RECLAMATION

Managing Water in the West

Hydraulic Laboratory Technical Memorandum, PAP-1110

Erosion Tests and Index Properties of Soil Specimens from Paonia Reservoir

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Materials Engineering Research Laboratory
Denver, Colorado

July 2014

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Hydraulic Investigations and Laboratory Services, 86-846000

Technical Memorandum PAP-1110

Erosion Tests and Index Properties of Soil Specimens from Paonia Reservoir

Digitally signed by TONY WAHL
DN: c=US, o=U.S. Government, ou=Department of the Interior, ou=Bureau of Reclamation, cn=TONY WAHL, 0.9.2342.19200300.100.1.1=14001000107789
Date: 2014.10.31 14:36:20 -06'00'

Prepared: Tony L. Wahl, P.E. Date
Hydraulic Engineer, Hydraulic Investigations and Laboratory Services, 86-846000

ROBERT EINHELLIG

Digitally signed by ROBERT EINHELLIG
DN: c=US, o=U.S. Government, ou=Department of the Interior, ou=Bureau of Reclamation, cn=ROBERT EINHELLIG, 0.9.2342.19200300.100.1.1=14001000107692
Date: 2014.10.31 15:04:18 -06'00'

Technical Approval: Robert F. Einhellig, P.E. Date
Manager, Hydraulic Investigations and Laboratory Services, 86-846000

Digitally signed by ROBERT RINEHART
DN: c=US, o=U.S. Government, ou=Department of the Interior, ou=Bureau of Reclamation, cn=ROBERT RINEHART, 0.9.2342.19200300.100.1.1=14001001522728
Date: 2014.11.01 10:46:27 -06'00'

Peer Review: Robert Rinehart, Ph.D., P.E. Date
Civil Engineer, Materials Engineering Research Laboratory, 86-818000

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Materials Engineering Research Laboratory
Denver, Colorado

July 2014

Introduction

Erosion and index properties tests were performed in May and June 2014 on soil samples obtained in June 2013 from depositional zones within Paonia Reservoir. Index properties tests were performed in the Denver soil mechanics laboratory by the Materials Engineering Research Laboratory (MERL) group. Submerged jet erosion tests (JET) were performed in the hydraulics laboratory using a jet test apparatus constructed by Reclamation in accordance with ASTM D-5852, *Standard Test Method for Erodibility Determination of Soil in the Field or in the Laboratory by the Jet Index Method*. More details of the test apparatus and its use are given in Wahl et al. (2008).

The submerged jet test simulates scour of a soil surface due to a perpendicular impinging jet. The test is typically run with a constant jet pressure. The jet is positioned over the soil surface of interest, and the initial elevation of the jet and the jet pressure are selected to apply a desired shear stress to the soil specimen. The depth of scour beneath the jet is measured over time and is used to estimate the critical shear stress needed to initiate erosion and the detachment rate coefficient relating the rate of erosion to the applied stress in excess of the critical value. Procedures for analyzing the test data have been improved since the publication of ASTM D-5852; the data from these tests were analyzed using the methods described in Hanson and Cook (2004). Recently, other analysis procedures have also been proposed (Daley, et al. 2013). The analysis is based on a volumetric form of the excess stress erosion model:

$$\dot{\varepsilon} = k_d\left(\tau - \tau_c\right)$$

where $\dot{\varepsilon}$ is the volume of material removed per unit surface area per unit time ($m^3/s/m^2$, or m/s), k_d is a detachment rate coefficient, τ is the applied stress (N/m^2=Pa), and τ_c is the critical shear stress (N/m^2=Pa). Typical units for k_d are $m^3/s/m^2/Pa$ which reduces to m/s/Pa or $m^3/(N \cdot s)$ in S.I. units; k_d is also commonly reported in $cm^3/(N \cdot s)$, or when working in U.S. customary units, k_d is usually expressed in ft/hr/psf [1 $cm^3/(N \cdot s)$ = 0.5655 ft/hr/psf = 10^{-6} $m^3/(N \cdot s)$].

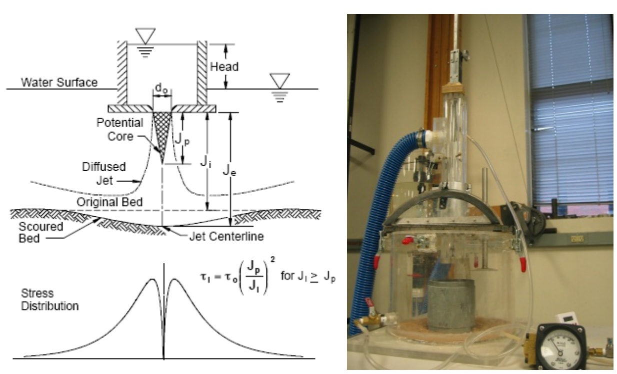


Figure 1. — Jet test schematic diagram and photo of laboratory test apparatus.

Testing

Soil specimens were obtained from the field in June 2013 by vibracore sampling and were stored until May 2014 in the 70% humidity storage facility of the MERL. The erosion specimens were contained in 3-inch diameter acrylic tubes. A few days before testing, identified sections of the specimens were cut for testing into 4- to 4.5-inch long segments using a band saw. The upper portion of each specimen was tagged so that jet erosion tests could be conducted on the top surface of each specimen, set in the original, natural orientation. A soil sample was collected from the tube segment immediately above the jet test specimen. Care was taken to limit the extent of the soil sampling to ensure that collected material was similar in character to that observed at the top end of each jet test specimen.

Erosion Testing

The jet pressure and initial nozzle distance above the specimen determine the initial hydraulic stress applied to the specimen. As the test proceeds, the applied stress at the erosion interface reduces as the scour hole deepens. The initial stress is often set based on the expected range of stresses that will be applied to the soil in the application of interest. In this case, initial observation of the specimens suggested that their erodibility would be high, so in order to keep erosion rates to a manageable level during the test, the initial jet distance was maximized (about 3.00 to 3.75 inches depending on soil specimen height) and the jet pressure was minimized (about 1 ft of head=0.43 lb/in^2) within the practical physical limits of the test facility. The initial shear stress for most tests was about 0.1 lb/ft^2 or 5 Pa. All water used for erosion testing was obtained from the tap water system in the hydraulics laboratory. This water originates from the Denver municipal water system. Water temperature at the time of the tests was about 16.5°C (62°F).

Table 1 lists the soil specimens and their approximate depth below ground surface. Each specimen was tested with the jet applied to the top surface of the specimen. The table also reports the soil type, plasticity index, and clay content for each specimen.

Jet erosion tests were performed during late May and early June 2014. Scour depths were recorded at relatively short intervals at the beginning of each test, typically 5 to 30 seconds depending on the initially observed erosion, and at increasing intervals as the tests continued. Most of the soil specimens were completely eroded during the tests, and tests of the most erodible specimens were completed with total exposure times of about 30 seconds to 2 minutes. Tests of the more erosion resistant soils typically lasted for 30 to 60 minutes. Figure 2 shows the pre-test condition of two soil samples. Figure 3 provides some post-test photographs.

Table 1. — Soil specimens for jet erosion testing.

Drill Hole	Sample Depth, ft	USCS soil classification	Liquid Limit (LL)	Plasticity Index (PI)	% clay*
1-DC-1	0.5' - 1.0'	SC – Sandy Clay	24	8	16
1-DC-1B	0.5' - 1.0'	SC – Sandy Clay	29	14	21
1-RC-1A	0.5' - 1.0'	CL – Lean Clay	32	15	15
1-RC-1A	2.5' - 3.0'	SM – Silty Sand	NV**	NP***	3
1-RC-1A	4.0' - 4.5'	s(ML) – Sandy Silt	NV	NP	5
4-RC-1	0.5' - 1.0'	CH – Fat Clay	52	29	33
4-RC-1	1.5' - 2.0'	SP-SM – Poorly Graded Sand with Silt	NV	NP	2
4-RC-1	3.0' - 3.5'	CL – Lean Clay	43	18	16
7-RC-1A	0.5' - 1.0'	CL – Lean Clay	35	17	14
7-RC-1A	2.0' - 2.5'	CL – Lean Clay	38	19	15
7-RC-1A	3.0' - 3.5'	SP-SM – Poorly Graded Sand with Silt	NV	NP	2
7-RC-1A	4.0' - 4.5'	CL – Lean Clay	33	11	10
7-RC-1B	1.0' - 1.5'	SM – Silty Sand	NV	NP	3
7-RC-1B	2.0' - 2.5'	s(ML) – Sandy Silt	24	3	6
7-RC-1B	3.5' - 4.0'	CL – Lean Clay	35	13	9
7-RC-1B	4.5' - 5.0'	SM – Silty Sand	NV	NP	4

* clay particles are defined here to be smaller than 0.002 mm.
** NV = no value
*** NP = non-plastic

Jet test results are plotted in Figure 4, along with lines that indicate erodibility categories proposed by Hanson and Simon (2001). These classifications were established to span the range of erodibilities observed in a study of natural cohesive streambed deposits in loess areas of eastern Nebraska, western Iowa, and northern Mississippi. They also represent typical ranges of erodibility measured in compacted soils used in civil engineering infrastructure, such as dams and levees (Wahl et al. 2008; Hanson et al. 2010). Five erodibility classes are recognized from the work of Hanson and Simon (2001): very resistant, resistant, moderately resistant, erodible, and very erodible.

Figure 4 shows that all of the tested specimens are in the very erodible category, with a few plotting near the edge of the erodible category. If a sixth erodibility category were to be defined and named ‘extremely erodible’, ten of the sixteen samples would probably be considered extremely erodible and six would remain very erodible.

For comparison, dotted vertical lines and labels at the bottom of the chart in Figure 4 show the critical shear stress values that would be expected for cohesionless soil particles of specific sizes, applying Shield’s criteria for incipient motion with a critical Shield’s parameter value of 0.047. In the jet test results the specimens with little or no plasticity (SP-SM, SM, and ML soil types) exhibited critical shear values that were comparable to fine sand or silt-size particles, and this is consistent with the makeup of these soils, most of which were predominantly sand with significant silt fractions. In contrast, most of the soils with significant plasticity (SC, CL, and CH soil types) exhibited critical shear stress values that were one to two orders of magnitude greater than would be expected for their predominant particle size (silt for most cases). This effectively illustrates the influence of cohesion in fine-grained soils.

Figure 2. — Representative jet test specimens from Paonia Reservoir, prior to testing. Specimens like the sandy soil at top were usually completely eroded to the bottom of the tube in less than 1 to 2 minutes.

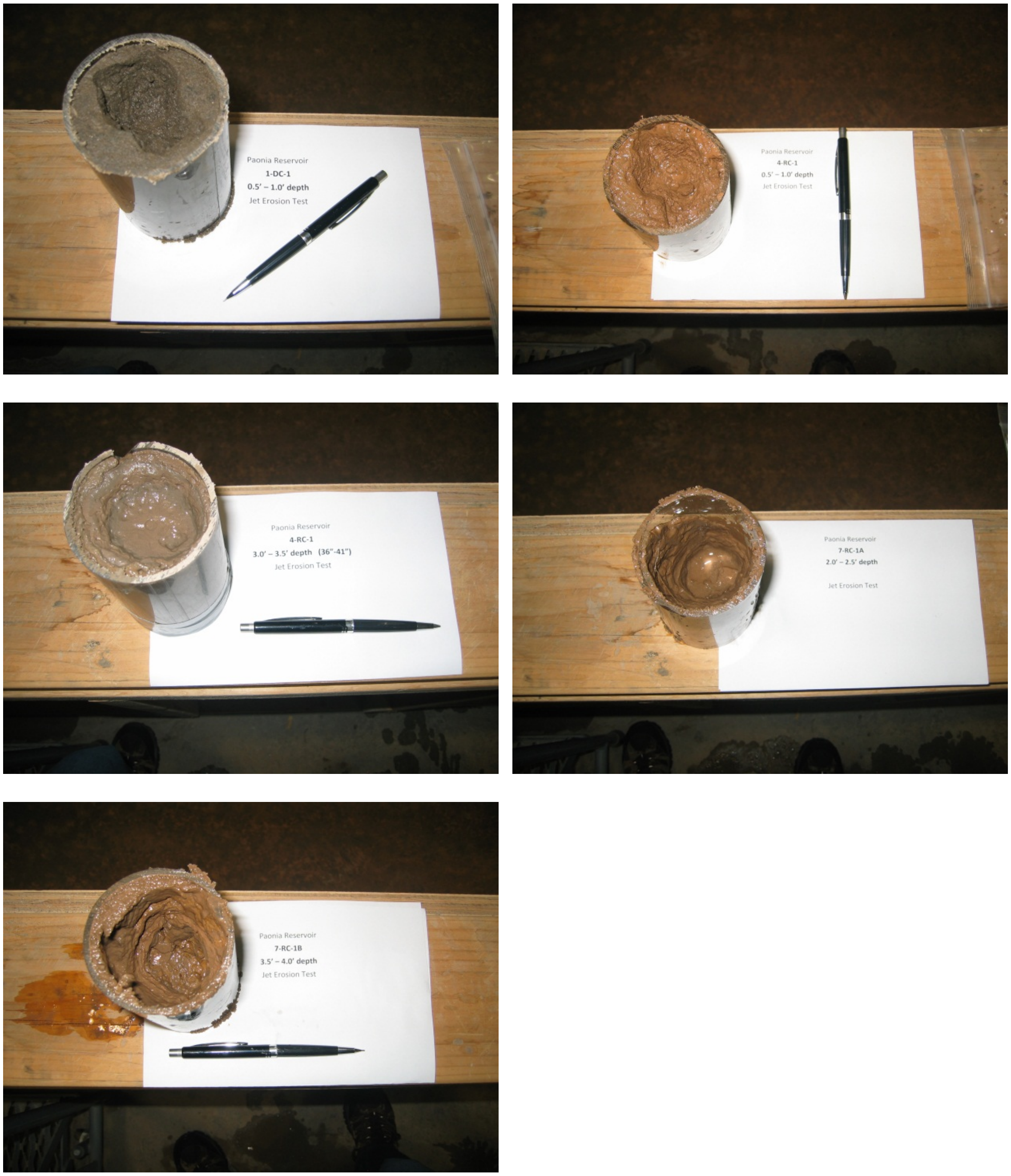


Figure 3. — Post-test photographs of jet test specimens that exhibited some erosion resistance. Most of these specimens were tested for about 30 – 60 minutes.

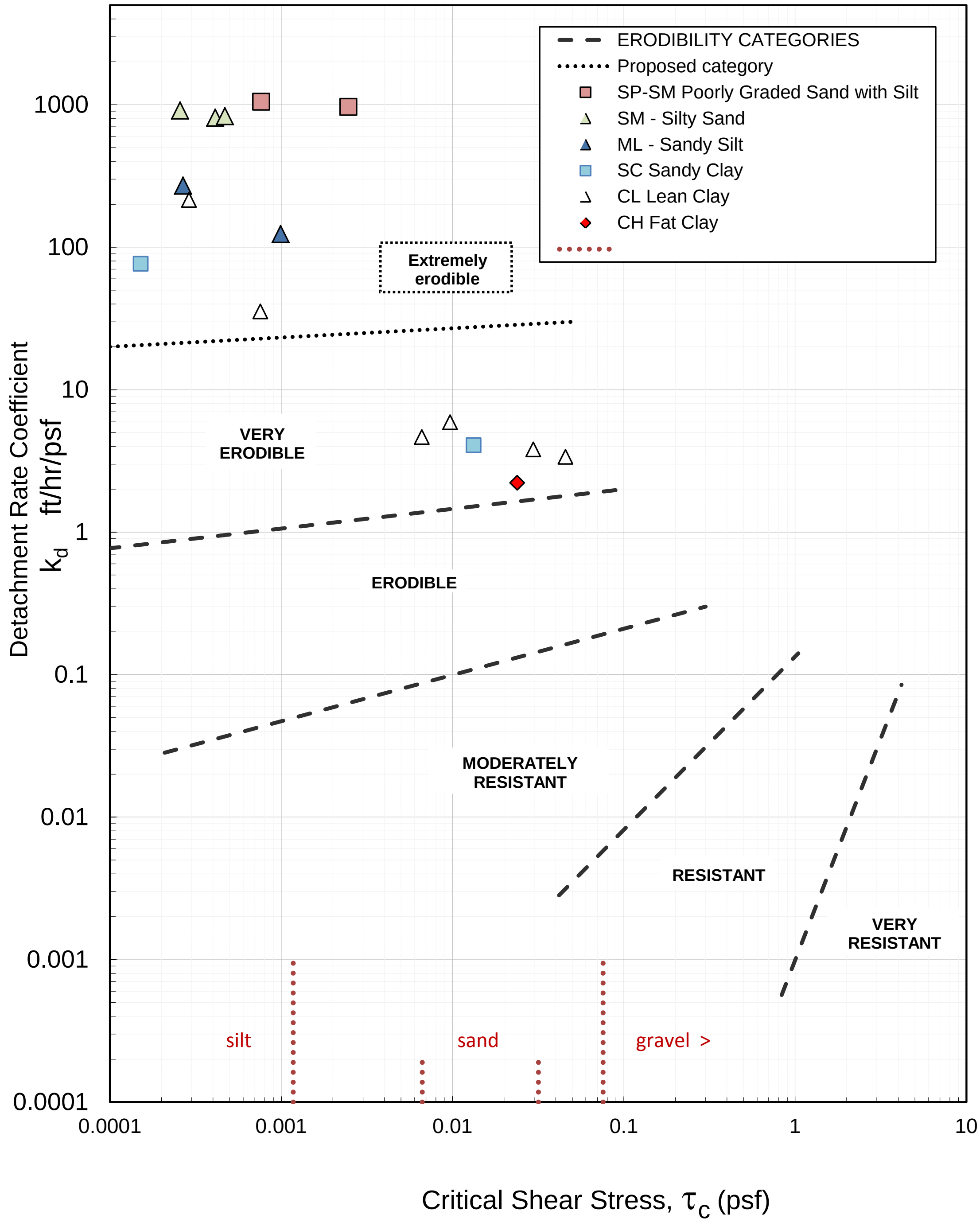


Figure 4. — JET erosion test results. Erodibility classifications are those proposed by Hanson and Simon (2001). Dotted vertical lines and labels indicate expected critical shear stresses calculated using the Shield’s parameter for cohesionless particles of the indicated size classes; the silt/clay boundary would plot at 0.00003 psf. Unit conversions: 1 $cm^3/(N\text{-}s)$ = 0.5655 ft/hr/psf; 1 Pa = 0.0209 psf.

Figure 5 shows relations between plasticity index, clay particle content, and detachment rate coefficient. The detachment rate coefficient is inversely related to both the plasticity index and clay content, and the latter are strongly correlated as expected.

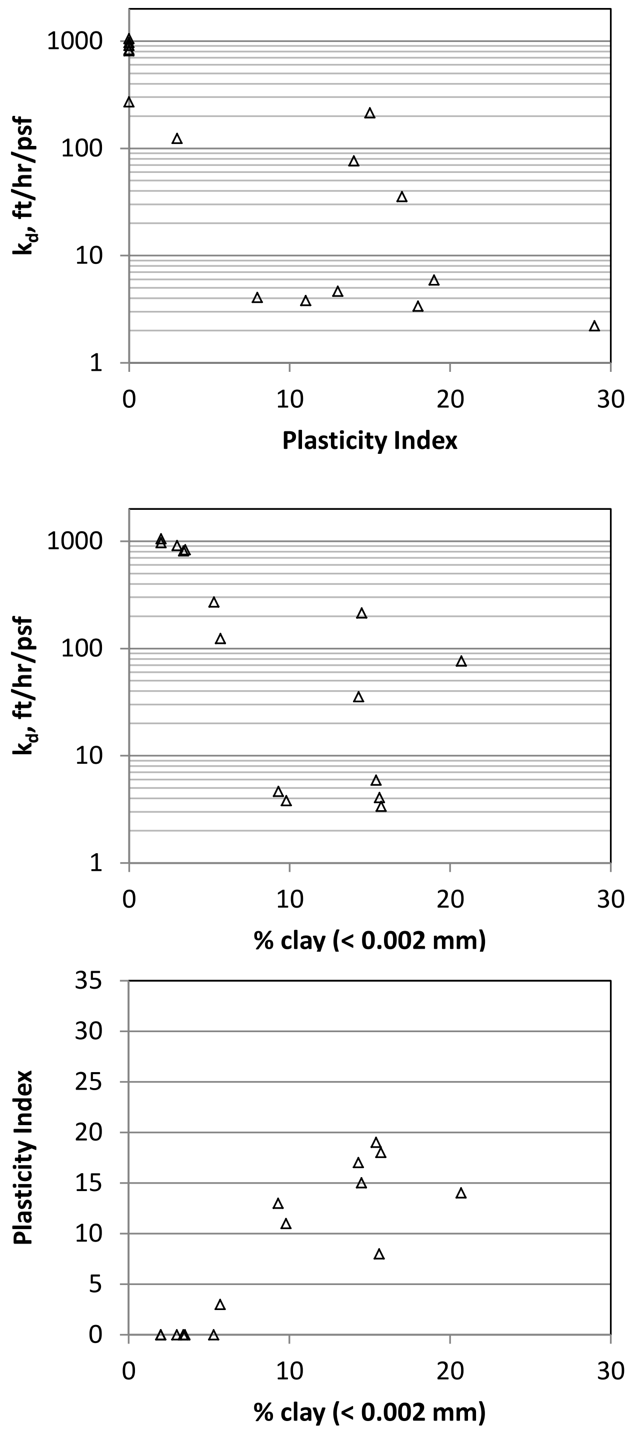


Figure 5. — Relations between plasticity index, clay particle content, and detachment rate coefficient.

Summary

Sixteen soil specimens obtained from Paonia Reservoir were analyzed in the Materials Engineering Research Laboratory to determine soil gradation, Atterberg limits (plasticity properties), and soil type using the Unified Soil Classification System (USCS). For samples with sufficient material to conduct the tests, specific gravity was also determined. Detailed results of these tests are provided in the Appendix.

Submerged jet erosion tests were performed in the hydraulics laboratory on accompanying specimens cut from the 3-inch diameter sample tubes. Erodibility results were strongly related to the soil classifications. Seven specimens with little or no plasticity (SP-SM, SM, or ML soil types) were extremely erodible, while nine specimens of clayey soils with plasticity indices of 8 or more (SC, CL, and CH soil types) were generally more erosion resistant and exhibited more variation of erosion resistance, although all were still considered very erodible to extremely erodible. Numerical values of critical shear stress for the low and no-plasticity specimens were typical of what would be expected for cohesionless soils based on particle size, while critical shear stress values for the clayey soil specimens were about one to two orders of magnitude greater than would be calculated for cohesionless particles of their size. This demonstrates the significant effect of cohesion on erodibility of fine-grained soils.

References

ASTM, 2007. Standard D-5852. Standard test method for erodibility determination of soil in the field or in the laboratory by the jet index method. *Annual Book of ASTM Standards*, Section 4: Construction, Vol. 04.08. Philadelphia, Penn.: American Society for Testing and Materials.

Bureau of Reclamation, *Earth Manual*, Part 2, 3rd Edition, Denver, CO, 1990.

Daley, E.R., G.A. Fox, A.T. Al-Madhhachi, and R.B. Miller, 2013. A scour depth approach for deriving erodibility parameters from jet erosion tests. *Transactions of the ASABE*, 56(6): 1343-1351 ISSN 2151-0032 DOI 10.13031/trans.56.10350

Hanson, G.J., and Simon, A., 2001. Erodibility of cohesive streambeds in the loess area of the midwestern USA. *Hydrological Processes*, Vol. 15, pp. 23-38.

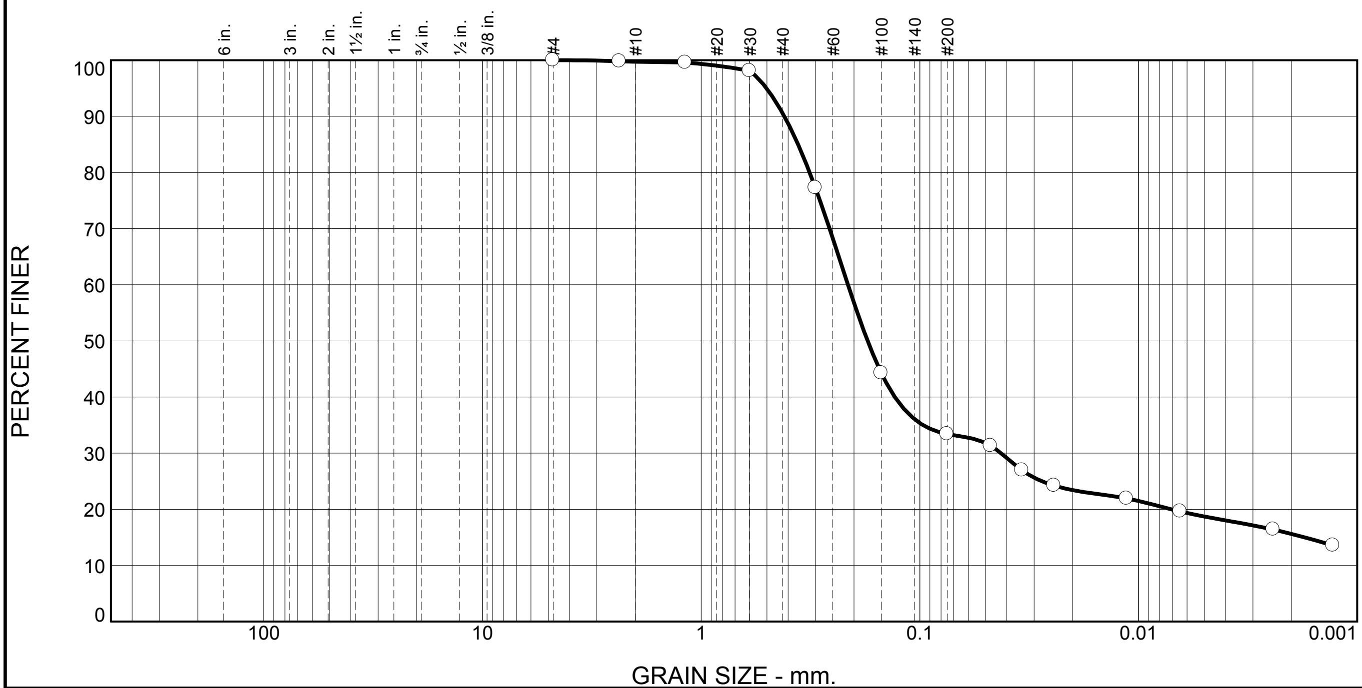
Hanson, G.J., and Cook, K.R., 2004. Apparatus, test procedures, and analytical methods to measure soil erodibility in situ. *Applied Engineering in Agriculture*, 20(4):455-462.

Hanson, G.J., T.L. Wahl, D.M. Temple, S.L. Hunt, and R.D. Tejral, 2010. Erodibility characteristics of embankment materials. In: *Dam Safety 2010*. Proceedings of the Association of State Dam Safety Officials Annual Conference, September 19-23, 2010, Seattle, WA. (CDROM).

Wahl, Tony L**.**, Regazzoni, Pierre-Louis, and Erdogan, Zeynep, 2008. *Determining Erosion Indices of Cohesive Soils with the Hole Erosion Test and Jet Erosion Test*, Dam Safety Technology Development Report DSO-08-05, U.S. Dept. of the Interior, Bureau of Reclamation, Denver, Colorado, 45 pp. http://www.usbr.gov/pmts/hydraulics_lab/pubs/DSO/DSO-08-05.pdf

Appendix – Soil Testing Reports

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.3	9.1	57.2	17.8	15.6

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	99.8		
#16	99.6		
#30	98.1		
#50	77.2		
#100	44.3		
#200	33.4		
0.0475 mm.	31.3		
0.0340 mm.	26.9		
0.0243 mm.	24.2		
0.0113 mm.	21.9		
0.0064 mm.	19.6		
0.0024 mm.	16.4		
0.0013 mm.	13.6		

* (no specification provided)

Material Description

Clayey sand

Atterberg Limits (ASTM D 4318)

PL= 16 **LL=** 24 **PI=** 8

Classification

USCS (D 2487)= SC **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 0.4164 D_{85}= 0.3605 D_{60}= 0.2131
D_{50}= 0.1732 D_{30}= 0.0425 D_{15}= 0.0017
D_{10}= C_u= C_c=

Remarks

No reaction with HCl

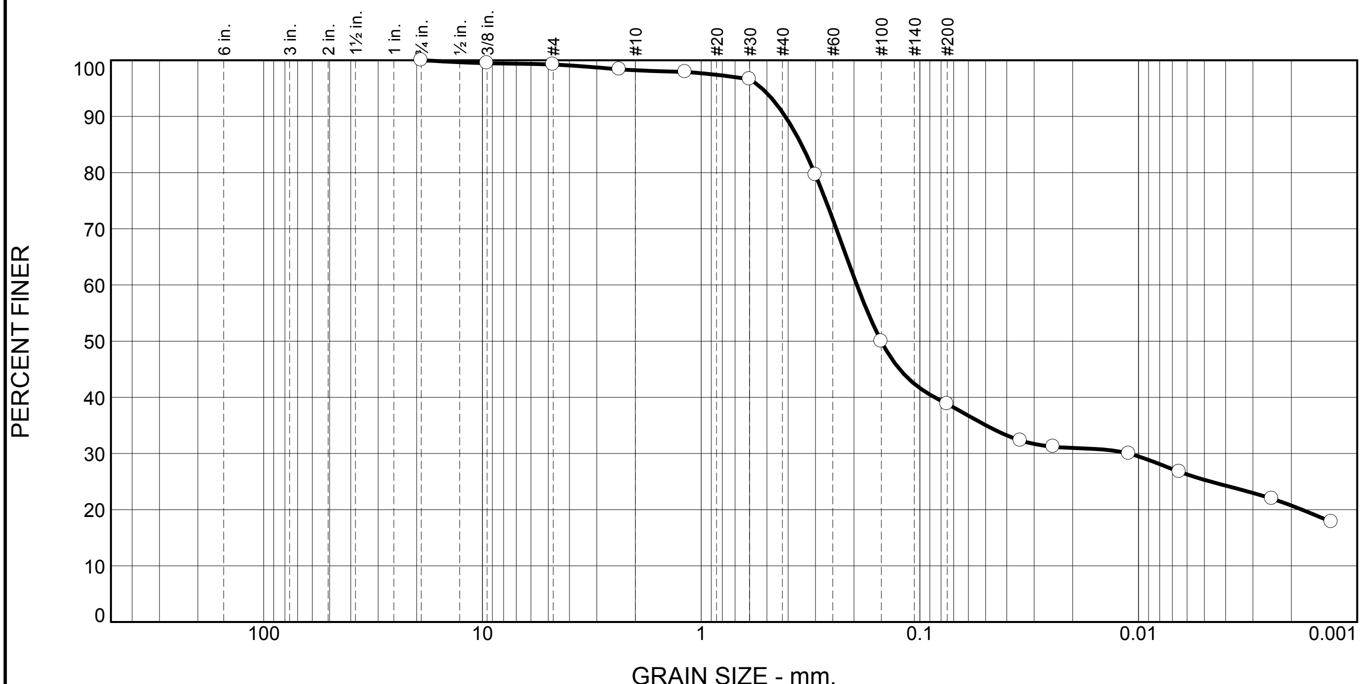
Date Received: **Date Tested:** 6/12/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 3-7 inches **Date Sampled:**
Sample Number: 28C-38 (1-DC-1)

BUREAU OF RECLAMATION

Client:
Project: PAONIA
Project No: 28C **Figure** 1

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.8	1.0	7.4	52.0	18.1	20.7

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/4	100.0		
3/8	99.5		
#4	99.2		
#8	98.4		
#16	97.9		
#30	96.6		
#50	79.6		
#100	49.9		
#200	38.8		
0.0346 mm.	32.3		
0.0245 mm.	31.2		
0.0111 mm.	30.0		
0.0065 mm.	26.7		
0.0025 mm.	22.0		
0.0013 mm.	17.8		

* (no specification provided)

Material Description

Clayey sand

Atterberg Limits (ASTM D 4318)

PL= 15 **LL=** 29 **PI=** 14

Classification

USCS (D 2487)= SC **AASHTO (M 145)=** A-6(2)

Coefficients

D_{90}= 0.4122 D_{85}= 0.3476 D_{60}= 0.1940
D_{50}= 0.1502 D_{30}= 0.0111 D_{15}=
D_{10}= C_u= C_c=

Remarks

Plus #4 Material: No reaction with HCl
Minus #4 Material: No reaction with HCl
Specific Gravity = 2.56

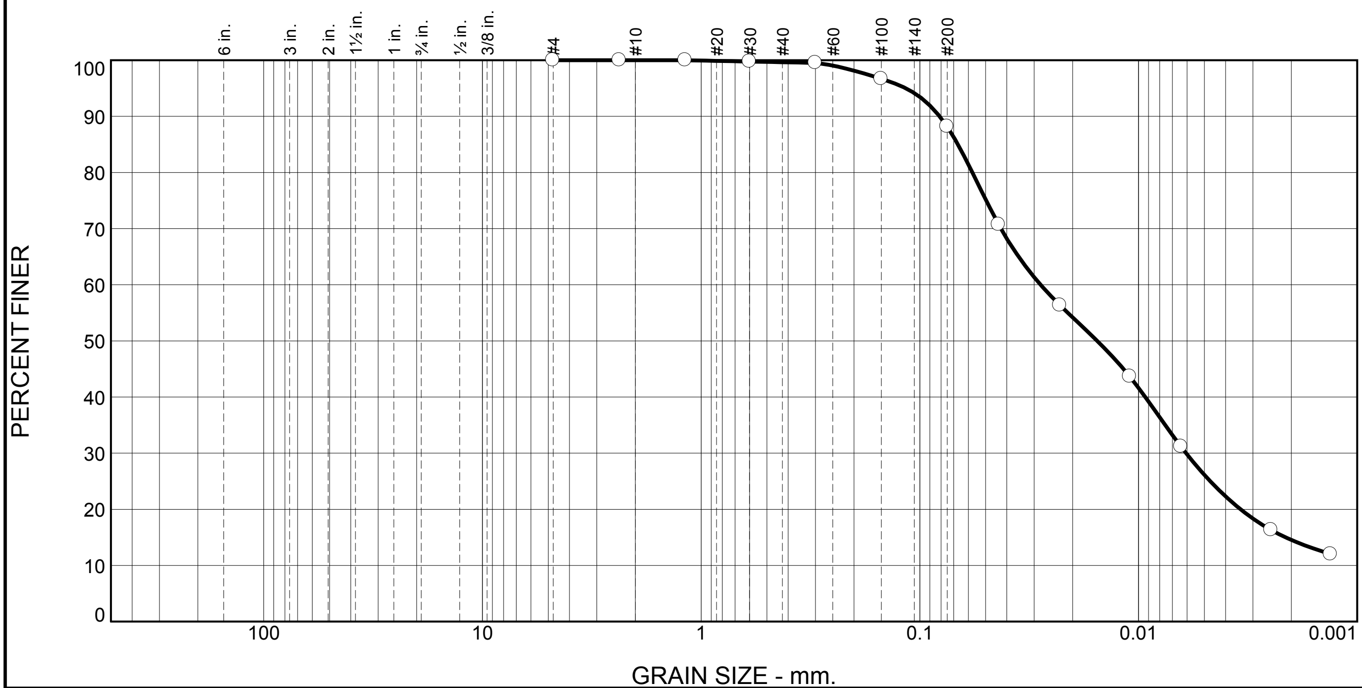
Date Received: **Date Tested:** 6/12/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 0-5 inches **Date Sampled:**
Sample Number: 28C-39 (1-DC-1B)

BUREAU OF RECLAMATION

Client:
Project: PAONIA
Project No: 28C **Figure** 2

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.4	11.4	73.7	14.5

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	100.0		
#30	99.8		
#50	99.5		
#100	96.7		
#200	88.2		
0.0436 mm.	70.7		
0.0228 mm.	56.3		
0.0110 mm.	43.6		
0.0064 mm.	31.2		
0.0025 mm.	16.3		
0.0013 mm.	12.0		

* (no specification provided)

Material Description

Lean clay

Atterberg Limits (ASTM D 4318)

PL= 17 **LL=** 32 **PI=** 15

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-6(12)

Coefficients

D_{90}= 0.0811 D_{85}= 0.0670 D_{60}= 0.0280
D_{50}= 0.0155 D_{30}= 0.0061 D_{15}= 0.0021
D_{10}= C_u= C_c=

Remarks

Strong reaction with HCl
Specific Gravity = 2.59

Date Received: **Date Tested:** 6/12/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

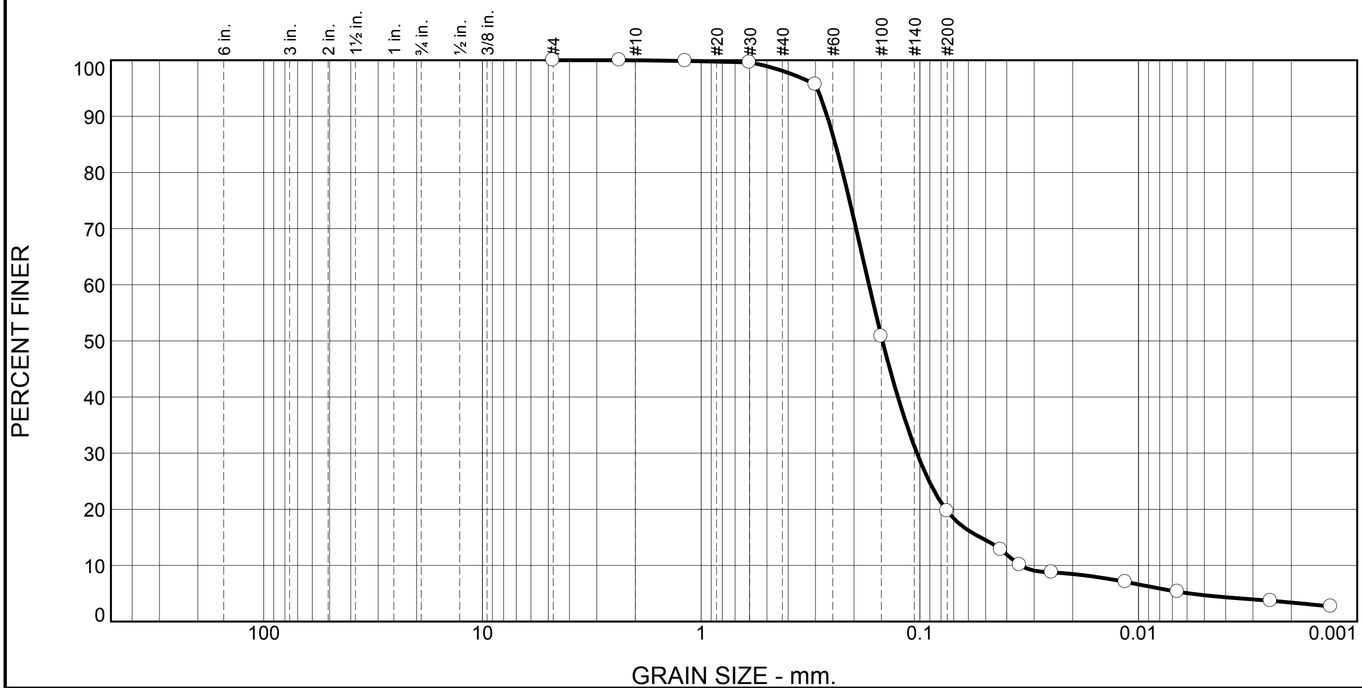
Source of Sample: PAONIA DAM **Depth:** 8-13 inches **Date Sampled:**
Sample Number: 28C-40 (1-RC-1A)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 3

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	1.9	78.4	16.3	3.4

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	99.9		
#30	99.6		
#50	95.7		
#100	50.8		
#200	19.7		
0.0426 mm.	12.8		
0.0350 mm.	10.1		
0.0249 mm.	8.8		
0.0115 mm.	7.1		
0.0066 mm.	5.3		
0.0025 mm.	3.7		
0.0013 mm.	2.7		

* (no specification provided)

Material Description

Silty sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 0.2649 D_{85}= 0.2431 D_{60}= 0.1708
D_{50}= 0.1482 D_{30}= 0.1031 D_{15}= 0.0527
D_{10}= 0.0346 C_u= 4.94 C_c= 1.80

Remarks

Strong reaction with HCl

Date Received: **Date Tested:** 6/12/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

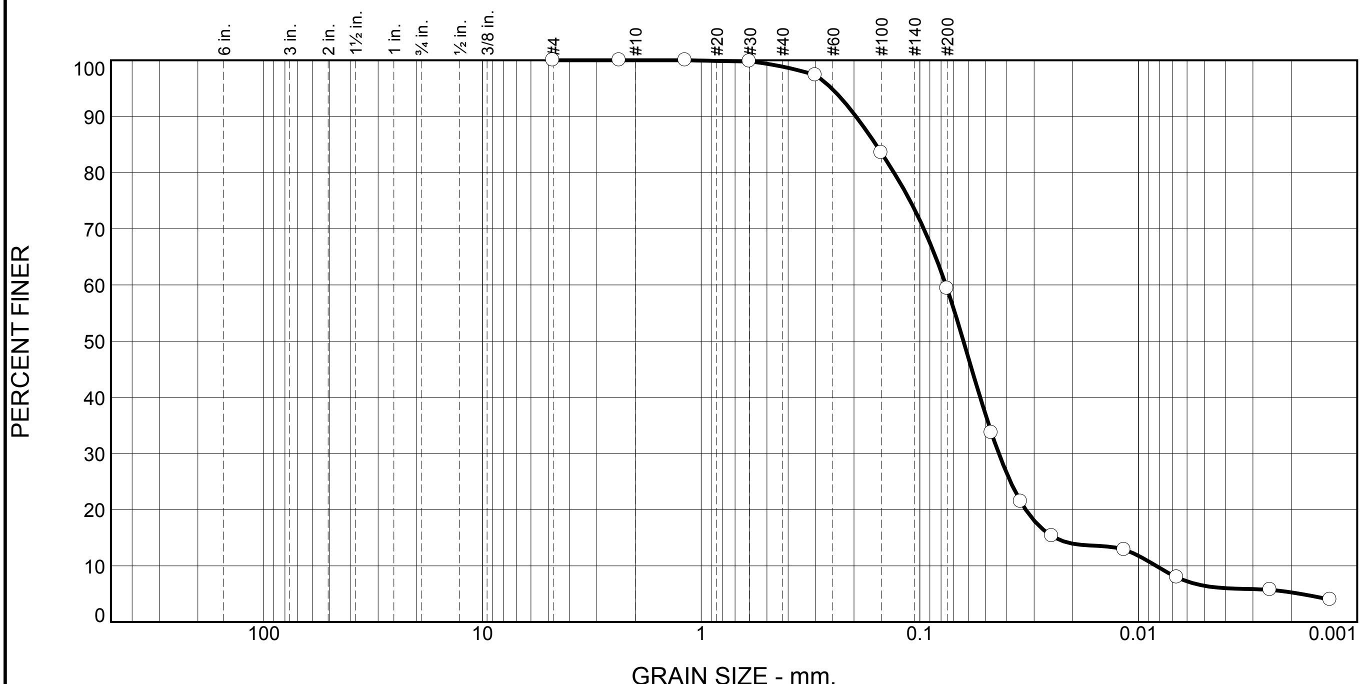
Source of Sample: PAONIA DAM **Depth:** 33-38 inches **Date Sampled:**
Sample Number: 28C-41 (1-RC-1A)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 4

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	1.1	39.6	54.0	5.3

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	100.0		
#30	99.8		
#50	97.4		
#100	83.5		
#200	59.3		
0.0470 mm.	33.7		
0.0346 mm.	21.4		
0.0249 mm.	15.3		
0.0116 mm.	12.9		
0.0067 mm.	8.0		
0.0025 mm.	5.7		
0.0013 mm.	4.0		

* (no specification provided)

Material Description

Sandy silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= ML **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 0.1959 D_{85}= 0.1589 D_{60}= 0.0760
D_{50}= 0.0631 D_{30}= 0.0435 D_{15}= 0.0240
D_{10}= 0.0083 C_u= 9.15 C_c= 3.00

Remarks

Strong reaction with HCl
Specific Gravity=2.63

Date Received: **Date Tested:** 6/12/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

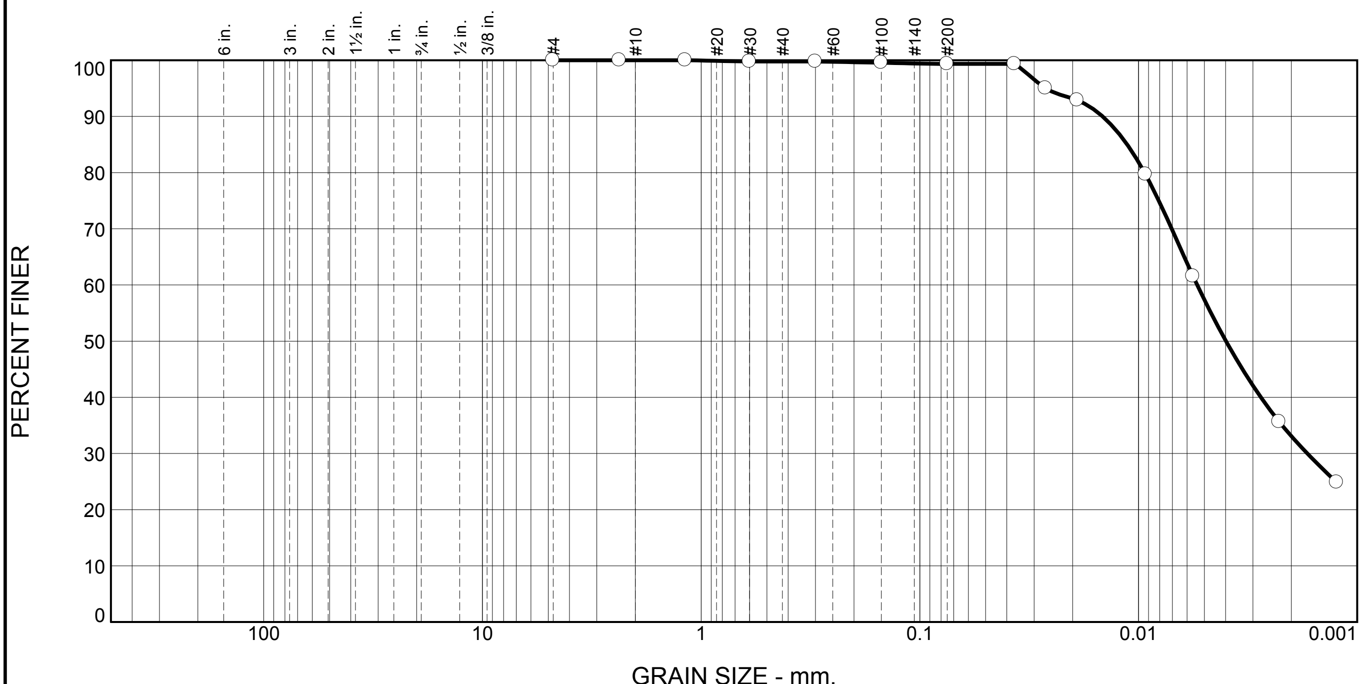
Source of Sample: PAONIA DAM **Depth:** 48-53 inches **Date Sampled:**
Sample Number: 28C-42 (1-RC-1A)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 5

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.2	0.4	66.3	33.1

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	100.0		
#30	99.8		
#50	99.8		
#100	99.6		
#200	99.4		
0.0369 mm.	99.4		
0.0266 mm.	95.0		
0.0190 mm.	92.9		
0.0093 mm.	79.7		
0.0056 mm.	61.6		
0.0023 mm.	35.6		
0.0012 mm.	24.8		

* (no specification provided)

Material Description

Fat clay

Atterberg Limits (ASTM D 4318)

PL= 23 **LL=** 52 **PI=** 29

Classification

USCS (D 2487)= CH **AASHTO (M 145)=** A-7-6(33)

Coefficients

D_{90}= 0.0146 D_{85}= 0.0113 D_{60}= 0.0054
D_{50}= 0.0040 D_{30}= 0.0017 D_{15}=
D_{10}= C_u= C_c=

Remarks

Strong reaction with HCl

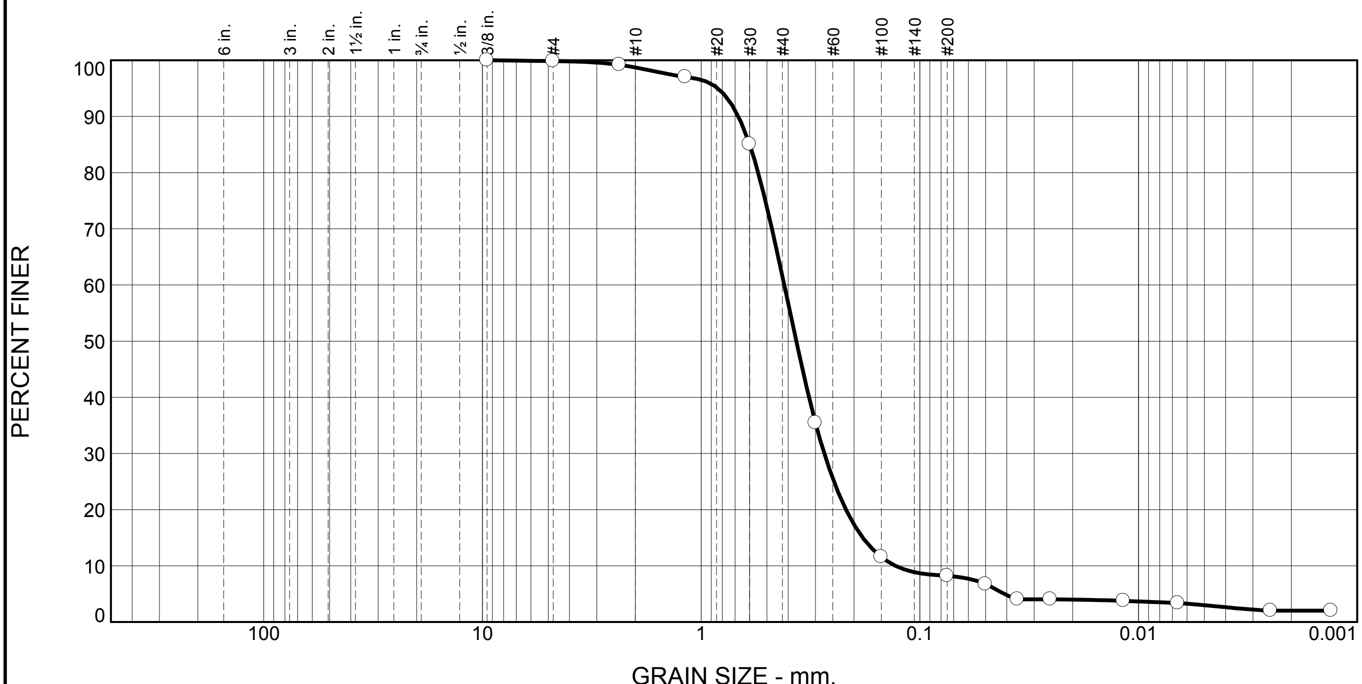
Date Received: **Date Tested:** 6/18/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 6-11 inches **Date Sampled:**
Sample Number: 28C-43 (4-RC-1)

BUREAU OF RECLAMATION

Client:
Project: PAONIA
Project No: 28C **Figure** 6

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.2	1.1	37.2	53.3	6.2	2.0

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8	100.0		
#4	99.8		
#8	99.2		
#16	97.0		
#30	85.0		
#50	35.4		
#100	11.6		
#200	8.2		
0.0500 mm.	6.7		
0.0357 mm.	4.0		
0.0253 mm.	4.0		
0.0117 mm.	3.8		
0.0066 mm.	3.4		
0.0025 mm.	2.0		
0.0013 mm.	2.0		

* (no specification provided)

Material Description

Poorly graded sand with silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-3

Coefficients

D_{90}= 0.6755 D_{85}= 0.5997 D_{60}= 0.4168
D_{50}= 0.3672 D_{30}= 0.2735 D_{15}= 0.1822
D_{10}= 0.1291 C_u= 3.23 C_c= 1.39

Remarks

Plus #4 Material: No reaction with HCl
Minus #4 Material: Strong reaction with HCL

Date Received: **Date Tested:** 6/18/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

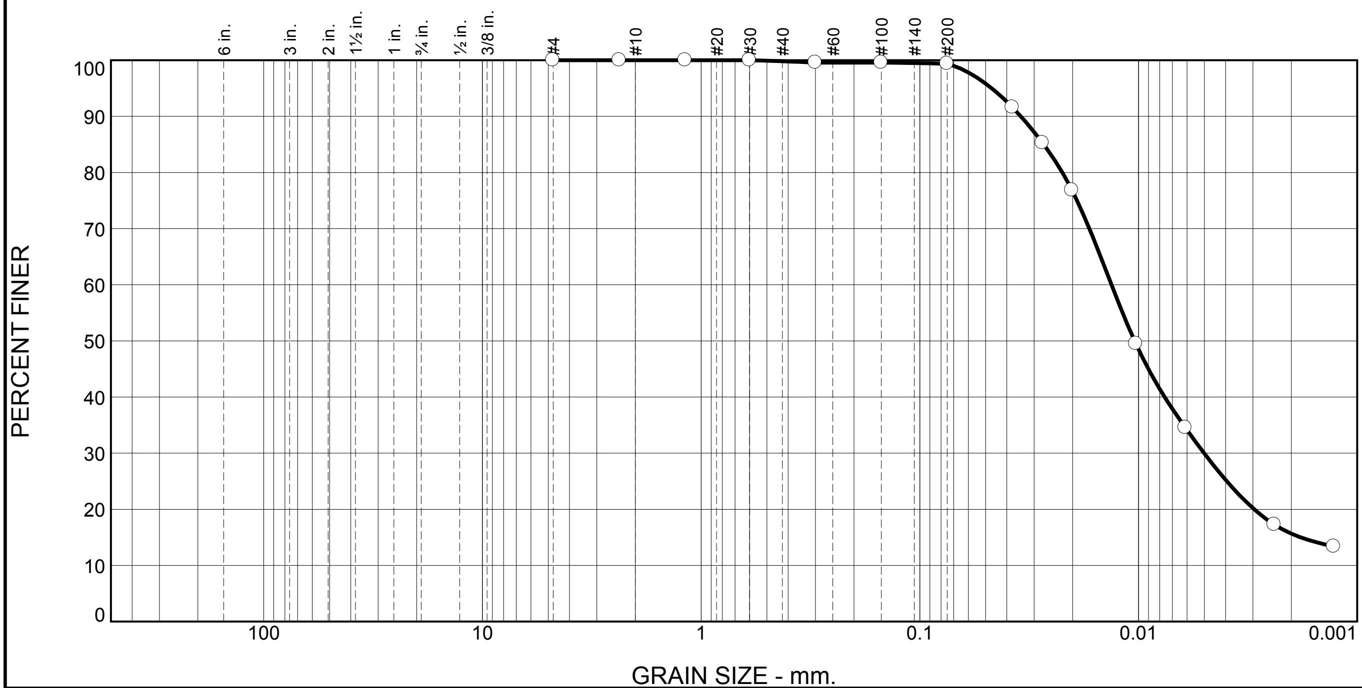
Source of Sample: PAONIA DAM **Depth:** 17-22 inches **Date Sampled:**
Sample Number: 28C-44 (4-RC-1)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 7

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.2	0.4	83.7	15.7

TEST RESULTS			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	100.0		
#30	100.0		
#50	99.6		
#100	99.6		
#200	99.4		
0.0377 mm.	91.6		
0.0275 mm.	85.3		
0.0201 mm.	76.8		
0.0103 mm.	49.5		
0.0061 mm.	34.5		
0.0024 mm.	17.3		
0.0013 mm.	13.4		

* (no specification provided)

Material Description

Lean clay

Atterberg Limits (ASTM D 4318)

PL= 25 **LL=** 43 **PI=** 18

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-7-6(20)

Coefficients

D_{90}= 0.0345 D_{85}= 0.0272 D_{60}= 0.0133
D_{50}= 0.0104 D_{30}= 0.0050 D_{15}= 0.0018
D_{10}= C_u= C_c=

Remarks

Strong reaction with HCl

Date Received: **Date Tested:** 6/18/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

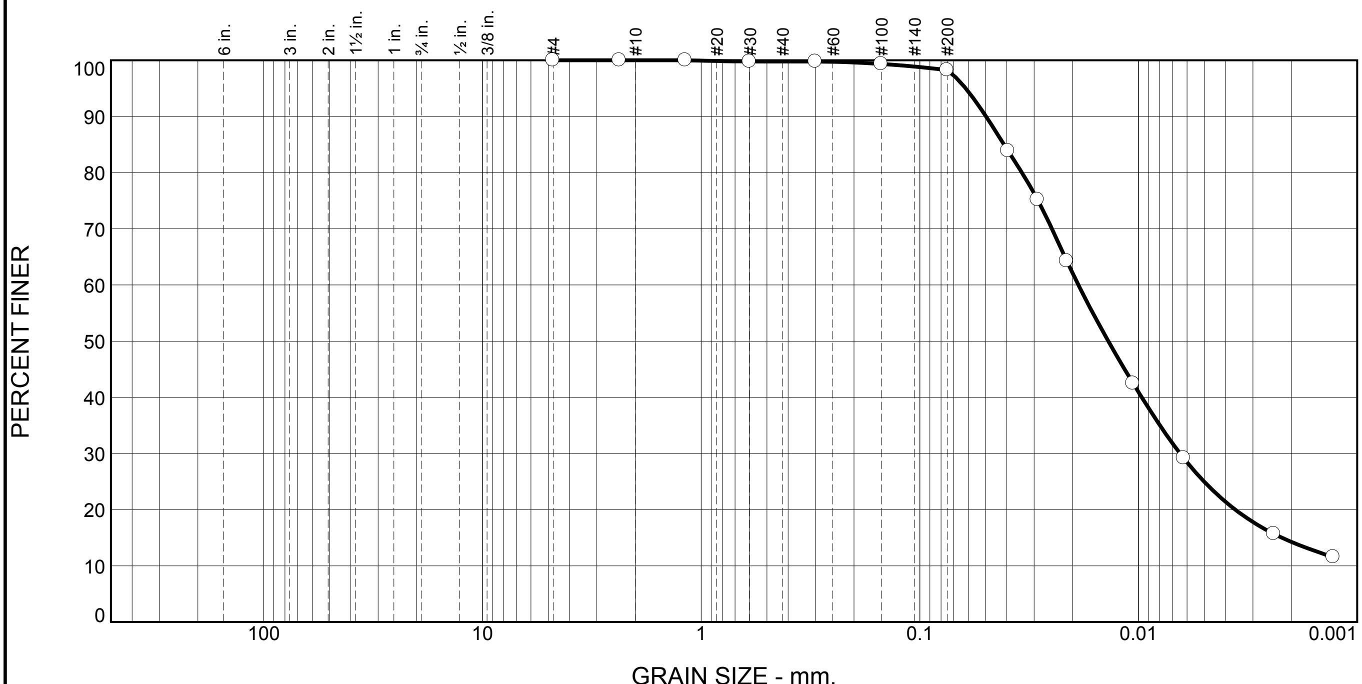
Source of Sample: PAONIA DAM **Depth:** 36-41 inches **Date Sampled:**
Sample Number: 28C-45 (4-RC-1)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 8

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.2	1.5	84.0	14.3

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	100.0		
#30	99.8		
#50	99.8		
#100	99.3		
#200	98.3		
0.0395 mm.	83.9		
0.0289 mm.	75.2		
0.0213 mm.	64.3		
0.0106 mm.	42.5		
0.0062 mm.	29.2		
0.0024 mm.	15.7		
0.0013 mm.	11.5		

* (no specification provided)

Material Description

Lean clay

Atterberg Limits (ASTM D 4318)

PL= 18 **LL=** 35 **PI=** 17

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-6(17)

Coefficients

D_{90}= 0.0498 D_{85}= 0.0412 D_{60}= 0.0188
D_{50}= 0.0137 D_{30}= 0.0065 D_{15}= 0.0022
D_{10}= C_u= C_c=

Remarks

Strong reaction with HCl

Date Received: **Date Tested:** 6/18/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

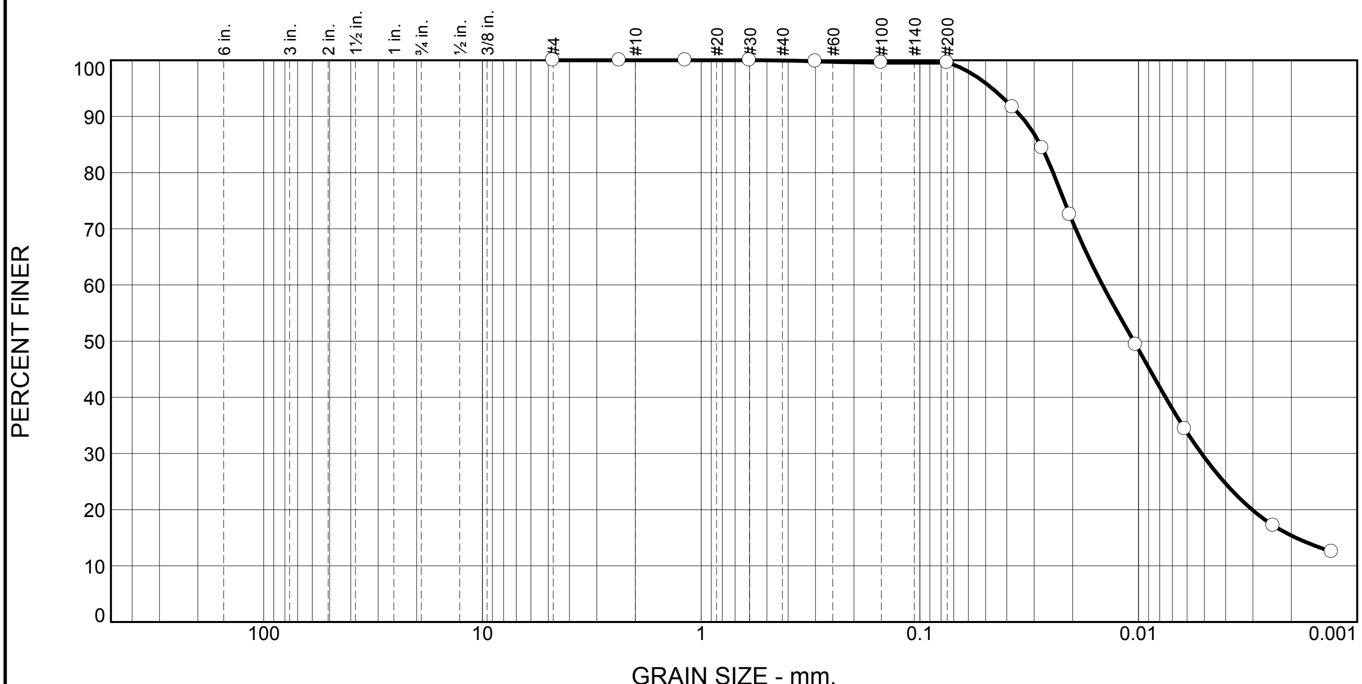
Source of Sample: PAONIA DAM **Depth:** 6-11 inches **Date Sampled:**
Sample Number: 28C-46 (7-RC-1A)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 9

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.0	0.4	84.2	15.4

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	100.0		
#30	100.0		
#50	99.8		
#100	99.6		
#200	99.6		
0.0377 mm.	91.7		
0.0276 mm.	84.4		
0.0206 mm.	72.5		
0.0103 mm.	49.4		
0.0061 mm.	34.4		
0.0024 mm.	17.2		
0.0013 mm.	12.5		

* (no specification provided)

Material Description

Lean clay

Atterberg Limits (ASTM D 4318)

PL= 19 **LL=** 38 **PI=** 19

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-6(20)

Coefficients

D_{90}= 0.0344 D_{85}= 0.0281 D_{60}= 0.0146
D_{50}= 0.0105 D_{30}= 0.0052 D_{15}= 0.0019
D_{10}= C_u= C_c=

Remarks

Strong reaction with HCl

Date Received: **Date Tested:** 6/18/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

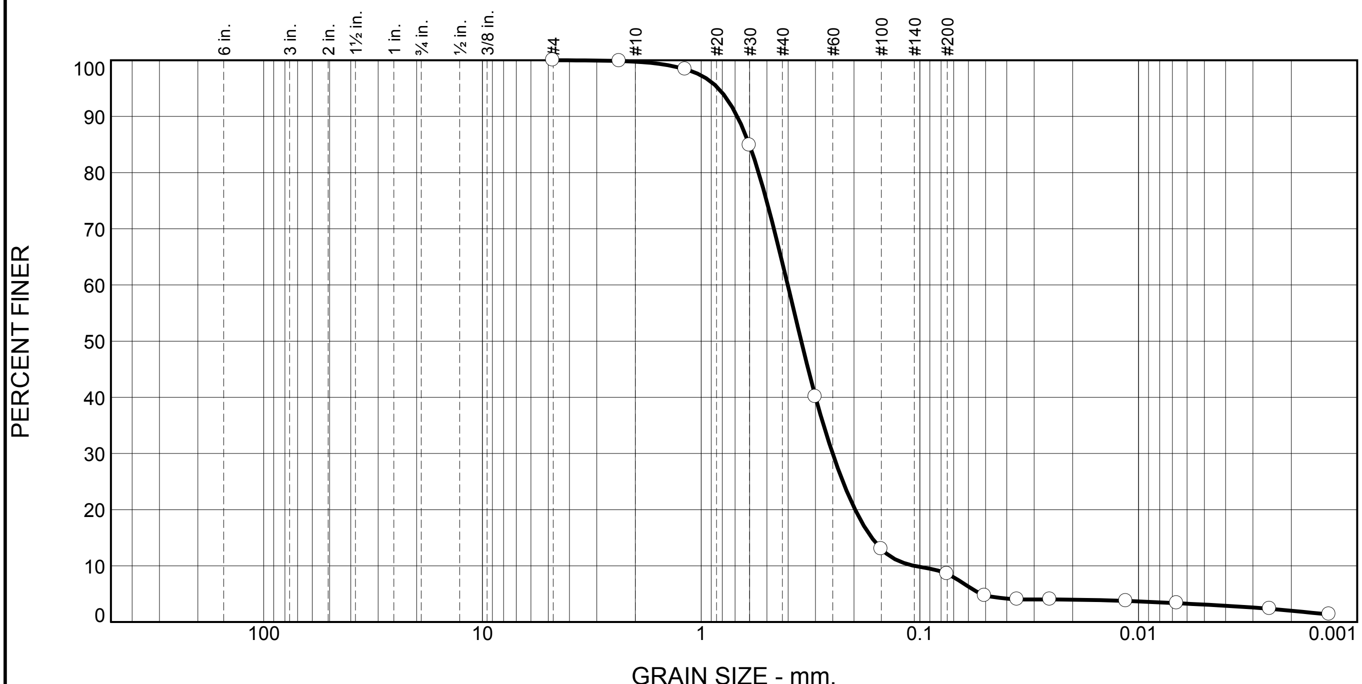
Source of Sample: PAONIA DAM **Depth:** 2-2.5 feet **Date Sampled:**
Sample Number: 28C-47 (7-RC-1A)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 10

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.2	35.9	55.3	6.6	2.0

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	99.9		
#16	98.4		
#30	84.9		
#50	40.1		
#100	13.0		
#200	8.6		
0.0504 mm.	4.7		
0.0358 mm.	4.0		
0.0254 mm.	4.0		
0.0114 mm.	3.8		
0.0067 mm.	3.4		
0.0025 mm.	2.3		
0.0013 mm.	1.3		

* (no specification provided)

Material Description

Poorly graded sand with silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-3

Coefficients

D_{90}= 0.6831 D_{85}= 0.6019 D_{60}= 0.4019
D_{50}= 0.3486 D_{30}= 0.2505 D_{15}= 0.1659
D_{10}= 0.1057 C_u= 3.80 C_c= 1.48

Remarks

Strong reaction with HCl

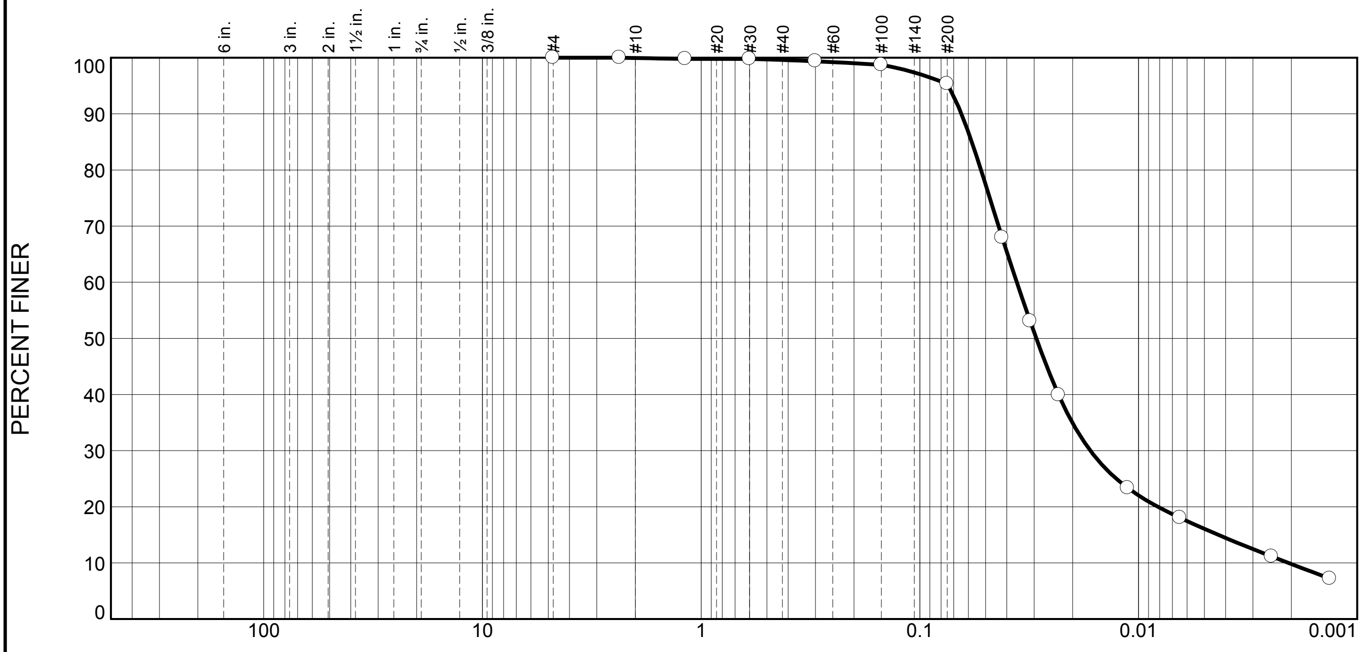
Date Received: **Date Tested:** 6/18/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 3-3.5 feet **Date Sampled:**
Sample Number: 28C-48 (7-RC-1A)

BUREAU OF RECLAMATION

Client:
Project: PAONIA
Project No: 28C **Figure** 11

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.4	4.3	85.5	9.8

TEST RESULTS			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	99.8		
#30	99.8		
#50	99.4		
#100	98.7		
#200	95.3		
0.0420 mm.	67.9		
0.0313 mm.	53.1		
0.0232 mm.	39.9		
0.0112 mm.	23.4		
0.0065 mm.	18.0		
0.0025 mm.	11.1		
0.0013 mm.	7.2		

* (no specification provided)

Material Description

Lean clay

Atterberg Limits (ASTM D 4318)

PL= 22 **LL=** 33 **PI=** 11

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-6(11)

Coefficients

D_{90}= 0.0646 D_{85}= 0.0579 D_{60}= 0.0360
D_{50}= 0.0293 D_{30}= 0.0166 D_{15}= 0.0043
D_{10}= 0.0021 C_u= 17.48 C_c= 3.71

Remarks

Strong reaction with HCl

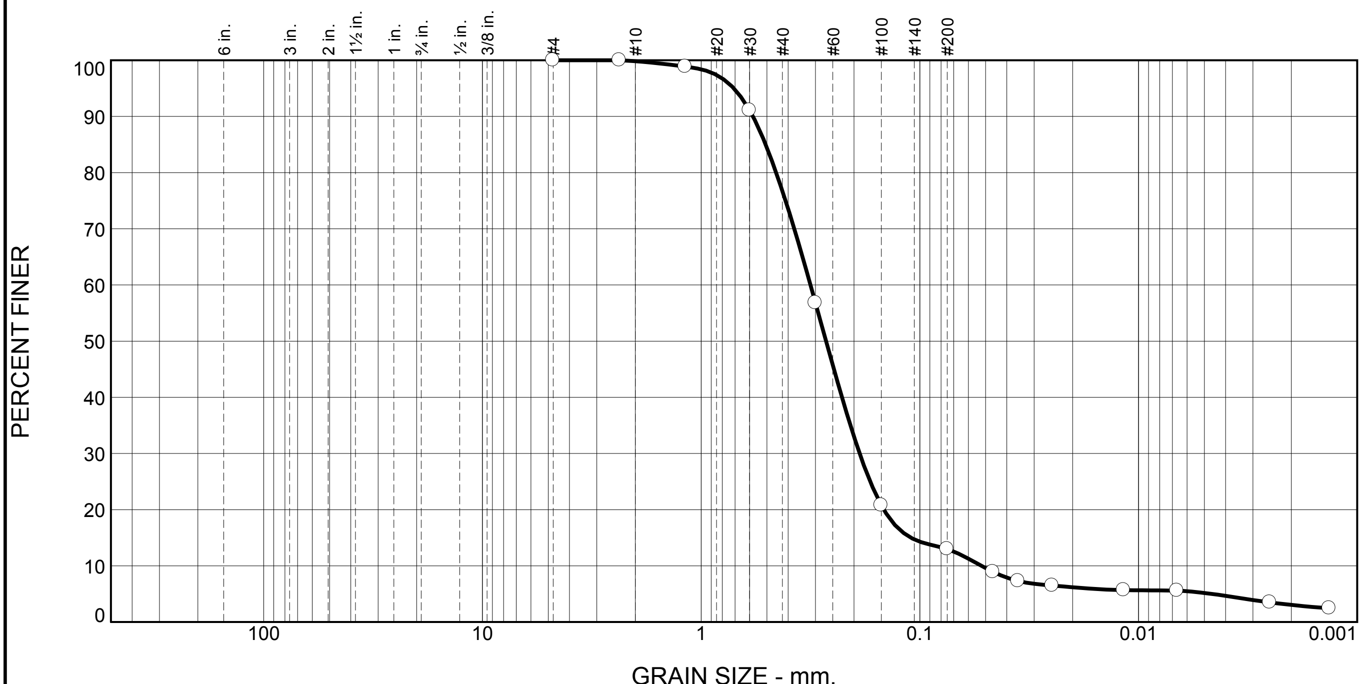
Date Received: **Date Tested:** 6/19/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 4-4.5 feet **Date Sampled:**
Sample Number: 28C-49 (7-RC-1A)

BUREAU OF RECLAMATION

Client:
Project: PAONIA
Project No: 28C **Figure** 12

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.2	23.1	63.7	10.0	3.0

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	98.9		
#30	91.1		
#50	56.8		
#100	20.8		
#200	13.0		
0.0462 mm.	8.9		
0.0355 mm.	7.3		
0.0248 mm.	6.5		
0.0117 mm.	5.7		
0.0067 mm.	5.6		
0.0025 mm.	3.5		
0.0013 mm.	2.4		

* (no specification provided)

Material Description

Silty sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 0.5797 D_{85}= 0.5069 D_{60}= 0.3162
D_{50}= 0.2683 D_{30}= 0.1884 D_{15}= 0.1099
D_{10}= 0.0522 C_u= 6.05 C_c= 2.15

Remarks

Strong reaction with HCl

Date Received: **Date Tested:** 6/19/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

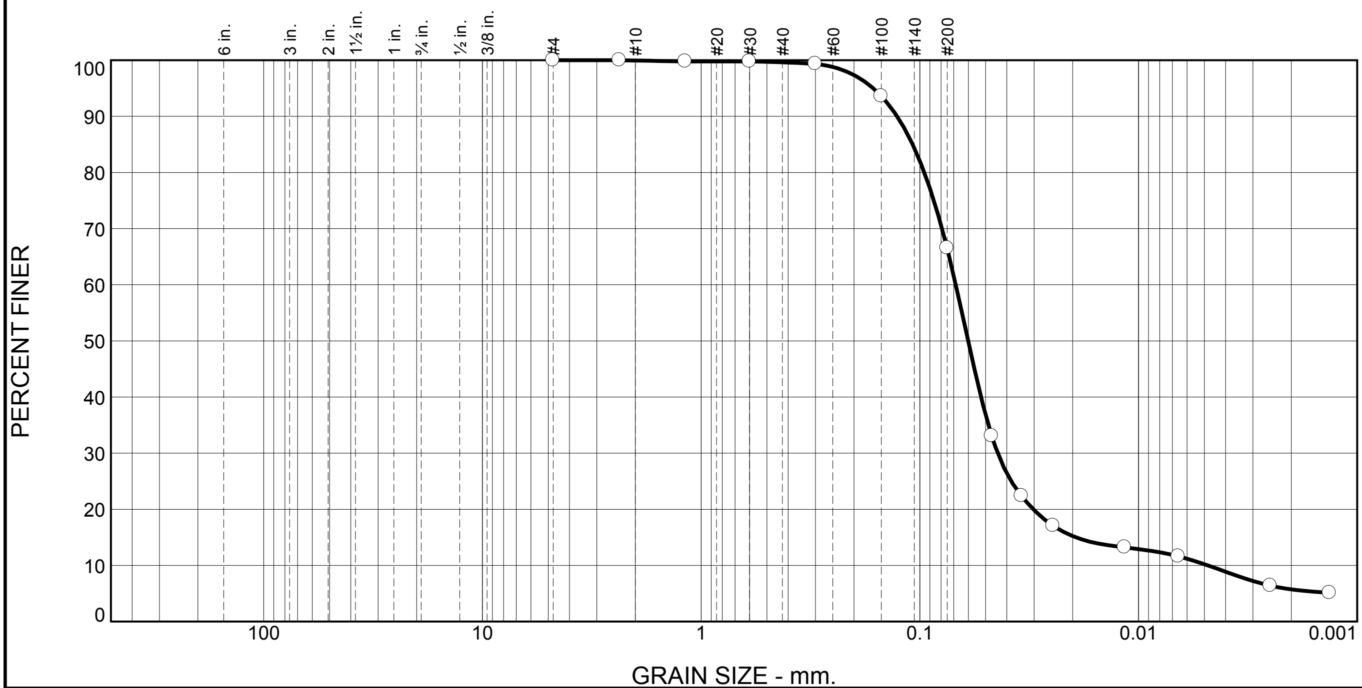
Source of Sample: PAONIA DAM **Depth:** 1-1.5 feet **Date Sampled:**
Sample Number: 28C-50 (7-RC-1B)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 13

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.4	33.1	60.8	5.7

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	99.8		
#30	99.8		
#50	99.4		
#100	93.6		
#200	66.5		
0.0469 mm.	33.0		
0.0343 mm.	22.4		
0.0246 mm.	17.1		
0.0116 mm.	13.2		
0.0066 mm.	11.6		
0.0025 mm.	6.4		
0.0013 mm.	5.1		

* (no specification provided)

Material Description

Sandy silt

Atterberg Limits (ASTM D 4318)

PL= 21 **LL=** 24 **PI=** 3

Classification

USCS (D 2487)= ML **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 0.1270 D_{85}= 0.1079 D_{60}= 0.0685
D_{50}= 0.0601 D_{30}= 0.0440 D_{15}= 0.0193
D_{10}= 0.0048 C_u= 14.22 C_c= 5.87

Remarks

Strong reaction with HCl

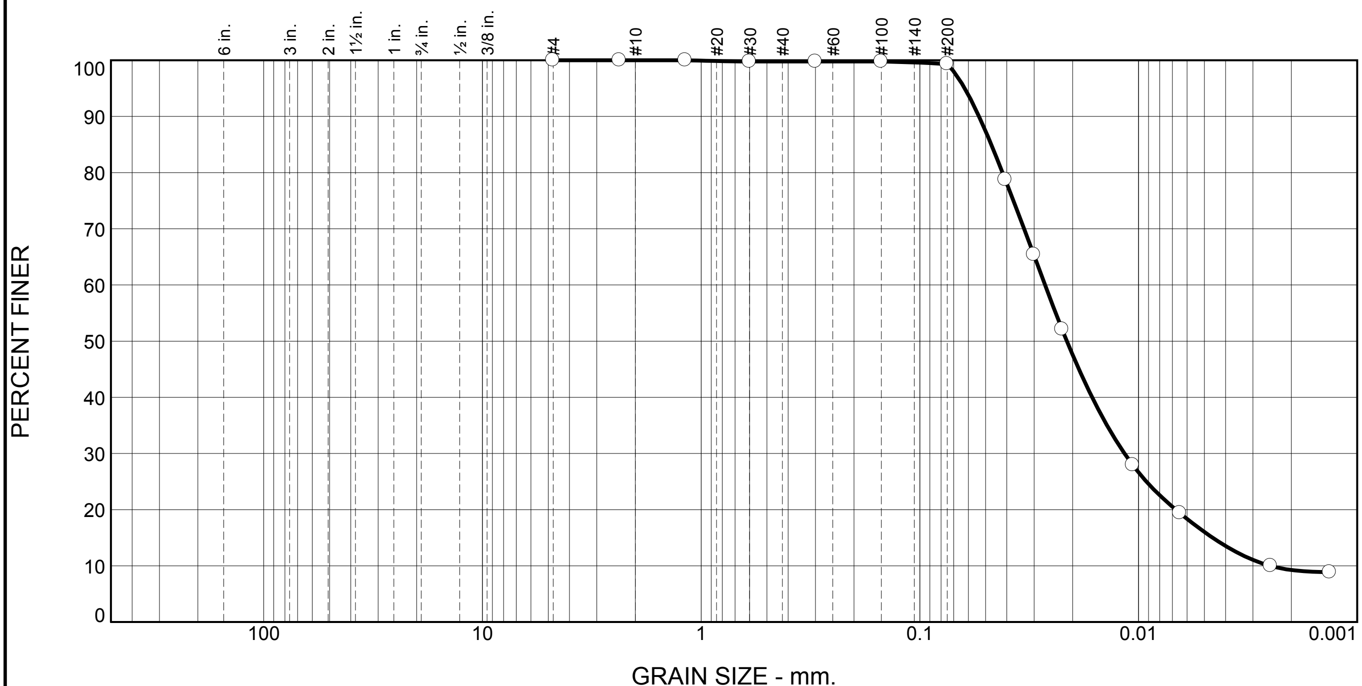
Date Received: **Date Tested:** 6/19/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 2-2.5 feet **Date Sampled:**
Sample Number: 28C-51 (7-RC-1B)

BUREAU OF RECLAMATION

Client:
Project: PAONIA
Project No: 28C **Figure** 14

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.2	0.5	90.0	9.3

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	100.0		
#16	100.0		
#30	99.8		
#50	99.8		
#100	99.8		
#200	99.3		
0.0406 mm.	78.7		
0.0301 mm.	65.4		
0.0224 mm.	52.1		
0.0106 mm.	27.9		
0.0065 mm.	19.4		
0.0025 mm.	10.0		
0.0013 mm.	8.9		

* (no specification provided)

Material Description

Lean clay

Atterberg Limits (ASTM D 4318)

PL= 22 **LL=** 35 **PI=** 13

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-6(14)

Coefficients

D_{90}= 0.0536 D_{85}= 0.0472 D_{60}= 0.0267
D_{50}= 0.0213 D_{30}= 0.0116 D_{15}= 0.0046
D_{10}= 0.0025 C_u= 10.71 C_c= 2.01

Remarks

Strong reaction with HCl

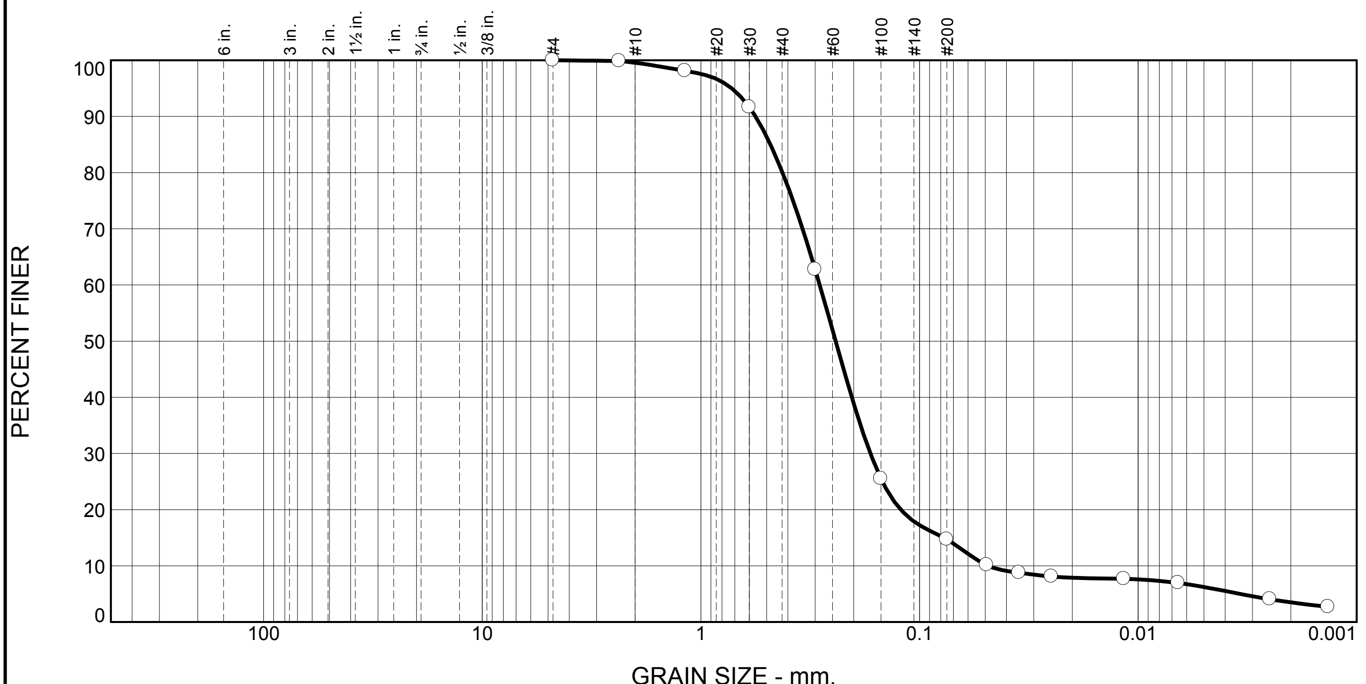
Date Received: **Date Tested:** 6/19/2014
Tested By: J. Waller
Checked By: Z. Erdogan
Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 41-46 inches **Date Sampled:**
Sample Number: 28C-52 (7-RC-1B)

BUREAU OF RECLAMATION

Client:
Project: PAONIA
Project No: 28C **Figure** 15

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.4	19.4	65.5	11.2	3.5

TEST RESULTS			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	99.9		
#16	98.1		
#30	91.6		
#50	62.8		
#100	25.5		
#200	14.7		
0.0492 mm.	10.1		
0.0350 mm.	8.8		
0.0249 mm.	8.1		
0.0116 mm.	7.7		
0.0066 mm.	7.0		
0.0025 mm.	4.0		
0.0014 mm.	2.7		

* (no specification provided)

Material Description

Silty sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 0.5625 D_{85}= 0.4806 D_{60}= 0.2860
D_{50}= 0.2418 D_{30}= 0.1677 D_{15}= 0.0773
D_{10}= 0.0484 C_u= 5.91 C_c= 2.03

Remarks

Strong reaction with HCl

Date Received: **Date Tested:** 6/19/2014

Tested By: J. Waller

Checked By: Z. Erdogan

Title: Civil Engineer

Source of Sample: PAONIA DAM **Depth:** 4.5-5 feet **Date Sampled:**
Sample Number: 28C-53 (7-RC-1B)

BUREAU OF RECLAMATION

Client:
Project: PAONIA

Project No: 28C **Figure** 16