

### **3.0 GEOTECHNICAL INVESTIGATION**

#### **3.1 Regional Geology**

Union Reservoir is located on the west flank of the Denver Structural Sedimentary Basin. Strata on the west flank of the basin dip gently to the east off of the igneous and metamorphic core of the Colorado Rocky Mountain Front Range. The igneous and metamorphic core is approximately 14 miles west of the reservoir. In the Union Reservoir area, Colton (1978) indicates the bedrock is locally disrupted by several northeast trending, inferred faults. One of these faults is mapped near the south side of the reservoir.

In the area bedrock is commonly overlain by eolian (wind deposited) clay, silt, and sand soils and local alluvial (water deposited) sand and gravel deposits. The sand and gravel deposits sometimes occur as ridge forming pediments (approximately 1.3 miles southwest of Union Reservoir) or sometimes underlie surface eolian soils in lower lying areas such as in Spring Gulch and on the south side of the reservoir.

Regional geologic mapping by Colton (1978) indicates the near surface bedrock at the reservoir site is claystone, shale, sandstone, and gradations between these three rock types known as the Upper Transition Member of the Pierre Shale. Colton (1978) maps bedrock at the surface near the natural reservoir inlet on the northwest side of the reservoir. Colton (1978) maps eolian soils at the surface around the remainder of the area surrounding the reservoir.

#### **3.2 Geotechnical Field Investigations**

Site subsurface conditions along potential dam alignments and in potential borrow areas were investigated by drilling borings and excavating test pits in the reservoir area during the 1986 and current investigations. Further geotechnical information has been obtained from geotechnical studies by others. The geotechnical studies by others focus on proposed residential developments near the reservoir.

The 1986 feasibility study included the drilling of 14 exploratory borings (**Figure 3.1**). The boring locations were not surveyed and the locations shown on **Figure 3.1** should be considered approximate. The majority of these borings were drilled along the 1986 proposed dam alignment on the south side of the reservoir. Fourteen logs of these borings were documented in cross-sectional view in the 1986 report and are again provided herein on **Figure 3.2**.

To supplement the 1986 study and to provide data on newly acquired properties and newly proposed dam alignments and borrow areas, 31 additional borings (TH-19 through TH-49) were drilled at the approximate locations shown on **Figure 3.1**. In addition, 12 backhoe test pits (TP-1 through TP-12) were excavated at the approximate locations shown on **Figure 3.1**. Summary logs of the current investigation borings and test pits are provided on **Figures 3.3 through 3.11**. The current investigation drilling program included bedrock coring and packer permeability testing. Core and packer test intervals are shown on the summary logs. Piezometers were installed in borings TH-19, TH-38, TH-39, and TH-45.

Three geotechnical reports by others were provided by the City of Longmont or were available in Tetra Tech RMC's files. These reports are described as follows:

1. Terracon (2001): This report is a Preliminary Geotechnical Engineering Report for a proposed residential development on the Willis property on the west side of the reservoir. Six exploratory boring logs were drilled for this study and are designated Terracon-1 through Terracon-6 on **Figure A-1 of Appendix A**.
2. CTL Thompson (1999): This report is a Geologic and Preliminary Geotechnical Investigation for a proposed residential development on the east side of Union Reservoir. This study included the drilling of 22 borings designated CTL99-1 through CTL99-22 on **Figure A-1**.
3. CTL Thompson (2002): This report is also a Geologic and Preliminary Geotechnical Investigation for a proposed residential development on the southeast side of Union Reservoir. This study included the drilling of seven exploratory borings designated CTL02-1 through CTL02-7 on **Figure A-1**.

The locations of borings from these three reports were not surveyed and are approximately shown in **Appendix A**. The boring logs from those reports are also presented in **Appendix A**. Data from these borings was utilized to supplement our analysis of subsurface conditions in the reservoir area.

### **3.3 Geotechnical Laboratory Testing**

Soil and bedrock samples obtained from the various investigations outlined above have been analyzed for physical and engineering properties at geotechnical laboratories. Results of the laboratory testing for the 1986 and current feasibility investigations are summarized on **Tables 3.1 through 3.3** of this report. The purpose of the laboratory testing was two-fold in that properties of foundation soils and bedrock, as well as properties of potential dam construction materials from proposed borrow areas were investigated.

Testing for physical properties included unit weight, moisture content, Atterberg limits, grain size analysis, and Standard Proctor moisture/density relationships. The engineering property tests included remolded consolidated undrained triaxial compression tests and pin hole dispersion tests of proposed embankment borrow materials as well as consolidation unconfined compressive strength tests of embankment foundation soils. Analyses of the triaxial strength testing are included on **Figure 3.12**. The detailed laboratory results are presented in **Appendix B**.

### **3.4 Site Subsurface Conditions**

Based on the above outlined field and laboratory investigations, the site soils and bedrock can be divided into three distinct stratigraphic units: eolian soils, sand and gravel, and bedrock. Descriptions of the general occurrence, interrelationships, and properties of each of these units, as well as a general discussion of the occurrence of groundwater are described below. Geologic cross-sections of the site are shown on **Figures 3.13 and 3.14**.

### 3.4.1 Eolian Soils

#### Occurrence

Eolian soils consisting of clays and sandy clays are present at the ground surface throughout the investigated embankment and borrow areas. These soils appear to be at the surface around the entire reservoir perimeter with the possible exception of the northwest inlet area where subsurface investigations have not been performed and regional mapping by Colton (1978) shows bedrock at the surface. On the west and north sides of the reservoir, as well as on the north part of the east side of the reservoir the eolian soils form a thin layer directly overlying shallow bedrock. In these areas the eolian soils are generally three to five feet thick locally extending to depths of eight feet and locally can be as thin as two feet.

On the south part of the east side of the reservoir, the eolian soils are thicker and directly overlie bedrock. Borings in this area encountered eolian soils ranging from approximately 17 to 26 feet in thickness.

On the south side of the reservoir the eolian soils are again relatively thick, but overlie sand and gravel particularly in the low lying central part of the south side. On the east part of the south side of the reservoir the eolian soils directly overlie bedrock. Boring data indicates the eolian soils on the south side of the reservoir are commonly 15 to 25 feet thick, but are locally as thin as six to 13 feet where the underlying sand and gravel unit is thicker and in the lower lying areas south of the reservoir.

#### Properties

Results of the geotechnical testing and Unified Soil Classifications for the eolian soils are summarized on **Table 3.1**. Review of **Table 3.1** shows the testing resulted in natural dry densities ranging from 90.5 to 110.0 pcf, moisture contents from 8.6 to 27 percent, percent fines passing the 200 sieve ranging from 45 to 97, liquid limits ranging from 23 to 42, and plasticity indices ranging from 3 to 25. Casagrande plots of soil plasticity are presented on **Figure 3.15**. Consolidation testing on four eolian samples resulted in consolidation between 2.4 and 11.8 percent under a 10 kip load. Pinhole dispersion testing on one sample resulted in a classification as a non-dispersive soil (ND-1). Using the Unified Soil Classification system, nearly all of the samples tested classified as clay, clay with sand or sandy clay (CL). One sample classified as clayey sand (SC) and another sample classified as silt with sand (ML).

A closer look at the data indicates the eolian soil on the southeast side of Union Reservoir near borings TH-45 through TH-48 tends to be slightly more plastic (with liquid limits over 40 and plasticity indices over 20) and tends to have less constituent sand (typically less than 10 percent). Eolian soils in the other sample areas tend to be less plastic (with liquid limits in the upper-20s and low to mid-30s and plasticity indices in the teens) and to have greater constituent sand (typically in the 20 to 40 percent range). The more plastic and less sandy eolian soils on the southeast side of the reservoir actually tend to have physical properties similar to the on-site claystone bedrock (see

below) indicating the parent material for the eolian soil on the southeast side of the reservoir may be the claystone bedrock.

### **3.4.2 Alluvial Sand and Gravel**

#### Occurrence

Alluvial sand and gravel underlies eolian soils and overlies bedrock on the south and southwest side of the reservoir. **Figure 3.16** is an isopach map showing the approximate thickness of the sand and gravel, as well as the approximate limits of the deposit. This sand and gravel appears to be the same unit that is in Spring Gulch west and south of the site. As the isopach map indicates, the sand and gravel layer is relatively thin (approximately one to three feet thick) on the east part of the unit, is thicker near the reservoir outlet, and thickest (11 feet thick) in the area of boring TH-16.

Observation of seepage from the sand and gravel layer is visible in the outlet channel immediately below the outlet pipe. This seepage appears to indicate the sand and gravel is in contact with reservoir water and is a route for seepage from the reservoir.

#### Properties

Laboratory testing on three samples of sand and gravel is summarized on **Table 3.2**. The laboratory sieve analyses resulted in percent fines passing the 200 sieve between 1 and 11 percent. On the two samples on which complete gradations were performed, one classified as sandy gravel and the other as gravelly sand. Packer permeability testing of sand and gravel at boring TH-40 resulted in a calculated permeability of  $1.4 \times 10^{-3}$  centimeters per second.

### **3.4.3 Bedrock**

#### Occurrence

Claystone is the predominant near surface bedrock type at the site and is present around nearly the entire perimeter of the reservoir. Some sandstone is present on the north part of the east side of the reservoir as encountered in borings TH-19, TH-20, and borings TH-22 through TH-27. The depth to bedrock around the site is shown on **Figure 3.17**. The bedrock occurs at shallow depths on the west and north sides of the reservoir as well as on the north part of the east side of the reservoir. In these areas the bedrock was typically encountered at depths of three to five feet, but was also locally as shallow as two feet and as deep as eight feet.

On the southern part of the east side of the reservoir the bedrock is abruptly deeper. Borings in this area encountered bedrock at depths ranging from approximately 17 to 26 feet. On the south side of the reservoir the bedrock was commonly encountered at depths of approximately 18 to 22 feet. Towards the west part of the south side of the reservoir bedrock was encountered at somewhat shallower depths of six to 12 feet near borings TH-10 through TH-14. Bedrock also is shallower in the lower lying area south of WCR 26 where bedrock in borings TH-41 through TH-44 was at depths ranging from approximately 13 to 19 feet.

## Properties

The uppermost claystone bedrock is commonly very weathered and excavates easily. At depth the claystone excavates in larger slabs and is locally an indurated shale. Geotechnical laboratory testing on the bedrock is summarized on **Table 3.3**. Testing on the claystone samples resulted in natural dry densities ranging from 100.5 to 128.3 pcf, moisture contents ranging from 11.4 to 23.9 percent, percent fines passing the 200 sieve ranging from 86 to 99 percent, liquid limits ranging from 33 to 48, and plasticity indices ranging from 17 to 31 (**Figure 3.15**). Packer permeability tests performed in borings TH-35 and TH-40 resulted in no water intake. Packer permeability testing in TH-45 resulted in a calculated permeability of  $8 \times 10^{-6}$  centimeters per second.

The sandstones are typically very fine to fine grained and blocky sometimes breaking on joints. Laboratory testing on three sandstone samples resulted in dry densities of 114.0 and 117.6, moisture contents of 10.3 to 14.9 percent, and percent fines passing the 200 sieve of 19 to 44 percent.

### **3.4.4 Groundwater**

Groundwater depths encountered at the time of drilling and measured in site piezometers are shown on the summary logs and the geologic cross-sections. Groundwater was commonly encountered adjacent to the reservoir and in low lying areas on the south side of the reservoir. In other areas, groundwater was commonly not encountered except for local areas where water was perched on top of bedrock. Where groundwater or perched groundwater was encountered the affected eolian soils and uppermost bedrock were sometimes very soft.

Piezometers were installed in four borings: TH-19 on the east side of the reservoir, TH-38 on the west side of the reservoir, and TH-39 and TH-45 on the south side of the reservoir. In order to establish a long-term baseline of groundwater elevations on the site, we recommend the City monitor these on a quarterly basis. A draft water level monitoring table is included as Table 3.4.