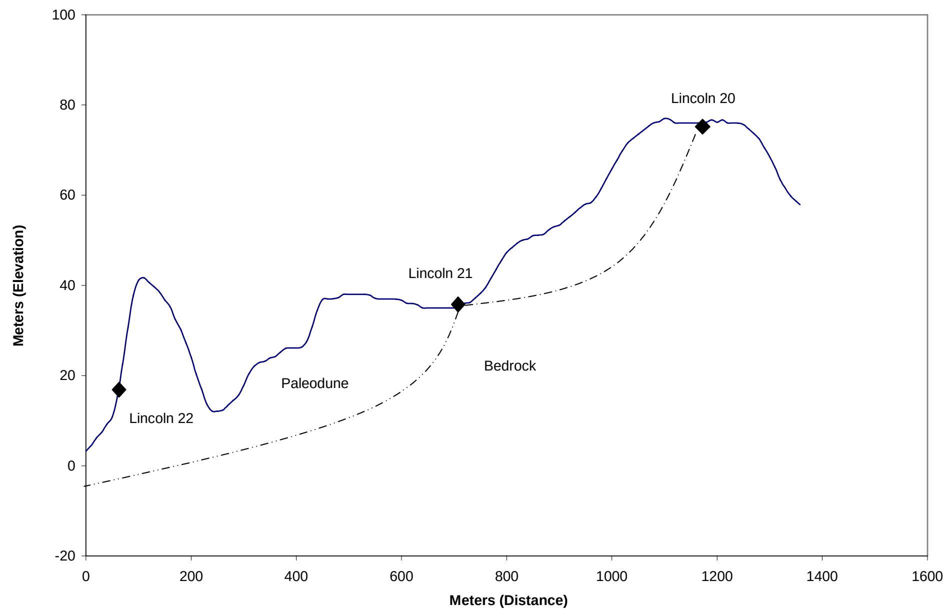

Figure 50: Cross section orientated East West, showing the depth to bedrock at SW Bard Street in Lincoln City.

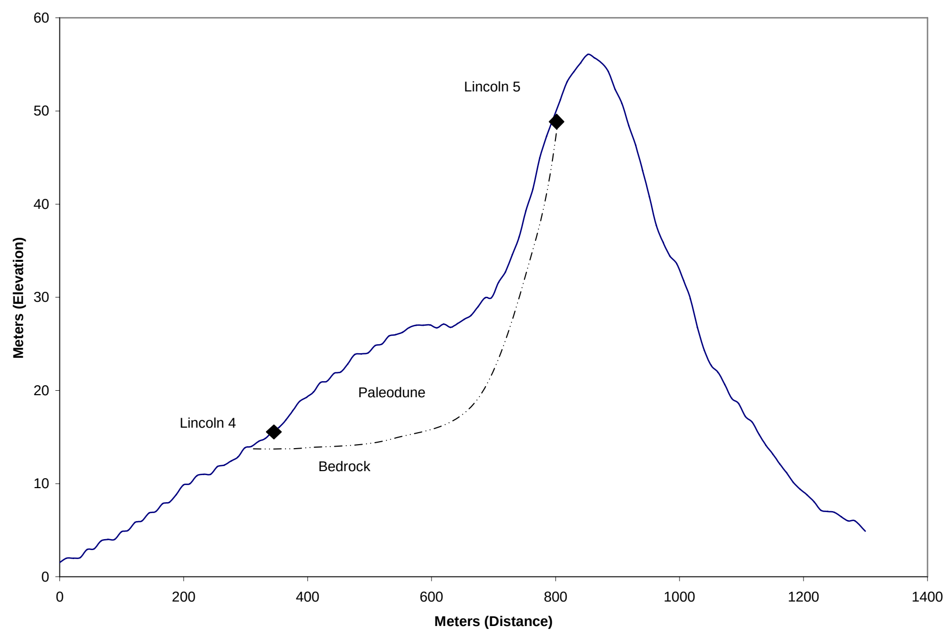

Figure 51: Cross section orientated S30E, showing the depth to bedrock at NW 40th Street in Lincoln City.

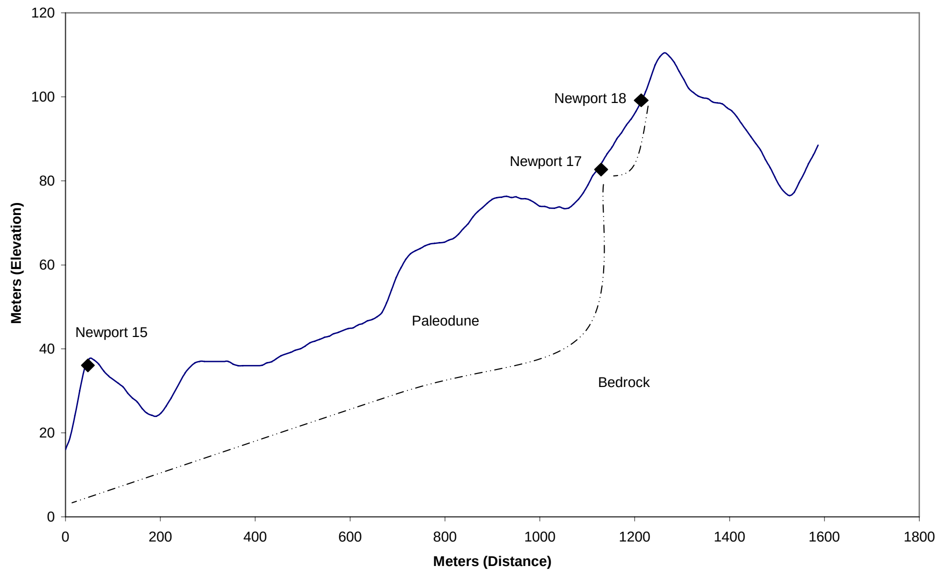

Figure 52: Cross section orientated S15E, showing the depth to bedrock approximately 2 miles north of the UGB for Newport.

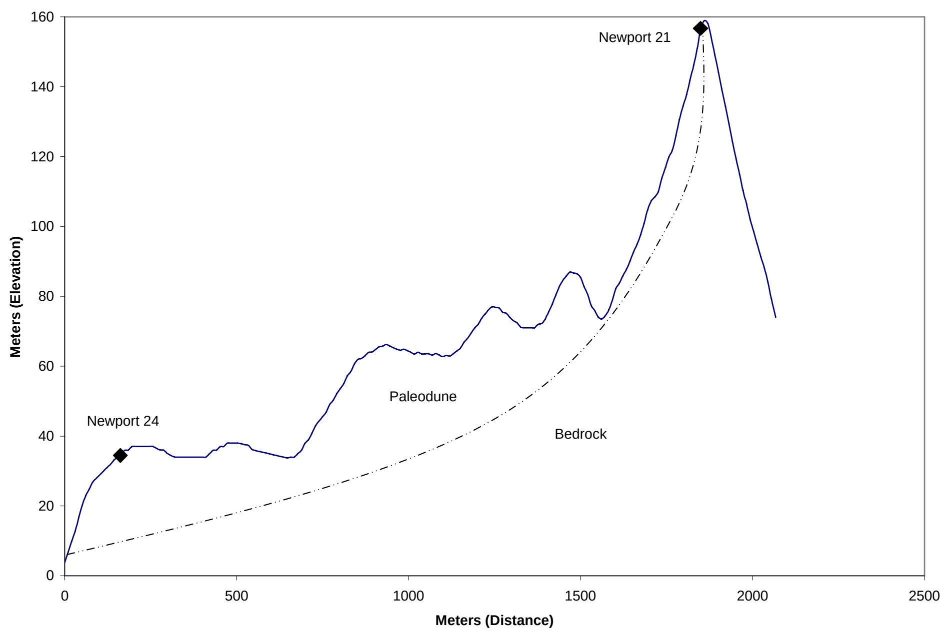

Figure 53: Cross section orientated N15E, showing the depth to bedrock approximately 1 mile North of the UGB for Newport.

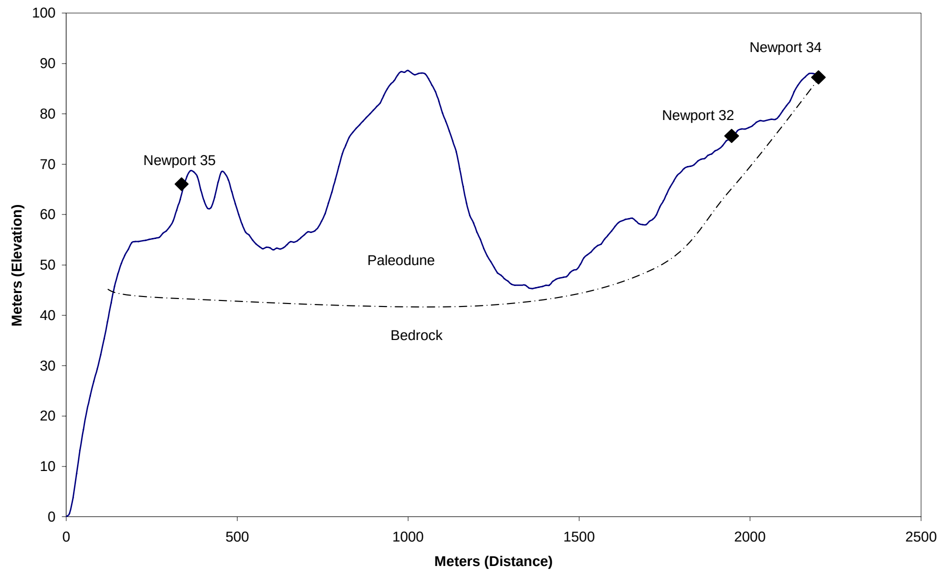

Figure 54: Cross section orientated N9E, showing the depth to bedrock at NW Lighthouse Drive in Newport.

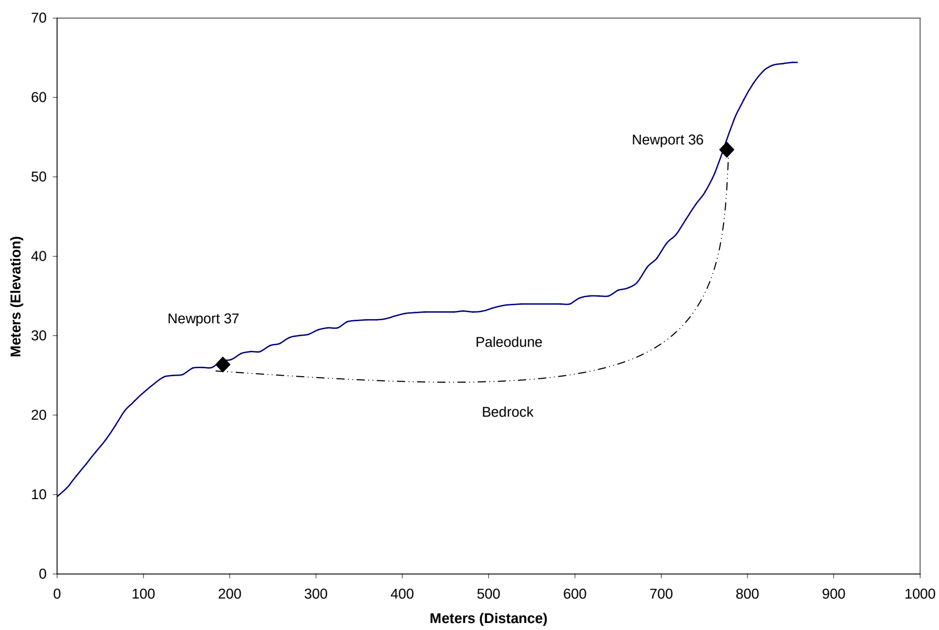

Figure 55: Cross section orientated N9E, located at NW Lighthouse Drive in Newport.

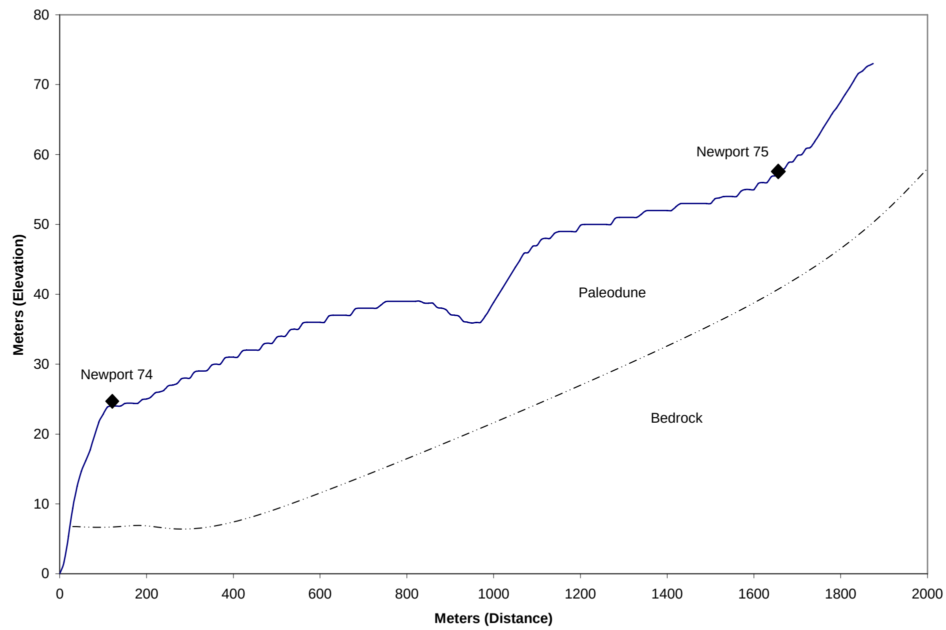

Figure 56: Cross section orientated East-West, showing the depth to bedrock at SW 97th Court in Newport.

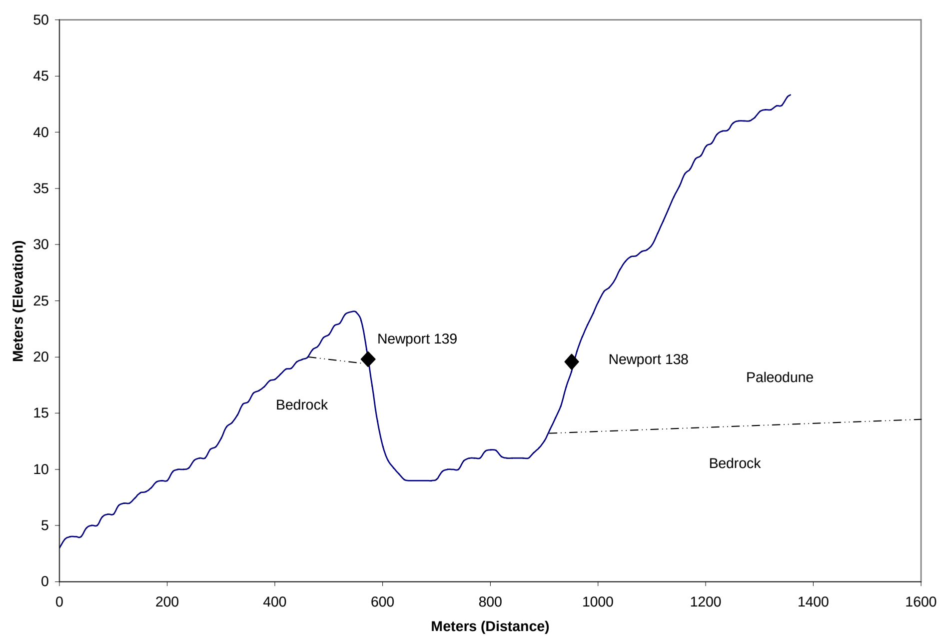

Figure 57: Cross section orientated N5E, showing the depth to bedrock at US Forest Service Road 1045 south of Waldport.

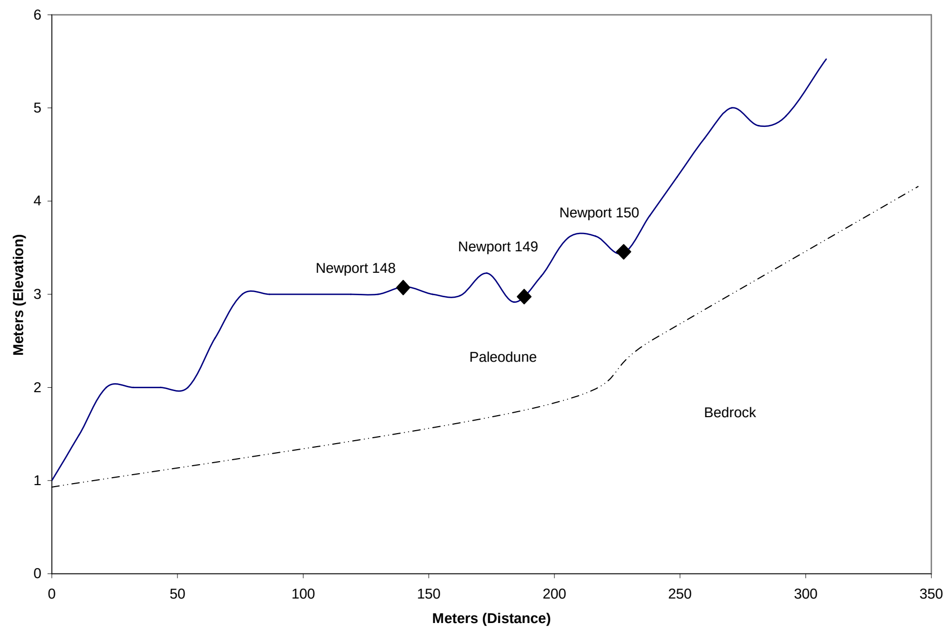

Figure 58: Cross section orientated S70E, showing the depth to bedrock at W 7th Street in Yachats.

An important aspect of the GIS map analysis is the identification of spatial data gaps. The dune sheet 'depth' cross-sections shown in Figure 50, Figure 51, Figure 52, Figure 53, Figure 55, Figure 56, Figure 57, and Figure 58, demonstrate the potential for variable unit thickness across the dune sheets. The figures also show our current lack of detailed data outlining depth to bedrock for the field area (see Discussion).

Paleodune's Influence on Development

One of the primary objectives for this project is to make geologic data accessible to non-geologists involved in land-use planning. To stress the importance of the unique hydrologic and geotechnical properties of the paleodune deposits to ongoing development the corresponding civil infrastructure is quantified by area coverages. For example the percentages of the following county and city infrastructure types are collected to be within the paleodune sheets of 1) county and city roads, 2) the Urban Growth Boundary (UGB), and 3) Lincoln County pond and bogs upland habitats are calculated.

According to the GIS shapefile supplied by Lincoln County there are 1,188 miles (1,911 km) of roads in Lincoln County. Approximately 29% (351 miles, 565 km) of the roads are in the paleodune deposits. Based on the GIS shapefile from the state of Oregon, Lincoln County's coastal city UGB covers approximately 25 square miles, and 56% (14 square miles, 36 square km) of this UGB occur in the paleodunes (Figure 59, Figure 60). The surface area of upland pond and bog habitat in the coastal plain is 57 acres (Figure 61), with approximately 0.2% of the pond and fresh water bog habitat in the paleodune deposits (see further discussion of ponds and wetlands below). The percentages above illustrate the significant amount of development that is taking place within the paleodune sheets.

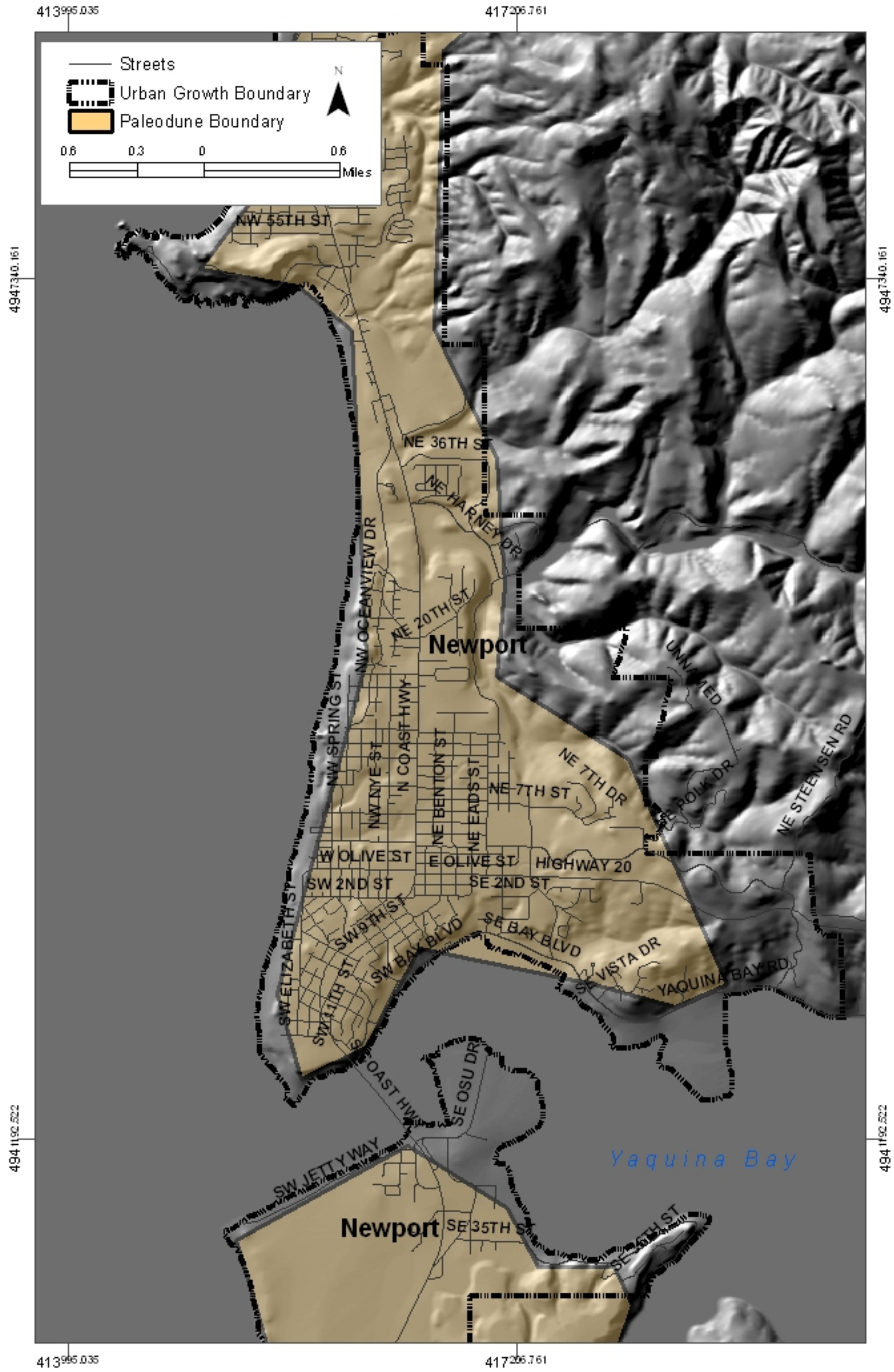

Figure 59: North of Yaquina Bay in Newport is an example of the high concentration of development including streets that occur in the paleodune deposits.

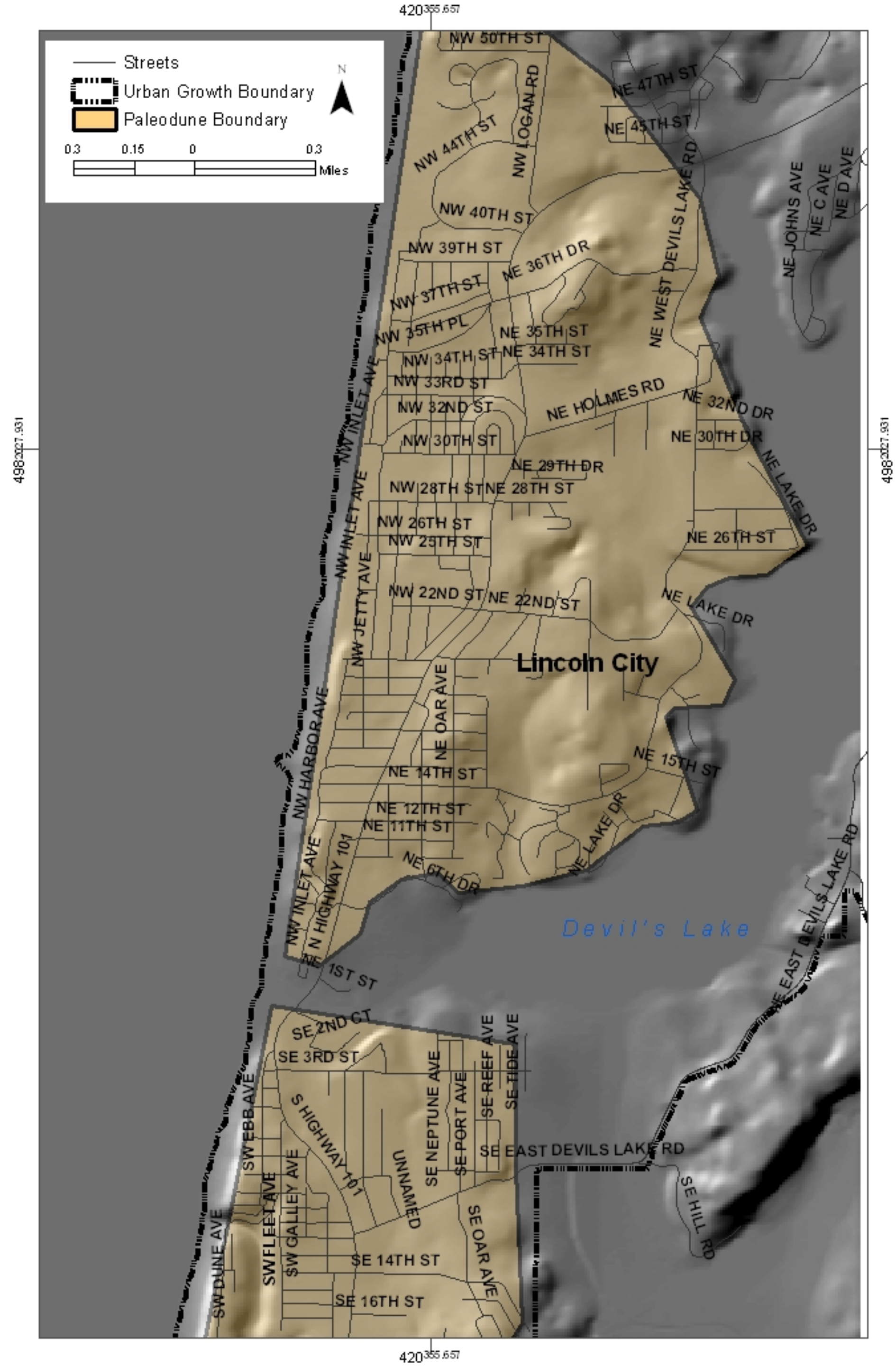

Figure 60: The Lincoln City area illustrates how much of the paleodune deposits occur within the Urban Growth Boundary.

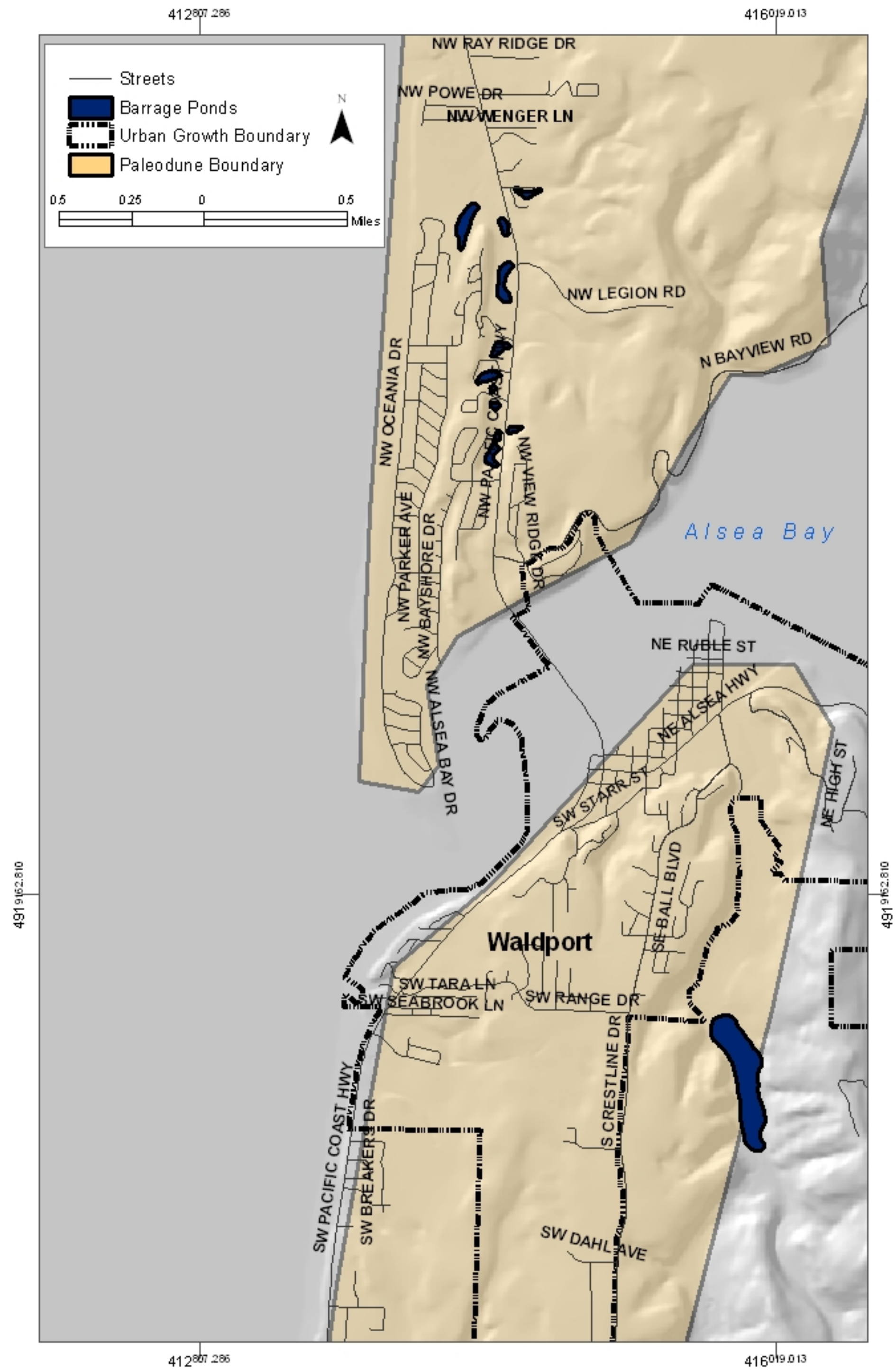

Figure 61: South of Waldport upland pond and bog habitat occur.

As the population continues to grow in the coastal plain of Central Oregon more roads will be built in the paleodune deposits. Previous studies (Clough, 2005) have recognized that slope instability occurs in road cuts containing oversteepened slopes in the paleodune deposits. Clough's study included direct shear testing on the paleodune deposits to determine the angle of internal friction (phi) for both the dune facies and paleosol facies. The internal angle of friction for the dunes ranged from 20° to 43° for the dune strata and 36° to 37° for the paleosols. A 'steep slopes' layer is created in the dune GIS geodatabase to highlight areas where natural slopes exceed the minimum phi values in areas around the paleodunes. An example of the steep slope layer is shown below in Figure 62. For this analysis the artificially steep slopes associated with road cuts in flat or slope settings are not considered because the slopes often are too small to show up on the DEM. The slopes of road cuts need to be analyzed from onsite ground truthing.

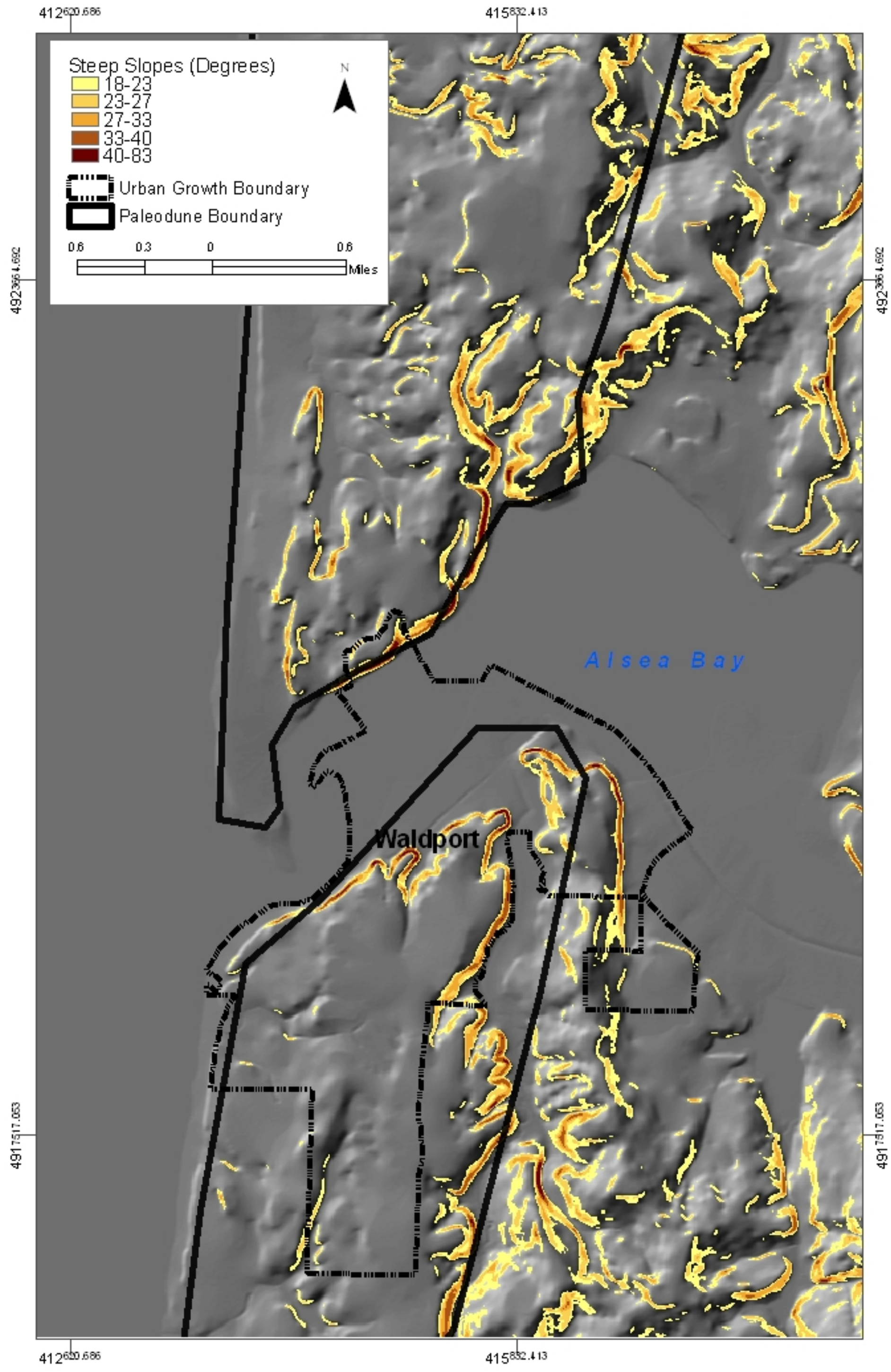

Figure 62: An example of the steep slopes in the Waldport area.

With the ongoing residential development and aging septic and sewer systems the potential for groundwater contamination in the dune aquifer will increase in the paleodunes. It is vital that we understand the interaction between groundwater flow paths, paleosol hardpans, and bedrock aquitards in the dune sheet aquifers to minimize contamination of sensitive wetland habitat and beaches in the area. There are 24,717 acres of coastal wetlands in Lincoln County according to the NRCS wetland GIS shapefile. About 19,452 acres (78%) of the upland wetlands occur within the paleodunes. The wetland habitats along with groundwater flow paths are included in the geodatabase as a reference for land use planners. The groundwater flow paths are established by GIS/DEM slope angle. Examples of the flow paths are shown in Figure 12, Figure 63, and Figure 64. Figure 63 shows the flow direction in the Newport area, there a number of large drainages in this vicinity. Figure 64 shows the flow direction the Waldport area, this area contains a number of barrage ponds where the flow of water is impeded by Holocene dune sand. As previously noted in the Geospatial Relationships section much of the dune aquifer flow is concentrated at impermeable paleosols in the paleodune deposits or at the basal contact of the dune aquifers with impermeable bedrock (Figure 65). The flow paths generated for this study are based on dune aquifers surface slopes. Better estimates of subsurface flow directions can be made from mapping groundwater surface slopes from wells or GPR profiles in the coastal dune deposits (Blakemore, 1995; Peterson et al., 2007).

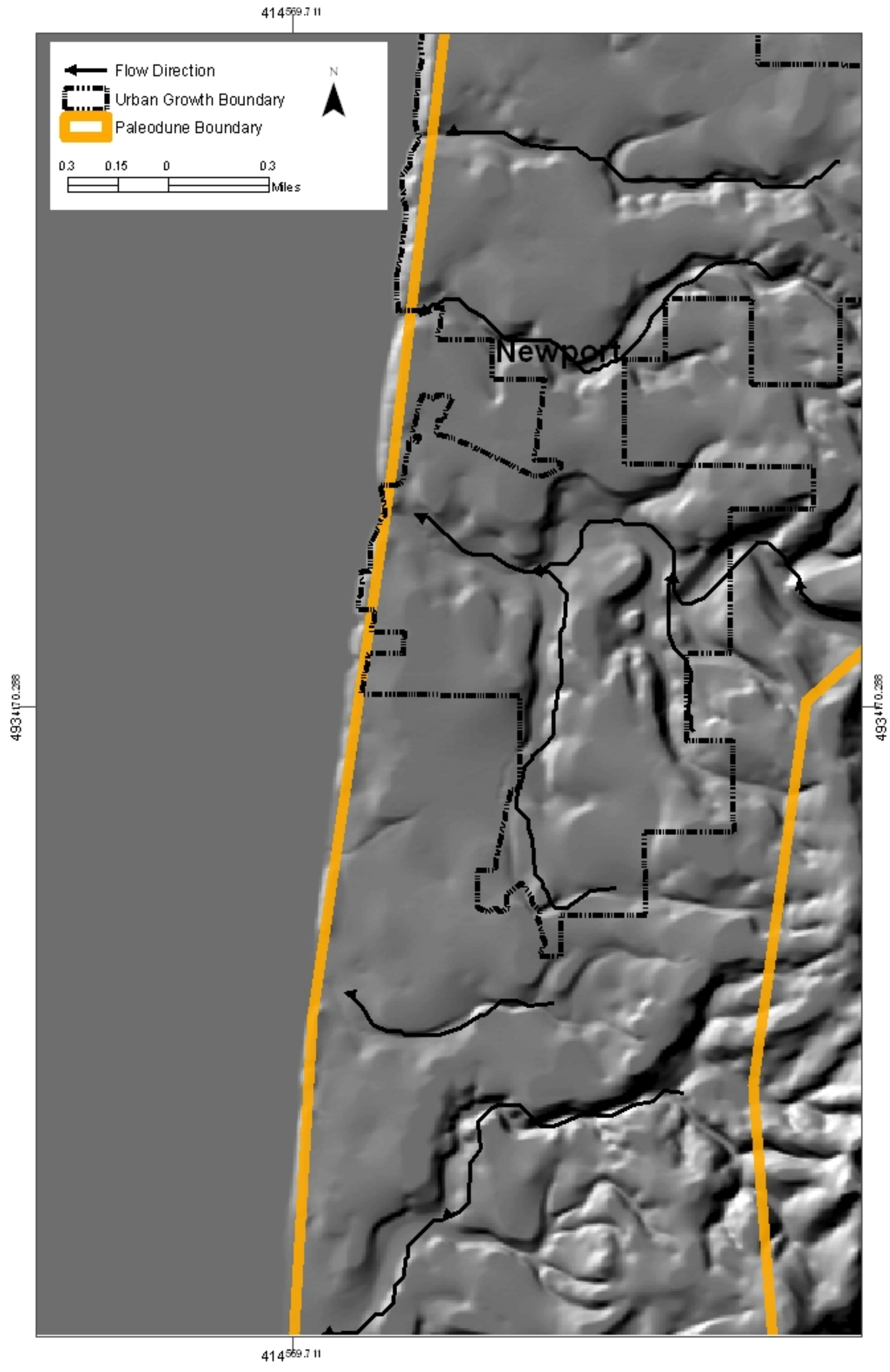

Figure 63: Map showing the flow direction that was created from the DEM in the Newport area.

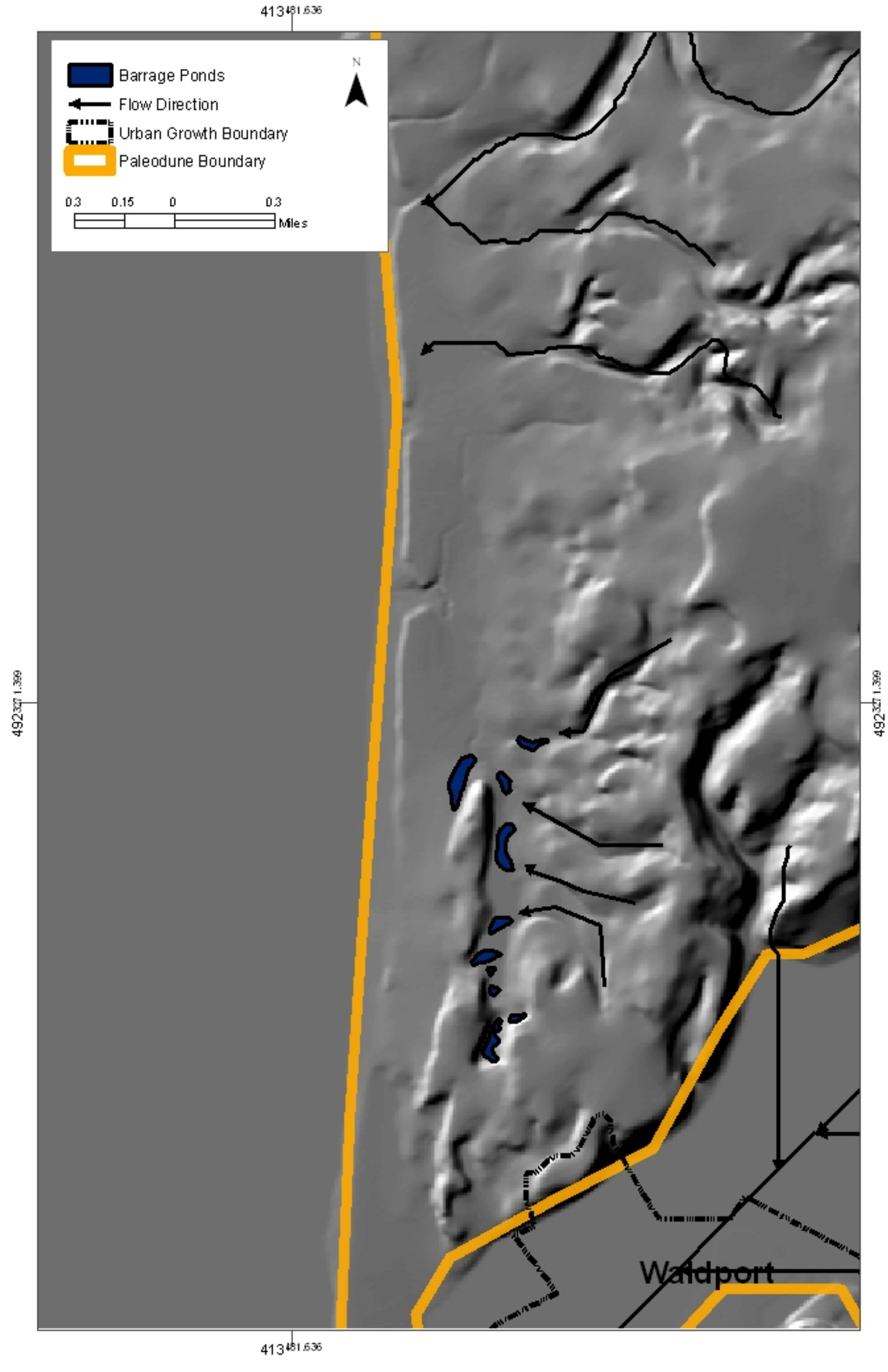

Figure 64: Map showing the flow direction that was created from the DEM in the Waldport area.

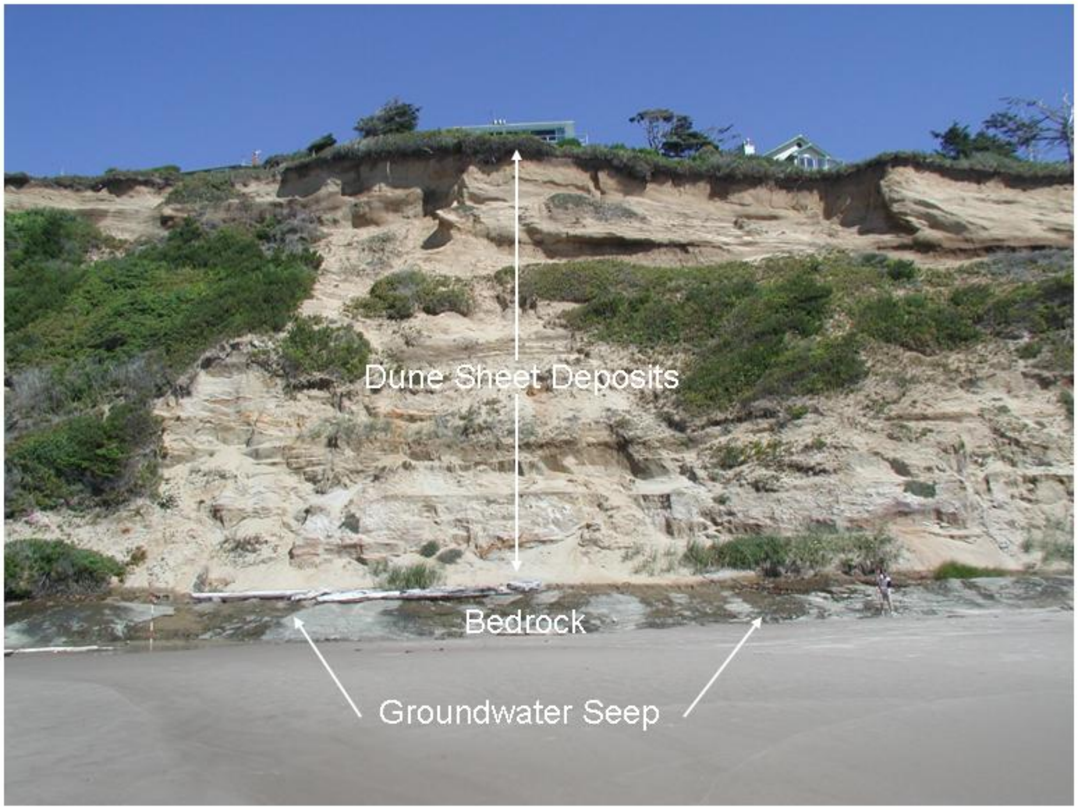

Figure 65: Picture of the sea cliffs with ground water seeping from the contact between the dune deposit and bedrock in the Newport dune sheet.

Another unique property of the paleodunes is the formation of barrage ponds at the boundary between Pleistocene and Holocene age dunes. The barrage ponds form when the Holocene dune sand blows into river channels, thereby blocking the flow of water and creating a pond (Pilkey and Fraser, 2003). Generally, the barrage ponds in this area are in a north south orientation. The barrage ponds provide important habitat for many aquatic and avian species (IUCN, 1997). The ponds are potentially susceptible to non-point source pollution from septic field drainage and fertilizer run-off (Figure 46). In addition to these risks, habitat fragmentation is a concern with the increased residential development around and between these wetland habitats. The development generally surrounds the ponds, thereby cutting off migration paths for amphibians to other ponds and streams in the vicinity (Figure 66). A shapefile of barrage ponds is also included in the geodatabase because of their sensitivity to contamination and habitat fragmentation due to increased area development.

Figure 66: A barrage pond located north of Alsea Bay, these ponds are being surrounded by residential development.

The boundary between the Pleistocene and Holocene age dunes is also highlighted in two coverages in the geodatabase because of the differing geotechnical and hydrologic properties (Figure 68). One of these coverages is drainage. The Pleistocene age dunes contain a number of interbeds making drainage unpredictable and very site specific. In contrast, the Holocene age dunes are more homogeneous with no interbeds, therefore they drain more uniformly. It is important to predict the different drainage properties for intalling septic systems and citing water wells in the dune aquifer (Figure 67).

The Pleistocene and Holocene dunes coverages can be used to predict the potential for coseismic liquefaction. The Pleistocene paleodunes contain cemented layers that decrease the potentials for liquefaction (Table 12, Table 13,Table 14,and Table 15). The Holocene sand contains little or no cementation, making them more susceptible to earthquake liquefaction during a coseismic event (see pocket penetrometer data tables in Results Geospatial Relationships section) (Knudsen et al., 1997). With this coverage planners will be able to make preliminary risk assessments for liquefaction and can require appropriate site inspections for necessary foundation design.

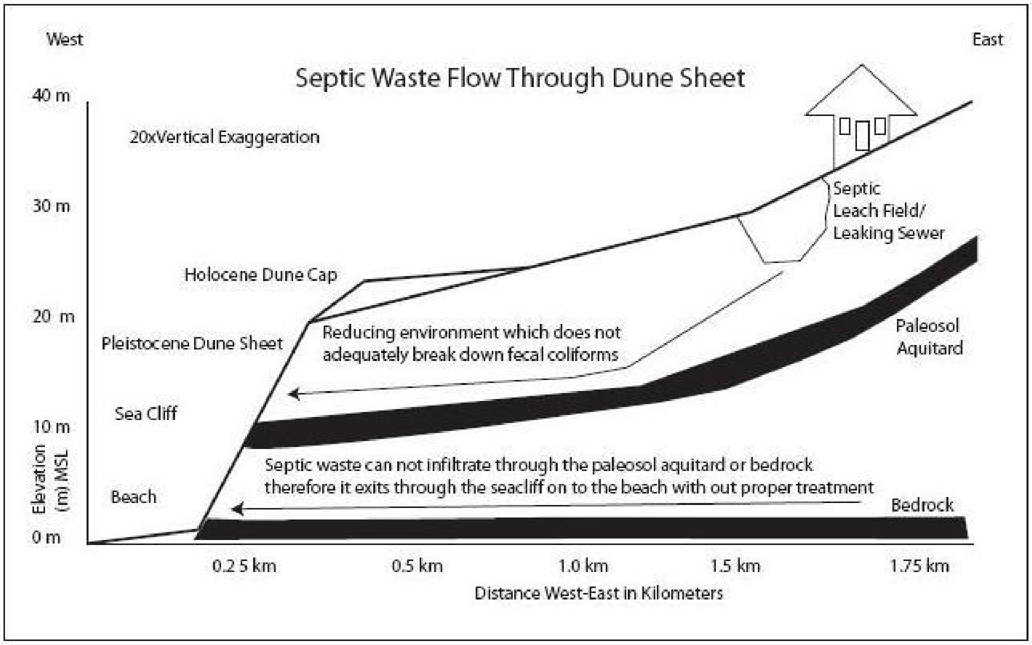

Figure 67: Conceptual model of septic waste flow through the dune sheet. Both paleosols and bedrock act as aquitards, which does not allow adequate break down of fecal coliforms before exiting to public beaches.

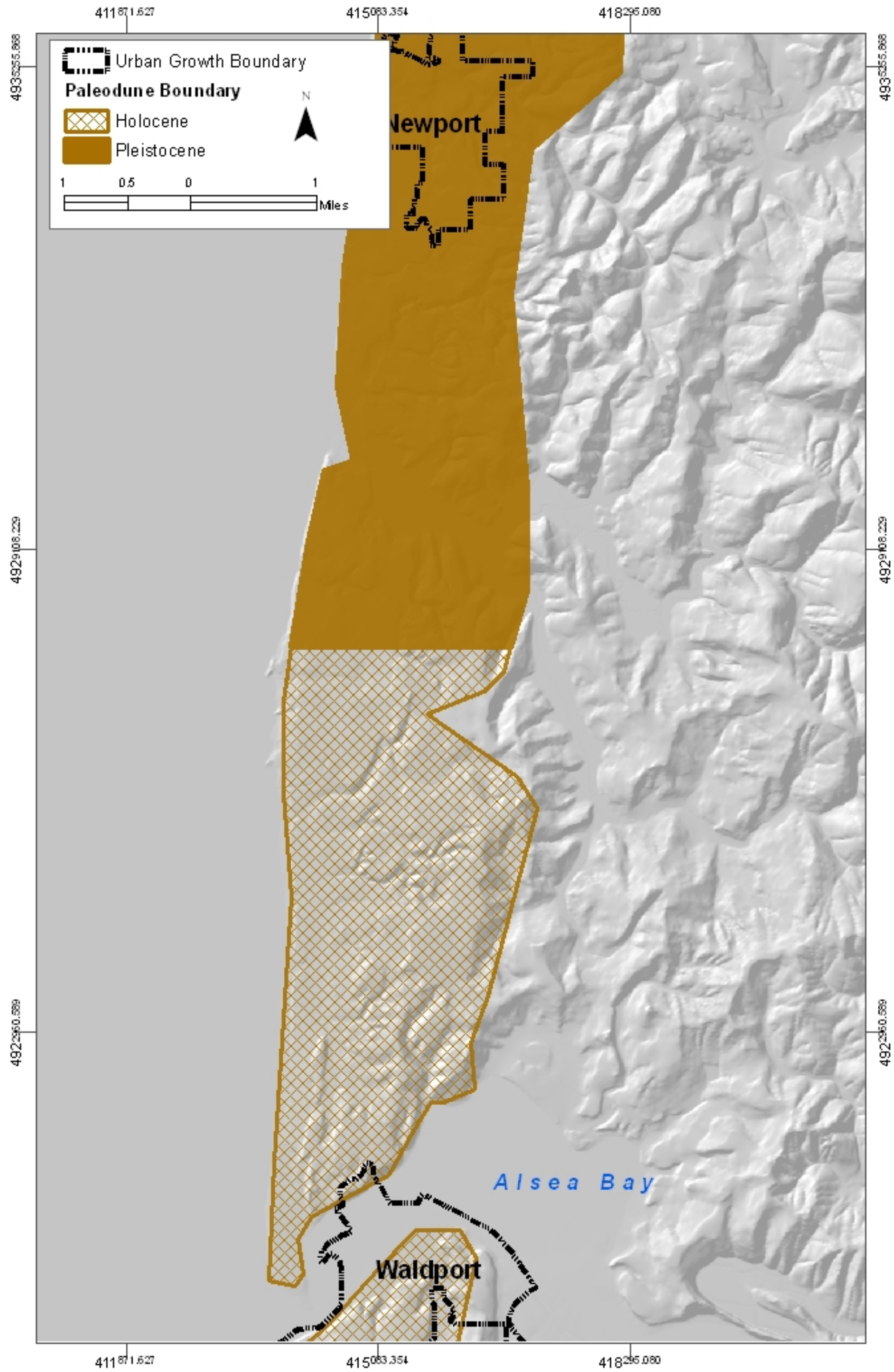

Figure 68: South of Newport where the color change occurs is where the Holocene dune sands cap the Pleistocene paleodunes. The Holocene dune caps have infiltration rates that are consistent throughout their profile, whereas the Pleistocene dunes have infiltration rates that significantly vary over the profile because of hardpans and variable cementation.

Discussion

Survey

The results from the survey provided some acumen on dataset end user preferences. However, the results should be interpreted with caution because of the limited sample population and the format of the survey. Surveying end users about preferences for scientific data is not common, references and examples are limited for this type of survey. Therefore social surveys were used to model the results obtained in this study survey.

One fault of the survey was the way the participants were asked to rank their preferences. The options for the respondents to rank was least, moderately, and most. This allowed the respondents to not address every option, for example the question "What attributes are you interested in?" Yielded 8 responses for geological and 6 responses for environmental. Because of the inconsistent number of answers the responses were normalized by the number of responses for each question. A better way to rank would have been a numbered scale that corresponded to the choices given (Table 2). For example, for the question on preferred GIS Format there were five choices; the questionnaire should have had the respondents rank the choices on a scale of one to five. This format would have produced more consistent participation for each question.

The primary challenge with this survey was recruiting participants and that is evident by the sample population. The initial target was 15 to 20 respondents, however only 9 respondents were found that met the criteria for representative end users. The study timing was affected by some constraints required by the Human Research Review Committee (PSU). Furthermore the necessary expert knowledge of Lincoln County land use and GIS capabilities yielded a small pool of acceptable respondents.

Due to the surficial geology aspects of the study geologists were targeted for the private sector of the survey. It would have been valuable to expand the population to also include environmental consultants that include biologists, hydrologists and ecologists. The responses for the questions regarding risks and attributes reflect the biased sample population of geologists.

Although there were faults with the survey portion of the project, it added tremendous value to the project. Useful suggestions from the respondents came in the form of additional written comments. Both the survey and comments were taken into consideration in the design of the paleodune surficial GIS map. The key points that were taken from the survey are 1) surficial geology for the coastal plain needs to be updated, and 2) geologic information needs to be in digital formats for planners and other government agency employees using GIS technology. This initial study provides a foundation for future projects involving GIS, land use planning, and surficial geology in the Central Oregon Coast.

Development

The GIS approach used in this project provides quantified relations between surficial geology and development trends on regional scales. The surficial map for this project demonstrates how much development has already occurred in the paleodune deposits. The dune sheet deposits extend well landward from the beach, where dunes are typically anticipated by most planners and engineers. There are five major coastal communities in Lincoln County including, Lincoln City, Depoe Bay, Newport, Waldport and Yachats. Three of the communities, Lincoln City, Newport and Waldport are located on bays where the dune sheet extends inland surrounding the bays. Lincoln City and Newport, the two largest cities are located on marine terraces covered by the dune sheets. Development is impacted by the dune sheets because the conditions that lead to the dune sheet deposition are the same ones that lead to commercially driven development, e.g. flat building sites in the narrow coastal plain.

The UGB is used as a way to measure the potential for new development in the paleodunes. Fifty six percent of the UGB is located within the dune deposits for the coastal communities in Lincoln County. In addition, approximately 29% of the roads in Lincoln County are within the paleodune deposits. These statistics confirm that development on the coast is primarily occurring within the dune sheets that cover the low marine terraces rather than in the foothills of the Coast Range (Figure 69).

Figure 69: An example of residential development lots for sale in the paleodune deposits bordering Highway 101 on the Central Oregon Coast.

Distribution

Recent studies by Clough (2005) and Peterson el al. (2006) have shown that sustainable development in the coastal plain necessitates a better understanding of the stratified paleodunes. The unique geotechnical and hydrologic properties of the dune deposits have a direct impact on development through foundation soils, cut slope stabilities and subsurface drainage. Previous studies by Vokes et al. (1949), Baldwin (1956), and Snavely (1976) have established the bedrock geology in the area. Schlicker et al. (1973) created a comprehensive report of the geologic hazards and engineering geology concerns for Lincoln County, which includes the coastal plain.

Although the previous studies, largely completed over 50 years ago, have served land use planners in the past they do not address new issues of coseismic hazards, development of steeper slopes, and increased non-point source pollution of coastal dune aquifers.

The Schlicker et al. (1973) report recognizes that the coastal plain is covered in Pleistocene surficial deposits. However these deposits are not delineated in terms of beach deposits, dune deposits or alluvium; they are grouped as "marine terrace deposits." Recent studies (Clough, 2005, Peterson et al., 2006) demonstrate that the unique geotechnical and hydrologic properties of the dune deposits need to be addressed under increasing development pressures in the narrow coastal plain. In this study the updated geologic information is compared to a newly digitized version of marine terrace deposits mapped by Schlicker et. al (1973).

A major difference in the two datasets is that the marine terrace deposits are not mapped continuously down the coastline. An example of this is the area north of Newport (Figure 37). The paleodunes extend farther inland than the terraces and they can be seen continuously along road cuts in this area. The marine terraces are mapped as if they are individual outcrops. By comparison, the Pleistocene dune sheets ramped eastward onto the foot hills of the Coast Range. The mapped marine terraces distributions do not accurately reflect the distribution of paleodune sheet (Figure 15, Figure 17, Figure 19, Figure 21, Figure 23, Figure 25, Figure 27, Figure 29, Figure 31, and Figure 33). Another area where there is a significant difference between the terraces and the paleodunes is south of Lincoln City. The terraces are mapped more continuously than the section north of Newport but there are still significant gaps in their coverage in this area. The terraces generally only extend 0.36 miles (0.5 km) inland whereas the paleodunes extend 0.5 miles (0.8 km). The actual extent and continuity of the paleodune sheet is important as the dune sheet aquifer is thought to be the conduit of *E. coli* to the public creeks, ponds and beaches (Peterson et al., 2003). New development is occurring in the dune sheets and is expected to continue for the next several decades.

Hydrologic

Hydrogeochemical models of the paleodunes presented by Clough (2005) is more complicated than previously thought. In Clough (2005) the upper sections of the dune deposits are hypothesized to be oxygenated (high redox); thereby preserving Bw horizons (see Figure 45). The lower sections of the deposits are reported to include low redox conditions that favor preservation of Bg soil horizons. Analysis of the Bw and Bg horizons in this study shows abundant Bg horizons in the upper dune sheet sections (Figure 39, Figure 40, Figure 41, Figure 42, Figure 43, and Figure 44). There are also more Bw horizons in the lower section than Bg horizons, demonstrating the presence of higher redox groundwater in the underflow (Table 10).

These results indicate that there is seasonal, variable depth to groundwater level in the paleodunes. Figure 46 shows a new conceptual groundwater flow model. The top sections of the paleodunes are more reducing than expected. These reducing conditions do no permit rapid breakdown of fecal coliforms. Together with a rapid subsurface transport through the dune aquifer the live bacteria reach the public beaches. The low redox conditions of the upper dune sections in the sea cliffs might arise from an influx of organics from interdune environments (Bortleson et al., 1989).

In summary, these redox conditions locally reduce the ability of septic leaching fields and/or seepage from leaking sewer systems to properly break down waste. Because the top sections of the paleodunes are somewhat reducing the bacteria are not degraded adequately. Both septic and leaking sewer lines then deliver fecal coliforms to the dune sheet aquifer that rests above the bedrock aquitard, as observed along some beaches (Figure 70).

Figure 70: Close up picture of ground water seeping at the contact between the paleodune deposits and bedrock at the public beach in Lincoln County.

Geotechnical

Understanding the geotechnical properties of the paleodunes is important for wise development in the coastal plain as shown by the Capes Slope Failure (1997) in Tillamook County (Wang et al., 2002). Informal investigations by Clough (2005) have noted that seacliff slope failures are occurring at the contact between the paleodunes and bedrock. In this thesis I hypothesize that these basal bedrock layer failures are due to cement leaching by excessive groundwater flow. This hypothesis is tested by analyzing the relative cementation in the basal dune deposits (Table 12, Table 13, Table 14, and Table 15).

To quantify the relative cementation of the paleodunes a pocket penetrometer was used to estimate unconfined shear strength. Statistical analysis of the data indicates that cementation values of the lowest sections of the sea cliffs are substantially less than the middle and upper sections (Table 15). Based on the groundwater flow model from this and previous studies (Easterly, 2005), it is thought that the allophane cement (Grathoff et al., 2003) is being leached by groundwater at the contact between the bedrock and paleodune. Field observations of slope failures conducted during the field testing for this study indicate a high frequency of failures at the bedrock and paleodune interface (Figure 72). Such weak zones are also likely to occur where cut dune sheet facies intersect bedrock aquitards in creek valleys at inland sites (Figure 71).

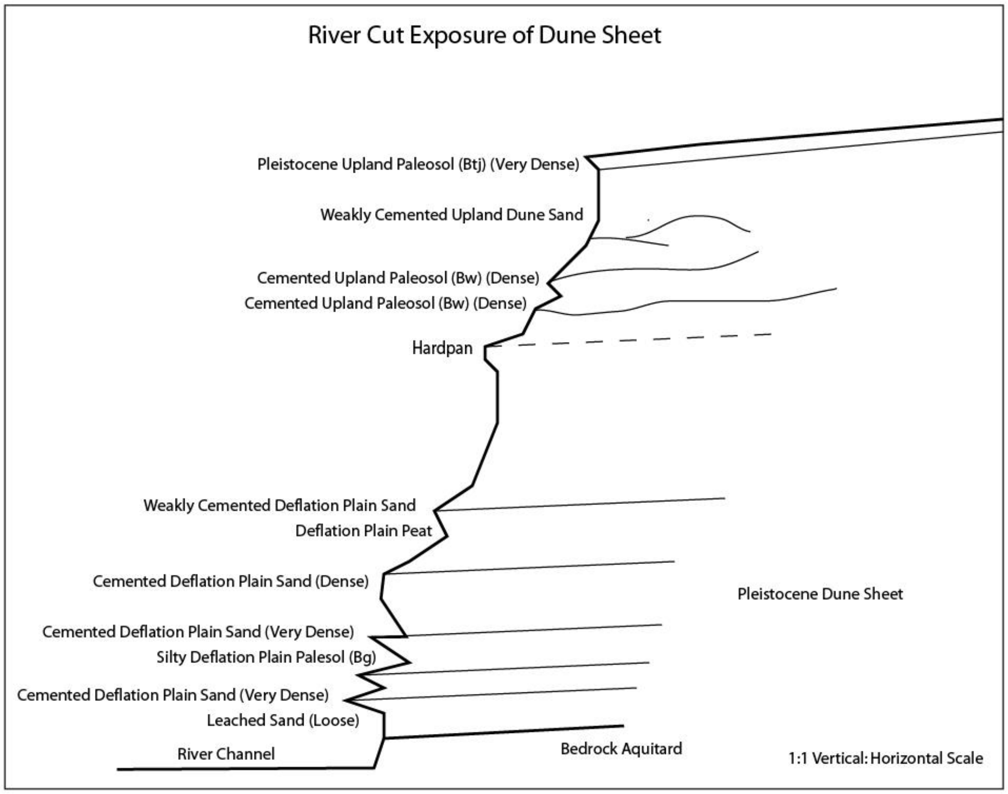

Figure 71: River cut conceptual model of the paleodune deposits. The basal bedrock act as aquitards, the concentrated groundwater flow leaches the cement from the lower section of the paleodune weakening the basal layer of the dune sheet. Modified from Clough (2005).

Figure 72: A slump slope failure in the Newport dune sheet. The bedrock acts as an aquitard allowing the ground water flow to concentrate at the contact between the paleodune deposits and the bedrock. The concentration of ground water leaches out the cement from the dune sheet deposits weakening the basal layer.

Knowing the depth to bedrock would not only aid in mitigation efforts for slope failures but would also help engineers in the design of structures. Figure 50, Figure 51, Figure 52, Figure 53, Figure 54, Figure 55, Figure 56, Figure 57, and Figure 58 illustrate how variable the thickness of the paleodunes are likely to be across the dune sheet (approximately 1 m to 22 meters thick). A depth to bedrock map would help planners evaluate potential geotechnical issues prior to zoning changes and issuing permits. Ultimately, foundation inspection tests will need to be completed for specific site development. However, knowledge of the dune sheet thickness variability will encourage geotechnical engineers to validate foundation conditions across the planned sites and sensitive nearby slopes.

Regional Implications and Further Studies

This study provides a framework for other coastal areas undergoing development on dune sheets. Other dune sheet areas on the North America West Coast include Central California, Southern California and Baja, Mexico (Cooper, 1958). With rising population densities and property values the potential for loss from cut slope instability is increasing. New residential development will increase non-point source pollution to the dune aquifers. The GIS approach to mapping the extent and potential down slope flow of ground water will provide planners with the means to identify risks to sensitive habitats (dune ponds) and public reaction areas in dune creeks and beaches

For this project a DEM was used to establish groundwater flow paths. For a better understanding of the subsurface flow directions the groundwater surface should be mapped directly from 1) wells 2) subsurface ground water imaging and 3) subsurface mapping of the dune-bedrock aquitard. In addition, the bedrock surface profiles from the Geospatial Relationships section are inferred. Detailed depth to bedrock data would strongly benefit new development planning in the Lincoln County area. For purposes both to predict fate of non-point source pollution and leaching of basal sand layer cementation a groundwater flow model could be produced. MODFLOW or another groundwater modeling program would require DEM topography (provided in this thesis), depth of paleodune aquifer, and representative values of permeability or hydraulic conductivity.

Conclusions

Fifty six percent (56%) of the UGB occurs in paleodune sheets of Lincoln County. Expected development and UGB expansion in the Central Oregon coastal plain will increase that percentage over time. As shown in this study the paleodune deposits have distinct geotechnical and hydrologic properties. These properties are attributed to initial higher permeability and secondary cementation that occurs during their formation history. The paleodune deposits in the study area are largely limited to the low-stand Pleistocene dunes that migrated episodically across the inter-shelf and onto the landward marine terraces.

Previous studies have not differentiated the paleodune strata from alluvium or beach strata that locally overlie the marine terraces. The surficial GIS model created in this project integrates geologic analysis of the paleodunes with thematic data such as surface hydrology, roads, and jurisdictional boundaries. These geospatial relations of will enable the end user to better predict development impacts on slope stability, surface water drainage, dune aquifer contamination, and dune pond habitat. An end-user survey established that the coastal plain surficial geology needs to be up to date and electronically accessible for incorporation into their GIS datasets. Area analysis of infrastructure in Lincoln County shows that development is primarily occurring in the coastal plain in Lincoln County rather than the foothills of the Coast Range. GIS analysis of the dune aquifer's spatial extent and the slope of the basal aquitard show that public beaches, creeks and ponds are directly connected to non-point source contamination through the dune aquifer's groundwater. GIS compilation of redox conditions interpreted from dune strata logs indicates that there is rapid, deep seasonal drainage through the paleodunes. In addition, the top sections of the dune sheet are seasonally reducing thereby limiting the natural biodegration of bacterial and/or other contaminants in the dune aquifer. Ground truthing of relative cementation in sea cliffs reversed a previously reported model of dune slope stability. The initial data compilation reflected biased sampling performed earlier (Peterson et al., 2000). The new sampling of basal dune deposits established cement leaching of the dune-bedrock contact. Field observations confirmed that the some slope failures are initiated in the weakest basal dune strata, where excessive groundwater flow leached away the Pleistocene dune cement.

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Appendix A: Survey Results

	Number of Respondents for		
Preferred GIS Format	least	moderately	most
ArcInfo	3	3	1
ArcView	3	1	4
ArcMap	1	3	3
CAD	1	1	4
Open Source	1	0	1
Coverage Area			
Region	2	3	1
County	0	3	6
City	1	2	4
Drainage Basin	3	2	0
Base Map Scale			
1:5,000	0	1	6
1:12,000	0	3	4
1:24,000	1	5	1
1:100,000	6	0	0
Attributes			
Geological	1	1	6
Topographical	1	2	5
Geotechnical	1	3	3
Hydrological	0	4	4
Environmental	2	4	0
Jurisdictional	6	0	1
Infrastructure	3	3	1
Risks			
Unstable Slopes	0	1	7
Liquefaction	0	4	3
Drainage	0	5	2
Contaminant Flow Path	4	2	1
Drainage Basin	3	2	1
Habitat Impacts	5	2	0
Product Delivery			
CD	0	1	7
FTP	3	2	2
Hardcopy	3	1	3
Respondents			
Planners	2		
Engineers	1		
Geologists	3		
GIS Analysts	1		
Consultants	1		

Appendix B: CD containing GIS Dune geodatabase and Access data tables