

## 7.0 SITE INVESTIGATION OF UPPER RESERVOIR BARRIERS

### 7.1 INTRODUCTION

The Upper Reservoir Barriers were investigated by several methods:

- Review of documents, FERC interview transcripts, construction records, and operation and maintenance history.
- Discussions with AmerenUE personnel.
- Geologic and engineering property mapping of the exposed foundation within the Breach Area as discussed in *Section 3.0*.
- Mapping and description of the debris torrent in the Breach Channel below the Breach Area as discussed in *Section 3.0*.
- Subsurface drilling.
- Laboratory testing of Breach Area soils and Dike material.

### 7.2 GEOLOGIC MAPPING

Geologic mapping was performed on January 19 and 20, 2006. RIZZO geologists mapped both geology and engineering properties following the guidelines and terminology given in the US Bureau of Reclamation Field Geology manual (<http://www.usbr.gov/pmts/geology/>). The mapping is mostly based on discontinuity survey combined with other parameters such as weathering, hardness, lithology, etc. These maps are described in *Section 3.0* and presented as *Plates 3.1 and 3.2*.

In addition to the geologic mapping of the Breach Area, RIZZO geologists mapped and described the sediments deposition patterns on the property owned by AmerenUE in the Breach Channel below the Breach Area. This information is also presented above in *Section 3.0*.

### 7.3 TEST BORING PROGRAM

A Test Boring Program has been undertaken with two primary objectives:

- Sampling and characterization of the material comprising the Rockfill Dike, including the interface zone near the bedrock.
- Sampling and characterization of the bedrock from rock core samples and in-hole testing.

The subsurface conditions of the Upper Reservoir Dike were explored by drilling seven (7) borings designated as TS-1 through TS-7. All borings were advanced to the top of the bedrock using a sonic drill rig. Please refer to **Section 7.1.3** for additional information regarding the sonic drilling technique. The locations of all seven borings are shown on the boring location plan presented on **Plate 7.1**. For specific details associated with the subsurface materials encountered at each boring, please refer to the boring logs provided in **Appendix D**. All of the borings have been drilled either from the crest or from access roads on the north and east sides of the Dike. Also shown on **Plate 7.1** are the areas where soil samples were obtained by hand at or below the ground surface. These samples were obtained in the Breach Area at locations designated by RIZZO field people.

### 7.4 DRILLING AND SAMPLING OF THE ROCKFILL DIKE

Miller Drilling Inc. of Lawrenceburg, Tennessee, was subcontracted to perform the drilling and sampling of the Rockfill Dike, basically above the bedrock interface. Miller was chosen for this work as they operate several Versa Sonic® Drill rigs. This type of rig advances a borehole with sound waves focused on the shoe of the drill bit. The sound waves destroy material that contacts the bit. Most importantly these rigs can advance a bore hole through rip rap and rock fill.

Additionally, sonic drills have the capability of obtaining a continuous sample over a ten foot run. This is accomplished by employing a hollow drill bit the same size as the drill rods being

used. Sonic rigs can sample 4 inch, or 6 inch diameter samples. When collecting 4 inch samples, the 4 inch drill stem is first advanced 10 feet; subsequently, an outer 6 inch drill stem is advanced over top of the 4 inch drill stem to keep the hole open; the 4 inch drill stem is withdrawn from the hole and the material inside the drill pipe is extruded out of the drill stem into a plastic bag or a bucket. Additional information about sonic drilling provided by Miller drilling is included below:

A sonic drill is a machine that uses high frequency mechanical oscillations developed in the special drill head to transmit resonant vibrations and rotary power through the drill tooling to the drill bit. These oscillations allow it to achieve exceptional drilling penetration rates without the need for drilling fluids or air to effectively take overburden core samples. This is accomplished by the oscillator's conversion of centrifugal force generated by counter rotating, chambered rollers to sinusoidal or longitudinal force. Frequencies in excess of 180 Hz (as previously mentioned) are generated. These frequencies match the natural frequency of the drill tooling, resulting in little or no dampening of the vibratory wavelength to the bit. Therefore, this sonic vibratory action fluidizes the soil particles, destroying the shear strength and pushing the particles away from the tip of the drill bit and along the sides of the drill string. This liquefaction process allows for clean, rapid and smooth penetration of overburden formations. This unique methodology allows the machine to perform overburden and even bedrock core sample drilling with speed, precision, and an absolute minimal amount of disturbance and compaction that cannot be accomplished by any other equipment.

One of the main advantages of the sonic technology is its superior ability to produce continuous core samples of both unconsolidated and consolidated formations with significant detail and accuracy. The core samples can be analyzed to provide a precise and detailed stratigraphic profile of any overburden condition including dry or wet/saturated sands and gravels, cobbles and boulders, clays, silts and hard tills. Recovery of a sample is consistently close to 100 percent.

The sonic method uses a dual line of drill pipe. The inner string of drill rods has the core barrel(s) attached. All overburden core sampling is done ahead of the outer string of drill casing with no fluid or air added to insure accurate, representative, undiluted samples. After the core barrel has been advanced, the outer drill casing is advanced to the same depth. This can best be

accomplished with water; however, dry casing advancement methods can also be employed and are done so often by Miller Drilling. With the outer casing left in place to hold the hole open, the core barrel is then removed from the borehole. The core sample can then be extracted into plastic sleeves, stainless steel sample trays, wooden core boxes or virtually any container. The outer drill casing ensures there is no sample contamination from uphole material by sealing it off prior to each sample run. When water use is permitted for casing advancement, it is by far the quickest and most effective means of combating heaving sands without the use of drilling mud or bentonite.

The outer casing also serves to hold the borehole open for installation of monitoring wells, piezometers, vents, observation wells, instrumentation or other downhole equipment. The outer drill casing has nominal diameters of 6 inches and 8 inches, allowing ample space to install 2 and 4 inch wells with a 1 inch or 1 ¼ inch tremie pipe to place sand packs, seals, slurries and grouts into the annular space between the well screen/riser and the outer casing and borehole annulus. The drill bits used on the outer drill casing are open and are 5 7/8 inch through 8 ½ inch diameter depending on borehole size requirements.

Drilling started on January 17, 2006, and is complete as far as the forensic investigation is concerned. Drilling and sampling is continuing to obtain information to evaluate the possibility of a re-build of the Upper Reservoir, including rock coring using conventional drilling.

In the first boring undertaken with the sonic drill, both 4 inch and 6 inch diameter samples were collected. The smaller 4 inch sample had poor recovery and it appears that the drill rods pushed the material aside rather than sampling it. Thereafter, it was decided to continue only with 6 inch sampling. This resulted in the collection of at least 20 percent of the theoretical maximum amount of material during the sampling of a 10 foot run. Very commonly, 40 percent of the material was collected. In the upper 20 feet of the Dike, where the material was compacted fill, often 60 to 80 percent of the material was collected.

Because of space limitation on the crest of the Dike as shown on *Figure 7-1*, the material was placed directly into buckets. *Figures 7-2 and 7-3* show the sample collection procedures utilized in the field. These samples were shipped to Geotechnics Laboratory in East Pittsburgh, PA for classification and additional testing as addressed below in *Section 7.1.6*



**FIGURE 7-1**

**SPACE LIMITATION ON THE CREST OF ROCK FILL DIKE**



**FIGURE 7- 2**

**SAMPLING ROCKFILL**



**FIGURE 7-3**

**TYPICAL ROCKFILL SAMPLE**

The rockfill material obtained from the borings generally consists of boulders, gravel, and sand with a small percentage of fine material (i.e., less than 10 percent).

**7.5 LABORATORY TESTING OF BREACH AREA SOILS AND DIKE MATERIAL**

Laboratory testing was performed on the soil samples that make up the Taum Sauk Dike and its foundation soils. The laboratory testing program is summarized in *Table 7-1*. Samples of the Dike material obtained during sonic drilling were placed in five gallon plastic buckets for shipment to the soils laboratory. Block samples of cohesive soil obtained by hand from the breach area were wrapped in cellophane and also placed in five gallon plastic buckets. Upon arrival at the laboratory, the samples were placed in large pans and photographed. These samples are designated as TS-Soil-01 to 04. In addition, two Shelby Tubes of foundation soil from the Breach Area were also obtained. These Shelby tubes were pushed by hand. Shelby tube samples are designated as TS-ST-01 and TS-ST-02.

**TABLE 7-1**

**LABORATORY TESTING SUMMARY**

TEST NAME	ASTM DESIGNATION	NUMBER OF SAMPLES
Sieve Analysis	D-422	74
Atterberg Limits	D-4318	33
Consolidated Undrained Triaxial Test with Pore Pressure Measurements (CU)	D-4767	3
Rock Density	-	1
Direct Shear Testing	D-3080	2
Water Content	D-2216	5
Flex-Wall Permeability (cohesive samples)	D-5084	2
Rigid Wall Permeability (gravel samples)	D-2434	3

The results from the sieve analyses and Atterberg Limits were used for classifying the samples in accordance with the Unified Soil Classification System (USCS). Classification information is used to identify material properties. Permeability test data has been used to confirm parameters used in seepage analyses in the forensic investigation. Triaxial and Direct Shear tests have been used to confirm estimates of shear strength parameters used for stability analyses. A density test result was used to confirm the estimated density value used in the forensic investigation. The results from the laboratory testing program are provided in *Appendix E*.

**7.5.1 Sieve Analysis Results**

The results from all of the grain size analyses completed at the publication of this report are provided in graphical form on *Figure 7-4*. These grain size curves are representative of rockfill samples that have been scalped of the material retained on a six inch sieve considering that the diameter of the borehole was six inches.

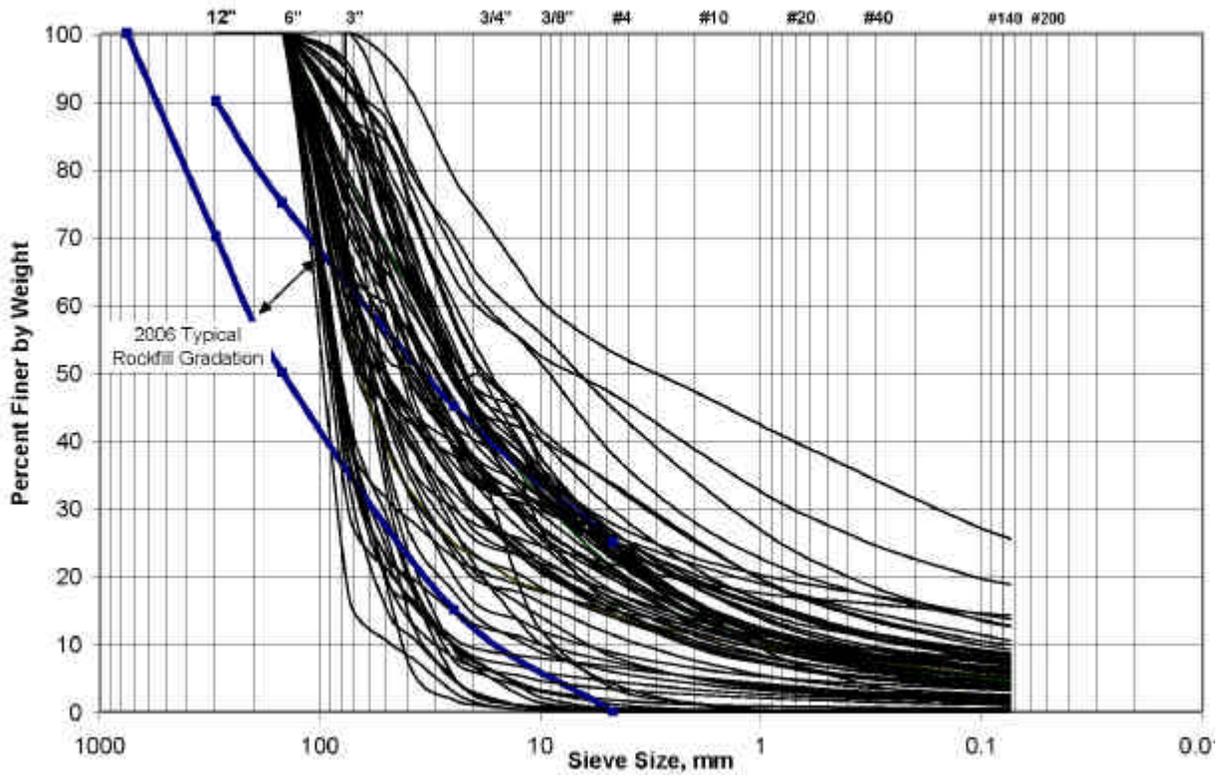
We have estimated the actual range of grain size curves of the rockfill by adjusting the upper and lower limits of the grain size curves shown in *Figure 7-4* by assuming that 10 to 30 percent of the rockfill would be retained on the 6 inch sieve. This assumption is consistent with typical

rockfill gradations. These results are provided on *Figure 7-5* along with gradation limits for typical 2006 rockfill specifications taken from the Saluda Dam Remediation project.

Our review of our best estimate rockfill grain size for the Taum Sauk Dam relative to typical modern rockfill gradation specifications shown on *Figure 7-5* is summarized below:

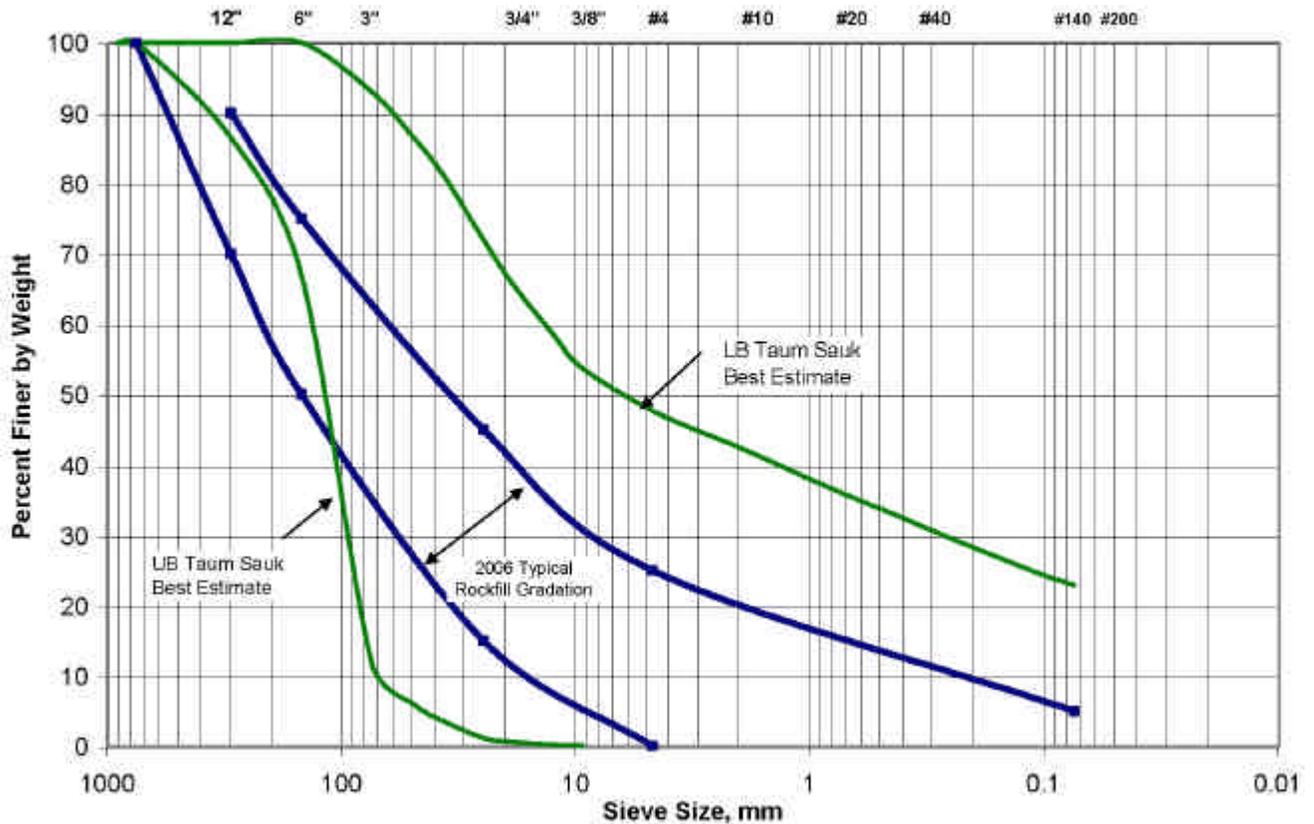
1. The material has a wider variation in gradation than a typical 2006 rockfill specification;
2. The material has a larger percentage of fines (up to 25% passing No. 200 sieve) than a typical 2006 rockfill specification (i.e., maximum 5%); and
3. The material is poorly graded with respect to a typical 2006 rockfill specification.

We also conclude that the fines content is not high everywhere in the Upper Reservoir Dike but it is definitely high (i.e., up to 25 percent) in some locations, due to the way the Dike was built. Current (2006) construction practices would include a grain size distribution specification and test methods to verify compliance. In the 1960's, only limited means were typically utilized to control actual grain size of the placed rockfill.



**FIGURE 7-4**

**ROCKFILL GRADATION  
(6" SCALPED)**



**FIGURE 7-5**

**BEST ESTIMATE OF ROCKFILL GRADATION**

**7.5.2 Atterberg Limits Results**

Atterberg limits have been performed on the fine (minus No. 40 sieve) portion of the dike material and foundation soils. The results are provided in *Appendix E*. The fine portion of the rockfill is classified as CL-ML; silty clay to clayey silt of low plasticity.

**7.5.3 Permeability Test Results**

As shown in *Table 7-2*, it appears that the measured permeability differs greatly from the permeability assumed in the SEEP2D (Boss International and Brigham Young University, 1999) Model (refer to Section 8.3). Recall that values assumed in the SEEP2D Model were back-calculated to match existing conditions. This can be explained by reviewing the original design drawings. In the original design, french drains are provided in the foundation soil layer at the

downstream toe of the Rockfill Dike to convey seepage. Also, in some sections of the Dike, filter beds are provided under the rockfill. Most of the seepage quantity flows in the in the french drains and drainage blankets. Therefore, the permeability of the foundation soil layer does not significantly influence the calibration of the seepage quantity in the SEEP2D program. The permeability of french drains and filter beds control the quantity of seepage exiting from the downstream toe.

A much closer correlation exists with respect to the measured and assumed permeability of the rockfill. The permeability value utilized in the SEEP2D model is based on the calibration of the model from measured seepage quantity. In the case of the HDPE (synthetic) lined rockfill, the permeability of the rockfill has a negligible influence on the overall flow net pattern of the rockfill dike.

**TABLE 7-2**  
**SUMMARY OF PERMEABILITY TEST RESULTS**

<b>BORING NO.</b>	<b>SAMPLE NO.</b>	<b>DEPTH (FT)</b>	<b>MATERIAL TYPE</b>	<b>PERMEABILITY (CM/SEC)</b>	<b>ASSUMED PERMEABILITY (CM/SEC)</b>
TS-ST-01	NA	0-2	Silty Clay	$1.30 \times 10^{-6}$	$1.60 \times 10^{-1}$
TS-ST-02	NA	0-2	Silty Clay	$3.80 \times 10^{-7}$	
TS-4	S1+S2A,B,C	0-20	Rockfill	$5.47 \times 10^{-1}$	$1.00 \times 10^{-2}$
TS-4	S3+S4A,B	20-40	Rockfill	$2.50 \times 10^{-1}$	
TS-4	S6+S7	50-70	Rockfill	$4.33 \times 10^{-1}$	

#### **7.5.4 Shear Strength Test Results**

Three consolidated undrained triaxial tests with pore pressure measurements (CU) were performed on undisturbed foundation soil samples. In addition, two drained direct shear (DS) tests were also performed. In the drained test on normally consolidated clay samples, the strength envelop passes through the origin (i.e. no cohesion). The Best Fit Data as reported by the laboratory is shown in *Table 7-3*. This data contains both cohesion (c) and angle of internal

friction ( $\phi$ ). These test results have been corrected for normally consolidated conditions by recalculating the failure envelope without cohesion.

**TABLE 7-3**  
**SUMMARY OF SHEAR STRENGTH TEST RESULTS**

BORING NO.	SAMPLE NO.	DEPTH (FT)	TEST TYPE	SHEAR STRENGTH PARAMETERS				ASSUMED FOR ANALYSIS
				BEST FIT DATA		PASSING THROUGH ORIGIN		
				c (psi)	$\phi$ (degrees)	c' (psi)	$\phi'$ (degrees)	
TS-ST-01	NA	0-2	CU	2.78	34.0	0	37	<u>Lower Bound</u> C' = 0 $\phi'$ = 30°
TS-Soil-02	S-3	12-19		6.58	29.6	0	38	
TS-Soil-03	S-2	7-15		4.2	30.2	0	33	<u>Best Estimate</u> C' = 0 $\phi'$ = 33°
TS-Soil-02	S-2	7-12	DS	7.58	21.3	0	28	<u>Upper Bound</u> C' = 0 $\phi'$ = 35°
TS-Soil-04	S-2	5-11		4.95	28.6	0	36	

The modified (effective friction) angles with cohesion equal to zero are shown in *Table 7-3*. These values vary from 28 to 38 degrees with an average value of 34 degrees. In the slope stability analyses, RIZZO assumed effective friction angles of 30 to 35 degrees with a best estimated value of 33 degrees. The best estimated value is based on the back calculation of incipient failure angle of an old slide at Taum Sauk site and found to be in a very close agreement with the laboratory measured value.