FINAL SUBMITTAL

GEOTECHNICAL INVESTIGATION AND SITE CONDITIONS REPORT

KENAI RIVER BLUFF EROSION

KENAI, ALASKA

CONTRACT NO. W911KB-05-D-0004
DELIVERY ORDER NO. 0010
MODIFICATION NO. 01

Prepared for:

U.S. ARMY ENGINEER DISTRICT, ALASKA
P.O. Box 6898
Elmendorf AFB, Alaska 99506

February, 2007

R&M CONSULTANTS, INC.

R&M CONSULTANTS, INC.
9101 Vanguard Drive, Anchorage, Alaska 99507
(907) 522-1707, FAX (907) 522-3403, www.rmconsult.com

February 14, 2007

R&M No. 1209.10

U.S. Army Engineer District, Alaska
ATTN: Mr. Chuck Wilson (CEPOA-EN-ES-SG)
P.O. Box 6898
Elmendorf AFB, Alaska 99506

RE: Geotechnical Investigation and Site Conditions Report
Kenai River Bluff Erosion
Kenai, Alaska
Contract No. W911KB-05-D-0004, Delivery Order No. 0010, Modification No. 01

Gentlemen:

Attached find our final report for the above-referenced geotechnical investigation. This report was prepared under the terms of Contract No. W911KB-05-D-0004, Delivery Order No. 0010, Modification No. 01. This final submittal includes the incorporation of your verbal review comments of February 6, and February 13, 2007.

We trust that this report is found to be responsive to your requirements. Should you have any questions or require further information, please contact us.

Very truly yours,

R&M CONSULTANTS, INC.

Charles H. Riddle, C.P.G.
Vice President

CHR*slv

Z:\project\1209.10\wp\Final Report\Final Geotech Report.doc

FINAL SUBMITTAL

GEOTECHNICAL INVESTIGATION AND SITE CONDITIONS REPORT

KENAI RIVER BLUFF EROSION

KENAI, ALASKA

CONTRACT NO. W911KB-05-D-0004
DELIVERY ORDER NO. 0010
MODIFICATION NO. 01

Prepared for:

U.S. ARMY ENGINEER DISTRICT, ALASKA
P.O. Box 6898
Elmendorf AFB, Alaska 99506

Attention:
Mr. Chuck Wilson
CEPOA-EN-ES-SG

Prepared by:

R&M CONSULTANTS, INC.
9101 Vanguard Drive
Anchorage, Alaska 99507

February, 2007

GEOTECHNICAL INVESTIGATION
AND SITE CONDITIONS REPORT

KENAI RIVER BLUFF EROSION

KENAI, ALASKA

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

GEOTECHNICAL INVESTIGATION AND SITE CONDITIONS REPORT

KENAI RIVER BLUFF EROSION

KENAI, ALASKA

1.0 INTRODUCTION

1.1 Background

For many years, the City of Kenai has been concerned with the ongoing erosion of a one mile portion of the steep bluff along the right bank of the Kenai River within the city. This erosion has required the relocation of privately owned buildings as well as city infrastructure and utilities. Unless measures to control the erosion and protect the bluff are implemented, bluff erosion is expected to continue, further threatening existing buildings, infrastructure, and utilities within proximity to the bluff.

The U.S. Army Corps of Engineers - Alaska District (USACE-AD) has conducted a geotechnical investigation to provide design-level information for the Kenai River Bluff Erosion Project. The geotechnical investigation provides site-specific geotechnical design information necessary to establish an erosion control method that is technically feasible and satisfies resource agency needs. The work consisted of drilling and logging test borings, installing groundwater monitoring wells, laboratory testing, and the preparation of various reports. Ultimately, the geotechnical data obtained will be used, in conjunction with other considerations, in developing the specifications and design criteria for the project. An area map is provided as Figure 1.

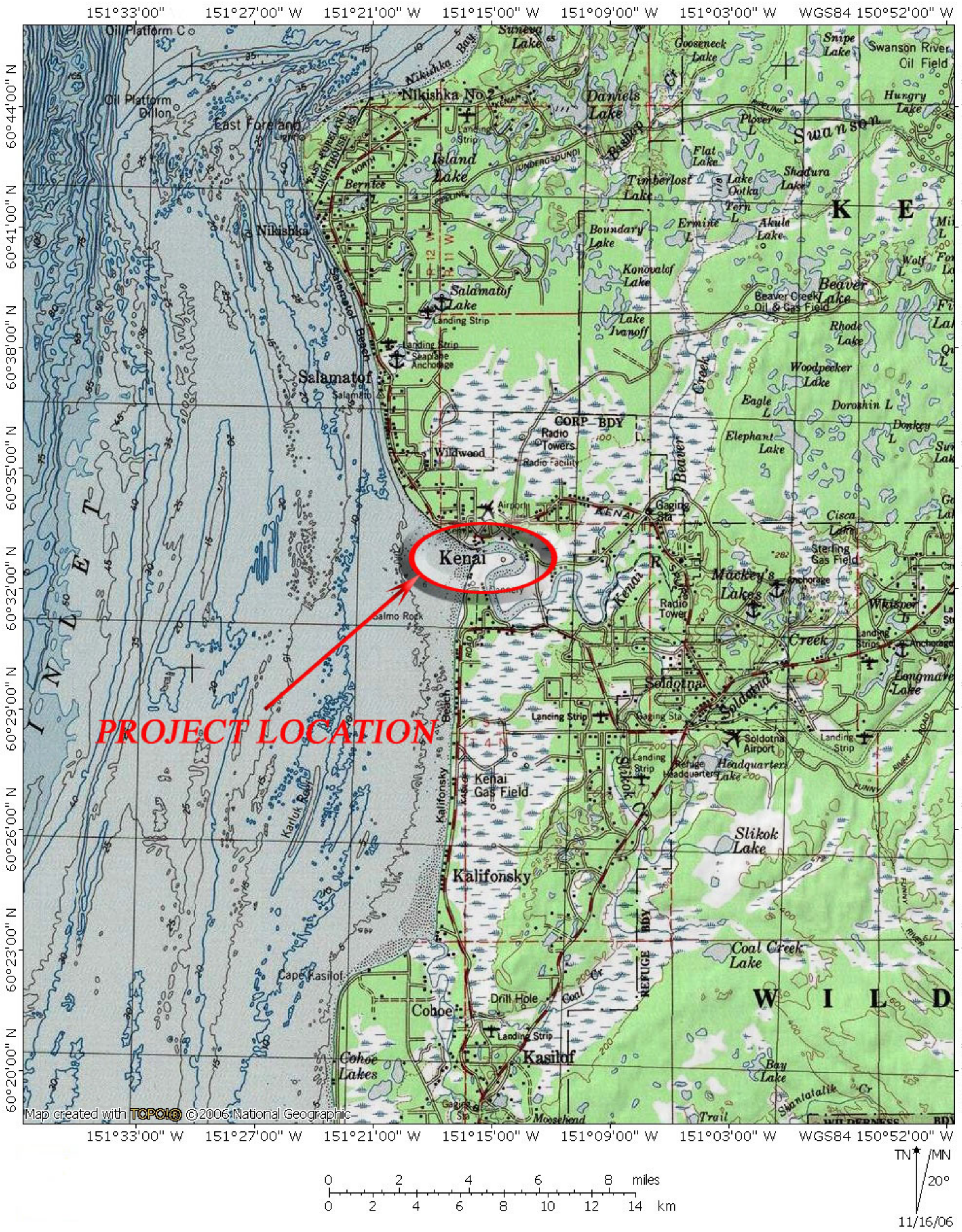
R&M Consultants, Inc. (R&M) has been tasked by the USACE-AD to provide professional geotechnical services for the project. Drilling, sampling, and groundwater monitoring well installation services were performed by Discovery Drilling, Inc. of Anchorage, Alaska under direct contract to R&M.

To gain a better understanding of the area and to formulate the scope-of-work needed for this exploration, a reconnaissance visit to the area was undertaken by personnel from the USACE-AD and R&M. As a result of the reconnaissance and previous meetings, two areas were selected for exploration. These are designated as the bluff crest and the bluff toe. General bluff conditions are discussed in R&M's prior geotechnical scope-of-work report (R&M, 2006). All test boring explorations along the bluff toe were performed in the Kenai River Habitat Protection Area and within 50 feet of the ordinary high water (OHW) zone, thus requiring special permits and minimal disturbance to the drill sites.

During the geotechnical field investigations, a total of 20 test borings were drilled and sampled at the project site. Fourteen (14) of these test borings were completed as groundwater monitoring wells. Soil samples have been subjected to a number of laboratory tests for the determination of

FIGURE 1

AREA MAP



soil classification and engineering properties useful in geotechnical/geohydrologic analysis and future civil design.

The site conditions presented herein are based on our current understanding of the project as outlined within this report and illustrated on the drawings in Appendix A. Any deviation from the proposed locations may necessitate further evaluation of subsurface conditions.

1.2 Contract Authorization

This work was completed under the terms of Contract No. W911KB-05-D-0004 between the U.S. Army Corps of Engineers – Alaska District and R&M Consultants, Inc. The geotechnical investigation and this report were completed in specific fulfillment of Delivery Order No. 0010, Modification No. 01.

Measurements and weights presented in this report are generally shown as U.S. customary units. Where previous investigations and reports have utilized SI units, we have retained the units expressed in the original document. A conversion chart is included as Table 1 for use in conversion from U.S. customary units to the International System (SI) units. Actual conversion should be made with the appropriate numbers carried to three or more significant figures.

1.3 Purpose and Scope-of-Work

The intent of this investigation has been to provide geotechnical information to evaluate the subsurface conditions for the analysis and design of a bluff stabilization project. Geotechnical investigations were performed in accordance with procedures outlined in “Geotechnical Investigations” (USACE, 2001), “Soils and Geology” (USACE, 1983), and “Soil Sampling” (USACE, 1996). This report presents a summary of the results of R&M’s field exploration programs and our interpretation of subsurface conditions.

This work was performed under a Statement-of-Work prepared by the USACE-AD, revised 13 September 2006. The Statement-of-Work is presented as Appendix E to this report.

The Scope-of-Work for R&M’s geotechnical investigation was comprised of seven tasks (with various subtasks) as follows:

Task 1: Planning
Subtask 1a – Work Plan
Subtask 1b – Rights of Entry, Utility Locates and Permits
Task 2: Geologic Logging of Bluff
Task 3: Location Surveys of Test Borings
Task 4: Drilling and Groundwater Monitoring Well Installation
Task 5: Laboratory Testing
Task 6: Report Preparation
Task 7: Groundwater Monitoring

No geotechnical analysis or recommendations were required under the Statement-of-Work. Additionally, groundwater monitoring will continue on a periodic basis. A groundwater monitoring report will be submitted under separate cover.

1.4 Existing Information

R&M reviewed the following documents, provided by the USACE-AD, which included some geologic and/or geotechnical information specific to the subject project.

Peratrovich, Nottingham, and Drage, Inc. (PN&D). 2000. Kenai Coastal Trail & Erosion Control Project, Design Concept Report. *Prepared for* City of Kenai, Alaska.

Smith, O., W. Lee and H. Merkel. 2001. Erosion at the Mouth of the Kenai River, Alaska; Analysis of Sediment Budget with regard to the proposed Kenai Coastal Trail & Erosion Control Project. University of Alaska Anchorage. *Prepared for* Peratrovich, Nottingham, and Drage, Inc.

Tibbetts-Abbett-McCarthy-Stratton (TAMS). 1982. City of Kenai, Bluff Erosion Study, Draft Report. *Prepared for* City of Kenai, Alaska.

U.S. Army Corps of Engineers (USACE-AD). 2004. Geotechnical Findings Report, Kenai River Bluff Erosion, Kenai, Alaska. Alaska District, Soils and Geology Section.

Note that only the 2004 USACE-AD report included any factual data pertaining to the geologic and geotechnical conditions in the project area (e.g. test hole logs, laboratory soil tests, groundwater levels, etc.). Exploration logs from the 2004 USACE-AD report are reproduced in Appendix B of this report. Well logs by American Environmental are also included in Appendix B. In addition, a number of U.S. Geological Survey documents and other technical reports were reviewed in regards to regional conditions. These various reports are cited herein and listed in the references section of this report.

2.0 REGIONAL SETTING AND GENERAL SITE CONDITIONS

2.1 Regional Setting

2.1.1 Location

The City of Kenai is located about 65 air miles southwest of Anchorage, Alaska. The bluff area that is the subject of this investigation lies along the right bank of the Kenai River near where the river empties into Cook Inlet. The project site is located on U.S. Geological Survey (USGS) Kenai (C-4) Quadrangle, Township 5 North, Range 11 West, Sections 5 and 6, Seward Meridian, Alaska. A site map is included as Figure 2.

A fortified post called Fort St. Nicholas was built in the area by Russians in 1791. The village was also called Paul's Fort. In 1869 a U.S. Military Post, named Fort Kenai for the Indians living in the area, was established (Orth, 1967).

2.1.2 Regional Geology

Kenai is situated on the Kenai Peninsula, which lies within the Cook Inlet-Susitna Lowland physiographic province (Wahrhaftig, 1965). The area is characterized as a glaciated lowland containing areas of ground moraine and stagnant ice topography, drumlin fields, eskers and outwash plains with rugged mountains located to the east.

The Kenai Peninsula is bounded by Turnagain Arm to the north, Cook Inlet to the west, the North Pacific Ocean to the south, and includes the Kenai Mountains to the east (see Appendix A, Drawing A-01). The Kenai Lowland is the portion of the peninsula located west of the Kenai Mountains; it is part of the larger Cook Inlet-Susitna geologic structural basin which is surrounded by the Chugach, Talkeetna, and Alaska Mountain Ranges. The Cook Inlet-Susitna basin and adjacent Kenai Mountains are in a relatively active seismic zone and are bisected by several inactive and active faults. Within the basin, bedrock is generally overlain by relatively thick unconsolidated glacial, fluvial, and marine sediments, whereas in the adjacent mountains bedrock is commonly exposed at the surface or covered with a relatively thin veneer of soil.

Bedrock beneath the lowland consists mainly of poorly consolidated coal-bearing rocks of Tertiary-age, generally mildly deformed or flat-lying. This poorly consolidated bedrock is mantled by glacial moraine and outwash, and marine and lake deposits.

This portion of southcentral Alaska was covered with glacial ice during glacial advances of early to middle Pleistocene-age (Coulter et al., 1965), as evidenced by local topography and soil stratigraphy. This region of Alaska is considered to be generally free of permafrost except where isolated masses of permafrost occur in lowland areas where ground insulation is high, such as peat bogs and swamps (Ferrains, 1965).

FIGURE 2

SITE MAP

Not to Scale

Regional geologic mapping for the area has been published at a scale of 1:250,000 (1 inch = 4 miles) by the U.S. Geological Survey (Magoon et al, 1976). Quaternary geology of the Kenai Lowland has also been published at a scale of 1:250,000 (Karlstrom, 1964). Additionally, Karlstrom (1958) has mapped ground conditions and surficial geology of the Kenai-Kasilof area at a scale of 1:63,360 (1 inch = 1 mile). Although quite dated, Martin et al. (1915) present data on the geology and mineral resources of the Kenai Peninsula.

2.1.3 General Seismicity

Southcentral Alaska, including the Kenai Peninsula, is located in a very active seismic region associated with the collision of two tectonic plates (Plafker et al., 1993). The Pacific Plate is being thrust under the North American Plate along a northwestward-dipping Aleutian subduction zone. This under-thrusting produces compression in the crust of the overlying North American Plate expressed as folds and high-angle reverse and thrust fault systems. Evaluations of seismic hazards in southcentral Alaska typically recognize four faults or faulting zones, including: the Megathrust and Benioff segments of the Aleutian subduction zone, the Lake Clark-Castle Mountain Fault System, and the Border Ranges Fault Zone.

The Aleutian subduction zone is represented as two distinct planes, Megathrust and Benioff, each with different characteristic earthquakes. From the Aleutian Trench, about 200 miles east-southeast of Kenai, the subduction plane maintains a shallow dip to the northwest extending to a depth of about 12 to 15 miles (Megathrust zone). The seismicity of the Megathrust zone is characterized by shallow, very large magnitude, but infrequent earthquakes. The 1964 Great Alaska Earthquake (Moment Magnitude, 9.2 Mw) occurred within this zone, with the epicenter about 125 miles northeast of Kenai in Prince William Sound. At a depth of about 25 to 30 miles, the subducting Pacific plate dips steeply to the northwest (Benioff or Intra-Plate zone). The seismicity of the Benioff zone is characterized by deep (>30 miles), moderate magnitude and frequent earthquakes. Based on theoretical models, maximum credible earthquakes (MCE) of magnitude 9.5 Mw and 7.5 Mw have been predicted for the Megathrust and Benioff zones, respectively (WCC, 1982).

The Castle Mountain Fault is a prominent, right-lateral strike-slip, reverse fault which traces from the Talkeetna Mountains northeast of the Matanuska Glacier, southwesterly through the lowlands along the Susitna River and southern flank of Mount Susitna (Determan et al., 1974). Kenai is about 60 miles south of the fault trace. A magnitude 5.2 Ms earthquake in 1984 about 125 miles northeast of Kenai was attributed to a rupture along this fault (Lahr et al., 1986). A MCE of magnitude 7.5 Mw has been predicted for the Castle Mountain Fault (WCC, 1982).

The Border Ranges Fault zone is a major reverse fault, locally positioned along the western flank of the Kenai Mountains, and interpreted to be an ancient subduction zone from the Mesozoic or early Tertiary time (MacKevett and Plafker, 1974). A surface trace of this fault in the area is unknown, but has been mapped within about 35 miles west of the site (Magoon et al., 1976). The seismic activity along this fault subsequent to early Tertiary time is unknown. In terms of considering seismic risk for building design, the MOA Geotechnical Advisory Commission (GAC, 1997) characterized the Border Ranges Fault zone as exhibiting a relatively low rate of seismic activity and not capable of producing large magnitude earthquakes.

According to the U.S. Geological Survey (Stanley, 1968 and Plafker et al., 1969), the two communities most seriously affected by coastal erosion following the 1964 Great Alaska Earthquake were Homer and Kenai. Stanley (1968) states that, "During the earthquake the area (Kenai) subsided 12 to 18 inches… After regional subsidence, the pre-earthquake accumulation of sloughed debris along the toe of the bluffs was quickly removed. Undercutting by waves and by the river began a few days after the earthquake, and within three months the bluff had receded as much as 20 feet."

2.1.4 Climate

Lying between Cook Inlet and the Kenai Mountains, Kenai has a transitional climate which may be characterized as variable with the influence of both maritime and continental climate regimes. Kenai receives an average of about 19.1 inches of precipitation per year. The temperature ranges from daily extremes of about minus 47°F to 93°F with an annual mean of 34°F. The mean monthly temperature ranges from about 12.5°F in January to 54.7°F in July. The annual heating degree days (base temperature equals 65°F) for the Kenai area is 11,288°F days (Hartman and Johnson, 1984).

A summary of climatological data obtained from the Kenai FAA Airport recording station is presented in Table 2.

2.2 General Site Conditions

2.2.1 Topography

Topography of the project site is marked by the Kenai River bluff, a feature which drops 60 to 70 feet at slope angles ranging from about 18 degrees to 90 degrees from the City of Kenai to the Kenai River (Figure 2). The project site may thus be divided into two distinct topographic areas, the bluff crest and the bluff toe. The bluff crest area is relatively flat. The bluff toe area slopes gently from the base of the bluff to the river's edge and is inundated by high tides.

2.2.2 Surface Drainage

Surface drainage at the site is interpreted to occur through two mechanisms, infiltration and surface flow to natural drainage courses. The two primary natural drainage courses within the project site are Ryan's Creek and Cemetery Creek, both of which are shown on Figure 2.

2.2.3 Vegetative Cover

The project site is located within a Bottomland Spruce-Poplar Forest system (AEIDC, 1974), as characterized by the local white spruce forests with large cottonwood and balsam poplar trees. Alaska paper birch, quaking aspen, and black spruce trees are also in evidence, along with willow and alder shrubs. Much of the bluff crest portion of the project site has been developed, though segregated stands of primarily spruce trees are present along intermittent portions of the bluff crest. Toppling of these trees is in evidence where the bluff has been receding in recent years. The toe of the bluff area is primarily devoid of vegetation, with the exception of localized grasses and the occasional shrub in the summer months. The area of the bluff toe that abuts Cemetery Creek, however, is vegetated with grasses and shrubs, as well as cottonwood, birch, willow and the occasional spruce tree.

2.2.4 Soils

Soils exposed along the bluff at Kenai consisted of marine, glacial, and alluvial deposits that have been altered by glacial action and erosion (Figure 3). The surficial soils and features in the area around Kenai have been created by several major Pleistocene glacial events. These included the deposition of marine sandy clays of the Bootlegger Cove Formation (Reger, 1997) in glacioestuarine waters approximately 16,500 years ago. A Killey-age tidewater glacier then passed over the site from the northwest. It apparently floated over the site as the effects of the glacial override did not penetrate deeply into the marine clay. Submarine-fan deposits were spread over the clay. Folding and displacement of the marine sediments occurred when the glacier grounded.

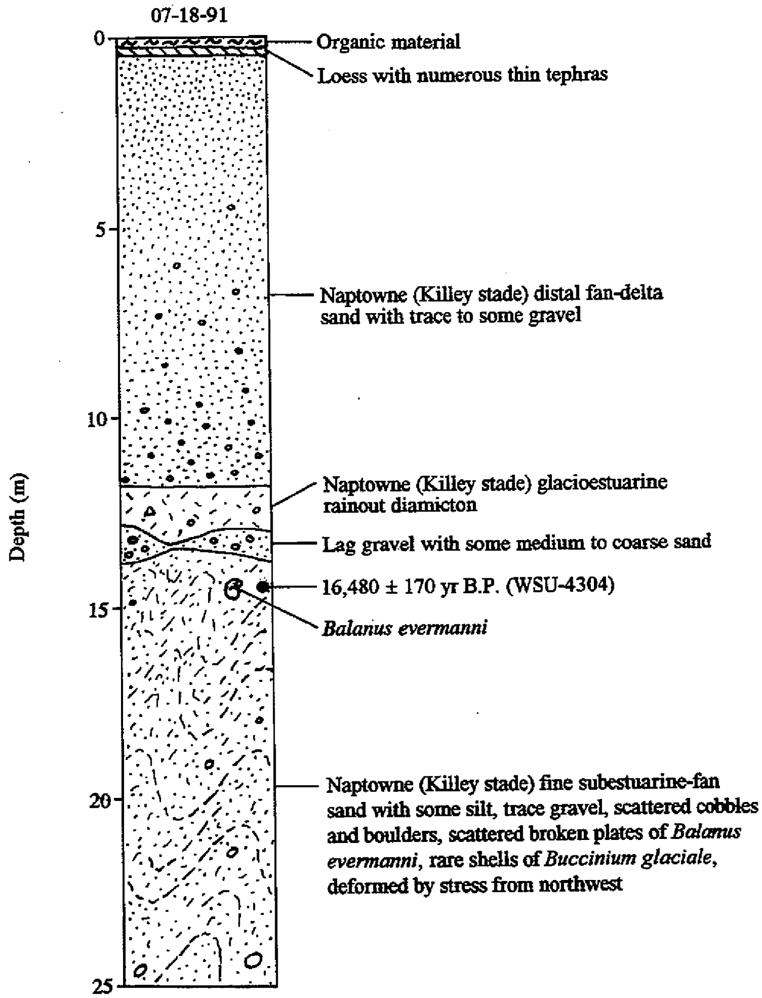
The first recorded description of the geology at the bluff at Kenai was provided by Moffit in 1906. He described partially cemented (ferruginous) sands overlying bluish-black silt (till). He also noted springs flowing from the bluff on top of the glacial till. Site-specific soils data obtained from the current bluff logging and test borings are provided in Section 5.0.

2.2.5 Bedrock

The Kenai area is reportedly underlain by rocks of the Sterling Formation which is the upper unit of the Tertiary Kenai Group (Hartman et al., 1972). The Sterling Formation consists of sandstone deposited during late Tertiary – early Quaternary-age. The sandstone is similar to sand deposits in the overlying Quaternary material and thus it is difficult to define the top of the formation. However, on the Kenai Peninsula depths to the formation of approximately 500 to 3,000 feet were indicated. Kirschner and Lyon (1973) present additional information on the stratigraphic and tectonic development of the area. Bedrock was not encountered in any of the 20 test borings drilled for this program.

FIGURE 3

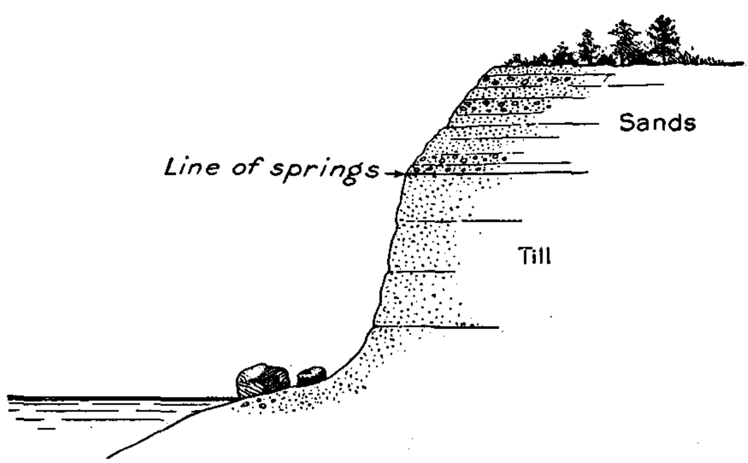
RIVER BLUFF STRATIGRAPHY



a. Stratigraphy exposed near project site (60º33'07"N, 151º14'17"W), Kenai C-4 SE Quadrangle.

After Reger et al., 1996.

b. Diagrammatic sketch showing relations of stratified sands and till at Kenai.



After Moffit, 1906.

On the basis of available information, it appears that bedrock is located at a considerable depth beneath the project site. Therefore, bedrock is not expected to be involved with any design or construction consideration.

2.2.6 Groundwater

Various water resources and groundwater studies have been performed in the area. Freethey and Scully (1980), explain regional groundwater potential in terms of geologic materials, depositional environment, and sediment thickness. The document also describes aquifers in five different areas and estimates groundwater yield. Anderson (1971) presents data on groundwater exploration and testing at Beaver Creek Valley near Kenai. The report further documents that an artesian aquifer is the principal source of groundwater. Anderson and Jones (1972), provide additional data on the water resources of the Kenai-Soldotna area. Bailey and Hogan (1995), in cooperation with the Federal Aviation Administration, give an overview of environmental and hydrogeologic conditions near Kenai while Glass (1996) documents groundwater conditions and quality in the area.

Each of the above cited studies focuses on area-wide groundwater conditions. Discussion of site-specific groundwater conditions is presented in Section 5.0.

3.0 FIELD INVESTIGATION

Methods of field investigation for the Kenai River Bluff Erosion geotechnical study can be divided into the following six categories.

- Planning and Site Reconnaissance
- Geologic Logging of Bluff
- Test Borings
- Groundwater Monitoring Well Installation
- Groundwater Monitoring
- Location Surveys

Following is a brief description of each of these categories along with methods and procedures used in acquiring the various geologic and geotechnical information.

3.1 Planning and Site Reconnaissance

On 29 June 2006, Robert (Buzz) Scher, P.E., R&M's senior geotechnical engineer, and John Rajek, P.E., USACE-AD geotechnical engineer, visited the project site to observe the stratigraphy, groundwater and erosion conditions exposed along the bluff at that time. During this visit, Scher and Rajek walked the entire length of the project area, along both the toe and crest of the bluff. Detailed observations of site conditions are presented in the Final Geotechnical Scope-of-Work (R&M, 2006) that was compiled to guide this geotechnical investigation. Based on the observations set forth in that document, as well as further research of existing information, the following geotechnical explorations were planned.

- Detailed Bluff Log
- Geotechnical Borings
- Geohydrology Borings
- Laboratory Soil Testing

Once the scope of geotechnical explorations was decided upon, R&M began laying the necessary groundwork to facilitate field work. This effort included obtaining rights of entry from property owners adjacent to the bluff, utility locates for subsurface utility lines, and permits to allow stream crossings and drilling adjacent to the Kenai River.

3.2 Geologic Logging of Bluff

During the period of December 10 through 13, 2006, a team of two R&M geologists/engineers obtained soil profiles at 10 locations along the bluff face (Soil Profiles SP-A through SP-J). At each profile location, an engineer, secured by harness and climbing rope, traversed the bluff from top to bottom (Figure 4). Data collection included measuring the slope profile using a rope tape and a four-foot digital level. Shallow test pits were excavated to expose soils and collect samples. A detailed description of soil and groundwater conditions was also made. Soil profiles are presented in Appendix D. Soil profile locations are shown in plan on Drawings A-02 and A-

FIGURE 4

BLUFF MAPPING PHOTOGRAPHS

a. Rappelling down the bluff face at Soil Profile SP-D. The four-foot yellow electronic level was used to measure slope angle. Slope distances were measured using the white tape. October, 2006.

b. Measuring water flow from the bluff at Soil Profile SP-E.
The procedure involved catching the flow and then measuring in a bucket. October, 2006.

03 of Appendix A. Soil profile locations are also shown on the annotated photo mosaic presented as Drawings A-08 through A-10.

Groundwater flow measurements were made at three locations (Soil Profiles SP-E, SP-F and SP-I) using a section of six-inch PVC pipe cut in half lengthwise. The end of the PVC pipe was pushed into the slope on top of the glacial till where water was issuing out of the bluff so as to seal off water flow under the pipe. The water was collected in a calibrated bucket for a period of five minutes and an approximate flow rate determined. The calculated flow rates are as follows:

- SP-E 0.75 gallons per minute per foot
- SP-F 1.5 gallons per minute per foot
- SP-I 0.25 gallons per minute per foot

3.3 Test Borings

Test borings were located and drilled to meet two primary objectives. The first objective involves delineating the subsurface soil conditions, and the second entails a study of the groundwater regime in the area.

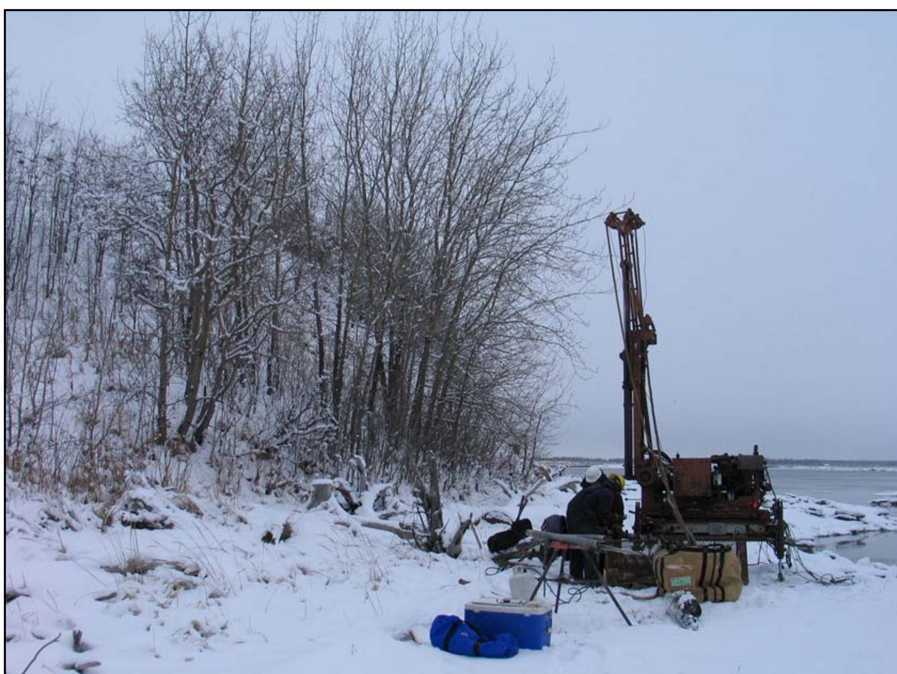
A total of twenty (20) test borings were drilled by R&M at the project site during the period of November 9, 2006 through December 16, 2006, fourteen (14) of which were completed as groundwater monitoring wells. Each of the borings was logged in accordance with standard engineering practices, and data obtained in this manner were utilized to determine geotechnical site conditions. The depth of the test borings ranged from 30 to 101.5 feet. The total number of feet drilled during the field program was approximately 1,135. Drilling and sampling operations were performed by Discovery Drilling, Inc. of Anchorage, Alaska under direct contract to R&M. Approximate test boring locations are shown on Drawings A-02 through A-06 of Appendix A. Logs of the test borings are illustrated in Appendix B, Drawings B-03 through B-17. A key to the test hole log general notes and an example of a typical log are illustrated on Drawings B-01 and B-02, respectively. Table 3 provides a summary of all R&M test borings performed for the project.

Soil boring, sampling, and groundwater well installation on the bluff crest were performed utilizing a truck-mounted CME-75 drill rig (Figure 5a). Soil boring and sampling operations on the bluff toe were performed either with a Nodwell-mounted CME-75 drill rig (Test Boring AP-627 as shown in Figure 6b) or with a helicopter portable CME-45 drill rig (Test Borings AP-622 through AP-626 as shown in Figure 5b). Maritime Helicopters of Homer, Alaska provided a Bell Model 207 helicopter under contract with Discovery Drilling. Test borings were advanced using continuous flight, hollow-stem augers. Representative soil samples were generally obtained at the surface, at 2.5 feet and five feet, and then at approximately five-foot intervals or at obvious changes in soil strata. However at each grouping of three groundwater monitoring well installations (e.g. AP-608-MW through AP-610-MW), only one of the three borings was sampled and logged in detail. The other two borings were only sampled at the bottom of the boring.

FIGURE 5

PHOTOGRAPHS SHOWING DRILLING OPERATIONS

a. Drilling at Group 4 borings. November, 2006.



b. Drilling at Test Boring AP-622 with helicopter portable drill rig. December, 2006.

FIGURE 6

PHOTOGRAPHS SHOWING DRILLING OPERATIONS

a. Tide flats at high tide along the eastern part of the project.
High tides made it difficult to access drills along the beach. October, 2006.

b. Drill struck in mud near Senior Center.
The soft mud made it difficult to use tracked equipment on tide flats. November, 2006.

The drilling program was conducted under the supervision of an experienced engineering geologist who maintained a detailed log of the materials encountered and the samples attempted and recovered. Representative soil samples generally were collected either by means of grab samples taken directly off of the augers, in the case of the surface sample, or via split-spoon samplers. In all but one boring, disturbed samples were obtained using a 2.5-inch I.D. (3.0-inch O.D.) split-spoon sampler driven by means of a 340-lb hammer with a 30-inch free-fall stroke.

Both manual (rope and cathead) and automatic (hydraulic) hammers were used on this project, as denoted for each sample on the logs of test borings in Appendix B. The penetration resistance, defined as the number of blows required to drive the sampler the last 12 inches of an 18-inch interval, gives an indication of the in-place relative density for unfrozen cohesionless soils. Blow counts reported per six-inch interval are shown on boring logs in Appendix B. Penetration resistances thus obtained can be corrected to approximate the Standard Penetration Test (SPT) "N" values by an energy to area ratio adjustment. A correction factor should be used to convert actual blow counts to the corresponding approximate SPT blow counts. Note, however, that the blow counts appearing on the logs of test borings are actual values, not converted SPT values. The Standard Penetration Test (SPT) was performed in the upper 40 feet of Test Boring AP-617-MW utilizing the 1.4-inch I.D. (2.0-inch O.D.) drive sampler and a 140-pound automatic drop hammer. When judged appropriate by the field geologist, brass liners were used inside the split-spoon sampler to retain soil for later laboratory testing. Most of the soils encountered proved unsuitable for "undisturbed" Shelby tube sampling (ASTM Designation D 1587), but one such sample was able to be collected in Test Boring AP-622.

It should be noted that heaving or flowing sands interfered with sampling in every test boring along the bluff toe, as well as in the deeper test borings located on the bluff crest. The logs of test borings in Appendix B include notes on whether a sampler was overfilled with heaving sand, or whether samples were not attempted below a certain depth due to heaving sand flowing up into the augers.

All soils recovered were visually classified and logged in the field following ASTM Designation D 2488. After visual and tactile classification in the field, all soil samples were returned to the R&M laboratory. Representative samples were then selected for further examination and testing.

3.4 Groundwater Monitoring Well Installation

After completion of drilling, fourteen (14) of the test borings on the crest of the bluff were completed as groundwater monitoring wells. Groundwater monitoring wells were installed in general accordance with ASTM Designation D 5092, "Design and Installation of Groundwater Monitoring Wells in Aquifers". Each monitoring well was constructed to allow for the accurate measurement of groundwater depths relative to the top of the well riser. The well riser pipe was constructed of 2-inch I.D. polyvinyl chloride (PVC) pipe. A locking steel protective over casing was installed around the well riser pipe extending approximately three feet below and three feet above the top of ground surface. Bollards were placed around some of the installations to protect the wells from traffic and snow removal equipment.

Groundwater levels were measured upon completion of the installation and will be measured monthly for one year, with a total of 13 readings for each monitoring well. Groundwater elevations and a groundwater monitoring report will be furnished to the USACE-AD after completion of the groundwater monitoring program.

A typical groundwater monitoring well schematic is presented as Figure 7. Monitoring well photographs are shown in Figure 8.

3.5 Groundwater Monitoring

Groundwater monitoring will occur on a monthly basis in the 14 R&M test borings that were converted to monitoring wells and the three pre-existing American Environmental monitoring wells. This monitoring is anticipated to continue to occur on this basis for a period of one year from the installation date. Access to the protective over casings is gained and a Solinst Model 101 water level meter is lowered down the well to measure the groundwater level. The water level meter tape is measured against a constant point on each well casing to ensure a consistent measuring point.

3.6 Borehole Location Surveys

Survey information was based on a field survey performed by R&M Consultants, Inc. during January, 2007. The project coordinates are ACS83 Zone 4, U.S. Survey Feet. The project datum is NAD83 (CORS). The project coordinates and datum were established by ties to CP 1 and USC&GS BM NO. 3 1966 from the DOWL Engineers drawing "Kenai River Bluff Erosion Survey Topography" dated July 16, 2003. The vertical datum was established by holding USC&GS BM NO. 3 1966 with an elevation of 31.44 feet. The drawing indicates that the vertical datum is referenced to Mean Lower Low Water (2003) in U.S. Survey Feet.

Monitor wells and test borings were located horizontally using RTK GPS techniques and vertically by a combination of RTK GPS and differential leveling techniques. The RTK GPS accuracy was quality controlled by taking three-dimensional check shots on established control positions. All of the check positions fell within the tolerances defined in the scope of the project.

The elevations for the top of the pipe of the monitor wells were determined by differential levels run from TBMs with elevations established by RTK GPS. The wells were broken up into four groups based on proximity. One TBM was established for each group of wells with RTK GPS. Differential levels were then run from the TBM to the group of wells in the surrounding area. All level loops closed well within the tolerances defined in the scope of the project.

FIGURE 7

TYPICAL GROUNDWATER MONITORING WELL GROUP

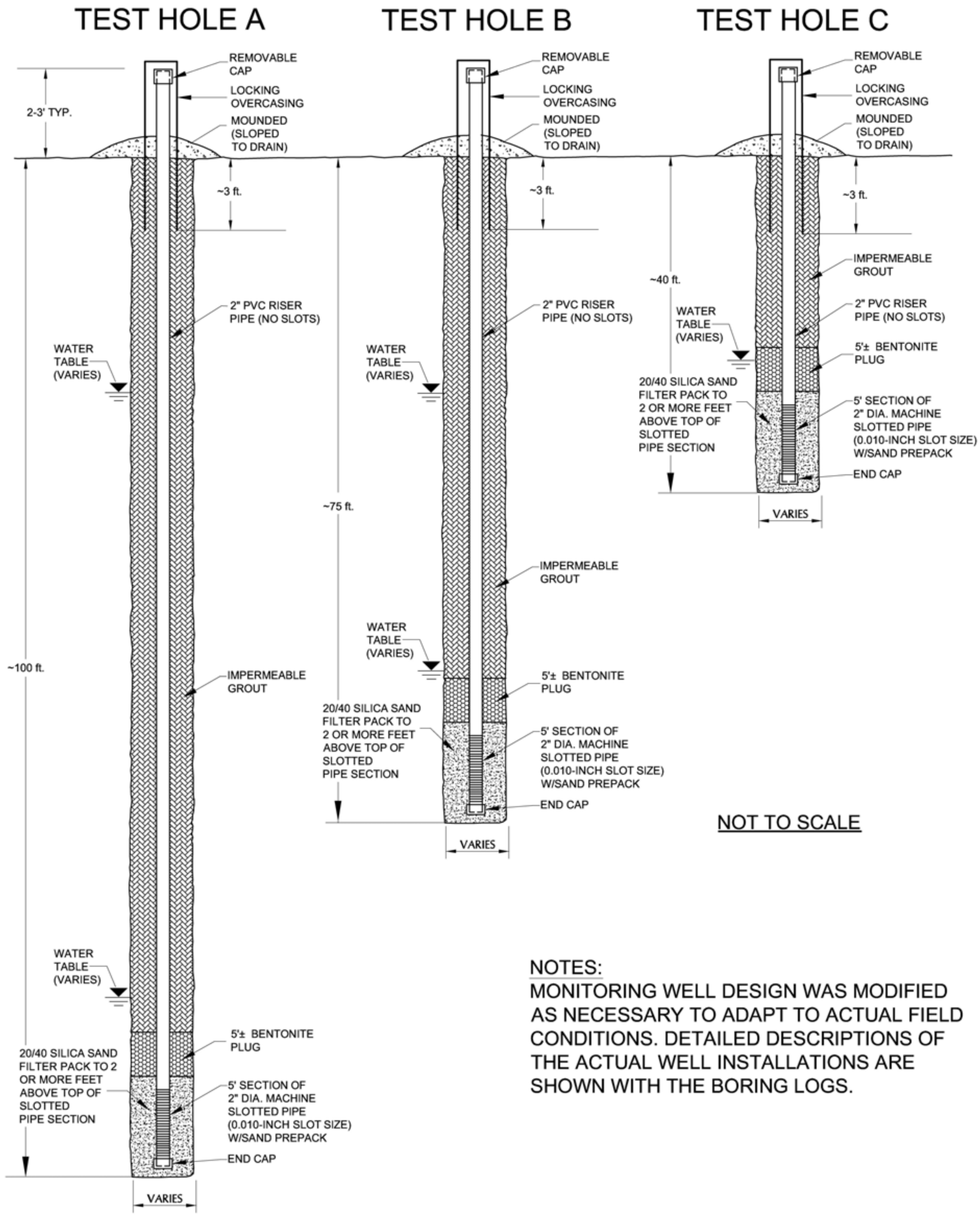


FIGURE 8

PHOTOGRAPHS SHOWING MONITORING WELLS

a. Monitoring well installation at Group 3 borings with protective bollards. December, 2006.

b. Grouting at Group 2 borings. November, 2006.

4.0 LABORATORY TESTING PROGRAM

The laboratory testing program was developed to provide data on the important subsoil characteristics necessary for subsurface characterization of the site. A select number of the soil samples collected during the bluff logging field work and recovered from the test borings were tested both to measure key index properties and to determine the engineering or mechanical properties of the soils. These tests verified and allowed modification of the field descriptions, thereby improving the data base for engineering application and geotechnical interpretation of site conditions.

4.1 Index Testing of Soils

Selected soil samples were tested to measure index properties, which are important for classification and grouping of the soils into general units. Laboratory index testing and soil classification were performed in accordance with the following ASTM designations (ASTM, 2006).

TEST	ASTM DESIGNATION
Description and Identification of Soils (Visual-Manual Procedure)	D 2488
Classification of Soils for Engineering Purposes	D 2487
Laboratory Determination of Water (Moisture) Content	D 2216
Particle Size Analysis (Sieve)	D 422
Particle Size Analysis (Hydrometer)	D 422
Liquid Limit, Plastic Limit, and Plasticity Index of Soils	D 4318
Specific Gravity of Soil Solids by Water Pycnometer	D 854

In addition to the ASTM version of the Unified Soil Classification (USC) System, the samples received a frost classification based on the Army Corps of Engineers Method (USACE, 1992). Each classification method (USC and USACE) is presented on the log of test borings for those representative samples tested. When a classification was estimated, the estimated classification symbol is followed by an asterisk (*) on the test boring log and the laboratory data summary sheets.

A summary of soil index property data is provided in Appendix C, Drawings C-03 through C-06. Particle size distribution (gradation) curves are presented for Soil Profile samples only in Appendix D, Drawings D-11 through D-16. Gradation curves for glacial till samples with a 24-hour hydrometer are shown on Drawings C-19 and C-20 of Appendix C. For clarification of soil call outs, Drawing C-01 defines the classification of soils for engineering purposes. Drawing C-02 provides an explanation of the USACE Frost Design Soil Classification.

It should be noted that the size of the gravel particles obtained with either the 1.4-inch or 2.5-inch I.D. drive samplers is limited by the size of the opening of the sampler, and the sample may thus not necessarily be representative of the coarse gravel fraction.

4.2 Engineering Properties Testing of Soils

Selected soil samples were tested to measure certain engineering properties, such as shear strength and permeability. This testing was performed in accordance with the following ASTM designations (ASTM, 2006).

TEST	ASTM DESIGNATION
One-Dimensional Consolidation Properties of Soils Using Incremental Loading	D 2435
Consolidated Undrained Triaxial Compression Test for Cohesive Soils	D 4767
Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils	D 2850
Permeability of Granular Soils (Constant Head)	D 2434

4.2.1 One-Dimensional Consolidation Tests

One-dimensional, incremental loading consolidation tests were conducted on selected specimens to assess stress history and compressibility characteristics. Tests were performed following ASTM D 2435-04. All samples were trimmed into brass rings prior to testing to produce initial specimen dimensions of approximately 2.4 inches in diameter and one inch in height. Tested samples were set with an initial seating load, and then loaded in the following increments of 1/8-ton per square foot (tsf), ¼ tsf, ½ tsf, 1 tsf, 2 tsf, 4 tsf, 8 tsf, 12 tsf, and 20 tsf. Samples were kept saturated throughout the test.

Results of the consolidation tests are presented graphically in Drawings C-07 through C-09 of Appendix C. Plots are provided as void ratio versus load.

4.2.2 Triaxial Compression Tests

Triaxial shear strength tests were performed for the purpose of determining the stress-strain behavior of the glacial till unit. Triaxial tests were conducted on drive-sampled plastic liner specimens. Consolidated-undrained (CU) tests were performed following ASTM D 4767-02. Unconsolidated-undrained (UU) tests were conducted following ASTM D 2850-03.

The CU tests could not be run at a rate slow enough to allow equalization of pore pressure. The tests were performed on specimens with diameters of approximately 2.4 inches. Specimen height/width ratios were between 2.0 and 2.5. Because of the presence of small gravel particles in the material it was not possible to trim the specimens to smaller diameters. Filter strips were applied to the perimeter of the specimens to allow radial drainage. However, even with radial drainage, the measured consolidation rate required strain rates of about 0.02 to 0.03% per minute for the equalization of pore pressure. The CU tests were run at about 0.1% per minute, which is the slowest strain rate the test equipment can accommodate. Photographs showing triaxial test procedures are presented in Figure 9.

FIGURE 9

TRIAXIAL COMPRESSION TEST PHOTOGRAPHS

a. Triaxial test apparatus.

b. Sample TB-2C No. 16 (AP-611-MW) after testing. Note failure plane.

Triaxial test data are presented in Drawings C-10 through C-16. Pore pressures were measured in CU tests, utilizing a pressure transducer connected to the base of the specimen. Total deviator stress, and pore pressure are plotted against axial strain in the drawings. Mohr diagrams for both CU and UU tests are shown on Drawing C-17.

4.2.3 Permeability Tests

Constant head permeability tests (ASTM Designation D 2434) were performed to assess the permeability of the granular alluvial material. The tests were performed on specimens in brass liner sampling tubes. Results from all permeability tests are tabulated on Drawing C-18.

5.0 GEOTECHNICAL CONDITIONS

Our field investigation has revealed variable subsurface conditions at the Kenai River Bluff Erosion site. To facilitate a discussion of the soil and groundwater conditions, the following sections have been set out to characterize each parameter on an individual basis. The reader is referred to the drawings included within the appendices of this report for graphic representation of the various conditions encountered.

A field log was prepared for each boring by the field geologist. The log contains information concerning the boring methods, samples attempted and recovered, and descriptions of the various soils and groundwater conditions encountered. It also contains the field geologist’s interpretation of the conditions in intervals between recovered samples. Therefore, these logs contain both factual and interpretive information. The final drafted logs also represent additional interpretation of the contents of the field logs and the results of the laboratory tests of samples. The final logs are included within Appendix B of this report. It is emphasized that because of the inclusion of laboratory data, our interpretations are based on the contents of the final logs and the information contained therein, and not solely on the field logs.

The final drafted logs included in Appendix B have a two-fold function: they serve as a format for the presentation of some of the significant raw field and laboratory data gained from the test boring as well as illustrating the interpretation of this data – the delineating of the different soil strata encountered. From the standpoint of preparing the test boring logs, the first function involved the mechanical extraction and transferal of data, whereas the second function requires knowledge of soil mechanics, and a good understanding of field soil sampling techniques and geomorphic processes, especially those of the northern environment.

Soil profiles are provided as Drawings D-01 through D-10 of Appendix D. An annotated photo mosaic is presented on Drawings A-08 through A-10. Additionally, a generalized subsurface profile showing interpreted soils and groundwater conditions is presented in Appendix A, Drawing A-11. Soil units reflect those found on the soil logs in Appendix B, but have been generalized and abbreviated for clarity of presentation.

5.1 General Soil Stratigraphy

Between the mouth of Cemetery Creek and the Pacific Star Seafoods Plant (Drawings A-02 and A-03), the river bluffs were underlain by alluvial deposits overlying glacially modified marine deposits (glacial till). The two units were separated by a thin layer of lag gravel from which a year-round flow of groundwater emerges from the bluff.

The upper alluvial deposits consisted of sands that were interpreted by Reger in Karl et al., (1997) to be a distal fan and/or delta deposits (see Figure 3). The deposits had previously been interpreted by Karlstrom (1964) to be reworked alluvial/lake deposits, laid down along the shoreline of a proglacial lake during the retreat of the Naptowne Glaciers. Paleosols buried in the sands indicate an intermittent depositional environment.

Generally, the glacial till unit was interpreted to have originally consisted of Quaternary-age marine clays similar to the Bootlegger Cove deposits near Anchorage. However, the material contained more gravel ("dropstones") than was typically found in the Bootlegger deposits. These marine deposits at Kenai were reportedly older than the Bootlegger Cove deposits (Karl et al., 1997). The marine clays were overridden by one or more glaciers, consolidating and deforming the clay deposits and incorporating significant amounts of coarser gravel, cobbles, boulders, and larger glacial erratics into the clay. Layers of fine sands deposited either before or interbedded with the clays also formed irregularly shaped pockets.

The interlayered lag gravel was interpreted to be a residual accumulation of coarse, hard rock remaining on the glacial till surface after the fines were washed or blown away. Thus, it assumes an unconformity exists between the alluvial deposits and glacial till after the retreat of the glacial ice. An unconformity can be defined as a period in the geologic record when deposition ceased and erosional processes dominated (Bates and Jackson, 1980).

5.2 Soil Conditions

Generally, the soils encountered in the 20 test borings drilled during the current program can be divided into two major units. These units were an upper alluvial unit overlain by surficial silts and a lower glacial till unit; separated from the alluvial unit by a thin bed of lag gravel formed at the unconformity between the two units. The glacial till unit contains distinct pockets of nonplastic sand that for the purposes of this discussion are described as a subunit. Minor stream/coastal deposits were encountered near the mouth of Cemetery Creek and a large man-made disposal site was identified near the Group 1 test borings. General interpretations and compilations of laboratory test data are presented below.

COMPILATION OF LABORATORY TEST RESULTS*
Average / [Range]
(Number of Tests) "Standard Deviation"

	Avg. % Gravel [(1)]	**Avg. % Sand**	**Avg. % Fines**	**Avg. Liquid Limit**	**Avg. Plastic Index**	**Avg. % Moisture Content**
Alluvial Unit	**6** / [0-32] (28) "12"	**88** / [45-99] (28) "10"	**5.6** / [1-52] (28) "2"	**NV** / [--] (1) "4"	**NP** / [--] (1) "1"	**7** / [1-27] (28) "6"
Lag Gravel	**45** / [39-54] (5) "6"	**53** / [46-59] (5) "6"	**1.4** / [0.5-2.7] (5) "1"	**No Tests**	**No Tests**	**8** / [3-13] (5) "4"
Glacial Till Unit	**6** / [0-22] (43) "6"	**25** / [8-56] (43) "10"	**68** / [42-91] (43) "12"	**27** / [18-38] (30) "4"	**11** / [6-20] (30) "3"	**17** / [11-78] (46) "10"
Sand Pockets	**2** / [0-12] (17) "3"	**95** / [83-99] (17) "5"	**3.6** / [1-11] (17) "3"	**No Tests**	**No Tests**	**13** / [2-24] (18) "7"

* Test results for five samples – two of the surficial soils (AP-611-MW #2 and AP-624 #1), one of interlayered sand and clay (AP-614-MW #19) and two of soils interpreted to be stream or coastal deposits (AP-622 #2 and #5) – were omitted from this table.

(1) As previously mentioned, the size of the gravel particles in samples obtained with the 1.4-inch and 2.5-inch I.D. drive samplers used in test borings at this site was limited by the size of the opening of the sampler, and the

sample was thus not necessarily representative of the coarse gravel fraction. Results from surface grab samples contained larger particles of gravel, but the sample sizes still were not large enough to be entirely representative.

5.2.1 Surficial Soils

Surficial deposits at the top of the bluff consisted of an organic mat overlying silt grading to sandy silt (ML), with localized deposits of clayey gravel with sand (GC). These surficial deposits ranged up to four feet thick. In some places, the upper one to two feet of the surficial soils were bound together by roots and overhung the lower slopes as the sand raveled down the bluff. Large trees have tended to break off “chunks” of this organic mat and pulled them downhill as the slope retreats.

5.2.2 Fills

Small fills containing construction debris were observed dispersed throughout the surficial soils along the crest of the bluff, which included abandoned parking lots, abandoned utility trenches, and building foundations. At the west end of the project there was a large fill consisting of debris, organic material and silty soils located near the Group 1 test borings (see Figure 10a). This area was reportedly used as a disposal site for many years until a portion of the fill failed and some of the material slid down onto the tidal flats. Based on observations of the slope and data from the test borings, it appeared that fill material was dumped over the bluff between Hansen Park and Mission Avenue near Broad Street. Most of the remaining fill was encountered on the property on which the Group 1 test borings were drilled and the property to the west between the Group 1 borings and Hansen Park. It appeared that the fill slope was being undercut near these two properties as the slope was actively raveling (see Figure 10b).

5.2.3 Alluvial Unit

Alluvial deposits were found underlying the entire upper bluff area to a depth of about 40 feet (37.5 to 42.5 feet). The material consisted of a thick layer of medium dense, fine to medium sand interspersed with layers of sand with gravel (SP, SP-SM). The gravel was rounded to subrounded, and ranged up to two inches in diameter. The sand with gravel layers typically ranged up to one foot thick. At Test Boring Groups 1 and 3, five-foot thick sand with gravel layers were noted. This unit exhibited horizontal layering and cross bedding. Measured slope angles in the sand ranged from 30 to 40 degrees (see Figure 11a). Slope angles were steepest at Soil Profiles SP-B, SP-C, and SP-D, near the west end of the project. Near Soil Profile SP-C, what appeared to be dark brown to black ferruginous cementation was observed in the sands. The cementation apparently allowed the slopes to stand steeper here than elsewhere (Figure 11b). A temporary increase in drilling resistance noted in the sand layer at other locations may also indicate the presence of cemented sands.

FIGURE 10

PHOTOGRAPHS OF EXISTING FILL MATERIAL

a. Area adjacent to Mission Road where fill was pushed over the edge of the bluff.
The black material on the flats was broken asphalt.
The fill slopes have reportedly failed during the past. September, 2006.

b. Photograph taken at bottom of slope on left side of photo above.
Note undermining of the slope and "Marston Mat" in foreground. October, 2006.

FIGURE 11

PHOTOGRAPHS OF ALLUVIAL DEPOSITS

a. Slope in alluvial unit at Soil Profile SP-F.
Overhanging surficial soil layer can be seen at upper left. October, 2006.

b. Cemented layers of sand at Soil Profile SP-C.
Cementation appears to allow the sand to stand almost vertical. October, 2006.

5.2.4 Lag Gravel

Lag gravel consisted of a relatively thin layer of more highly permeable material on top of the glacial till. For the most part, this layer was observed to be less than one foot thick; however near Soil Profile SP-C it was approximately six feet thick (see Figure 12).

Typically, on a geotechnical exploration project for foundation evaluation, a layer this thin would not be differentiated from the glacial till below, except that in this case it was the principal avenue for water flowing out of the bluff face.

This unit consisted of sand and gravel with cobbles (SP, SW and GP). The layer contained significantly more gravel and cobbles than the alluvial unit above. The coarse material was subrounded to rounded and hard. Laboratory tests indicate the material contained 0.5 to 2.7 percent fines and the sand was predominately medium to coarse-grained. For the most part, the material was saturated with moisture contents ranging up to 13 percent. Near Soil Profile SP-C, the gravel appeared to be cemented and no water was observed flowing from the bluff at that location.

5.2.5 Glacial Till Unit

The glacial till consisted of a very hard, heterogeneous mixture of clay, sand, and gravel, with cobbles and boulders ranging widely in shape and size. The glacial till stood near vertical close to the top of the unit (Figure 13a). In some locations the glacial till had the appearance of soft, poorly indurated bedrock similar to the Tertiary-age Kenai Group found on the lower Kenai Peninsula (Figures 13b and 14a). The clay was very hard when dry, becoming softer when exposed to water. It could be carved with a knife, excavated with difficultly using a hand pick, and scratched readily with the fingernail. The clay was plastic with an average liquid limit of 27 and a plasticity index of 11. The plasticity index generally appeared to decrease with increasing sand content.

Thin layers of sand were observed throughout the clay. These layers ranged from as thin as 1/16-inch up to ¼-inch thick and were oriented at 25 to 60 degrees from the horizontal. The layers were observed to be both dry and wet. They also appeared as sand fillings of fractures or fissures in the clay. The clay apparently contained fine to coarse sand dispersed throughout and was classified in most places as a sandy lean clay.

The marine clay appeared to contain gravel scattered throughout. These gravel particles have been interpreted to be dropstones (Karl et al., 1997). Dropstones are defined as stones that drop out of glacial ice when the ice melts over water (Figure 14b). Layers of gravel with cobbles and boulders up to six feet thick were observed scattered throughout the upper portion of the glacial till unit. Typically, the large cobbles and boulders were hard, and subangular to angular. The gravel and some small cobbles were hard and rounded to angular. More and larger gravel and cobbles were observed exposed in the upper portion of the glacial till than lower in the glacial till along the tide flats.

FIGURE 12

PHOTOGRAPHS OF LAG GRAVEL DEPOSIT

a. Cemented lag gravel (darker center bed in photo) at Soil Profile SP-C.
The light gray bed below it was the dense glacial till with cobbles and boulders.
There was no water observed seeping from the bluff at this location. October, 2006.

b. Thin layer of lag gravel near Soil Profile SP-H. Layer ranged from two to six inches thick and can be seen between the rust stained glacial till below and brown sand above.
Water was observed flowing out of the gravel at this location. October, 2006.

FIGURE 13

PHOTOGRAPHS OF GLACIAL TILL DEPOSIT

a. Top of glacial till unit at Soil Profile SP-H. Note gravel layers in till. October, 2006.

b. Glacial till exposed at the bottom of the bluff.
Note the bedrock-like jointed appearance of the clay. October, 2006.

FIGURE 14

PHOTOGRAPHS OF GLACIAL TILL DEPOSIT

a. Large chunks (boulders) of clay found at bottom of bluff.
From a distance, these chunks can be mistaken for cobbles and boulders. October, 2006.

b. Scattered gravel in clayey glacial till.
Much of this gravel may be "dropstones" derived from floating glacial ice. October, 2006.

Large glacial erratics were observed protruding from the bluff in several places and there were many large boulders located on the tide flats (Figure 15). Bates and Jackson (1980) define erratics as rock fragments carried by glacial ice and deposited at some distance from the outcrop from which they were derived. Erratics are often randomly scattered throughout glacially derived material.

The tide flats located at the base of the bluff lie on a marine platform cut into the glacial till. The platform slopes gently toward the river for a horizontal distance of about 100 to 200 feet. The platform was covered with what appeared to be a thin veneer of boulders, cobbles, gravel and sand apparently washed down from the bluff above. Under this veneer of soil, the clays had become soft in many places making travel on the tide flats treacherous for vehicles or personnel (Figure 6b).

5.2.6 Sand Pockets in the Glacial Till

Sand pockets within the glacial till consisted predominately of fine sand with some fine to medium dark gray nonplastic sand (SP and SP-SM). Larger pockets of sand were also noted along the bluff (Figure 16a). The largest of these pockets ranged up to about 12 feet high and 100 feet long (Figure 17b). The size and incidence of the sand pockets appeared to increase toward the west end of the project and a significant portion of the glacial till unit was composed of this sand at the Group 1 test boring location.

These sand pockets often occurred along the toe of the bluff, where they were rapidly eroded leaving small caves in the bluff (Figure 16b). The presence of these caves along the toe of the bluff appeared to accelerate undermining of the glacial till (Figure 17a). There were significant quantities of sand encountered in the eight test borings drilled along the tide flats. It appeared that the sand unit was becoming continuous and that the clay lenses were decreasing with depth.

The material consisted of a dark gray, poorly graded sand (SP) and sand with silt (SP-SM). The sands heaved when encountered during drilling, particularly in the test holes drilled on the tide flats. Layers of clay in the sand bed were noted in several of the borings, ranging from two inches to three feet thick. Samples of the material indicated the sand has an average fines content of 3.6 percent and a sand content of 95 percent. The sand ranged from fine to coarse but had little of the very fine sands (P140). There were minor amounts of gravel to 1.5 inches in diameter in some samples. Blow counts indicate the sand was medium dense to dense.

5.3 Groundwater Conditions

Observations along the bluff face coupled with test borings and measurements of monitoring wells indicate that there were two groundwater aquifers in the project area, within the 100-foot depth explored. Fourteen groundwater monitoring wells were installed in test borings drilled during this program (AP-608-MW through AP-621-MW) to provide ongoing groundwater measurements. Three monitoring wells (MW-1 through MW-3) previously installed by

FIGURE 15

PHOTOGRAPHS OF GLACIAL ERRATICS

a. Large boulder protruding from glacial till unit in bluff near Soil Profile SP-E.
The boulder was approximately five feet in length. October, 2006.

b. Large boulders on beach near Soil Profile SP-C. October, 2006.

FIGURE 16

PHOTOGRAPHS OF SAND POCKETS IN BLUFF

a. Sand pocket in glacial till showing signs of erosion. October, 2006.

b. Caves interpreted to have been created by the erosion of sand pockets along bottom of the bluff near Soil Profile SP-C. October, 2006.

FIGURE 17

PHOTOGRAPHS OF SAND POCKETS IN BLUFF

a. Caves formed in bluff by erosion of sand pockets.
Note caving of clay caused by undermining due to removal of sand. October, 2006.

b. Light gray material in center of photo was part of a large
sand pocket observed west of Soil Profile SP-C. October, 2006.

American Environmental in June, 2000 were also included in the groundwater monitoring program. Groundwater measurements in all wells will continue monthly for one year and will be published in a separate project report.

Initial groundwater measurements are presented in the following table.

GROUNDWATER MEASUREMENTS AT COMPLETION OF DRILLING PROGRAM 20-21 NOVEMBER 2006

MW ID	TOTAL DEPTH	Depth to GWT	Elev. of GWT	AQUIFER
Wells Installed by R&M in November, 2006				
AP-608-MW	100	67.3	21.1	Lower
AP-609-MW	75	67.2(1)	21.4	Lower
AP-610-MW	40	34.5	54.4	Upper
AP-611-MW	100	75.5	15.6	Lower
AP-612-MW	75	38.0(2)	53.3	Upper (?)
AP-613-MW	40	33.2	57.8	Upper
AP-614-MW	100	82.9	11.0	Lower
AP-615-MW	75	53.2(3)	40.3	Upper (?)
AP-616-MW	40	36.9	56.8	Upper
AP-617-MW	100	78.7	14.2	Lower
AP-618-MW	70	38.2(4)	54.9	Upper
AP-619-MW	40	29.8	63.3	Upper
AP-620-MW	40	28.3	63.9	Upper
AP-621-MW	40	21.7	71.0	Upper
Wells Installed by American Environmental in 2000				
MW-1	25	21.8	69.0	Upper
MW-2	25	20.3	72.0	Upper
MW-3	30	25.9	67.0	Upper

(1) A concerted effort to lower the water level with a manual baler resulted in only a 0.2-foot drop in the water level.

(2) The water level was lowered to 56.1 feet below ground surface after this reading by using a manual baler. The water level had recovered to 52.9 feet two hours later. The measured water level on December 27, 2006 was 52.1 feet. Thus, it appeared the upper aquifer had been sealed off and the water level measured in the monitoring well may have been either an aquifer in the clay or water remaining in the drill hole and/or surrounding formation after installation.

(3) The water level was lowered to 69.8 feet below ground surface after this reading by using a manual baler. The water level had recovered to 52.8 feet two hours later. The measured water level on December 27, 2006 was 59.5 feet. Further monitoring will be required to determine if this well was reading an aquifer in the clay or whether it was reading water remaining in the drill hole and/or surrounding formation after installation.

(4) After this reading the water level was lowered to 47.3 feet below ground surface by manual baling. Two hours later the water level had returned to 38.2 feet. This indicates that the well is recording water levels in the upper aquifer due to leakage in the seal or due to water entering the well from around the seal.

One of the prominent features of the Kenai River bluff within the project area was the groundwater flow from the upper aquifer at the contact between the upper alluvial deposit and the lower glacial till. Water flowing over the glacial till creates bright orange rust staining of the glacial till (Figure 18). The upper aquifer appeared to be perched on the glacial till and flowed south and west toward the bluff face. Measured depths to groundwater in this aquifer during November, 2006 varied from 20.3 feet to 38.2 feet. The groundwater table appeared be higher, the further from the bluff the monitoring well was installed. East of about Ryan's Creek, American Environmental reported a southwesterly water table gradient of about six feet in 400 feet, or approximately a 1.5 percent grade. Measurements taken from the monitoring wells in Group 4 indicated a steeper gradient closer to the bluff face (see Drawing A-11 of Appendix A). While there was less data available west of Ryan's Creek, it appeared that the groundwater gradient in that area may be lower.

Groundwater from the upper aquifer flowed out of the bluff face through a lag gravel layer that varied in thickness from about two inches to six feet. This flow occurred along the entire bluff face with the exceptions of areas near Soil Profile SP-C. Aufeis formed along the vegetated slopes between the project area and South Spruce Street in November, 2006 and it appeared that groundwater flow from the bluff face was also occurring there (Drawing A-08).

Water was noted flowing out of a sand layer near the top of the glacial till unit near the Senior Center facility. This was interpreted to be groundwater from the upper aquifer entering the glacial till through thin sand layers. Small isolated pockets of groundwater in the sand may also occur. Otherwise, there appeared to be no notable aquifer in the glacial till.

Near Soil Profile SP-C, groundwater seepage was observed as being minor or nonexistent. A significant amount of cementation was noted in the alluvial deposits and lag gravels at Soil Profile SP-C and this may have been the cause of the decreased flow in this immediate area (see Figure 12a). However, the cementation itself may be a result of lower groundwater flow. Water levels in Test Boring AP-620-MW and in Group 2 borings indicate there may be a lower groundwater gradient toward the bluff face in this area, but with limited data this was not conclusive. Flow rates out of the bluff varied, with higher flow rates at locations where the top of the bluff was slightly lower. This appeared to concentrate water flow across the flats producing small drainages that become more apparent in the winter (Figure 19).

The lower aquifer lies at about sea level and may in part be connected to the river. As shown in the table below, water levels in the Test Boring AP-617-MW monitoring well were noted to vary over time, possibly in relation to tide levels. However, if this was true there appeared to be about a four to six hour lag between the tide and measured groundwater levels.

FIGURE 18

PHOTOGRAPHS OF GROUNDWATER SEEPAGE

a. Groundwater seeping out of bluff at Soil Profile SP-D west of Ryan's Creek. October, 2006.

b. Small stream flowing out of bluff face near Soil Profile SP-I,
east of Ryan's Creek. October, 2006.

FIGURE 19

PHOTOGRAPH OF TIDE FLATS, NOVEMBER, 2006

Looking east along tide flats from Group 2 test borings at low tide on one of the first cold days of the winter. Later in the winter the flats were completely covered by ice.
Note the high water line above (white area on left side of flats) and the frozen streams of fresh water as they flow into the river.

WATER LEVEL MEASUREMENTS OVER TIME
IN TEST BORING AP-617-MW (21 NOVEMBER 2006)

Time (AST)	Depth bgs (feet)	Tides (1)
8:00 AM	78.7	
10:00 AM	82.3	Low Tide 10:30 AM 4.7 feet
12:30 PM	83.8	
4:00 PM	75.3	High Tide 3:58 PM 22.4 feet

(1) From NOAA http://tidesandcurrents.noaa.gov; Kenai River Entrance

5.4 Bluff Erosion

The cause of continued bluff erosion within the project area was interpreted to be removal of material from the toe of the bluff by river and tidal action. This can be seen when one compares the bluff within the project area to its continuation to the west where the toe was set back from the water (Drawing A-08). Without the removal of debris at the toe by river and tidal action, the slope in that area stabilized at an angle of about 38 degrees and became vegetated. No active erosion was observed in that area. There is no reason to believe that soil conditions to the west of the project area were significantly different than those within the project area. The bluff face tends to retreat due to continuous removal of both in-place material and material sloughed off the slope face.

Numerous secondary processes were interpreted to be involved in the raveling and sloughing of the bluff face, including the following:

- Softening of the clay by water, particularly the water flowing off the top of the glacial till and river water along the toe of the bluff.
- Undercutting of the alluvial sand by retreat of the glacial till.
- Undermining of glacial till by erosion of sand pockets as described in Section 5.2.6.
- Groundwater sapping undercutting the base of the alluvial sand along the bluff face.
- Falling trees dragging the organic mat down the slope.
- Frost action.

It appeared that the very hard clay would soften when exposed to water (slaking). In areas where the clay was exposed to standing or slow moving water it was soft. This did not occur in areas where water was observed to be actively flowing over the clay, which may have been due to flowing water carrying the clay away as it softened it. As the clay retreats, it undermines the alluvial sands above causing them to also retreat.

Small local areas of what appeared to be groundwater sapping were noted along the bluff. Groundwater sapping occurs where groundwater flows out of a bank or hillslope laterally as seeps or springs and erodes soil away. This may cause the slope above to be undermined and fail. In areas along the bluff where sapping appeared to have occurred, a relatively higher rate of flow was observed. These areas were typically between 10 and 20 feet wide. The steep walled gully through which Ryan’s Creek flowed may have been created by groundwater sapping. Groundwater sapping appeared to have only a locally significant effect on erosion along the bluff.

Trees that had fallen at the crest of the bluff were observed to drag large sections of topsoil in their root wads down the bluff, accelerating the erosion along the top of the bluff. Where trees had been cut, the organic mat would lie over the slope, apparently slowing the erosion.
During the November, 2006 drilling program the lower slopes of the bluff were covered by a thick layer of ice. One afternoon temperatures warmed into the upper 30s with the sun shining directly on the bluff face. We noted cobbles and boulders falling out of the bluff face as it thawed. Large pieces of ice also slid down the slope carrying soil with it. It appeared that a significant amount of material moved downslope during the four to five hours these conditions existed.

Debris piles were also observed along the toe of the slope. These debris piles consisted of a heterogeneous mixture of wet, very soft clay, sand, gravel, organic material. This material appeared to have raveled or flowed downslope from the bluff above. It also included trees that have broken off from the crest of the slope. Flow failures were noted in the debris slopes where they had been undercut.

Presumably, if the erosion of the toe by current and wave action stopped, the debris piles would build up. As the slope retreated back to an angle of about 35 to 40 degrees, vegetation would become established which would further stabilize the slope. The stable slope condition which occurs in the absence of toe erosion can be seen in Soil Profile SP-A.

6.0 CONCLUSIONS

The following conclusions are based on data collected from library searches, report reviews and R&M's field work and testing. Geotechnical investigations for the Kenai River Bluff Erosion Study reveal that:

1. The site is located within the Kenai Lowland portion of the Cook Inlet-Susitna Lowland physiographic province.

2. Segregated stands of primarily spruce trees are present along intermittent portions of the bluff crest. The toe of the bluff area is primarily devoid of vegetation.

3. Soils at the project site generally consist of alluvial deposits overlying glacially modified marine deposits (glacial till). The two units were separated by a thin layer of lag gravel from which a year-round flow of groundwater emerges from the bluff.

4. On the basis of currently available information, it appears that bedrock is located at a considerable depth beneath the project site. Therefore, bedrock is not expected to be involved with any construction considerations.

5. Observations and monitoring well readings indicate that there were two separate groundwater aquifers within the upper 100 feet at the project area. The upper aquifer flows from the bluff at the contact between the upper alluvial deposit and the lower glacial till. Technical studies and reports have noted seeps and springs emerging from the bluff at this contact for at least the past 100 years.

6. The elevation of the lower aquifer along the face of the bluff appeared to be influenced by tides.

7. Permafrost has not been encountered, nor should it be expected, within the project area.

8. Cemented layers of sand and gravel appeared to allow the soil to stand near vertical where the cementation occurred. There was no water observed seeping from the bluff at some of these cemented locations.

9. Marine clay within the glacial till unit was plastic with an average liquid limit of 27, and a plasticity index of 11.

10. Permeability tests conducted on the alluvial material indicated a permeability in the vertical direction of about 10^{-4} ft/sec. It is likely that this value does not represent the overall permeability of the unit. The presence of gravel layers would likely result in a much higher permeability in the horizontal direction.

11. Consolidation and triaxial strength tests conducted on the glacial till material indicated that the material was hard, overconsolidated, and strong. The average dry density of the specimens was 118 pcf. The compression index (C_c) ranged from 0.06 to 0.07.

12. Geologic logging of the bluff and the test borings indicated that the soils contain a large number of boulders. Therefore, any excavation contractor should be prepared to deal with said over-size material.

13. Contractors should also be prepared to deal with the soft, quick conditions of the soils along the tide flats (see Figure 20).

14. Within three months of the 1964 Great Alaska Earthquake, the bluff had receded as much as 20 feet within the project area. This was attributed to regional subsidence, rapid removal of sloughed debris along the toe, and undercutting by waves and the river.

15. The retreat of the bluff appears to be caused by several processes including erosion at the toe of the bluff by river and tidal action, slaking of the glacial till by groundwater and surface water, groundwater sapping of the alluvial sand, and frost action.

16. It is expected that in the absence of river and tidal action, the slope will naturally flatten to an angle between 35 and 40 degrees and become vegetated.

FIGURE 20

DRILL RIG STUCK ON TIDE FLATS

a. Nodwell stuck in mud near Test Boring AP-627 at low tide. November 10, 2006.

b. The Nodwell has sunk into unfrozen mud below the high tide line (edge of snow covered area). The surface of the mud was frozen under the snow covered area. November 10, 2006.

7.0 CLOSURE

The interpretations of geotechnical conditions presented in this report are based on our understanding of the project requirements, our limited bluff logging and test boring explorations, and other pertinent information listed herein. Significant alteration of any of these concepts or site locations could substantially alter the foregoing interpretations. We would, therefore, appreciate having the opportunity to review and evaluate the final design, and where necessary, present any required changes to our present conclusions. Additionally, because subsurface characteristics can change significantly within a given area, and with the passing of time, the possibility exists that important subsurface conditions not disclosed during our current investigation may be discovered during any future investigation or construction. Should this situation occur, the influence of the new information on the present interpretations should be evaluated without delay.

R&M Consultants, Inc. performed this work in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions. No warranty, express or implied, beyond exercise of reasonable care and professional diligence, is made. This report is intended for use only in accordance with the purposes of study described within.

We appreciate the opportunity to perform this geotechnical investigation. Should you require further information concerning the investigation or this report, please contact us at your convenience.

Very truly yours,

R&M CONSULTANTS, INC.

Peter K. Hardcastle
Senior Engineering Geologist

Charles H. Riddle, C.P.G.
Vice President

STATE OF ALASKA
49TH
Robert M. Pintner
CE 8525
2/14/07
REGISTERED PROFESSIONAL ENGINEER

Robert M. Pintner, P.E.
Senior Geotechnical Engineer

CHR*slv

8.0 REFERENCES

Anderson, G.S. and Jones, S.H., "Water Resources of the Kenai-Soldotna Area, Alaska", U.S. Geological Survey Open-File Report 72-7, prepared in cooperation with the Kenai Peninsula Borough, 1972.

Anderson, G.S., "Groundwater Exploration, Beaver Creek Valley Near Kenai, Alaska", U.S. Geological Survey Open-File Report 71-6, prepared in cooperation with the City of Kenai and the Kenai Peninsula Borough, June, 1971.

American Environmental, "Underground Storage Tank Removal and Site Assessment Report 2000, City of Kenai Daubenspeck Property, Kenai, Alaska", prepared for City of Kenai, March 5, 2001.

American Society for Testing and Materials (ASTM), "Annual Book of ASTM Standards", Vol. 04.08, Soil and Rock, 2006.

Arctic Environmental Information and Data Center (AEIDC), "Alaska Regional Profiles-Southeast Region", Vol. IV, University of Alaska, 1976.

Bailey, B.J. and Hogan, E.V., "Overview of Environmental and Hydrogeologic Conditions Near Kenai, Alaska", U.S. Geological Survey Open-File Report 95-410, prepared in cooperation with the Federal Aviation Administration, 1995.

Bates, Robert L. and Jackson, Julia A., "Glossary of Geology", American Geological Institute, 1980.

Coulter, H.W., et al., "Map Showing Extent of Glaciations in Alaska", U.S. Geological Survey Miscellaneous Geologic Investigations Map I-415, 1965.

Department of the Army, U.S. Army Corps of Engineers (USACE), "Geotechnical Investigations", EM 1110-1-1804, 1 January 2001.

Department of the Army, U.S. Army Corps of Engineers (USACE), "Soil Sampling", EM 1110-1-1906, 30 September 1996.

Department of the Army, U.S. Army Corps of Engineers (USACE), "Chapter 18 - Seasonal Frost Conditions", IN Pavement Design for Roads, Streets, Walks, and Open Storage Areas, TM 5-822-5, June, 1992.

Department of the Army, U.S. Army Corps of Engineers (USACE), "Soils and Geology, Procedures for Foundation Design of Buildings and Other Structures", TM 5-818-1, October, 1983.

Detterman, R.L., et al., "Surface Geology and Holocene Breaks Along the Susitna Segment of the Castle Mountain Fault, Alaska", USGS Misc. Field Studies Map MF-618, 1974.

Ferrains, Jr., O.J., "Permafrost Map of Alaska", U.S. Geological Survey Miscellaneous Geological Investigations Map I-445, 1965.

Freethey, G.W., and Scully, D.R., "Water Resources of the Cook Inlet Basin, Alaska", U.S. Geological Survey Hydrologic Investigations Atlas HA-620, Scale 1:1,000,000, 1980.

Glass, Roy L., "Groundwater Conditions and Quality in the Western Part of Kenai Peninsula, Southcentral Alaska", U.S. Geological Survey Open-File Report 96-466, prepared in cooperation with the Alaska Department of Natural Resources, Kenai Peninsula Borough and Kenai Soil and Water Conservation District, 1966.

Hartman, C.W. and Johnson, P.R., "Environmental Atlas of Alaska", University of Alaska, 1984.

Hartman, D.C., Pessel, G.H. and McGee, D.L., "Kenai Group of Cook Inlet Basin, Alaska", Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, Open-File Report Number 49, 1972.

Karl, Susan et al., "Road Log for the 1997 Guide to the Geology of the Kenai Peninsula", IN 1997 Guide to the Geology of the Kenai Peninsula, Alaska, Karl, S.M., Ryherd, T.J. and Vaughn, N.R. Eds., Alaska Geological Society, Anchorage, Alaska, 1997.

Karlstrom, Thor N.V., "Ground Conditions and Surficial Geology of the Kenai-Kasilof Area, Kenai Peninsula South-Central Alaska", U.S. Geological Survey Miscellaneous Geologic Investigations Map I-269, Scale 1:63,360, 1958.

Karlstrom, Thor N.V., "Quaternary Geology of the Kenai Lowland and Glacial History of the Cook Inlet Region, Alaska", U.S. Geological Survey Professional Paper 443, 1964.

Kirschner, C.E. and Lyon, C.A., "Stratigraphic and Tectonic Development of Cook Inlet Petroleum Province", IN Proceedings of the 2nd International Symposium on Arctic Geology, M.G. Pitcher, Ed., American Association of Petroleum Geologists, 1973.

Lahr, J.C., Page, R.A., Stephens, C.D., and Fogleman, K.A., "Sutton, Alaska, Earthquake of 1984: Evidence for Activity on the Talkeetna Segment of the Castle Mountain Fault System", Bulletin of the Seismological Society of America, 76(4): 967-983, 1986.

MacKevett, E.M. and Plafter, G., "The Border Ranges Fault in South-Central Alaska", J. Research U.S.G.S., 2(3): 323-329, 1974.

Magoon, L.B., Adkins, W.L. and Egbert, R.M., "Map Showing Geology, Wildcat Wells, Tertiary Plant Fossil Localities, K-AR Age Dates, and Petroleum Operations, Cook Inlet Area, Alaska", U.S. Geological Survey Miscellaneous Investigations Series Map I-1019, Scale 1:250,000, 1976.

Martin, G.C., Johnson, B.L. and Grant, U.S., “Geology and Mineral Resources of Kenai Peninsula, Alaska”, U.S. Geological Survey Bulletin 587, 1915.

Moffit, F.H., “Gold Fields of the Turnagain Arm Region”, IN Mineral Resources of Kenai Peninsula, Alaska, U.S. Geological Survey Bulletin 277, 1906.

Municipality of Anchorage Geotechnical Advisory Commission (GAC), “Amendments to the 1997 UBC with Respect to Local Seismic Sources”, December 30, 1997.

Orth, Donald J., “Dictionary of Alaska Place Names”, U.S. Geological Survey Professional Paper 567, 1967.

Peratrovich, Nottingham & Drage, Inc. (PN&D), “Kenai Coastal Trail and Erosion Control Project – Design Concept Report”, prepared for City of Kenai, January, 2000.

Plafker, G., Kachadoorian, R., Eckel, E.B. and Mayo, L.R., “Effects of the Earthquake of March 27, 1964 on Various Communities”, U.S. Geological Survey Professional paper 542-G, 1969.

Plafker, G., Gilpin, L.M., and Lake, J.C., “Neotectonic Map of Alaska”, Scale: 1:2,500,000, Plate 12, Geology of Alaska, Vol. G-1 of the Geology of North America, The Geological Society of America, 1993.

R&M Consultants, Inc. (R&M), “Geotechnical Scope of Work, Kenai River Bluff Erosion Study, Kenai, Alaska”, Final Submittal, Contract No. W911KB-05-D-0004, Delivery Order 0009, prepared for U.S. Army Engineer District, Alaska, 9 August 2006.

Reger, R.D., Pinney, D.S., Burke, R.M. and Wiltse, M.A., “Catalog and Initial Analyses of Geologic Data Related to Middle to Late Quaternary Deposits, Cook Inlet Region, Alaska”, Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys Report of Investigations 95-6, 1996.

Smith, O., Lee, W. and Merkel, H., “Erosion at the Mouth of the Kenai River, Alaska – Analysis of Sediment Budget with Regard to the Proposed Kenai Coastal Trail and Erosion Control Project”, University of Alaska Anchorage School of Engineering, April 5, 2001.

Stanley, Kirk W., “Effects of the Alaska Earthquake of March 27, 1964 on Shore Processes and Beach Morphology”, U.S. Geological Survey Professional Paper 543-J, 1968.

Tippetts-Abbett-McCarthy-Stratton (TAMS), “Bluff Erosion Study, Kenai River Sedimentation Study, Kenai, Alaska”, Draft Report, prepared for City of Kenai, November, 1982.

U.S. Army Corps of Engineers – Alaska District (USACE-AD), “Geotechnical Findings Report, Kenai River Bluff Erosion, Kenai, Alaska”, prepared by Soils and Geology Section, October, 2004.

U.S. Geological Survey (USGS), “Kenai (C-4) Quadrangle”, Scale 1:63,360, Topographic Series, 1951, Minor Revision 1972.

U.S. Geological Survey (USGS), “Kenai (C-4) SE Quadrangle”, Alaska-Kenai Peninsula Borough, Scale 1:25,000 Series, Provisional Edition 1986.

Wahrhaftig, Clyde, “Physiographic Divisions of Alaska”, U.S. Geological Survey Professional Paper 482, 1965.

Western Regional Climate Center (WRCC), http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?akkena.

Woodward-Clyde Consultants (WCC), “Anchorage Office Complex Geotechnical Investigation, Anchorage, Alaska – Volume 1 Seismic Hazards Evaluation”, Prepared for Alaska DOT&PF, 1982.