Appendix E

LITHOLOGIC BORING LOGS

MAJOR DIVISIONS			SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS OVER 60%>No 200 SIEVE SIZE	GRAVELS MORE THAN 1/2 OF COARSE FRACTION> No 4 SIEVE SIZE	CLEAN GRAVELS WITH LESS THAN 5% FINES	GW	Well-graded gravels or gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GRAVELS WITH OVER 15% FINES	GM	Silty gravels, gravel-sand mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS MORE THAN 1/2 OF COARSE FRACTION< No 4 SIEVE SIZE	CLEAN SANDS WITH LESS THAN 5% FINES	SW	Well-graded sands or gravelly sands, little or no fines
			SP	Poorly graded sands or gravelly sands, little or no fines
		SANDS WITH OVER 15% FINES	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS OVER 60%<No 200 SIEVE SIZE	SILTS & CLAYS LIQUID LIMIT 50% OR LESS		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS & CLAYS LIQUID LIMIT GREATER THAN 50%		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silty clays, organic silts
HIGHLY ORGANIC SOILS			PT	Peat and other highly organic soils
DEBRIS ZONE*				Metal, concrete, plastic, brick, wood, etc.
CONSTRUCTION DEBRIS*				Concrete, wood, rebar asphalt

SYMBOLS KEY

- Bulk or classification sample
- No sample recovery
- "Undisturbed" sample
- First-encountered groundwater level
- Static groundwater level
- (10YR 4/4) Munsell soil color chart 1990 edition

GRAIN SIZE CHART

CLASSIFICATION	RANGE OF GRAIN SIZES	
	U.S. Standard Sieve Size	Grain Size in Millimeters
BOULDERS	Above 12"	Above 305
COBBLES	12" to 3"	305 to 76.2
GRAVEL	3" to No.4	76.2 to 4.75
coarse	3" to 3/4"	76.2 to 19.1
fine	3/4" to No 4	19.1 to 4.75
SAND	No 4 to No.200	4.75 to 0.075
coarse	No 4 to No.10	4.75 to 2.00
medium	No 10 to No.40	2.00 to 0.425
fine	No 40 to No.200	0.425 to 0.075
SILT & CLAY	Below No.200	Below 0.075

Source ASTM D 2488-90, based on Unified Soil Classification System
* Not part of ASTM Classification System

SOILCLS2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Unified Soil Classification

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
3		0		SM, silty sand, fine- to medium-grained sand, some clay 10 YR 6/4 - light yellowish brown loose nonplastic, dry alluvium
8				
11				
12				
15				
11				Color change to 10 YR 7/4 - very pale brown
7				
7				
6				
4		5		
4				
5				ML, sandy silt, very fine- to medium-grained sand 10 YR 6/4 - light yellowish brown loose, slightly plastic slightly moist calcareous alluvium
4				
5				
6				
7				
9				
10				
7				SM, silty sand very fine-grained sand, some clay 10 YR 7/3 - very pale brown, loose nonplastic slightly moist, calcareous micaeous alluvium
8		10		
10				
12				Color change to 10 YR 6/4 - light yellowish brown
13				
15				
10				CL, clay with silt and medium-grained sand 10 YR 5/6 - yellowish brown medium dense nonplastic dry
14				
15				
9				10 YR 6/6 - brownish yellow
19				
20		15		Color change to 7 5 YR 5/6 - strong brown
17				
33				
50				Color change to 10 YR 5/6 - yellowish brown
29				
35				
31				Color change to 10 YR 8/2 - white caliche due to increase in calcium carbonate
19				
19				
26				Increase in coarse-grained sand, color change to 10 YR 5/6 - yellowish brown, abundant white caliche
20		20		
32				
65				Color change to 10 YR 7/4 - very pale brown
23				
28				
35				Color change to 2.5 Y 5/4 - light olive brown
17				
28				
47				SANDSTONE, very fine- to fine-grained sand, 10 YR 6/6 - brownish yellow locally very thinly laminated low hardness friable, moist, calcareous weathered bedrock
40				
96		25		

Notes LAll HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

Prepared for:
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Commerce City, Colorado

Prepared by:
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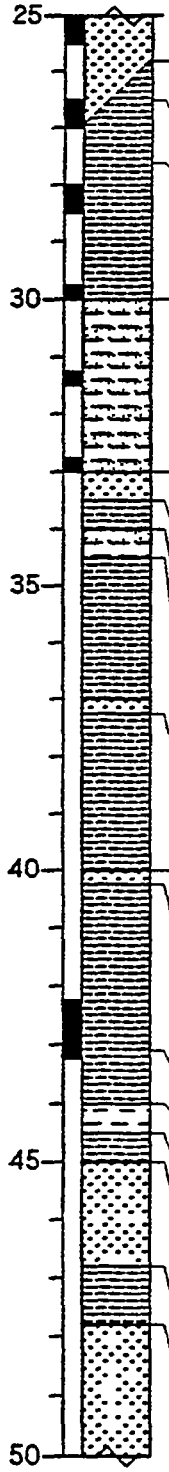
Figure 1

Log of Boring BRB11084

Equipment Mobile CME-75 HSAs

Elevation 5199.23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)
23	
41	
83	
48	
64	
58	
32	
53	
71	
30	
65	
50	
26	
123	
100	
26	
63	
75	
24	
38	
50	



CLAYSTONE, 10 YR 6/2 – light brownish gray soft plastic moist black lignite fragments, gypsum weathered bedrock

Abundant iron oxide and gypsum, minor lignite

Color change to 2.5 Y 5/3 – light olive brown

INTERBEDDED CLAYSTONE AND SILTSTONE TO SANDSTONE, 2.5 Y 5/2 – grayish brown, splitting along sandy layers at 1– to 2–inch intervals, weathered bedrock

SANDSTONE, very fine–grained sand to silt 2.5 Y 6/4 – light yellowish brown, low hardness, friable dry noncemented to locally weakly cemented weathered bedrock

CLAYSTONE, 2.5 Y 5/3 – light olive brown locally dark gray, laminated, fractured soft, plastic, iron oxide weathered bedrock

INTERBEDDED CLAYSTONE AND SILTSTONE, 10 YR 5/3 –light olive brown, low and high angle fractures some slickensides weathered bedrock

CLAYSTONE, very fine–grained sand, 2.5 Y 5/6 – light olive brown soft, plastic weathered bedrock

Color change to 2.5 Y 5/0 – gray high angle fractures with iron oxide and slickensides

SANDSTONE to SILTSTONE, very fine–grained sand to silt massive no bedding, not fractured, moderately hard, moderately strong, 10 YR 4/2 – dark grayish brown, calcareous, weathered bedrock

CLAYSTONE, locally intensly fractured with iron–oxide fractures/joints, breaks in blacky to concoidal fragments 2.5 Y 4/2 – dark grayish brown weathered bedrock

Color change to 2.5 Y 4/3 – olive brown

SILTSTONE, clayey 2.5 Y 5/4 – light olive brown, thinly laminated, low hardness, friable, weathered bedrock

CLAYSTONE, 2.5 Y 4/3 – olive brown, fractured, weathered bedrock

SANDSTONE, very fine– to fine–grained sand, 2.5 Y 6/4 – light yellowish brown low hardness, friable, compacted, uncemented, weathered bedrock

CLAYSTONE, 2.5 Y 4/3 – olive brown, weathered bedrock

SANDSTONE, very fine– fine–grained sand, locally silty, 2.5 Y 6/4 – light yellowish brown and 2.5 Y 7/6 – yellow low hardness, friable, compacted noncemented

FMA2

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Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		50		CLAYSTONE, 2.5 YR 5/2 – grayish brown, thinly laminated closely fractured soft, plastic, slightly to nonweathered bedrock, iron oxide fractures and horizontal partings silty lamination, trace thin black lignite laminations, bedrock
				2 5 Y 4/2 – to 2 5 Y 3/2 – dark gray brown to very dark gray brown, very thinly laminated, closely fractured
		55		
		60		Becomes lignitic, color change to 2 5 Y 3/2 – to 2 5 Y 2/0 – very dark gray brown to black, thinly laminated
				Color change to 2 5 Y 5/3 – light olive brown due decrease in lignite
				SANDSTONE. very fine-grained sand silty, clayey 2 5 Y 5/3 – light olive brown, moist, low hardness friable compact non-to weakly cemented noncalcareous bedrock
		65		CLAYSTONE, 2 5 Y 4/2 – dark grayish brown thinly laminated soft plastic iron oxide on low angle to horizontal parting spaced 1 to 3 inches bedrock
				Becomes lignitic color change to 10 YR 3/2 – very dark grayish brown, very thinly laminated, soft plastic lignite fragments bedrock
				Mottled olive and gray
		70		
				LIGNITE, 2 5 Y 2/0 – black flaky coal-like material moist bedrock
				CLAYSTONE, 10 YR 3/2 – very dark gray brown, 10 YR 3/2 to 10 YR 2/2 – very dark brown thinly laminated low hardness plastic iron oxide, waxy, bedrock
		75		LIGNITE black thinly laminated low hardness friable fissile locally clayey, moist, bedrock

RMA2

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Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		75		Contains thin laminations of crushed olive-brown blocky clay fragments and very light grayish ashy material
		80		
		85		CLAYSTONE, 2 5 Y 3/0 – very dark gray low hardness plastic moist iron oxide bedrock Becomes silty
				SANDSTONE, very fine- to fine-grained sand, some silt, 2 5 Y 7/0 – light gray low hardness, friable moist bedrock
				CLAYSTONE, 2 5 Y 3/0 – very dark gray, massive (no fracturing) low hardness plastic moist bedrock 2 5 Y 3/2 – very dark grayish brown
		90		
		95		Silty 2 5 Y 4/0 – dark gray to 2 5 Y 2/0 – black, low and high angle slickensides
		100		

RMA2

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Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/84

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		100		
		105		Becomes lignitic color change to 2 5 Y 2/0 – black to 2.5 Y 3/ 0 – 2.5 Y 3/0 – very dark gray, thinly laminated local shiny black lignite layers slickensides at 107 8 ft , soft plastic, locally fissile locally waxy moist, lignite content decreases downward at 109 0 ft. becomes ashy
		110		
		115		SANDSTONE, very fine-grained sand, 2 5 Y 5/0 – gray and 2 5 Y 4/0 – dark gray, layered, bedrock
				INTERBEDDED SILTSTONE to CLAYSTONE, some very fine-grained sand 5 Y 3/1 – very dark gray (moist) 5 Y 7/1 – light gray (dry) soft to low hardness plastic to friable moist local slickensides bedrock
		120		Increase in sand content laminated, locally interbedded, becomes moist
		125		Trace silt

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Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199.23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		125		Increase in clay and silt content
				Interbedded silty claystone, clayey siltstone and very fine sandstone
		130		Color change to 5 Y 5/1 – gray
				SANDSTONE, very fine- to fine-grained sand, locally clayey, 5 Y 5/1 – gray low hardness friable, moist bedrock
		135		CLAYSTONE and SILTSTONE, alternating light gray and dark gray laminations
				SANDSTONE, very fine- to fine-grained sand, 2 5 Y 5/1 – gray, local thin layer lignitic laminations low angle low hardness friable, moist bedrock
				CLAYSTONE, occasional silty sandy laminations, high angle fractures silt content increases, bedrock
				SILTSTONE, minor clay, 2 5 Y 4/1 – dark gray, low hardness friable moist bedrock
		140		CLAYSTONE AND SILTSTONE, black waxy, massive soft, low hardness, plastic slickensides bedrock
				SANDSTONE, fine-grained sand, some medium-grained sand, 2 5 Y 5/0 – gray to 5 Y 4/1 – dark gray, low hardness, friable, moist, noncalcareous bedrock
		145		CLAYSTONE, 5 Y 2 5/1 – black, thinly laminated zones, little fracturing low hardness, plastic, moist unweathered, bedrock, somewhat fissile, high angle slickensides
		150		

RW A2

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Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		150		INTERBEDDED CLAYSTONE AND SILTSTONE, 5 Y 6/1 – gray and 5 Y 4/1 – dark gray, massive thin laminated fractured low to moderately hard, plastic, friable moist bedrock Silt content increases downward interbedded claystone and very fine– to fine-grained sandstone/sandy siltstone
				Interbedded sandstone and clayey siltstone
		155		
		160		
				LIGNITE, fractured deformed bedrock
		165		
				CLAYSTONE, 2 5 Y 2/0 – black, massive little fractured, soft, low hardness plastic moist bedrock
		170		
				Color change to 5 Y 3/1 – very dark gray
		175		Total depth = 175 1 ft

RMA2

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Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)
17	
16	
8	
10	
9	
5	
5	
5	
5	
7	
7	
8	
8	
6	
4	
1	
5	
20	
27	
28	
17	
17	
13	
8	
10	
8	
8	
8	
10	
19	
25	
35	
18	
40	
32	
17	
28	
36	
20	
27	
28	
17	
31	
33	
105	
50	
35	
70	
107	

Depth (ft.) 0, 5, 10, 15, 20, 25

Sample

ML, silty with medium-grained sand, 10 YR 5/4 – yellowish brown stiff nonplastic dry, minor roots, alluvium

CL, clay with some silt and sand 10 YR 5/4 – yellowish brown, very stiff, nonplastic, dry, alluvium

SM, silty sand with clay medium-grained sand, 10 YR 6/4 – light yellowish brown, loose, nonplastic, dry, minor white calcium carbonate, silt and sand content decrease with depth, alluvium

ML, silt with some fine- to medium-grained sand and clay, 10 YR 6/3 – pale brown nonplastic, dry to very slightly moist, carbonate matrix alluvium

Increase in very fine-grained sand

CL, clay with medium- to coarse-grained sand, some silt 10 YR 6/4 – light yellowish brown medium stiff nonplastic slightly moist, calcareous matrix alluvium

Color change to 10 YR 8/2 – white, very stiff, dry

CL/SC clay with fine- to medium-grained sand and silt 10 YR 7/4 – very pale brown stiff,

Color change to 10 YR 7/6 – yellow

Zone of white calcium carbonate crystals, color change to 10 YR 6/4 – light yellowish brown

SILTSTONE, 2 5 Y 6/6 – olive yellow very fine-grained sand and silt to trace clay, low hardness, friable dry locally weakly cemented, calcareous matrix oxidized, weathered bedrock

CLAYSTONE, 5 Y 4/3 – olive, fractured, high and low angle with iron oxide on fracture, soft plastic slightly moist gypsum and calcium carbonate weathered Denver

Color change to 2 5 Y 5/2 – grayish brown trace silt, dry, iron oxide gypsum oxidized noncalcareous, weathered bedrock

Low angle fractures spaced 1/2 to 1 inch, high angle fractures spaced 2 to 6 inches

Color change to 2 5 Y 4/0 –dark gray along fractures oxidized to 2 5 Y 6/2 – light yellowish gray

Color change to 2.5 Y 5/2 – grayish brown, intensely fractured to crushed

INTERBEDDED CLAYSTONE and SILTSTONE to VERY FINE-GRAINED SANDSTONE, 2 5 Y 7/3 – pale yellow low hardness, friable, dry to slightly moist with very minor iron oxide on low angle fractures layers 1/2 to 2 inches thick, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Figure 2

Log of Boring SAB11194

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		
62 71 80				CLAYSTONE, paper thin silty parting spaced 1 to 2 inches apart 2 5 Y 4/2 – dark grayish brown, low angle fractures, intensely fractured to crushed, soft, plastic, slightly moist, iron oxide on fractures, oxidized weathered bedrock
				Color change to 2 5 Y 5/2 – grayish brown
				SANDSTONE, medium-grained sand 10 YR 4/6 – dark yellowish brown, low hardness fraible, weathered bedrock
		30		
				CLAYSTONE, 2 5 Y 4/2 – dark grayish brown, papery to shaly, thinly laminated intensely fractured, soft, plastic, moist, iron oxide on fractures laminations, weathered bedrock
		35		
				Becomes lignitic, color change to 5 Y 3/1 – very dark gray closely fractured
		40		
				Thin sand lens approximately 0 1 inch thick
				Thin sand lens approximately 0 1 inch thick
				SANDSTONE, 2 5 Y 6/4 – light yellowish brown, compact noncemented soft to low hardness, friable, loose moist weathered bedrock
		45		
				INTERBEDDED CLAYSTONE AND SILTSTONE, 2 5 Y 4/2 – dark grayish brown locally shaley thinly laminated closely fractured soft, plastic, moist, local iron oxide, weathered bedrock
				Sandstone lenses fine– to very fine-grained sand 2.5 Y 5/6 – light olive brown, moist
		50		

RMA2

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Figure 2

Log of Boring SAB11194

Equipment Mobile CME-75 HSAs

Elevation 5262.79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		50		SANDSTONE, 2.5 Y 5/6 – light olive brown very fine-grained sand, locally clayey with occasional very thin bedded gray claystone, thinly laminated no to low hardness, no strength moderately fractured moist, weathered, varible iron oxide along laminations, weathered bedrock
		55		
		60		
		65		INTERBEDDED SILTSTONE/CLAYEY SILTSTONE/ SILTY CLAYSTONE, 2.5 Y 5/6 – light olive brown somewhat platey, thinly laminated closely fractured low angle soft to low hardness base of iron oxide oxidation, weathered bedrock
		70		SILTY CLAYSTONE, 5 Y 3/1 – very dark gray, shaley laminated, closely fractured, low and high angle, soft, plastic, moist, bedrock
				LIGNITE, 2.5 Y 2/0 – black, shaley, thinly laminated closely fractured, low hardness, friable, moist, coal-like, bedrock
		75		

PMA2

Prepared for:
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Harding Lawson Associates

Figure 2

Log of Boring SAB11194

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		75		
		80		CLAYSTONE, 2 5 Y 4/0 – dark gray, occasional shaley laminated close to moderately fractured, soft plastic unweathered, moist, trace lignite fragments bedrock Lignitic from 78 7 to 79 2 feet Thin sand lens, gray very fine-grained sand uncemented
		85		SANDSTONE, fine-grained sand silt, 10 YR 4/1 – dark gray, thinly laminated low hardnmess friable, unweathered moist bedrock, thin zone approximately 0 1 inch thick, moderately cemented locally clayey Pyrite nodule CLAYSTONE, 10 YR 4/1 – very dark gray slabby, locally laminated, moderate to little fractured soft plastic moist bedrock Pyrite and lignite at 85 9 to 86 0 feet, some high angle slickensides
		90		Intensely to closely fractured claystone, slickensides
		95		INTERBEDDED CLAYSTONE, SILTSTONE, SANDSTONE, 2 5 Y 2 5/1 – black (claystone) to 5 Y 5/1 – gray (sandstone) thinly laminated interbedded claystone and siltstone thinly bedded sandstone, little fractured to massive soft to low hardness plastic to friable, moist soft sediment deformation features in interbedded siltstone claystone varied fracture filling, sandstone lenses 3 to 4 inches thick poor to moderately cemented fine-grained sand, well sorted rounded, quartz, iron oxide, feldspar, bedrock Color change to 5 Y 2.5/1 – black
		100		

RMA2

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Commerce City, Colorado

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Figure 2

Log of Boring SAB11194

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample	
		100		LIGNITIC CLAYSTONE, black to very dark brown-black occasional shaley, thinly laminated close to moderately fractured with occasional slickensides, soft to low hardness, plastic, locally friable, moist bedrock
				CLAYSTONE, 2 5 Y 2/0 black, blocky to massive, locally thinly laminated, moderately fractured, plastic, moist, bedrock
		105		INTERBEDDED CLAYEY SILTSTONE, SANDSTONE and MINOR CLAYSTONE, 2 5 Y 5/0 - gray, massive to blocky, locally thinly laminated (alternating siltstone/claystone laminations) moderately fractured, low angle, occasional high and vertical fractures, soft to low hardness locally weak to friable to plastic moist bedrock pyrite nodule at 107 0 feet
				SANDSTONE, thinly laminated, low to moderately hard, weak to friable, moist bedrock
		110		
				CLAYSTONE, locally silty with minor siltstone interbeds mottled, 2 5 Y 5/0 - gray and 2 5 Y 3/0 - very dark gray, blocky to massive, locally thinly laminated, moderate to little fractured, soft to low hardness, plastic, moist, soft sediment deformation features trace lignite, waxy bedrock
		115		
				Grades to very dark gray claystone
				Color change to 2 5 Y 4/0 - dark gray
		120		SILTSTONE, 2 5 Y 5/0 - gray, massive to blocky, thinly laminated, moderately fractured low and high angle, slickensides (high angle), bedrock
		125		

RMA2

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Figure 2

Log of Boring SAB11194

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		125		
		130		
		135		SANDSTONE, 2 5 Y 4/0 – dark gray, caliche fracture filling high angle fracture contact, 2 5 Y 6/1 – gray with green cast, low hardness, friable, moist bedrock
		140		CLAYSTONE, 2.5 Y 2/0 – black, locally mottled to 2 5 Y 5/0 – gray, some green-black streaks massive to blocky occasional thinly laminated close to moderately fractured occassional high angle slickensides soft to low hardness, plastic, moist, scattered white flecks bedrock
		145		INTERBEDDED CLAYSTONE AND SILTSTONE, 5 Y 5/1 – gray, massive thinly bedded occasionally thinly laminated moderately to closely fractured high and low angle fractures, low hardness, friable moist trace organics, bedrock
		150		CLAYSTONE, 2 5 Y 2/0 – black, massive occasional shaley, occasional thin laminated, closely fractured soft to low hardness, plastic, moist unweathered, waxey, slickensides on high angle fracture black organic (lignite), fracture filling and fragments, bedrock

RMA2

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Figure 2

Log of Boring SAB11184

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		150		Color change to 5 Y 3/1 – very dark gray
		155		Black coal seam, approximately 0 5 inches thick, brittle blocky break Becomes lignitic, 2 5 Y 2/0 – black, thin laminated closely fractured high angle slickensides, low hardness, plastic moist scattered fine-grained white flecks bedrock High angle slickensides
		160		Lignitic claysonte black and lignite fragments, pyrite and calcite fracture filling SANDSTONE, fine-grained sand to 5 Y 5/1 – gray, slabby to blocky, laminated to very thinly bedded moderately fractured, low to medium abgle with thin black organic material on fracture low to medium hardness, weak to friable moist bedrock
		165		SILTSTONE, 2 5 Y 5/0 – gray, thinly laminated (varved) low to moderately hard friable to weak, unweathered, bedrock Interbedded to thinly laminated claystone CLAYSTONE, 2 5 Y 5/0 – and 2 5 Y 4/0 – gray and dark gray occassional silty massive occassional intensely fracutured, high angle slickensides soft to low hardness, plastic, moist, bedrock
		170		Total depth = 170 0 ft
		175		

RMA2

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Figure 2

Log of Boring SAB11194

Equipment Mobile CME-75 HSAs

Elevation 5239.41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
4		0		SC, sand, very fine-grained sand with silt and clay 10 YR 6/4 – light yellowish brown, loose, plastic dry, fine roots alluvium
8				
8				CL, clay with silt and fine- to medium-grained sand, 10 YR 6/4 – light yellowish brown, medium stiff, plastic dry caliche alluvium
6				
5				
4				
6				
9				SC, sand with clay matrix, fine- to very fine-grained sand, some granules 7 5 YR 5/4 – brown, medium dense, loose, dry, caliche alluvium
12				
7		5		
8				CL, clay with medium- to coarse-grained sand 10 YR 8/2 – white very stiff plastic dry abundant caliche matrix, iron-oxide staining alluvium
10				
10				
13				
18				
18				
17				
21				Increase in coarse-grained sand granules and fine pebbles color change to 10 YR 6/4 – light yellowish brown
12				
14		10		
12				SW, 10% clay matrix silt to very coarse-grained sand some granules and small pebbles 10 YR 7/3 – very pale brown mediumk dense, locally plastic moist alluvium
7				
8				
10				CL, clay with sand and gravel 10 YR – 7/3 – very pale brown stiff to very stiff plastic moist, with thin layers of very fine-grained sand locally caliche with minor caliche, sand lenses – SW to SP 0 01-inch to 0 10- inch thick alluvium
6				
12				
11				
7				
10				
13		15		
7				SW, sand with some silt very fine- to very coarse-grained sand, 10 YR 6/4 – light yellowish brown, medium dense nonplastic moist fining downward alluvium
8				
8				SP, very fine-grained sand lens
12				
24				CL, clay with sand and granules (pea gravel), 10 YR 6/4 – light yellowish brown, medium dense (very stiff) nonplastic moist alluvium
21				
6				Color change to 10 YR 5/3 – brown, becomes plastic
11				
10				
4		20		SW, sand, very fine- to very coarse-grained sand with silt and gravel 10 YR 7/3 – very pale brown dense loose dry alluvium
8				
8				SP, sand, very fine-grained sand 10 YR 6/3 – pale brown medium dense nonplastic moist, noncalcareous subrounded alluvium
13				
12				
20				CL, clay with 40% very fine-grained sand and silt, 10 YR 6/4 – light yellowish brown stiff, plastic moist iron-oxide staining on horizontal partings spaced micaceous, alluvium
22				
14				
5				SW, sand very fine- to very coarse-grained sand with granite pea gravel occasionally up to 3/4-inch grains dense dry alluvium
7				
8		25		
				SP, sand 10 YR 7/3 – very pale brown medium dense loose dry, alluvium

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated.
2 Munsell color chart used

RMA2

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 3

Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5239 41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		Very fine gravel 1/10-inch to 1/4-inch gravel
5				
6				
6				SANDSTONE, very fine-grained sand and silt, 2.5 Y 7/3 - pale yellow, low hardness friable dry to slightly moist oxidized, fines downward to siltstone 2 Y 7/2 -light gray, weathered bedrock
13				
20				
47				
28				CLAYSTONE, silt and very fine-grained sand, 2.5 Y 7/2 - light gray, locally 2 5 Y 6/8 - olive yellow, soft plastic to friable, slightly moist, weakly cemented slightly cohesive, oxidized, weathered bedrock
42				
50		30		
50				
100				SANDSTONE, fine- to coarse-grained sand rounded silty, no hardness no strength, moist, weathered local weak cement oxidized, weathered bedrock
56				
68				
50				
		35		
				Color change to 2 5 Y 7/3 - pale yellow, friable
				Medium- to coarse-grained sand some gravel, color change to 2 5 Y 5/6 - light olive brown
		40		
		45		
		50		Slightly more cohesive occasional horizontal iron-oxide stained layers, color change to 2 5 Y 5/4 - light olive brown

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
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Figure 3

Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5239 41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample	
		50		
		55		
		60		
		65		CLAYSTONE, 2 5 Y 4/4 – olive brown shaley laminated intensely fractured soft plastic moderately weathered, moist, bedrock, lignitic claystone, 2 5 Y 3/2 – very dark grayish brown, shaley, fractured soft, plastic, weathered, moist, local heavy iron oxide weathered bedrock
				SANDSTONE, medium-grained sand, low hardness friable moist weathered bedrock
				CLAYSTONE, 2.5 Y 2/0 – black, slabby, thinly laminated closely fractured soft plastic moist lignitic moderately weathered bedrock
		70		Color change to 2 5 Y 5/0 – gray interbedded with 2 5 Y 3/0 – very dark gray becomes silty/sandy with thin lignitic laminations, some layers have dark green black cast
				SANDSTONE, medium-grained sand, shaley, low hardness friable moist lignitic fragments, bedrock
		75		

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Program Manager for
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Commerce City, Colorado

Prepared by:
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Figure 3

Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5239 41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		75		
				CLAYSTONE, silty, 5 Y 5/2 – olive gray, closely fractured, soft to low hardness, plastic, moist, iron-oxide staining weathered bedrock
				Color change to 5 Y 4/1 – dark gray
		80		
				SANDSTONE, very fine-grained sand 2 5 Y 5/0 – 4/0 – gray to dark gray, slabby, thinly laminated moderate to little fractured low hardness friable interbedded with claystone and siltstone bedrock
		85		
		90		CLAYSTONE, silty, 10 YR 4/1 – dark gray, massive thinly laminated little fractured, low hardness plastic moist, bedrock
				SANDSTONE, silty to very fine-grained sand 5 Y 4/1 – or 10 YR 4/1 – dark gray, massive, thinly laminated little fractured to massive, low to moderately fractured, hard, friable to weak, moist cross-bedded sandstone bedrock
		95		
		100		

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Figure 3

Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5239.41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		100		
		105		CLAYSTONE, 5 Y 2 5/1 - black thinly laminated, closely fractured, high angle, slickensides low hardness (soft) plastic moist lignitic, bedrock
		110		
		115		Total depth = 112 9 feet

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Figure 3

Log of Boring ASB11284

Equipment Mobile CME-75 HSAs

Elevation 5199.23 ft Date 11/16/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
3		0		CL, clay, 35 percent very fine-grained sand, 10 YR 5/3 – brown, medium dense, nonplastic dry caliche, alluvium
6				
9				
14				Color change to 10 YR 6/4 – light yellowish-brown, increase in very fine-grained sand and trace medium-grained sand
3				
5				
5				
6				
3				
5		5		
6				Heavy white caliche zone
6				
9				
3				Heavy white caliche zone, clay increase to 45 percent
5				
6				
6				
		10		SP, silty sand very fine- to fine-grained sand 10 percent clay 10 YR 6/6 – brownish yellow, very dense, dry to slightly moist alluvium
17				
30				
45				Decrease in clay content to 5 percent, 10 percent very fine-grained sand 85 percent fine-grained sand
50				
25				
35				
50				
27		15		
37				
45				
50				
21				CLAYSTONE, 5 YR 4/1 – dark gray, unable to determine bedding medium hard to weak, iron-oxide stained, weathered bedrock
15				
14				
15				Claystone becomes bentonitic with orange oxidation
12				
21				
30		20		Total depth = 20 0 feet
34				
		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Prepared by:
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Figure 4

Log of Boring SAB11394

Equipment Mobile CME-75 HSAs

Elevation 5206.26 ft Date 11/15/94

Blows/6"	HNU/OVA (ppm)
4	
7	
9	
7	
4	
8	
7	
10	
8	
10	
18	
20	
4	
10	
8	
8	
10	
10	
9	
10	
5	
5	
6	
6	
6	
6	
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6	
6	
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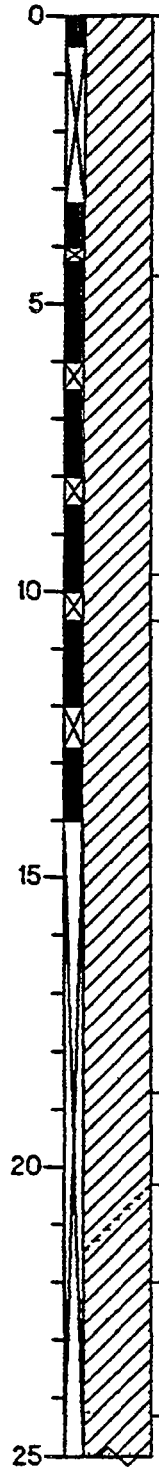
6	
6	
6	
6	
6	
6	
6	
6	



CL, sandy clay, 40 percent very fine-grained sand, 10 YR 5/6 – yellowish brown dense nonplastic dry, micaceous, cemented alluvium

Color changes to 10 YR 6/4 – light yellowish brown with increased caliche

Color changes to 10 YR 5/6 – yellowish brown mottled caliche

Coarsening downward becomes moist

Rounded granite cobble and decrease in clay content

Increased very fine- to coarse-grained sand low plasticity slightly moist

Change in color to 10 YR 6/4 – light yellowish brown

Thin layer of coarse-grained sand

Increase in coarse-grained sand and gravel, medium plastic

Interbedded thin medium- to coarse-grained sand lenses between 17 7 and 20 3 ft

Granite cobbles and pea gravel

SC, clayey sand, very fine- to medium-grained sand trace coarse sand 10 YR 5/4 – yellowish brown medium dense, medium plastic, moist, alluvium

Increase in clay content to 45 percent, sand coarsening

Color changes to 10 YR 6/4 – yellowish brown, decreased clay content

Some rounded gravel

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

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Commerce City, Colorado

Prepared by:
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Figure 5

Log of Boring WEB11484

Equipment Mobile CME-75 HSAs

Elevation 5206.26 ft. Date 11/15/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		Coarse sand layer with gravel from 26 0 26 3 ft with sequence coarsening downward to 29 6 ft
				Granite cobbles
		30		CLAYSTONE, 2 5 YR 5/3 – light olive brown, closely fractured medium hard, friable, weathered bedrock
				High angle fractures and color change to 10 YR 6/8 – brownish yellow, oxidation along fractures and bedding
				Thin interbedded very fine-grained sandstone layers alternating 10 YR 6/6 – olive yellow and 2 5 Y 7/7 – light gray sandstone
				Total depth = 33 7 feet
		35		

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Figure 5

Log of Boring WEB11494

Equipment Mobile CME-75 HSAs

Elevation 5211.37 ft. Date 11/16/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
4		0		CL, sandy clay, 40 percent very fine-grained sand 10 YR 4/3 – brown to dark brown, dense, nonplastic, dry alluvium
8				
10				
8				
4				
5				Color change to 10 YR 6/4 – yellowish brown due to increased caliche, trace coarse sand
7				
9				
10				
9		5		
8				Color change to 10 YR 8/3 – very pale brown due to increased caliche
4				
4				
5				Trace rounded gravel
8				
7				
7				SC, clayey sand, 20 percent clay, very fine- to fine-grained sand trace coarse sand 10 YR 6/3 – pale brown medium dense nonplastic dry alluvium
6				
5		10		
				Rounded cobbles Color change to 10 YR 6/6 – brownish yellow becomes moist
4				
5				
15				Granite cobbles
25				
15				
30				SANDSTONE, 90 percent fine-grained sand, trace clay 10 YR 6/6 – brownish yellow, weathered bedrock
50		15		
24				
35				
50				
35				
50				
35		20		Increase in clay to 15 percent and very fine-grained sand to 10 percent, decrease in fine-grained sand to 75 percent
50				
35				
50				
35				
45				
50		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

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Figure 8

Log of Boring ASB11584

Equipment Mobile CME-75 HSAs

Elevation 5211.37 ft Date 11/16/94

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample	
		25		
18				
30				
50				CLAYSTONE, 5 YR 4/2 – olive gray with white caliche brownish red oxidation zones, medium hard friable, weathered bedrock
8				
13				
19				
27				
		30		Total depth = 30 feet
		35		

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Commerce City, Colorado

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Figure 6

Log of Boring ASB11594

Equipment Mobile CME-75 HSAs

Elevation 5215 21 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)
2	
8	
18	
15	
7	
8	
7	
14	0 6
7	
7	
8	
11	
6	
14	
27	
50	0 9
7	
33	
50	
	1.4
	1 4

Depth (ft.) Sample

0

SC, clayey sand very fine- to fine-grained, 10 YR 4/4 - dark yellow brown to 10 YR 6/4 - light yellowish brown medium dense, nonplastic dry rooted caliche-rich, alluvium

90 percent caliche-rich clay

5

SP, sand, very fine- to fine-grained, 10 YR 6/4 - light yellowish brown, medium dense, nonplastic, dry, lightly cemented alluvium

SANDSTONE, very fine- to fine-grained sand, 10 YR 7/4 - very pale brown massive, no visible no visible fracturing low hardness, friable, noncemented weathered bedrock

1 percent medium-grained sand

10

Color change to 10 YR 6/6 - brownish yellow

15

20

Color change to 10 YR 5/8 - yellow brown

Color change to 2.5 YR 5/4 - light olive brown

25

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated.
2.Munsell color chart used

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Figure 7

Log of Boring ASB11694

Equipment Mobile CME-75 HSAs

Elevation 5215.21 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		CLAYSTONE, 10 YR 4/1 – dark gray to 10 YR – 7/1 light gray, unable to determine bedding closely fractured low hardness friable ashy welded appearance oxidized, weathered bedrock
7		30		
7	2.3			
21				
21				
		35		Color change to 2.5 YR 4/4 – olive brown, becomes slightly moist
		40		Color change to 10 YR 5/6 – yellowish brown
				Total depth = 43 feet
		45		

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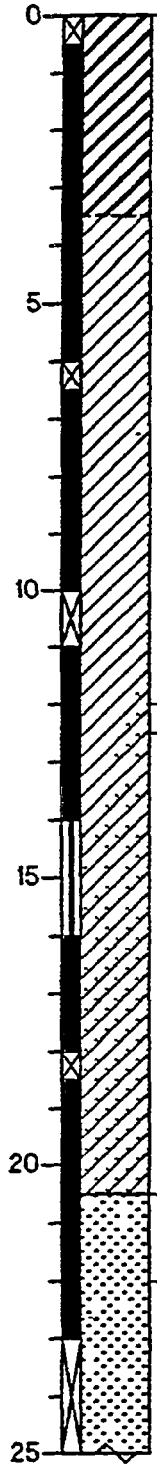
Figure 7

Log of Boring ASB11694

Equipment Mobile CME-75 HSAs

Elevation 5223 39 ft Date 11/17/84

Blows/6"	HNU/OVA (ppm)
5	
14	
18	
20	1 7
15	
16	
18	
20	
13	
12	3.5
17	
20	
9	
10	
8	
15	3 5
9	
2	
2	
2	
6	
7	2 0
9	
7	
8	
8	
10	
5	
10	
11	
8	
10	
12	
20	
8	
7	
16	
45	
45	
50	
25	
50	



CH, sandy clay, 40 percent very fine-grained sand, 10 YR 5/3 – brown hard nonplastic, dry rooted caliche cemented, alluvium

Heavy white caliche

SC, clayey sand, very fine- to fine-grained sand, 40 percent clay 10 YR 5/4 – yellowish brown medium dense to hard, dry, caliche, cemented, alluvium

Slight increase in clay content, low plasticity trace coarse sand and fine gravel

Color change to 10 YR 5/3 – brown to 10 YR 4/3 – dark brown with 10 YR 8/3 – very pale brown

Decrease in clay and caliche increase in very fine-grained sand

Sand becomes poorly sorted and 5 percent coarse-grained sand, trace gravel

Color change to 10 YR 5/4 – yellowish brown increase in clay

Cobbles encountered from 15 to 20 5 feet

SANDSTONE, fine-grained, 10 YR 7/1 – light gray with oxidized layers thin bedding no fracturing weak to moderately weak, weathered bedrock

10 percent clay 10 percent fine-grained sand, 68 percent medium sand 2 percent coarse-grained subangular sand color change to 2 5 YR 5.3 – light olive brown

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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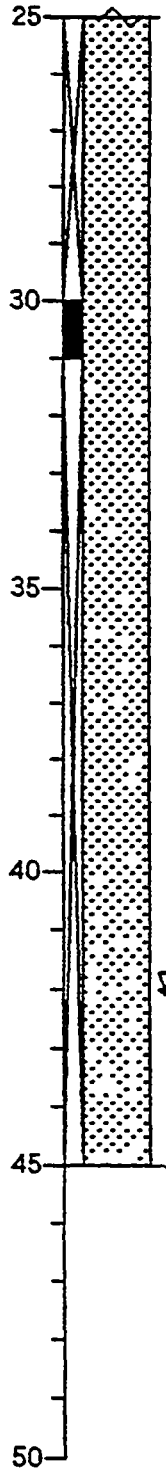
Figure 8

Log of Boring SAB11794

Equipment Mobile CME-75 HSAs

Elevation 5223.39 ft Date 11/17/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		
12 50		30		Decrease in medium grains to 50 percent, increase in fine-grained sand to 30 percent, 10 percent very fine-grained sand 5 percent coarse-grained sand
		35		Color change to 10 YR 6/4 – light yellow brown
		40		Water level estimated during drilling
		45		Becomes saturated Total depth = 45 0 feet
		50		



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Prepared by:
Harding Lawson Associates

Figure 8

Log of Boring SAB11794

Equipment Mobile CME-75 HSAs

Elevation 5240 78 ft Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
2		0		CL, clay, 10 YR 4/2 – dark grayish brown, stiff, low plasticity dry fractured, brecciated claystone fragments gypsum or caliche volcanoclastics, alluvium
5				
11				
14				Silt increasing color change to 10 YR 4/4 – dark yellowish brown
10				
10				Color change to 10 YR 7/4 – very pale brown with caliche
10				
				Increase in very fine-grained sand to 10 percent color change to 10 YR 6/3 – pale brown, becomes very stiff with caliche nodules
		5		
4				Increase in very fine-grained sand to 30 percent, color change to 10 YR 4/4 – dark brown with caliche
7				
6				
6				Heavy white caliche zone
5		10		
7				CLAYSTONE, clasts of clay, oxidized soft, siltstone layers weathered bedrock
9				
8				
7				Color 2 5 YR 5/2 – gray brown massive, closely fractured low hardness weak, iron-oxide stained, gypsum weathered bedrock
8				
10				
22				
7				SILTSTONE, 2 5 YR 6/2 – light olive brown, massive moderately fractured low hardness weak, gypsum crystals oxidation, weathered bedrock
		15		
13				Color change to 2 5 Y 5/4 – olive brown, trace coarse sand
21				
30				
		20		
15				
50				SANDSTONE, fine- to medium-grained sand, pale yellow thin-laminated, low hardness friable, dry weathered bedrock
		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

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Figure 9

Log of Boring ASB11894

Equipment Mobile CME-75 HSAs

Elevation 5240 78 ft Date 12/06/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		Color change to 2 5 Y 5/6 – olive brown, medium-grained sand becomes moist
		30		
		35		Total depth = 35 0 feet
		40		

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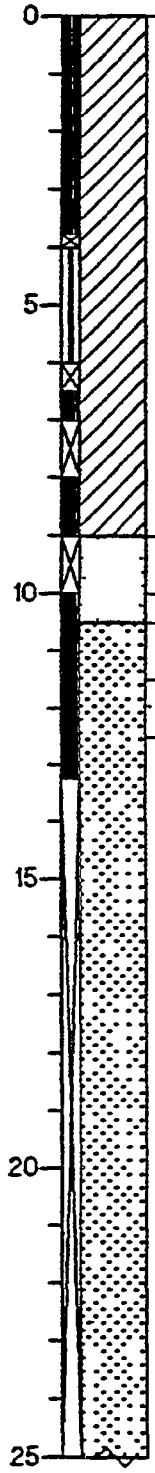
Figure 9

Log of Boring ASB11894

Equipment Mobile CME-75 HSAs

Elevation 5234 48 ft Date 12/07/94

Blows/6"	HNU/OVA (ppm)
4	
12	
25	
25	
14	
15	
19	
19	
6	
6	
7	
2	
2	
3	
4	
45	
42	
38	
36	
9	
28	
50	



CL. clay, fine- to coarse-grained sand, 10 YR 5/4 - yellowish brown hard nonplastic, moist, alluvium

White caliche zone

Color change to 10 YR 6/4 - light yellowish brown trace very coarse-grained sand, becomes soft, calcareous

SC, clayey sand fine- to medium-grained sand, trace coarse-grained sand, 10 YR 7/4 - very pale brown, nonplastic dry, alluvium

Color change to 10 YR 7/3 - very pale brown becomes very dense caliche-cemented

SANDSTONE, medium- to coarse-grained sand, trace fine-grained sand and silt, 10 YR 7/4 - very pale brown low hardness, friable dry, weathered bedrock

Slightly calcareous with iron-oxide staining

Slightly cohesive increase in coarse-grained sand, noncalcareous

Fine- to coarse-grained sand, quartz grains, 10 YR 6/4 - light yellowish brown

Color change to 2.5 YR 4/4 - light olive brown

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Figure 10

Log of Boring ASB11994

Equipment Mobile CME-75 HSAs

Elevation 5234 48 ft Date 12/07/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		
		30		Increase in medium-grained sand
		35		Trace silt becomes slightly moist, color change to 2 5 Y 5/6 – light olive brown
		40		CLAYSTONE, fine- to medium-grained sand 2 5 Y 4/4 – olive brown, moist, weathered bedrock
14 22 36 50		45		Color change to 10 YR 3/2 – very dark grayish brown massive to blocky to thinly laminated, moderately fractured iron-oxide stained, lignitic, weathered bedrock
		50		Total depth = 50 ft

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Figure 10

Log of Boring ASB11994

Equipment Mobile CME-75 HSAs

Elevation 5230 59 ft Date 11/18/84

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample	Description
8		0		ML, silt, very fine- to fine-grained, 10 YR 3/3 – dark brown medium dense, nonplastic, dry rooted alluvium
20				
21				
18				CL, sandy clay very fine-grained sand, 10 YR 6/4 – light yellow brown, medium hard, nonplastic dry alluvium
7				
8				
8				
12				Color change to 10 YR 4/4 – dark yellowish brown, increase in fine- grained sand and caliche
7				
7		5		
7				
8				Color change to 10 YR 6/4 – light brown increase in very fine-grained sand
3				
6				
5				
5				Color change to 10 YR 7/4 – very pale brown due to increase in caliche
4				
5				
4				
5		10		
7				
9				
7				SC, clayey sand very fine- to coarse-grained sand 7 5 YR 5/4 – brown medium dense nonplastic, dry alluvium
7				
11				Becomes well-cemented with caliche 10 percent cobbles and fine gravel
12				
13				Sand coarsening downward poorly sorted, cobbles
12				
8				
8		15		SP-SM, Poorly sorted to silty sand very fine- to very coarse-grained sand trace fine gravel, 7 5 YR 7/4 – pink loose dry, alluvium
10				
6				
6				Increase in clay to 5 percent, 3-inch-diameter granite cobbles
11				
9				
2		20		SW-SM, well-graded sand cobbles and gravel, 10 YR 6/4 – light yellowish brown loose, dry, oxidized alluvium
21				
26				
25				
15				Increase in clay content to 10 percent increase in gravel
16				
21				
18				
18				
36				
50		25		SANDSTONE, very fine- to medium-grained sand 10 YR 5/6 – yellowish brown very dense, weak noncemented very thin bedding, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used.

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 11

Log of Boring ASB12094

Equipment Mobile CME-75 HSAs

Elevation 5230.59 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
50		25		
35				
50				
		30		Color change to 10 YR 5/4 – yellowish brown, cobbles
		35		
		40		
		45		
		50		Total depth = 50 feet

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 11

Log of Boring ASB12084

Equipment Mobile CME-75 HSAs

Elevation 5249.27 ft Date 12/7/84

b

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
4		0		CL, sandy clay, fine- to coarse-grained sand, 10 YR 6/4 – light yellowish brown, stiff slightly plastic moist caliche alluvium
6				
12				
13				Color change to 10 YR 7/4 – very pale brown, sand becomes fine- to medium-grained
7				
9				
11				
11				
5				
8		5		
12				
14				Color change to 10 YR 8/2 – white sand becomes fine- to coarse-grained
11				
11				Becomes nonplastic rounded gravel 3/4-inch in diameter
12				
17				
10				
		10		
9				Abundant caliche
11				
14				SANDSTONE, very fine- to fine-grained sand 2 5 Y 7/3 – pale yellow low hardness friable dry, weathered bedrock
7				
17				Color change to 2 5 Y 6/4 – light yellowish brown due to increase in caliche
50				
4		15		
				CLAYSTONE, 10 YR 5/3 – brown to 2 5 Y 5/3 – light olive brown, low hardness, friable, dry, weathered bedrock
		20		Color change to 2.5 Y 5/3 – light olive brown due to increased caliche
9				
12				Color change to 2 5 Y 5/2 – grayish brown, lignitic iron oxide on fracture planes
17		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 12

Log of Boring ASB12184

Equipment Mobile CME-75 HSAs

Elevation 5249.27 ft Date 12/7/94

b

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		Color grades to 7 5 YR 3/2 – dark brown, lignitic clayshale to 34 ft
		30		
				Color change to 10 YR 3/3 – dark brown
		35		
		40		Color change to 2 5 Y 4/4 – olive brown, becomes soft moist
		45		SANDSTONE, medium- to coarse-grained sand, 2.5 Y 4/4 – olive brown moist, noncemented, weathered bedrock
		50		Total depth = 50 0 feet

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Program Manager for
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Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure 12

Log of Boring ASB12194

Equipment Mobile CME-75 HSAs

Elevation 5238.14 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
5		0		CL, sandy clay, 30 percent very fine-grained sand, 10 YR 4/3 - brown to dark brown, medium hard nonplastic dry, rooted, alluvium
10				
14				
15				Color change to 10 YR 6/4 - light yellowish brown due to caliche
5				
6				Decrease in very fine-grained sand to 15 percent with 15 percent silt
5				
7				Color change to 10 YR 5/4 yellowish brown with 10 percent silt and 20 percent very fine-grained sand
4				
5		5		
10				
13				Slight increase in very fine-grained sand content to 30 percent, cemented with white caliche trace coarse-grained sand
5				
5				
7				
7				Heavy caliche zone
6				
9				
9				
7		10		Heavy caliche zone
6				
9				
13				
13				Hard caliche zone
7				
9				
10				
10				Trace gravel with rounded granite cemented with caliche
5				
7		15		
12				
11				Sand size increasing with 7 percent coarse-grained sand with subrounded to rounded fine gravel
6				
9				
11				
11				40 percent poorly sorted sand
10				
13				
13				
15		20		
				SW, poorly sorted sand, very fine- to very coarse-grained sand 2 percent fine gravel 10 YR 6/6 - brownish yellow, medium dense dry, partially cemented, alluvium
14				
14				
9				
10				
5				Increase in clay content
10				
19		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 13

Log of Boring ASB12294

Equipment Mobile CME-75 HSAs

Elevation 5238 14 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
50		25		Becomes well-cemented, granite gravel and cobbles
12				Increase in gravel and cobbles to 25 percent
10				
20				
16				
13				
20				
25				Well cemented, cobble-rich, oxided layer
25				
7		30		CLAYSTONE, clay with very fine-grained sandstone lens 2 5 YR 6/4 light yellowish brown, thinly interbedded low hardness weak, dry weathered bedrock
15				
20				
25				
7				
15				
22				Color change to 2 5 YR 5/4 light olive brown, very fine- to fine- grained sandstone bed approximately 0 2 foot thick, oxidized, partially cemented friable
30				
		35		Cuttings become moist
		40		
		45		
		50		Total depth = 50 0 feet

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 13

Log of Boring ASB12294

Equipment Mobile CME-75 HSAs

Elevation 5248 06 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample	Description
5		0		CL, sandy clay very fine-grained sand, 10 YR 6/4 – light yellowish brown stiff, nonplastic dry rooted partially caliche cemented, alluvium
11				
13				
13				
7				
9				
9				
10				Color change to 10 YR 4/6 – dark yellowish brown
5				
7		5		Color change to 10 YR 8/2 – white due to heavy caliche cement
11				
26				
5				Very fine- to coarse-grained sand, trace fine gravel poorly sorted color change to 10 YR 6/4 – light yellowish brown
11				
13				
18				
9		10		
10				
12				SC, clayey sand very fine- to medium-grained sand trace coarse sand 10 YR 4/3 – dark brown medium dense low plastic dry, alluvium granite cobble
8				
2				
9				Color change to 10 YR 4/4 – dark yellowish brown slightly moist, thin oxidized stringers appears bentonitic
11				
12				
8				
11				SW/SM, sand to silty sand very fine- to coarse-grained sand 10 YR 7/4 – very pale brown medium dense nonplastic dry alluvium partially cemented, angular grains, trace fine granite gravel
12		15		
9				
7				
8				Becomes loose less well cemented
11				
13				
8				Gravel size and content increases some cobbles
12				
13				
15				
9		20		
11				
13				
15				CLAYSTONE, 2 5 Y 5/2 – grayish brown, blocky, closely fractured, moderately hard, weak dry, moderately weathered bedrock, heavy dark brownish orange oxidation along high angle fractures gypsum crystals limonitic
6				
8				
12				
13				
8				Interbeds of papery thin laminated, sandstone, very fine-grained sand 10 YR 6/2 – light brownish gray becomes less oxidized
12				
12		25		Becomes more oxidized heavy black mineralization

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 14

Log of Boring ASB12394

Equipment Mobile CME-75 HSAs

Elevation 5248 06 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
5		25		Carbonization
				Carbonaceous
		30		
				Becomes less carbonaceous
		35		
		40		Total depth = 40 0 feet
		45		

FHA2

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 14

Log of Boring ASB12384

Equipment Mobile CME-75 HSAs

Elevation 5272.46 ft. Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
5		0		CL, sandy clay fine- to medium-grained sand, 10 YR 4/4 - dark yellowish brown stiff plastic moist alluvium, noncalcareous rooted
11				
15				CL, silty clay trace fine- to coarse-grained sand, 10 YR 7/3 - very pale brown stiff, nonplastic dry alluvium local caliche
15				
				Color change to 10 YR 8/2 - white due to heavy caliche cement
4				
15				Color change to 10 YR 7/4 - very pale brown, some granite gravel
11		5		
10				SANDSTONE, very fine- to fine-grained sand, 2.5 Y 7/4 - pale yellow, low hardness, friable to weak weathered bedrock weakly cemented calcareous
5				
50				Siltstone/sandstone, very fine-grained sand 2.5 Y 7/3 - pale yellow, mottled with white caliche
				Color change to 2.5 Y 7/4 - pale yellow
		10		
		15		Becomes noncalcareous
		20		Sand fine- to medium-grained, 2.5 Y 5/6 - light olive brown, noncemented noncalcerous dry
		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Figure 15

Log of Boring ASB12494

Equipment Mobile CME-75 HSAs

Elevation 5272.46 ft Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		
		30		
		35		
				CLAYSTONE, 2.5 Y 3/3 – dark olive brown. massive thick bedded moderately fractured, soft, plastic, little weathered, bedrock, moist, minor lignite fragments, noncalcareous, iron-oxide stained fractures and partings
8 16 23 31		40		
				Trace silt
		45		
		50		Total depth = 50.0 feet

RMAA2

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Commerce City, Colorado

Prepared by:
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Figure 15

Log of Boring ASB12484

Equipment Mobile CME-75 HSAs

Elevation 5257.30 ft. Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
6		0		CL, clay, 10 YR 4/6 – dark yellowish brown, stiff, plastic moist, alluvium, rooted, trace sand and pea gravel
11				
13				Color change to 10 YR 7/3 – very pale brown mottled with white caliche some silt and very fine sand
15				
6				
6				
8				
7				Increase in sand and silt content, locally grades to SC clayey sand sand coarsens to fine– to coare–grained
5				
7		5		
8				
13				
3				SC, clayey silty sand fine– to medium–grained sand. 10 YR 6/4 – light yellowish brown medium dense nonplastic, dry alluvium, mottled with white caliche in veinlets and fractures
7				
12				
12				
8		10		
12				
14				
14				
6				CL, sandy silty clay, fine– to medium–grained sand 10 YR 6/4 – light yellowish brown stiff nonplastic, dry alluvium mottled with white caliche in veinlets and fractures
6				
12				
42				
13				Increase in sand and gravel content some fine– to coarse–grained sand fine gravel color change to 10 YR 6/4 – light yellowish brown and grades to 5 YR 7/4 – pink becomes hard
20				
17		15		
13				
4				Color change to 10 YR 5/6 – yellowish brown, becomes stiff decrease in caliche content
8				
12				Gradually grades to entirely white caliche color change to 10 YR 8/1 – white
13				
7				
13				SANDSTONE, 2.5 Y 7/4 – pale yellow, low hardness, weak weathered bedrock
8				
13				
6		20		CLAYSTONE, 2 5 Y 5/3 – light olive brown, slightly flaggy locally thin laminated, locally intensely fractured, soft plastic, weathered bedrock moist, local caliche, gypsum fracture filling, minor iron oxide
11				
13				
14				
		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

RMA2

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 18

Log of Boring ASB12594

Equipment Mobile CME-75 HSAs

Elevation 5257 30 ft Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		
		30		
		35		
		40		Color change to 2 5 Y 4/3 - olive brown
		45		Color change to 10 YR 3/3 - dark brown, some lignite may be present noncalcareous
		50		Total depth = 50 0 feet

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Commerce City, Colorado

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Figure 18

Log of Boring ASB12594

Equipment Mobile CME-75 HSAs

Elevation 5243.92 ft Date 11/23/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
2		0		SC, clayey sand very fine grained, 10 YR 5/4 – yellowish brown, medium dense 30 percent plastic clay dry alluvium, rooted
9				
15				
15				
9				Becomes partially caliche cemented
11				
13				
12				Color change to 10 YR 6/4 – light yellowish brown clay content decreases to 20 percent
5				
4		5		
7				
7				Clay content increases to 40 percent becomes silty
3				
3				CL, sandy clay, 30 percent very fine-grained sand 10 percent silt 10 YR 5/3 – brown stiff, nonplastic dry alluvium
5				
6				Clay content decreases silt content increases to 10 percent
5				
5				Heavy caliche cement
6		10		Mottled with caliche
4				
4				Caliche cemented
8				
15				
18				Trace fine rounded gravel
18				
				Increase in sand content very fine– to medium-grained sand
		15		
9				Trace to some coarse sand and fine rounded gravel color change to 10 YR 5/4 – yellowish brown, mottled with white caliche, ashy appearance, elongated black mineral grains well cemented
12				
14				
13				
4				Sand content decreases to 25 percent, micaceous color change to 10 YR 5/3 – brown
9				
11				
12				
7		20		Sand content increases to 60 percent very fine– to fine-grained, some medium– to coarse-grained sand, trace rounded gravel, color change to 10 YR 5/4 – yellowish brown, medium dense low plastic clay dry alluvium, elongate black mineralization
8				
15				
16				
3				
8				Locally very sandy, poorly sorted sand, very fine– to coarse-grained subrounded fine gravel layers 1-inch thick
8				
9				
3				Sand content decreases to 20 percent, very fine– to very coarse-grained sand poorly sorted trace fine subrounded gravel, medium hard caliche stringers contains several thin sandy veneers
6				
9		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated.
2 Munsell color chart used

RMA2

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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 17

Log of Boring ASB12694

Equipment Mobile CME-75 HSAs

Elevation 5243 92 ft Date 11/23/84

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
12		25		Sand content increases, thin, intercalated layers of sand and fine gravel
6				
9				
10				
10				Interbedded layers of sand and clay, slightly less well cemented
3				
4				
7				
8				Granite cobble
7		30		Decrease in sand content, trace fine gravel slightly moist
8				
8				Caliche
8				
6				Sandy
9				Increase in sand content very fine- to coarse-grained sand some gravel very well cemented
9				
10				
7				Caliche very thin layers of poorly sand, medium- to coarse-grained sand
8				
12		35		Quartz cobble
15				CLAYSTONE, 2 5 Y 5/3 – light olive brown, blockly, closely fractured medium hard, weak moderately weathered bedrock some caliche oxidized along fractures
9				
15				
27				
33				Very thin bedded slightly less fractured, caliche, mottled with orange oxidation to 38 feet
		40		
		45		Total depth = 45 0 feet
		50		

FMA2

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 17

Log of Boring ASB12694

Equipment Mobile CME-750 HSAs

Elevation 5268 37 ft Date 12/09/84

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
2		0		CL, clay, fine- to medium-grained sand, some silt 10 YR 4/6 – dark yellowish brown medium stiff, plastic moist alluvium, rooted, noncalcerous
6				
13				Color changes to 10 YR 7/3 – very pale brown
13				Some fine- to coarse-grained sand stiff, nonplastic dry, alluvium, calcereous, fine roots
7				
7				
8				
9				
3				
5		5		
8				
14				Trace pink granite gravel, color change to 10 YR 5/4 – yellowish brown slightly plastic slightly moist local white caliche locally very sandy
4				
8				
10				
16				Color change to 10 YR 6/6 – brownish yellow nonplastic
7				
7				
8				
6		10		Color change to 10 YR 4/6 – dark yellowish brown, stiff plastic, moist alluvium abundant caliche at contact
4				
4				CLAYSTONE, 2 5 Y 6/5 – light yellowish brown flaggy, intensely fractured, soft plastic weathered bedrock iron oxide on fractures gypsum crystals in voids
6				
8				
7				Color change to 10 YR 3/3 – dark brown moist
12				
12				
14				
		15		Becomes sandier fine- to medium-grained sand color change to 2.5 Y 6/5 light yellowish brown
		20		Interbedded clayshale and sand, color change to 2 5 Y 5/6 – light olive brown
		25		SILTSTONE, clayey sandy 2 5 Y 7/3 – pale yellow thin laminated, low hardness weak weathered, bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by.
Harding Lawson Associates

Figure 18

Log of Boring ASB12794

Equipment Mobile CME-750 HSAs

Elevation 5288 37 ft Date 12/09/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
50		25		SANDSTONE, very fine- to fine-grained sand, 2 5 Y 7/3 - pale yellow, low hardness, friable bedrock, dry, noncalcareous
				CLAYSTONE, silty sandy very fine- to fine-grained sand 2 5 Y 5/4 - light olive brown soft, plastic, bedrock, moist, noncalcerous
		30		
		35		Locally silty, some fine-grained sand, color change to 2 5 Y 5/3 - light olive brown, locally thin laminated intensely fractured, soft plastic, weathered bedrock, moist, noncalcareous, iron oxide on fractures
10				
50				Color change to 2 5 Y 5/4 - light olive brown, soft, plastic bedrock, moist noncalcareous small angular fragments
		40		
		45		
		50		Total depth = 50 0 feet

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 18

Log of Boring ASB12794

Equipment Mobile CME-750 HSAs

Elevation 5242 72 ft Date 12/13/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
10		0		SC, clayey sand, fine- to medium-grained sand, some silt, 10 YR 4/4 – dark yellowish brown, dense slightly plastic moist alluvium, rooted
13				
15				
12				Color change to 10 YR 8/3 – pale brown, mottled with white caliche
5				
2				
3				
3				Increase in clay content
5				
10		5		
9				
10				Locally sandy, trace gravel
4				
5				
5				
5				Scattered gravel caliche content increases
10				
10				
18				SC, clayey sand fine- to coarse-grained sand, 10 YR 8/4 – light yellowish brown, dense nonplastic, moist alluvium, mottled with white caliche
20		10		
10				
8				Trace scattered gravel
9				
9				Clay content gradually increases with depth
10				
18				
25				
35				
10				CL, sandy clay fine- to coarse-grained sand, 10 YR 4/4 – dark yellowish brown stiff slightly plastic moist, mottled with caliche, trace black lithic fragments alluvium
13		15		
9				
10				Color change to 10 YR 5/4 – yellowish brown
9				Some medium sand color change to 10 YR 6/4 – light yellowish brown trace iron oxide
10				
10				
10				
8		20		Sand content increases with depth interlayered clayey sand and sandy clay, trace scattered gravel
12				
12				SC, clayey sand fine- to coarse-grained sand, scattered gravel 10 YR 5/4 – yellowish brown, dense slightly plastic, moist alluvium, calcerous matrix
16				
8				
10				
11				
12				
8				
12				
13		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

RMA2

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Program Manager for
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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 19

Log of Boring ASB12894

Equipment Mobile CME-750 HSAs

Elevation 5242.72 ft Date 12/13/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
12		25		
6				
6				
8				Sand content increases with depth
10				
8				
9				
17				Color change to 10 YR 5/8 – yellowish brown
21				
5		30		
8				CL, clay some medium-grained sand, some silt, trace very coarse sand 2.5 YR 4/4 – olive brown, stiff, plastic moist alluvium
10				
14				
5				
7				Trace scattered gravel minor caliche minor iron oxide
7		35		
9				
4				
7				
10				
13				
4				
7				
14				SC, clayey sand, 10 YR 5/4 – yellowish brown to 2.5 YR 5/3 – light olive brown dense, plastic clay matrix, moist noncalcareous reworked Denver Formation alluvium
7				
10		40		
14				
20				Clay content decreases with depth, color change to 10 YR 6/4 – light yellowish brown, locally very sandy, layers of fine- to coarse-grained sand up to 0.2 foot thick, 10 YR 8/3 – very pale brown
5				
12				
15				
21				Sand coarsens with depth, fine- to very coarse-grained sand, trace gravel
10				
17				
15				Very coarse sand and pea gravel
19		45		
				SANDSTONE, fine- to coarse-grained sand, trace clay, 10 YR 6/4 – light yellowish brown, thin laminated, low hardness, friable to weak, minor local iron oxide staining minor caliche, weathered bedrock
		50		

Total depth = 50 feet

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 19

Log of Boring ASB12894

Equipment Mobile CME-750 HSAs

Elevation 5258 54 ft Date 11/28/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
8		0		SC, clayey sand fine- to fine-grained sand some silt 10 YR 3/6 – dark yellowish brown, dense 15 to 20 percent low plastic clay rooted, alluvium
15				
25				
20				
8				
8				Color change to 10 YR 6/4 – light yellowish brown lightly caliche cemented
9				
11				
4				
7		5		
11				
12				Clay content increases locally grades to CL, sandy clay becomes well cemented
4				
5				
7				White caliche
9				Sand becomes coarser grained 30 percent clay 10 YR 4/6 – dark yellowish brown local white caliche
5				
7				
9				
11		10		Color change to 10 YR 5/4 – yellow brown well cemented with caliche
10				
18				
18				
18				Clay content increases to 40 percent medium plastic clay, heavy caliche black mineralization
8				
10				
8				
7				
5				
7		15		Caliche content increases to 100 percent
9				
10				CL, sandy clay fine- to very coarse-grained sand, 10 YR 6/4 – light yellowish brown medium stiff medium plastic, moist caliche veining and fracture filling minor black mineral grains, alluvium
3				
5				
9				
11				
9				
13				Sand content increases with depth caliche content decreases
13				
8		20		
5				
7				SC clayey sand fine- to coarse-grained sand, gravel 10 YR 6/4 – light yellowish brown medium dense nonplastic dry, alluvium
7				
9				
6				
6				
9		25		

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 20

Log of Boring ASB12994

Equipment Mobile CME-750 HSAs

Elevation 5258 54 ft Date 11/28/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
15		25		SW, sand, fine- to coarse-grained sand, 10 YR 6/6 – brownish yellow medium dense nonplastic, dry alluvium
10				
30				CL, sandy clay fine- to coarse-grained sand pea gravel 10 YR 6/4 – light yellowish brown hard nonplastic dry alluvium, calcareous
48				
50				SANDSTONE, fine- to medium-grained sand, 2 5 YR 7/4 – pale yellow, low hardness friable, noncalcareous, rounded to subrounded grains, local iron oxide staining weathered bedrock
10				
43				
50				
50		30		Color change to 2 5 YR 6/4 – light yellowish brown, 5 percent medium-grained sand
		35		CLAYSTONE, 2 5 YR 5/2 – grayish brown, soft plastic weathered bedrock
35				SANDSTONE, laminated with claystone very fine-grained 2 5 YR 6/6 – olive yellow papery, moderately fractured at low angles low hardness friable moderately weathered bedrock iron-oxide staining along fractures
50		40		
		45		CLAYSTONE, 2.5 YR 5/4 – light olive brown, papery moderately fractured, soft, plastic moderately weathered, bedrock
				Becomes moist, claystone content increases with depth
				Becomes wet
		50		Total depth = 50 0 feet

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Commerce City, Colorado

Prepared by:
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Figure 20

Log of Boring ASB12994

Equipment Mobile CME-75 HSAs

Elevation 5258 30 ft Date 11/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
9		0		SC-SM, clayey sand to silty sand, very fine- to medium-grained, medium dense, nonplastic, dry alluvium lightly caliche cemented, trace silt
9				
11				
12				
9				
11				Increase in medium-grained sand
8				
9				Fining downward, increase in fine sand and clay content
6				
6		5		CL, sandy clay 10 YR 6/4 – light yellowish brown, low plastic clay, alluvium
9				
13				
5				
7				
9				
9				Decrease in clay content trace silt poorly sorted 5 percent medium sand 2 percent coarse-grained sand, less well-cemented
5				
8				
9				
9		10		SC, clayey sand poorly sorted, very fine- to coarse-grained sand 10 YR 6/4 – light yellowish brown, medium dense, 20 percent low plastic clay dry alluvium, trace subrounded quartz gravel
9				
15				Heavy white caliche
15				
15				Very well cemented with caliche
14				
15				
18				
20				Clay content increases to 35 percent
9				
11		15		
14				
22				
9				Color change to 10 YR 5/4 – yellowish brown scattered white caliche nodules, dense, very well cemented poorly sorted 5 percent silt
19				
21				
28				Increase in clay content 40 percent low to medium plastic clay
12				
20				
28				
18		20		CL, sandy clay very fine- to coarse-grained sand, 10 YR 5/3 – brown, very stiff, low plasticity dry, alluvium
8				
18				
18				
18				Ashy appearance some black mineral grains
13				
13				Trace fine gravel
19				
23				Becomes micaceous
11				
20		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Figure 21

Log of Boring BRB13094

Equipment Mobile CME-75 HSAs

Elevation 5258.30 ft. Date 11/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
20		25		
18				
9				
18				
15				
16				Sand size increasing, coarsening downward, coarse sand and fine subangular gravel, color change to 10 YR 4/3 – dark brown with white caliche, medium plasticity, black mineralization veining
8				
15				
40				
28		30		Increase in sand content very fine- to very coarse-grained sand, trace fine gravel poorly sorted color change to 10 YR 5/3 – brown with white caliche in nodules and anastomozing veinlets
18				
25				
25				
25				Some clayey sand layers, micaceous
8				
15				
9				
11				
		35		
8				Becomes gravelly, color change to 10 YR 6/4 – light yellowish brown
18				CLAYSTONE, 2 5 Y 6/4 – light yellowish brown to 2 5 Y 6/6 – olive yellow thick bedded little to moderately fractured low hardness weak moderately weathered bedrock
20				
22				
12				
18				Very carbonaceous
40				
40				
		40		
		45		Total depth = 45 0 feet
		50		

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Figure 21

Log of Boring BRB13094

Equipment Mobile CME-750 HSAs

Elevation 5258 30 ft Date 12/14/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
8		0		SC, clayey sand, fine- to medium-grained sand, some silt and clay, 10 YR 6/4 light yellowish brown dense, plastic clay matrix, moist noncalcareous thin clay layers, alluvium
10				
13				
11				Becomes calcareous
5				
6				
6				
7				CL, sandy, silty, clay fine- to medium-grained sand, 10 YR 6/4 – light yellowish brown, stiff, nonplastic, dry, calcareous minor white caliche mottling locally very sandy, alluvium
7				
11		5		
4				
15				
6				
6				SC, clayey sand, fine- to medium-grained sand some silt, 10 YR 6/4 – light yellowish brown, dense nonplastic, dry, calcareous, alluvium
9				
11				
10				CL, sandy silty, clay, fine- to medium-grained sand, 10 YR 6/4 – light yellowish brown, stiff nonplastic dry calcareous alluvium
11				
11				
14		10		SM, silty sand fine- to medium-grained sand, trace clay, 10 YR 6/4 – light yellowish brown dense nonplastic calcareous alluvium
9				
7				
4				CL, sandy clay scattered fine- to medium-grained sand 10 YR 6/4 – light yellowish brown, stiff, nonplastic dry, calcareous alluvium
11				
12				
10				Some coarse-grained sand trace pea gravel 10 YR 5/6 – yellowish brown, stiff slightly plastic, slightly moist, mottled with white caliche
12				
7		15		
9				
9				Some very coarse sand and pea gravel
8				
5				
6				
8				
8				
7				
12				
12		20		Color change to 10 YR 6/3 – pale brown non-plastic dry mottled with common white caliche rare pink granite gravel
14				
7				
12				
14				
19				
10				
44				
50				CLAYSTONE, fine- to coarse-grained sand, some silt flaggy, thin laminated soft to low hardness plastic to friable, white crystalline gypsum fracture filling calcareous, weathered bedrock
50				
6		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Figure 22

Log of Boring SAB13194

Equipment Mobile CME-750 HSAs

Elevation 5258 30 ft Date 12/14/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
16		25		Locally silty
16				
16				
9				
18				
15				SANDSTONE, clayey with pink granite gravel, 10 YR 6/4 – light yellowish brown, slight olive cast soft to low hardness, plastic to friable dry, white crystalline gypsum fracture filling, calacreous weathered bedrock
15		30		
				CLAYSTONE, olive brown (based on auger cuttings)
				Olive brown claystone some sand and gravel (based on auger cuttings)
12		35		INTERBEDDED CLAYSTONE AND SILTSTONE, claystone 2 5 Y 5/3 – light olive brown, fractured soft plastic, weathered bedrock, moist locally calcareous minor iron-oxide staining on fractures siltstone 2 5 Y 7/8 yellow, low hardness friable, dry weathered bedrock
16				
30				
35				
		40		Olive brown claystone soft plastic bedrock moist noncalcareous (based on auger cuttings)
		45		Olive brown claystone trace silt soft, plastic, bedrock moist, noncalcareous (based on auger cuttings)
		50		Total depth = 50 0 feet

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Figure 22

Log of Boring SAB13184

Equipment Mobile CME-75 HSAs

Elevation 5259 70 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
7		0		CLAY, clay with fine- to medium-grained sand, trace coarse-grained sand 10 YR 6/4 light yellowish brown stiff nonplastic dry alluvium
10				
12				Becomes calcareous
14				
5				
6				
5				
6				
7				
8		5		SC, clayey sand fine to coarse-grained sand 10 YR 4/6 – dark yellowish brown stiff, nonplastic dry mottled with caliche alluvium
9				
10				
7				
9				
13				
13				
		10		
15				
30				
50				
15				CL, clay with fine- to medium-grained sand 10 YR 7/2 – light gray hard nonplastic dry caliche-rich alluvium
21				
25				
21				
11				
15				
35		15		
50				
21				
27				SC, sandy clay clay coarse-grained sand, gravel 10 YR 5/4 yellowish brown hard, nonplastic slightly moist, alluvium
50				
7				
50				
23				
25				
26				
18		20		Color change to 2.5 Y 4/4 olive brown clay, increase in fine-grained sand with trace cobbles becomes moist
50				
30				
50				
50				
25				CLAYSTONE, sandy clayshale with trace coarse sand, 2 5 YR 4/4 – olive brown, fractured, soft, plastic moist, gypsum, calcareous iron oxide, weathered bedrock
26				
11				
19				
11				
30		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Figure 23

Log of Boring ASB13294

Equipment Mobile CME-75 HSAs

Elevation 5259 70 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
30		25	
30			
		30	
		35	
		40	
		45	
		50	

Total depth = 50 0 feet

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Figure 23

Log of Boring ASB13284

Equipment Mobile CME-75 HSAs

Elevation 5250 88 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
12		0		CL, clay fine-grained sand and silt, 10 YR 4/4 – dark yellowish brown very stiff, slightly plastic moist rooted alluvium
15				
15				
16				Caliche zone becomes stiff dry
7				
7				
8				
8				
		5		
5				
8				
8				
10				
5				
7				
6				
7		10		
10				
10				
11				
8				Color change to 10 YR 6/4 – light yellowish brown with white caliche
11				
11				
13				
8				
17				
17		15		
16				
8				SC, clayey sand fine- to coarse-grained sand, trace gravel, 10 YR 4/4 – dark yellowish brown dense nonplastic, dry calcareous moderately cemented, alluvium
20				
15				
12				
15				
20				Increase in gravel
50				
12		20		CL, sandy clay, clay with gravel, 10 YR 6/3 – pale brown to 10 YR 4/4 – light yellowish brown hard nonplastic, calcareous alluvium
25				
25				
18				
8				
12				
11				
12				
15				Color change to 10 YR 6/3 – pale brown with 20 percent fine- to coarse-grained sand
15				
16		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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Figure 24

Log of Boring ASB13394

Equipment Mobile CME-75 HSAs

Elevation 5250 88 ft. Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
23		25		Increase in sand to 40 percent with trace pebbles and gravel
11				
26				
33				
45				
19				
20				
22				SC, clayey sand sand and gravel, 7 5 YR 4/6 – strong brown, hard plastic moist, calcareous, alluvium
20				
12		30		Color change to 2 5 Y 5/4 – light olive brown to 2 5 Y 4/4 – olive brown, becomes slightly plastic
18				
22				Color change to 10 YR 7/1 – light grey with grey volcanics vuggy with iron-oxide staining, welded tuff
30				
11				
20				
23				
32				
12				CH, clay, trace gravel, 2 5 Y 4/4 – olive brown, hard, plastic, moist, reworked Denver Formation fragments, calcareous alluvium
14				
22		35		
26				
7				
10				
16				
17				
7				Color change to 2 5 Y 5/4 – light olive brown, noncalcareous
7				
10				
10				
4		40		
10				
14				
14				
7				
8				
11				
11				
5				
7				
8		45		
21				CLAYSTONE, 2 5 Y 5/4 – light olive brown, laminated soft, fractured, moist, iron-oxide on fractures, weathered bedrock
8				
16				
31				
36				
		50		Total depth = 50 0 feet

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Figure 24

Log of Boring ASB13394

Equipment Mobile CME-75 HSAs

Elevation 5242 02 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
6		0		CL, sandy silty clay, 20 percent sand 10 YR 5/4 – yellowish brown stiff, slightly plastic slightly moist, rooted alluvium
6				
7				
6				Decrease in sand content to 10 percent, color change to 10 YR 7/3 – very pale brown caliche
7				
7				
7				
5				Increase in sand to 40 percent color change to 10 YR 6/4 – light yellowish brown becomes medium dense and dry
7				
7		5		
6				
6				
5				Decrease in sand to 10 percent, becomes stiff
4				
10				
16				SC, clayey sand fine– to medium–grained sand 40 percent clay matrix 10 YR 6/4 – light yellowish brown hard nonplastic, dry, caliche–rich, alluvium
16		10		
20				
25				
23				
4				
16				
23				
18				
5				
6				
7		15		Decrease in fine– to medium–grained sand content to 25 percent
16				
4				Sand content increases downward to 40 percent
12				
15				
16				
8				
9				
16				
20				
10		20		CL sandy clay less than 40 percent fine– to medium–grained sand trace pea gravel 10 YR 5/6 – yellowish brown stiff slightly plastic, slightly moist caliche–rich alluvium
12				
15				
20				
6				Decrease in gravel
7				
18				
15				
8				
12				
16		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Figure 25

Log of Boring BRB13494

Equipment Mobile CME-75 HSAs

Elevation 5242.02 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
22		25		
8				SC, clayey sand fine- to coarse-grained sand, 10 YR 5/6 - yellowish brown, dense, slightly plastic moist alluvium
14				
14				
20				
7				
16				
26				
32				
10		30		Increase in clay content, color changes to 10 YR 6/4 - light yellowish brown
12				
13				
28				
11				Interbedded sandy clay and clayey sand with color change to 10 YR 5/6 yellowish brown stiff plastic with trace pea gravel
22				
14				
19				
6				
7				
10		35		
22				
5				
11				
14				
14				CL, sandy clay trace gravel 10 YR 5/6 - yellowish brown stiff plastic moist minor caliche, alluvium
6				
7				
8				
17				
3		40		
7				
12				
15				
3				
4				
7				
19				
4				
8				
12		45		
15				
5				
8				
12				
15				
5				Very fine- to fine-grained sand
5				
10				
12		50		

Total depth = 50.0 feet

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Figure 25

Log of Boring BRB13494

Equipment Mobile CME-75 HSAs

Elevation 5251.59 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
9		0		SC, clayey sand, very fine- to fine-grained sand, 10 YR 5/4 – yellowish brown, medium dense, nonplastic, caliche-rich, rooted, alluvium
12				
11				CL, clay very fine- to fine-grained sand, 10 YR 5/4 – yellowish brown, low plasticity, dry, caliche cemented alluvium
12				
8				
7				
9				
10				
7				
8		5		
12				
8				
5				Color change to 10 YR 6/4 – light yellowish brown
4				
4				
4				
4		10		Heavy caliche zone
4				
15				
18				
7				Sand becomes poorly sorted and micaceous
8				
11				
13				
9				
15				
19		15		
19				
8				
15				SC, clayey sand 10 YR 4/4 – dark yellow brown loose dry alluvuim
15				
15				
7				
13				
15				
17				
10		20		
15				CL, sandy clay 10 YR 5/6 – yellow brown, dry alluvrum
15				
15				
10				Heavy caliche zone
20				
20				
21				
4				Thin gravel layer slight increase in clay
15				
20		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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Figure 28

Log of Boring BRB13594

Equipment Mobile CME-75 HSAs

Elevation 5251 59 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
21		25		
2				
2				
5				
10				Increase in sand content, color changes to 10 YR 5/3 - brown, low plasticity dry, well-cemented, caliche-rich alluvium
5				
15				
18				
19				
4		30		Dendritic caliche, fine to coarse gravel
15				
21				
23				
7				Sand content increases to 15 percent, no caliche
20				
15				
20				
5				
10				
19		35		
20				
8				SC, clayey sand, very fine- to very coarse-grained sand 10 YR 5/2 - grayish brown to 10 YR 5/3 - brown medium dense nonplastic poorly sorted dry, alluvium
9				
14				
14				
8				Very fine- to medium-grained sand layers 1-inch thick
11				
11				Sand and gravel well-graded color change to 2 5 Y 5/3 - light olive brown, becomes slightly moist
11				
9		40		
9				
12				
12				Water level estimated during drilling at 41 5 feet
				Total depth = 42 0 feet
		45		

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Figure 28

Log of Boring BRB13594

Equipment Mobile CME-75 HSAs

Elevation 5287 15 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
3		0		SP, sand, very fine-grained to fine-grained sand 10 YR 6/4 – light yellowish brown medium dense, nonplastic, dry, rooted, lightly cemented, alluvium
18				
20				
20				Color change to 10 YR 6/6 – brownish yellow, less cemented, localized caliche veins
9				
10				
10				
12				
8				
8		5		
9				
8				SC, , clayey sand, 10 YR 6/4 – light yellowish brown, loose low plasticity, dry, caliche-cemented alluvium
6				
8				
7				
10				
10				
9				
8				
9		10		
6				
6				
6				
10				
12				Very heavy caliche dense well-cemented
22				
35		15		
35				
12				Sand becoming poorly sorted, 5 percent medium- to very coarse-grained trace fine subrounded, subangular gravel medium gravel
22				
22				
21				
9				
21				
20				
19				
5		20		Caliche in veins well-cemented, becoming fine-grained
14				
20				
25				
10				Very fine- to fine-grained sand trace medium-grained to coarse-grained cobbles
20				
20				
18				
12				Increase in clay to 40 percent
18				
30		25		

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated.
2 Munsell color chart used

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Figure 27

Log of Boring BRB13694

Equipment Mobile CME-75 HSAs

Elevation 5287 15 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
30		25		
6				Color change to 10 YR 5/4 – yellowish brown becomes very stiff to hard
24				
24				CLAYSTONE, 2 5 Y 5/2 – grayish brown, flaggy, closely fractured at high angles low hardness weak, iron-oxide stained, interbedded with siltstone and sandstone, weathered bedrock
19				
6				
17				Increase in very fine-grained sand color change to 10 YR 7/3 – very pale brown to 10 YR 7/6 yellow with oxidation zones from 29 5 to 34 feet
24		30		
22				
6				
24				
35				
50				
				Color change to 10 YR 4/2 – dark grayish brown
		35		
		40		Cuttings become plastic
		45		Cuttings become slightly moist, medium plastic
		50		Total depth = 50 0 feet

FR-A2

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Figure 27

Log of Boring BRB13694

Equipment Mobile CME-75 HSAs

Elevation 5269.04 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
11		0		SC, clayey sand fine- to medium-grained sand, 25 percent silt and clay 10 YR 5/4 – yellowish brown medium dense, nonplastic, moist, rooted, alluvium
16				
24				
20				Increase in clay color changes to 10 YR 5/6 – yellowish brown, becomes hard, dry
10				
7				Decrease in clay
7				
9				
		5		CL, sandy clay, fine- to medium-sand, 10 YR 6/4 – light yellowish brown, nonplastic dry, caliche-rich alluvium
10				
9				
10				
10				
12				Sand content increasing
16				
12				
13				
8		10		
10				
11				SC, clayey sand fine- to medium-grained sand 10 YR 6/4 – light yellowish brown stiff to hard nonplastic, dry alluvium
15				
10				
19				Color change to 10 YR 6/3 – pale brown due to increased caliche
24				
20				
10				
12				
14		15		
16				
6				
16				
20				
23				
11				
19				
19				Trace coarse-grained sand and gravel color change to 2/5 Y 6/3 light brown becomes dense slightly plastic moist
14				
10		20		
29				
30				
25				
10				Coarse gravel and cobbles composed of pink granite with white quartz
12				
20				CLAYSTONE, 2 5 YR 5/4 – light olive brown closely fractured soft plastic, moist iron-oxide stained weathered bedrock
13				
10				
20				Grades to 2.5 Y 5/2 grayish brown to 2 5 5/0 grey
30		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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Figure 28

Log of Boring BRB13794

Equipment Mobile CME-75 HSAs

Elevation 5269 04 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
32		25	X	Cuttings olive brown
		30		
		35		
		40		
		45		
		50		Total depth = 50 0 feet

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Figure 28

Log of Boring BRB13794

Equipment Mobile CME-75 HSAs

Elevation 5239.31 ft Date 1/8/94

Blows/6"	*HNU/OVA (ppm)	Depth (ft)	Sample	Description
9		0		CL, clay, fine- to medium-grained sand, 10 YR 4/6 dark yellowish brown low plasticity stiff, slightly moist, rooted, alluvium
9				
15				
18				Becomes calcareous
9				
6				
8				
7				
		5		
9				
10				
10				
9				
5				
7				SC, clayey sand 50 percent fine- to medium-grained sand 10 YR 6/6 – brownish yellow stiff, nonplastic dry, alluvium
7				
7				Becomes calcareous
10		10		
15				
11				
12				
5				Decrease in sand content to 20 percent color change to 10 YR 6/4 – light yellowish brown
7				
11				
13				
12				
22				
22		15		
22				
7				Slight increase in sand content to 25 percent
12				
12				
13				
13				
17				
14				
12				
6		20		White caliche filling fractures
6				
10				
10				
18				
32				
27				
34				
18				CL, sandy clay, less than 20 percent fine- to medium-grained sand 10 YR 6/4 – light yellowish brown stiff, high plasticity, slightly moist alluvium
23				
16		25		

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated.
2.Munsell color chart used

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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 28

Log of Boring BRB13884

Equipment Mobile CME-75 HSAs

Elevation 5239 31 ft Date 1/6/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
22		25		
7				
12				
12				
20				
18				Scattered pea-sized gravel
38				
38				
40				
8		30		
12				
18				
18				
5				Becomes moist
15				
20				
22				
8				
10				
14		35		
20				
9				Slight increase in sand content
17				
25				
29				
5				Increase in sand content
8				
14				
14				
8		40		
18				SC, sandy clay well sorted, poorly graded sand, fine- to medium-grained sand, 10 YR 7/3 - very pale brown, dense, nonplastic, moist, alluvium
25				
24				
10				Interbedded 1-inch thick clay layers
15				
15				
16				
9				
18				
17		45		
25				
20				
19				
18				
20				
10				Becomes very moist trace coarse sand
15				
16				
20				
		50		Total Depth = 50 0 feet

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 29

Log of Boring BRB13894

Equipment Mobile CME-750 HSAs

Elevation 5276 44 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
3		0		SC, clayey sand, very fine- to fine-grained sand, 10 YR 4/6 – dark yellowish brown grading to 10 YR 6/6 – brownish yellow, medium dense nonplastic dry trace silt, rooted lightly cemented alluvium
7				
18				
13				Caliche
9				
10				
12				
12				Thin layers of well sorted coarse sand up to 1/2 inch thick at 1 inch intervals, loose
6				
6		5		
7				
8				Some medium- and coarse-grained sand
6				
6				
7				
7				
5				
7				
6				
7		10		
6				Increase in clay content cemented
6				
6				
7				Color change to 10 YR 4/6 – dark yellowish brown with white caliche well cemented with caliche
4				
8				
5		15		
6				Heavy caliche trace fine glassy quartz with a welded appearance
10				
12				CL, sandy clay very fine- to coarse-grained sand 10 YR 8/4 – very pale brown stiff, low-plastic, dry trace fine glassy gravel, trace very coarse sand cemented alluvium
9				
17				
11				Color change to 10 YR 5/3 – brown well cemented caliche in white nodules trace fine subrounded gravel
9				
8				
13				
10		20		Becomes less well cemented heavy caliche
23				
21				
15				
5				
4				
5				
5				
4				Color change to 10 YR 5/4 – yellowish brown, slightly moist white crystals black mineralization, locally very sandy very fine- to fine-grained trace gravel
6				
6		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 30

Log of Boring SAB13884

Equipment Mobile CME-750 HSAs

Elevation 5278.44 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
7		25		
4				Clay becomes medium plastic
7				
5				
8				
4				Sand becomes coarse- to very coarse-grained
8				
10				
15				Fine gravel and cobbles, oxidized
4		30		Rounded gravel and cobbles
14				SC, clayey sand, poorly sorted sand,
28				Quartz cobbles
50				Granite cobbles
50				Well sorted medium sand, minor clay content loose black mineralization
				VOLCANOCLASTIC SANDSTONE, 10 YR 7/1 – light gray hard moderately strong, ashy appearance, glassy sand grains, weathered bedrock
10				
12				
25		35		SANDSTONE, 2 5 YR 7/6 – yellow very fine-grained, blocky, thick, moderately fractured low hardness, weak friable, minor 7 5 YR 6/8 – reddish yellow, oxidation moderately weathered bedrock
50				
10				
20				
35				Sandstone beds become thinner
37				
		40		
		45		
				Becomes moist, plastic
		50		
				Total depth = 50 0 feet

RMA2

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 30

Log of Boring SAB13994

Equipment Mobile CME-750 HSAs

Elevation 5279.99 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
11		0		SC, clayey sand, fine- to coarse-grained sand 10 YR 5/4 - yellowish brown dense nonplastic, moist rooted alluvium
12				
20				
16				Becomes calcareous, sand fining downward, color change to 10 YR 6/3 - pale brown, medium dense, dry
11				
8				
6				
6				
13				
10		5		
7				
6				
4				Increase in clay content becomes stiff
4				
6				
7				Granite and quartz-rich gravel
10				
12				Color change to 10 YR 8/2 - white well cemented with caliche
12				
14		10		
12				
12				
14				
16				Gravel layer
11				
15				
11				
12				
		15		
9				Color change to 10 YR 6/3 - pale brown to 2.5 Y 6/3 - light yellowish brown
21				CLAYSTONE, silty claystone 10 YR 4/2 - dark grayish brown fractured soft oxidized, weathered bedrock
28				
49				
12				
18				
21				
24				
19		20		SANDSTONE, silty sandstone 2.5 Y 5/6 - light olive brown slightly flaggy locally thin laminated to laminated, soft gypsum crystals weathered bedrock
29				
50				
				CLAYSTONE, silty claystone 2.5 Y 6/3 - light yellowish brown, thin laminated soft moist weathered bedrock
		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used.

RMA2

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 31

Log of Boring BRB14094

Equipment Mobile CME-750 HSAs

Elevation 5279 99 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
		25		
		30		Color change to 10 YR 4/2 – dark grayish brown
		35		Color change to 2 5 Y 4/3 – olive brown
		40		Color change to 2 5 Y 5/3 – light olive brown
		45		Color change to 2 5 Y 4/3 – olive brown
		50		Total depth = 50 0 feet

RMA2

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by·
Harding Lawson Associates

Figure 31

Log of Boring BRB14094

Equipment Mobile CME-750 HSAs

Elevation 5284.28 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
16		0		SC, clayey sand, fine- to medium-grained sand, 10 YR 4/4 - dark yellowish brown hard plastic, moist rooted alluvium
16				
15				Color change to 10 YR 6/4 - light yellowish brown becomes dense
14				
4				Color change to 10 YR 74 - very pale brown, becomes medium dense nonplastic, dry increase in caliche
5				
7				
8				
9				
11		5		
11				
13				CL, sandy clay fine- to medium-grained sand 10 YR 7/3 - very pale brown stiff nonplastic dry calareous, alluvium
7				
6				
5				
6				
12		10		
11				SC, clayey sand fine- to medium-grained sand and silt, 10 YR 6/4 - light yellowish brown stiff nonplastic dry calareous alluvium
12				
12				
8				Sand content increases
27				
22				
24				
14				Sand content decreases
14				
18		15		
20				
10				
28				
33				
41				
35				
35				
33				
42				
29		20		
3				
30				
30				Heavy caliche zone
27				
11				
17				
12				
14				
7				
11		25		CLAYSTONE, silty claystone 10 YR 5/2 - grayish brown thin laminated fractured soft, oxidized, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 32

Log of Boring BRB14194

Equipment Mobile CME-750 HSAs

Elevation 5264.28 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
21		25		Color change to 2.5 Y 6/3 – light yellowish brown, fractured, soft oxidized, slightly calcareous, weathered bedrock
38				
7				
7				
10				
24				
		30		
		35		
		40		Color change to 2.5 Y 5/4 – light olive brown
		45		
		50		Total depth = 50.0 feet

RMA2

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 32

Log of Boring BRB14194

Equipment Mobile CME-750 HSAs

Elevation 5242.76 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	
2		0		SC, clayey sand, fine- to coarse-grained sand, 10 YR 6/4 – dark yellowish brown stiff moist, rooted alluvium
7				
14				
12				
8				
16				
12				
14				
8				
6		5		
14				
10				CL, clay, 25 percent fine- to coarse-grained sand, 10 YR 6/3 – pale brown stiff nonplastic, dry, calcareous alluvium
3				
7				
12				
11				Heavy white caliche color change to 10 YR 8/2 – white
12				
22				
26				
31		10		
12				
28				
31				
16				Increase in gravel to 5 percent
16				
42				
26				
24				Increase in fine- to medium-grained sand to 15 percent color change to 10 YR 6/3 – pale brown
11				
19		15		
15				
				Increase in fine- to medium-grained sand to 20 percent color change to 10 YR 6/4 – light yellowish brown becomes slightly moist some caliche
7				Increase in sand content
9				
12				
14				
11		20		Pea gravel and calcium carbonate
4				
26				
19				
3				Color change to 10 YR 5/4 – yellowish brown
7				
7				
6				
		25		

Notes 1. All HNU/OVA readings equal to zero parts per million except as indicated
2. Munsell color chart used

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 33

Log of Boring BRB14294

Equipment Mobile CME-750 HSAs

Elevation 5242 76 ft Date 12/05/84

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
3		25	
11			
50			
5			
14			
18			
23			
6		30	
8			
12			
17			
6			
12			
20			
28			
4			
7			
9		35	
12			
4			
12			
16			
14			
5			
7			
7			
9			
3		40	
9			
17			
15			
14			
9			
8			
15			
5			
16			
30		45	
18			
5			
11			
15			
9			
3			
4			
4			
7			
		50	

SC, medium-grained sand trace silt, clay 10 YR 6/3 – pale brown dense slightly plastic moist, calcareous alluvium

CLAYSTONE, silty claystone very fine-grained sand, 10 YR 5/2 – to 10 YR 5/3 – grayish dark brown, stiff plastic moist, weathered bedrock

Color change to 10 YR 5/4 – yellowish brown with olive cast, becomes very moist

Total depth = 50 0 feet

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 33

Log of Boring BRB14294

Appendix F

BORING SURVEY LOCATIONS AND ELEVATIONS

Table F.1: Rocky Mountain Arsenal Task 93-03, Geotechnical Boring Program Boring Coordinates, Elevations, and Total Depths

Boring Number	Northing	Easting	Elevation (feet)	Total Depth (feet)
BRB11094	1732796 46	3185199.74	5262 79	175.0
SAB11194	1733519.50	3184717.12	526 1.09	170.0
ASB11294	1735065 73	3184067 77	5239.41	112 9
SAB11394	1737090 25	3185094.11	5199.23	20.0
WEB11494	1736578.29	3183652.39	5206.26	33 7
ASB11594	1736523.14	3184082.64	5211.37	30.0
ASB11694	1736517.92	3184942 96	5215.21	43 0
SAB11794	1735696 10	3184268 72	5223 39	45 0
ASB11894	1735535.45	3184941.71	5240.78	35.0
ASB11994	1735673.26	3185567.50	5234.48	50.0
ASB12094	1735318.49	3183567 17	5230.59	50 0
SAB12194	1734748 81	3184933.56	5249.27	50 0
SAB12294	1734602.71	3183908.97	5238.14	50 0
SAB12394	1734552 40	3184378.05	5248 06	40.0
ASB12494	1734198 45	3184942 70	5272.46	50.0
ASB12594	1734314 95	3185416 76	5257.30	50 0
SAB12694	1734039.94	3183924 62	5243.92	45 0
ASB12794	1733757 10	3184937.14	5268.37	50.0
SAB12894	1734085.12	3185832 84	5242.72	50 0
BRB12994	1733262 00	3183856 48	5256.54	50 0
BRB13094	1733214 84	3184323 49	5258.30	45.0
SAB13194	1733018 63	3184904 60	5264 65	50.0
ASB13294	1732998.91	3185633.99	5259.70	50.0
ASB13394	1733663 16	3185845 40	5250 88	50 0
BRB13494	1733215 95	3186095.84	5242 02	50.0
BRB13594	1733627 82	3184009.06	5251.59	42.0
BRB13694	1732773.51	3184382 37	5267 15	50.0
BRB13794	1732639.27	3184914 28	5269 04	50 0
BRB13894	1732718.00	3186237.23	5239 31	50 0
WEB13994	1732294 74	3184257 85	5276 44	50.0
BRB14094	1732290.62	3184924 20	5279.99	50 0
BRB14194	1732311 69	3185622 90	5264.28	50.0
BRB14294	1732309.24	3186349.99	5242.76	50.0

The boreholes were surveyed by a State of Colorado licensed surveyor using the 1983 horizontal datum and the 1988 vertical datum

Appendix G

GEOPHYSICAL LOGGING DATA
(not included in this copy)

Appendix H

COST ESTIMATES
(not included in this copy)

Appendix I

FINAL WORK PLAN FOR MATERIAL AND AREA FEASIBILITY STUDIES

Technical Support For Rocky Mountain Arsenal

Final Work Plan for Material and Area Feasibility Studies Soils Support Program Rocky Mountain Arsenal Commerce City, Colorado

Prepared for

Program Manager for Rocky Mountain Arsenal
Building 111, Rocky Mountain Arsenal
Commerce City, Colorado 80022-2180

HLA Project No 21907 102010 3
Contract No DAAA05-92-D-0003
Delivery Order No 0007 (Task 93-03)

THIS DOCUMENT IS INTENDED TO COMPLY WITH THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF THE ARMY UNLESS EXPRESSLY MODIFIED BY A SUBSEQUENT DOCUMENT THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT

November 9, 1994

Harding Lawson Associates
Engineering and Environmental Services
2400 ARCO Tower, 707 Seventeenth Street
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1.0 INTRODUCTION

This Work Plan was prepared for the Material and Area Feasibility Studies portion of the Feasibility Study (FS) Soils Support Program as Data Requirement A002, a contract deliverable under Delivery Order 0007 (Modification to Task 93-03 Feasibility Study Soils Support Program) of Contract DAAA05-92-D-0003 between Harding Lawson Associates (HLA) and the U.S. Department of the Army (Army) This report was prepared by HLA at the direction of the Army for the sole use of the Army and the signatories of the Federal Facilities Agreement (FFA) of Rocky Mountain Arsenal (RMA), the only intended beneficiaries of this work.

1.1 Document Purpose, Scope, and Organization

The purpose of this Work Plan is to outline the procedures and logic used to conduct the Material and Area Feasibility Subtasks for the FS Soils Support Program. The purpose of these additional subtasks is to (1) evaluate whether onsite materials are suitable for constructing landfill liners and caps, (2) identify a potential landfill site at RMA, and (3) evaluate the suitability of the proposed site for hazardous waste disposal.

The scope of this Work Plan includes a description of the Material and Area Feasibility field subtasks The Material Feasibility subtask includes borrow area selection, test fill construction, and infiltration testing (sealed double-ring infiltrometer [SDRI] testing and two-stage borehole [TSB] permeability testing) The Area Feasibility subtask consists of 3 deep boreholes (continuously cored for geologic data) and up to 30 boreholes (continuously sampled for geotechnical and geological data)

This Work Plan is organized to present the requisite task background and objectives; describe each subtask's design; provide construction, drilling, and sampling procedures for the field programs; present proposed geotechnical testing methods, and discuss data evaluation and reporting procedures and protocols Section 1 2 of this document presents task background and objectives, Section 2.0

presents test fill construction, testing procedures, and data evaluation, and Section 3 0 presents geologic and geotechnical subtask design, procedures, geotechnical testing, and data evaluation.

1.2 Task Background and Objectives

The primary objective of this task is to collect soil data to support the Detailed Analysis of Alternatives (DAA) portion of the Onpost Operable Unit at RMA and the Record of Decision (ROD) RMA task background and specific task objectives are discussed in the following subsections

1.2.1 Task Background

RMA was established in 1942 by the Army as a manufacturing facility for the production of chemical and incendiary munitions Military, industrial, and agricultural chemicals, primarily pesticides and herbicides, were also manufactured at RMA by several lessees from 1947 to 1982 The industrial waste liquid produced from operations performed by the Army and its lessees was initially discharged to Basin A, an unlined basin in Section 36. Subsequently, liquid wastes were discharged to other unlined basins and, after 1956, to Basin F, which was asphalt-lined. Although solid wastes were disposed of primarily in Section 36, other onpost disposal sites were also used. Some of the basins, pits, burn sites, sewers, and structures (buildings, pipes, and tanks) became sources of soil and groundwater contamination as a result of spills, leaks, or other releases

Based on the National Contingency Plan (NCP) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance, and consistent with the FFA, the Development and Screening of Alternatives (DSA) portion of the FS was performed to establish remedial alternatives capable of achieving the remedial action objectives (RAOs) for RMA. Alternatives retained after the screening process are currently being further evaluated as part of the DAA portion of the FS

The soils DSA focused on several remedial alternatives for the soils medium including onpost landfilling of materials and capping. The soils medium that is addressed in the soils DSA consists of unsaturated soils, bedrock, fill material, process water lines, chemical and sanitary sewer lines, lake

sediment, and soil/debris mixtures in disposal trenches or landfills, the term "soils" is used for convenience in this document to refer to any of these materials Recognizing that interactions will occur between soils and other contaminated media such as structures and groundwater during the implementation of remedial alternatives, the impacts and interactions of other media on remedial approaches developed for RMA are being addressed in the DAA portion of the FS Since landfilling and capping remedial alternatives were retained as remedial alternatives in the DAA, the Program Manager for Rocky Mountain Arsenal (PMRMA) identified additional data needs that are required to support completion of the DAA. The data needs addressed under this task are discussed below.

1.2.2 Task Objectives

The objective of the test fills and infiltration testing of the test fills (material feasibility) is to evaluate whether onsite materials are suitable for constructing landfill liners and caps The objective of the geologic/geotechnical borings (area feasibility) is to obtain adequate data regarding the geology and geotechnical characteristics of the site to evaluate the feasibility of constructing a landfill in the existing foundation materials The work will include constructing two clay soil test fills and conducting permeability tests on the test fills to evaluate the suitability of onpost materials for use as liner and cap material. The work also includes coring, geophysical logging, soil sampling, and physical property testing to evaluate the geologic and geotechnical characteristics of the preferred landfill area.

This program will support the evaluation of remedial alternatives in the DAA involving onpost landfilling of materials and capping The program is scoped as an FS-level investigation to validate and refine feasibility and cost information in the DAA-FS Investigations will be conducted in a manner consistent with the NCP and CERCLA as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA)

2.0 TEST FILL CONSTRUCTION AND TESTING

This section presents the test fill construction and testing program to be performed under the FS Soils Support Program, Subtask 1 entitled, Material Feasibility The test fill construction and testing program includes the construction of two test fills using two soil types native to RMA and the subsequent field testing of the test fills for in situ permeability The Material Feasibility portion of the FS Soils Support Program has two main objectives (1) to verify that onpost soils are capable of meeting the required liner permeability of less than or equal to 1×10^{-7} centimeters per second (cm/s) and (2) to evaluate the optimum lift thickness, moisture content, density, and the compactive effort necessary to achieve this permeability Permeability of the constructed test fills will be measured both in the field and in the laboratory to evaluate the suitability of the materials and methodology used to construct the test fills Adjustments to the material type, density, and moisture content of the recompacted soil liner may be necessary pursuant to the results of the test fill program.

2.1 Test Fill Location and Proposed Borrow Material

To simulate future landfill clay liner construction conditions as closely as possible, the test fills will be constructed at the site currently considered to be the preferred landfill location, the western half of Section 25 (Figure 2.1) (Ebasco, 1988) The site was approved by the U.S. Fish and Wildlife Service (USFWS) prior to construction of the test fills

Figure 2 1 also illustrates the two proposed borrow areas where soil for the test fill construction will be excavated The borrow areas were identified in the Draft Final Feasibility Study Soils Support Program Report (HLA, 1994a) to contain suitable borrow material. The borrow sites were also approved by USFWS for excavation provided the areas were reseeded following excavation. The revegetation plan for the borrow areas is presented in Section 2.2.

2.2 Test Fill Construction Procedures

Each of the proposed test fills will be approximately 100 feet long by 40 feet wide at the top of the test fill (Figure 2 2) The 100-foot length and 40-foot width will allow the SDRI and TSB

permeability testing equipment to be placed at the recommended 12 to 15 feet from the sides and slopes of each test fill to avoid encountering edge effects (as shown in Figure 2 3) The recommended spacing is designed to avoid contact with the sides and slopes of the test fill where the lift construction may not meet minimum specifications and therefore may not be representative of most of the clay liner test fill

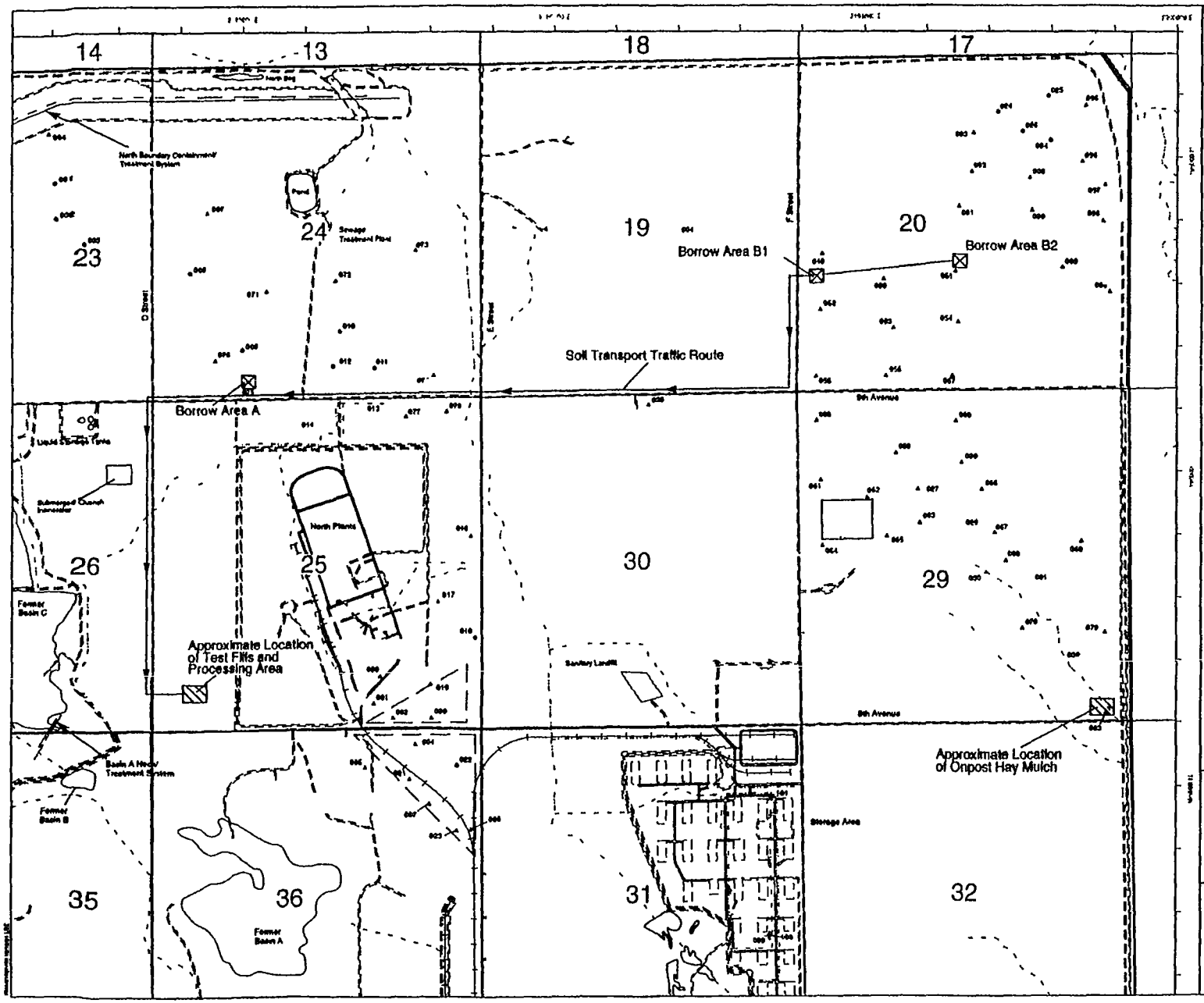
As described below in the construction procedures, the test fills will be constructed by first stripping approximately 4 inches of topsoil, then placing the various test fill layers on the prepared subgrade Test fill soil will be processed for clod size and moisture content prior to compaction. This will be accomplished in the large processing areas adjacent to the test fills

Each test fill surface will slope uniformly to one side at a 2 percent slope. This design will provide positive drainage and will simulate actual liner construction conditions Surface-water run-on control will not be necessary because of the above-grade configuration of the test fills

Upon completion of the test fills, the area will be regraded to smooth out the contours of the test fills and the immediate surroundings The stockpiled topsoil will be spread over the test fills and other disturbed areas This topsoil will prevent desiccation cracking of the test fill surface and also serve as the final "closure" layer of the test fill No further closure activities, other than seeding and mulching, will be performed.

2.2.1 Excavation

Topsoil will be stripped from the affected area of the borrow sites prior to excavation of actual test fill material This topsoil will be stored adjacent to each respective borrow site Necessary volumes of soil from each borrow area will be excavated under the supervision of the Engineer (HLA) The Engineer will visually inspect all borrowed material prior to transport. Scrapers and trucks will be used to excavate and transport borrow soils to the prepared stockpile areas. Once the excavation is



Explanation

- Boring location for Stage 1 of Boring Program Nunn Clay
- Boring location for Stage 1 of Boring Program Weld Clay
- Boring location for Stage 1 of Boring Program Brescer Clay
- Boring location for Stage 2 of Boring Program Nunn Clay
- Boring location for Stage 2 of Boring Program Weld Clay
- Surface sample location for Stage 2 Berm Material
- Railroad
- Ditch or stream
- Paved road
- Unpaved road
- 16 Section number

Containment Systems

- Physical barrier
- Hydraulic barrier
- Recharge trenches
- Barrier wall

Note:
The boring identification numbers shown have been abbreviated. The full boring identification number contains the soil unit before the number and 93 for 1993 at the end. For example, the complete boring identification number for Boring 012 is WEB01293

0 1500
Scale in feet

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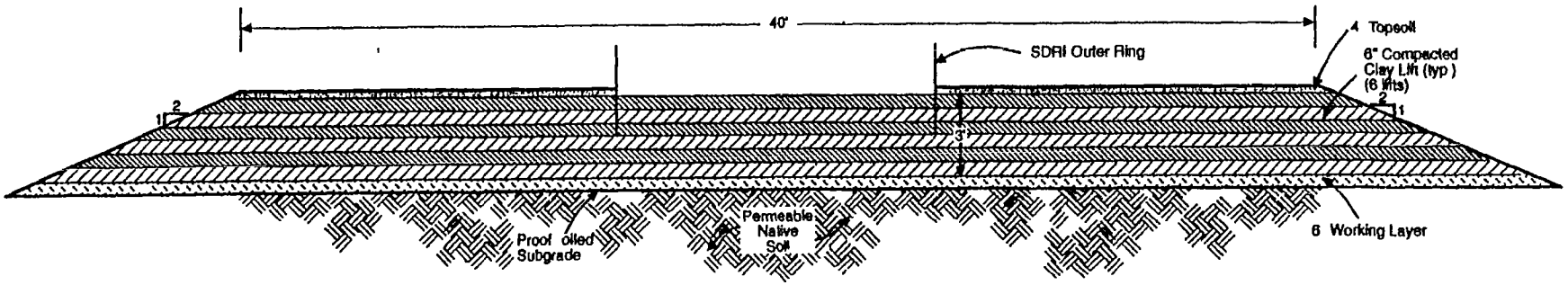
Figure 2 1

Site Vicinity Map

Typical Test Fill Section



Explanation

SDRI Sealed double-ring infiltrometer

Typ. Typical

Note Maximum slope shall be 2H:1V on long sides and 3H:1V on ends of test fill. Minimum slope shall be 3H:1V on long sides and 4H:1V on ends of test fill.

0 2.5 5
Scale in feet

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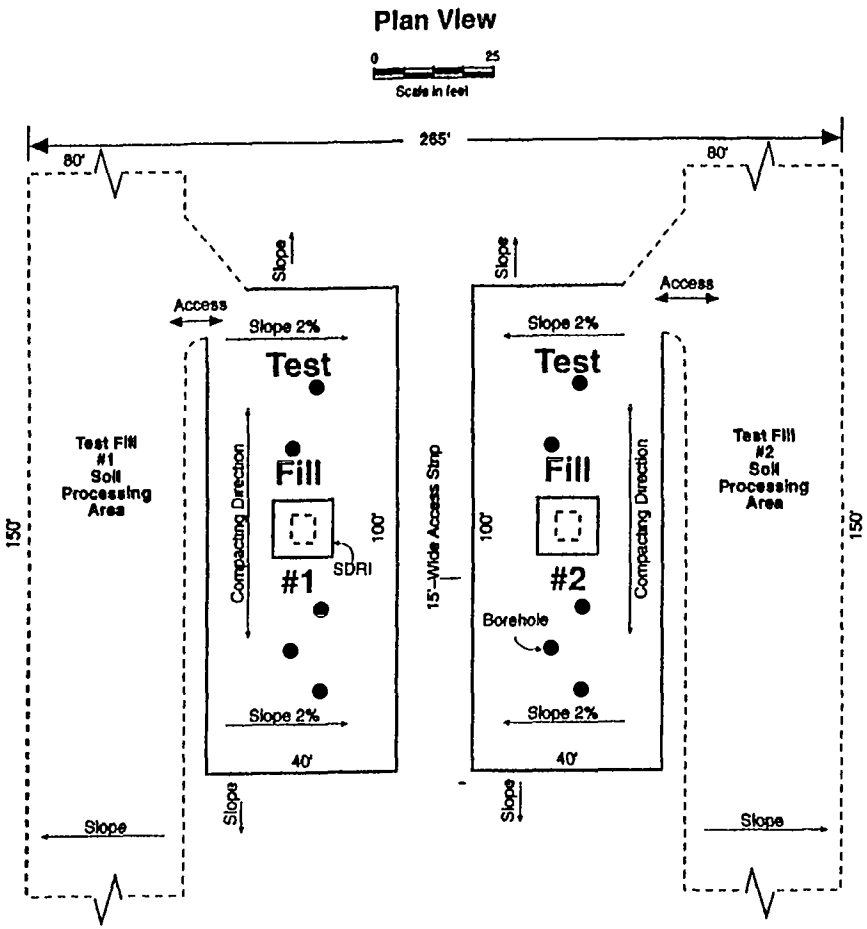
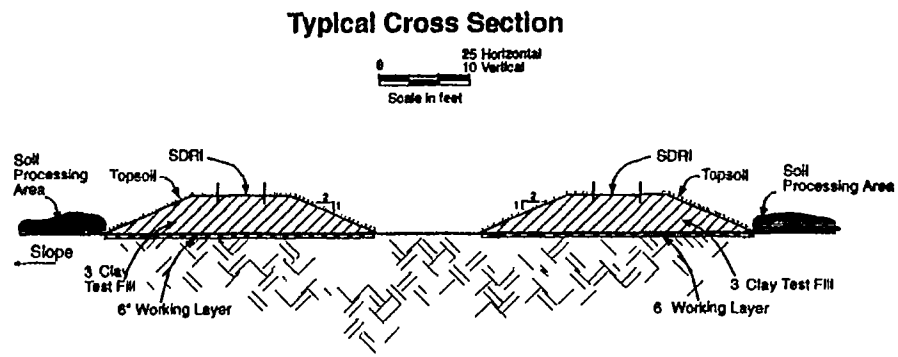
Figure 2.2

Typical Test Fill Section





Explanation

SDRI Sealed double-ring infiltrometer

● Two-stage borehole

Native soil

Working layer

Clay test fill

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Figure 2 3

Test Pill Layout

completed, the borrow pits will be graded smooth, covered with the adjacent stored topsoil, and seeded.

2.2.2 Processing Area Preparation

The processing areas adjacent to each proposed test fill will be stripped of topsoil. The surface will be smoothed (proof-rolled) with the pneumatic tires on the front-end loader This topsoil will be stored adjacent to the processing areas

2.2.3 Test Fill Area Preparation

The test fill area will be stripped of topsoil. The topsoil will be stored adjacent to the test fills along with topsoil from the processing areas Once stripping of the surface soil is completed, the test fill areas will be proof-rolled, scarified, and smooth-drum compacted.

2.2.4 Soil Processing

This portion of the work will be completed prior to actual test fill placement to allow adequate time for clod size reduction, moisture addition, blending, curing, and testing to verify the optimal moisture content range has been achieved. These activities will be performed using a dozer to spread and move soil, a disc harrow or other appropriate equipment to reduce clod size and blend moisture into soil, and a water truck with a sprayer to adjust moisture content Tests to be performed on processed material are included in Table 2.1

2.2.5 Subgrade Preparation and Working Layer Placement

To ensure that there is no head build-up in the test fills (which could adversely affect the permeability test results), the test fills will be constructed on a foundation of in situ sandy soil. The sandy soil will be thoroughly wetted to a depth of at least 1 foot prior to placement of the next layer to avoid surface tension and capillary effects on downward infiltration. Directly above the wetted sandy soil will be a 6-inch (compacted lift thickness) layer of clay borrow material that will be designated a "working layer " This layer is important to ensure proper placement, bonding, and compaction of the first lift within the test fills

2.2.6 Test Fill Placement

Once the subgrade and working layer are completed for each test fill, and the specified moisture content of the processed soil has been achieved, placement of the test fills will be initiated Using a front-end loader, dozer, or a backhoe, processed soil will be moved to the test fills The soil will be spread by a dozer into 8- to 9-inch loose lifts A heavy tamping foot or sheepsfoot compactor (Caterpillar Model 825 or equal) will be used to compact the clay into 6-inch compacted lifts. Six lifts will be constructed to form the 3-foot-thick test fill. Each lift surface will be scarified and/or rewetted as necessary to ensure adequate bonding between lifts.

Based on the results of the earlier soils testing program, failure to meet a specification of 95 percent of the Standard Proctor maximum dry density (American Society for Testing and Materials [ASTM] D 698-78) will require removal and replacement of that lift.

Moisture content shall be in the range of 1 to 4 percent wet of optimum moisture Each compacted lift will be tested using a nuclear gauge to verify that the compaction and moisture content specifications have been met. Additionally, to determine the appropriate number of equipment passes to meet the compaction requirement, the density will be measured after every two passes for each of the first three lifts This methodology will (1) enable the last three lifts to be constructed with the appropriate number of lifts and minimal testing and (2) enable development of a "compaction vs equipment passes" curve to use in preparing method specifications for the actual clay liner It is anticipated that three density test locations will be used for each lift at each test fill These and other tests that will be performed during construction are listed in Table 2.1.

2.2.7 Test Fill Completion and Permeability Test Preparation

To complete the test fills and provide a smooth, uniform surface, the top of the uppermost completed lift will be compacted and sealed with a smooth-drum roller The completed test fill surface must be protected from excessive desiccation cracking prior to and during the field permeability tests Therefore, a topsoil layer or plastic sheeting will be placed over both test fills, except for the

Table 2.1: Test Fill Testing Program (Per Test Fill)

Test	Method	Stockpile	Frequency During Construction	Post-Construction
Moisture Content	Oven drying ASTM D2216-90	3 initial; as needed during processing (approx 12); 3 final; estimate 18 total	3 per lift (18 total)	---
Moisture Content	Nuclear gauge ASTM D3017	---	3 per each 2 passes per lift for first three lifts; 3 per lift for lifts 4, 5, 6, estimate 45 total	---
Atterberg Limits	Grab sample ASTM D4318-84	3	---	---
Grain Size (incl clay content)	Sieve and hydrometer analysis ASTM D422-63	3	---	---
		3	---	---
Optimum Moisture Content and Max Dry Density	Standard Proctor test (grab samples) ASTM D698-78	3	---	---
In-place Density (% compaction)	Nuclear gauge ASTM D2922	---	3 per each 2 passes per lift for first three lifts; 3 per lift for lifts 4, 5, 6; estimate 45 total	---
Lift Thickness (loose)	Manual	---	25-foot intervals down centerline of test fill	---
Lift Thickness (compacted)	Manual	---	25-foot intervals down centerline of test fill	---

Table 2.1 (continued)

Test	Method	Frequency		
		Stockpile	During Construction	Post-Construction
Final Test Fill Thickness	Survey	---	---	3
Lift Bonding	Visual Test Pits	---	2 per lift (manual)	3 (backhoe)
Laboratory Permeability	Shelby tubes, flexible wall permeameter (falling-head test) ASTM D5084-90	---	---	3
Field Permeability (large-scale)	Sealed double-ring infiltrometer (SDRI)	---	---	1
Field Permeability (small-scale)	Two-stage borehole (Boutwell)	---	---	5
Shear Strength	Consolidated undrained ASTM D4767-88	---	---	2
Shear Strength	Unconsolidated undrained ASTM D2850-87	---	---	2

--- Not performed
ASTM American Society for Testing and Materials

immediate areas designated for the SDRI tests Each SDRI area, approximately 12 feet by 12 feet, will be blocked off and sealed with a tarp until the SDRI test set-up is initiated.

2.2.8 Field Permeability Tests

One SDRI and five TSB permeability tests will be performed at each test fill. The SDRI test will be located in the center of each test fill to avoid edge effects The TSB tests will be placed at least 15 feet from test fill edges. Figure 2.3 illustrates the proposed test locations Performance of the tests will include strict adherence to the published testing procedures and thorough documentation of all observations and results as described in Sections 2.3 and 2 4.

Protection of the SDRI areas from temperature changes and damage by animals will be accomplished by building a plywood cover built for each SDRI test site The SDRI area will be staked and marked with tape to prevent access by unauthorized personnel.

2.2.9 Test Fill Closure

Once the field permeability tests are completed and the testing apparatus disassembled, the SDRI areas and the center strip between the test fills will be seeded with native grasses and wildflower seed and mulched with native grass hay as specified by the USFWS

2.2.10 Test Fill Documentation

In addition to the test results from the formal testing program outlined in Table 2.1, the following information on test fill construction will be documented.

- Field description of the borrow material used in each test fill
- Soil processing procedures
- Soil transport traffic routes
- Dozer spreading and grading patterns
- Lift thicknesses (loose and compacted)
- Compaction patterns and number of passes

- Test locations
- Lift bonding check results and observations
- Any failed results and corrective action taken

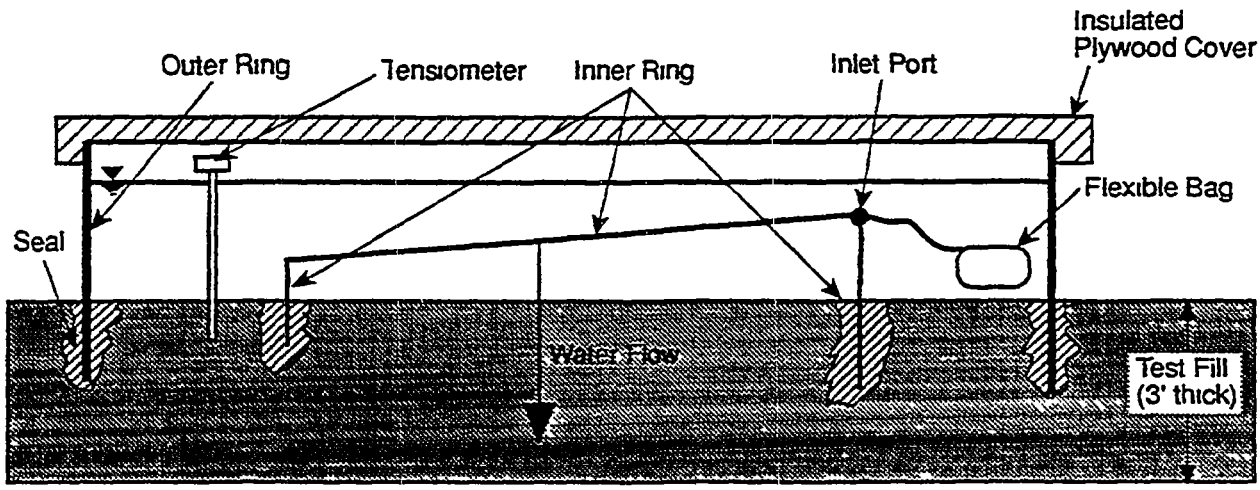
2.3 Sealed Double-Ring Infiltrometers

This section describes the test method, the installation, monitoring, and data reduction and evaluation procedures to be used for the SDRI tests. The SDRI test measures the vertical infiltration rate of water through the constructed test fills. The SDRIs are specifically designed to measure low infiltration rates in the range of 1×10^{-5} to 1×10^{-8} cm/s Based on previous laboratory results (HLA, 1994a), the permeability of the soil at the proposed borrow areas ranges from 3.02×10^{-9} to 8.24×10^{-8} cm/s. This range of soil permeability coincides with the optimal range for the SDRI test method

A summary of the SDRI test method is provided in Appendix A along with the manufacturer's installation and operating instructions A synopsis of the test method from the installation instructions (Appendix A) is as follows The SDRI consists of a 12-foot by 12-foot outer ring and a 5-foot by 5-foot inner ring, as illustrated in Figure 2 4. The rings are grouted within trenches excavated into the top of the test fill The outer ring is installed at a depth of 14 to 18 inches below ground surface (bgs), and the inner ring is installed to a depth of 4 to 6 inches bgs After grouting is complete, the area between both rings is filled with water The outer ring area is filled to a depth of approximately 12 inches, which completely submerges the inner ring. The inner ring area is sealed by placing a cover over the top of the inner ring This seals the water within the inner ring from the atmosphere

Monitoring the flow of water in the SDRI is accomplished by filling a flexible bag with a known weight of water and connecting the bag to a port on the inner ring. As the water infiltrates the ground and leaves the sealed inner ring, it is replaced with an equal amount of water drawn in from the flexible bag After a specified time interval, the flexible bag is removed and weighed. The weight loss is then converted into milliliters of water that has infiltrated into the test fill Infiltration rate is calculated using an equation with the following parameters: the volume of water loss, the

Cross Section



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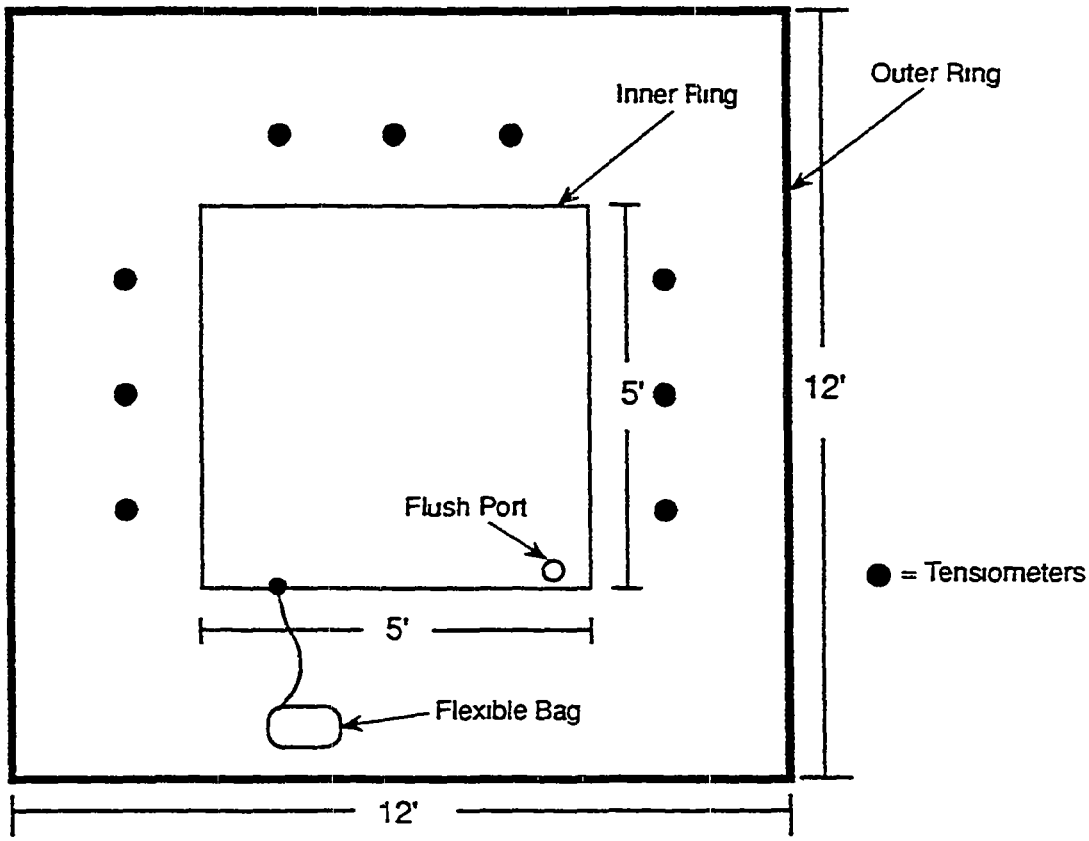
Plan View



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Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure 2 4 Proposed Sealed Double-Ring Infiltrometer Construction Schematic

area of the inner ring, and the interval of time that the bag was connected onto the inner ring The tests will be monitored until the infiltration rate reaches a steady state Upon completion, a plot of the infiltration rate over time is prepared For the purposes of this test, the specified permeability value to be achieved is 1×10^{-7} cm/s It is anticipated that the tests will require monitoring for approximately two to three months.

2.3.1 Sealed Double-Ring Infiltrometer Installation Procedures

The SDRIs will be installed immediately following completion of the test fills The SDRIs will be installed according to manufacturer's installation instructions under the direction of the installation subcontractor, Mr Steve Trautwein of Trautwein Soil Testing Equipment (manufacturer of the SDRIs). Further information regarding the installation of the SDRIs is presented in Appendix A.

2.3.2 Sealed Double-Ring Infiltrometer Monitoring Procedures

SDRI monitoring procedures will include flow measurements, water temperature readings, water level measurements, swell measurements, and tensiometer readings In general, the readings will be taken on a daily basis until the infiltration rate slows sufficiently to allow measurements to be collected every several days The readings will be taken by field personnel trained and experienced in taking SDRI measurements The readings will be recorded in field logbooks and then transferred onto the SDRI data forms (Appendix A)

2.3.3 Sealed Double-Ring Infiltrometer Data Reduction and Evaluation

Data reduction and evaluation will be accomplished by transferring the field measurements recorded on the data forms onto computer spreadsheets for ease of computation. The infiltration rate can be determined by using the following equation.

$I = Q/(At)$

where.

I = infiltration in cm/s

Q = volume of flow in cubic cm

A = area of flow in square cm

t = time interval in seconds

There are two factors that can have a significant effect on the infiltration rate of the SDRI temperature changes and soil swelling The field measurements of temperature and swell will be reviewed to evaluate whether they could have affected the infiltration rates of the SDRIs. If either factor is found to be significant such that it could account for as much as 10 percent of the total infiltration of the SDRI, corrections for these effects will be made

The hydraulic conductivity within the SDRI is calculated by using the following equation·

$k = Q/(iAt)$

where.

k = hydraulic conductivity in cm/s

Q = volume of flow in cubic cm

t = time interval in which Q was determined in seconds

i = $\Delta h/\Delta s$ (gradient) dimensionless

Δh = head loss

Δs = length of flow path for which Δh is measured

A = area of flow in square cm

Plots of the infiltration rate and hydraulic conductivity will be evaluated concurrently to evaluate when the tests can be terminated as discussed above (i e., when steady state conditions or the desired hydraulic conductivity has been achieved).

2.4 Two-Stage Borehole Permeameters

This section presents the installation, monitoring, and data reduction and evaluation procedures for the TSB permeameter tests The TSB procedure is a falling-head infiltration test conducted in a cased borehole The first stage of the TSB procedure is performed with a cased borehole that is open at the bottom The first stage of the test is used to calculate vertical permeability (k_v) The second stage of the test is conducted after advancing the borehole another 6 to 8 inches below the bottom of the casing and measuring the flow rates to calculate horizontal permeability (k_h).

2.4.1 Two-Stage Borehole Permeameter Installation Procedures

Five TSB permeameters will be installed at each test fill immediately following installation of the SDRIs The TSBs will be installed following the installation procedures described in Appendix B The boreholes will be excavated using a hand auger and reamed to the desired depth. Polyvinyl chloride (PVC) casing will be grouted in place, and the surface of the borehole will be completed with the measurement stand pipe and fill tube, as illustrated in Figure 2.5.

Along with five TSBs at each test fill, one temperature effect gauge (TEG) will be installed at each test fill. The purpose of the TEG is to measure any changes in flow rates that could be the result of temperature changes during the monitoring period. Field measurements on previous TSBs have indicated that rising temperature causes the water column in the standpipe to expand, thereby causing a lower apparent flow rate (see Appendix B) The net effect is a lower apparent permeability If the temperature decreases during the monitoring period, then the converse is true For this reason, TEGs will be installed and monitored throughout the testing program

TEGs are set up and installed similarly to the typical TSB with one exception; the bottom of the casing is sealed with a cap Because there is no flow of water from the TEG, any changes in the readings must be the result of changes in the ambient air temperature and/or barometric pressure As described in Appendix B, any changes noted in the TEGs can then be corrected for in the TSB

measurements The construction of the SDRI and the TSB will be supervised by the SDRI manufacturer's representative

2.4.2 Two-Stage Borehole Permeameter Monitoring Procedures

Monitoring of the TSBs will include flow measurements, water temperature readings, and TEG readings The monitoring equipment manufacturer's operating procedures are presented in Appendix B The readings will be taken by field personnel trained and experienced in TSB monitoring. The readings will be recorded in field logbooks and then transferred onto the TSB data forms (Appendix B)

2.4.3 Two-Stage Borehole Permeameter Data Reduction and Evaluation Procedures

Data reduction and evaluation will be accomplished by transferring the field measurements recorded on the data forms onto computer spreadsheets for ease of computation. Apparent permeability for both Stage 1 and Stage 2 of the TSB tests will be calculated using the following falling-head test equations as specified in the test method calculations (Appendix B)

$$k = R_T G \ln(H_1/H_2)/t_2-t_1)$$

where

k = permeability in cm/s

H_1 = initial head at $t=t_1$

H_2 = initial head at $t=t_2$

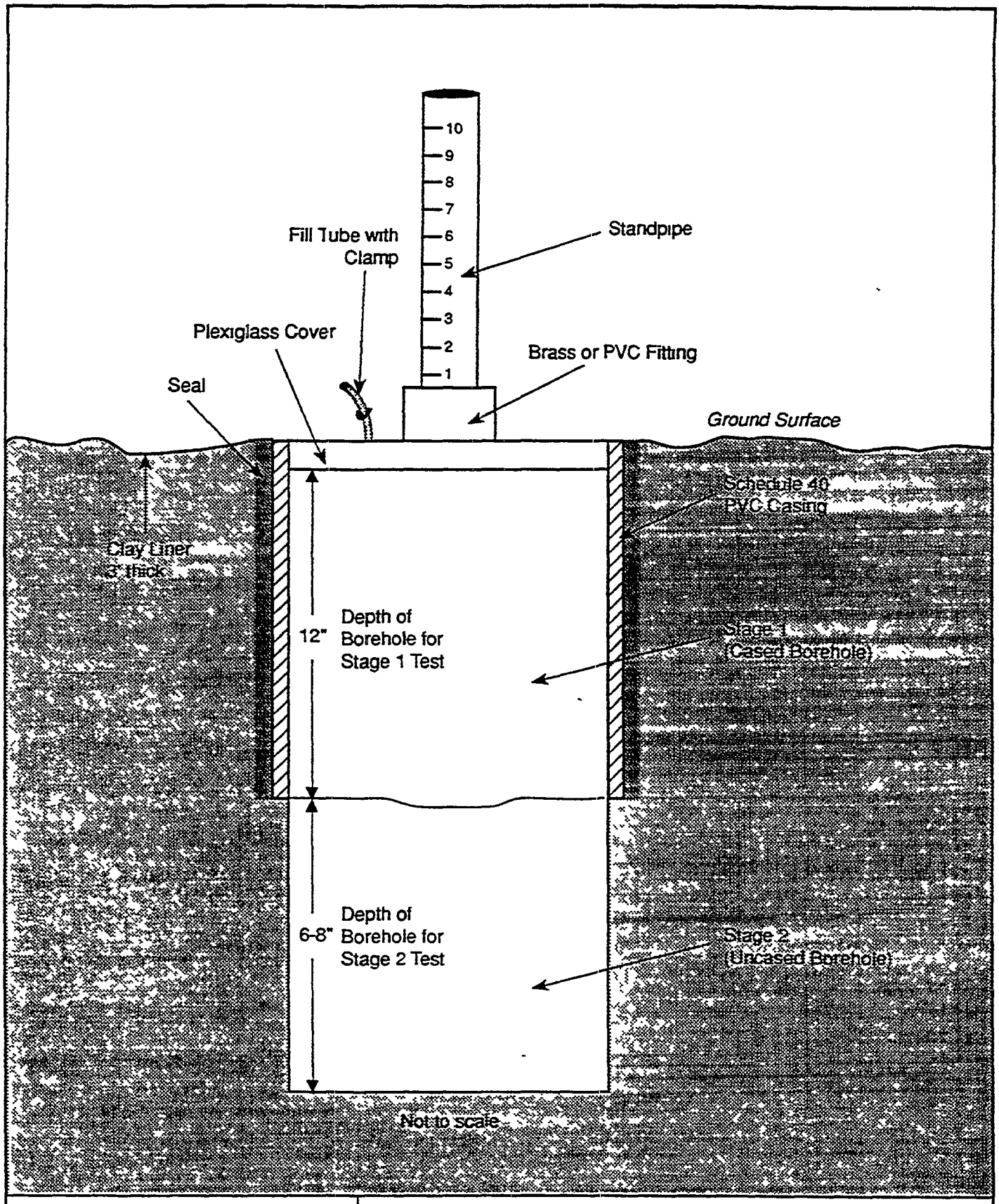
t_1 = initial time

t_2 = final time

ln = natural logarithm

G = geometric constant, depends on the individual test dimensions and is calculated separately for each test

R_T = kinematic viscosity correction to water at 68 degrees Fahrenheit as defined in ASTM D5084



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Harding Lawson Associates

Figure 2.5

Proposed Two-stage Borehole Permeameter Installation (cross section)

Throughout each stage of the tests, variations in apparent permeability will be evaluated, and the test will be terminated when steady-state conditions are achieved. It is anticipated that each stage of the two-stage test will require monitoring for approximately three weeks

3.0 GEOLOGICAL AND GEOTECHNICAL DRILLING, SAMPLING, AND TESTING

This section describes the geological and geotechnical drilling, sampling, and testing activities to be conducted under Task 93-03 Section 3.1 describes the selection process for locating the three deep boreholes within the proposed landfill site as well as the procedures for drilling, coring, sampling, and geological and geophysical logging Section 3.2 describes the rationale for shallow soil boring locations within the proposed landfill site Drilling, coring, and sampling procedures are also described. Section 3.3 describes the chain-of-custody (COC) procedures. Section 3.4 describes the geotechnical testing, and Section 3.5 describes data evaluation and reporting.

3.1 Borehole Coring Program

This subsection describes the rationale for the selection of the proposed landfill siting deep borehole locations, drilling equipment and procedures, and geological and geophysical logging procedures.

3.1.1 Borehole Locations

Three 150- to 175-foot boreholes will be located in the western half of Section 25 at RMA to further characterize the geology of this area as a potential landfill site The borehole locations were selected by reviewing existing geologic logs and cross sections prepared from those logs The boring locations were placed between existing well clusters and known borings to gather new data. These boring locations may be subject to minor changes in the field (with approval of PMRMA). Figure 3.1 shows the proposed borehole coring locations in Section 25

3.1.2 Drilling, Coring, and Geophysical Logging Equipment and Personnel

A drilling rig and crew will be furnished by the U.S Army Corps of Engineers Waterways Experiment Station (WES) The drilling rig is capable of both auger and rotary drilling. The WES drilling crew will also provide a supply truck and water truck. Drilling in the alluvium will be accomplished using an 8-inch-outside-diameter (OD) solid auger Continuous core samples of the alluvium will be collected by hammering a 24-inch-long, split-barrel sampler in the open borehole Continuous cores

of bedrock will be collected in a 5-foot-long, 4 5-inch-OD split-spoon sampler using a rotary core drilling technique

Drilling activities will be directed by an HLA field geologist. The geologist will be responsible for directing the drilling crew, logging the core samples recovered, and directing the geophysical logging subcontractor (Colog, Inc.)

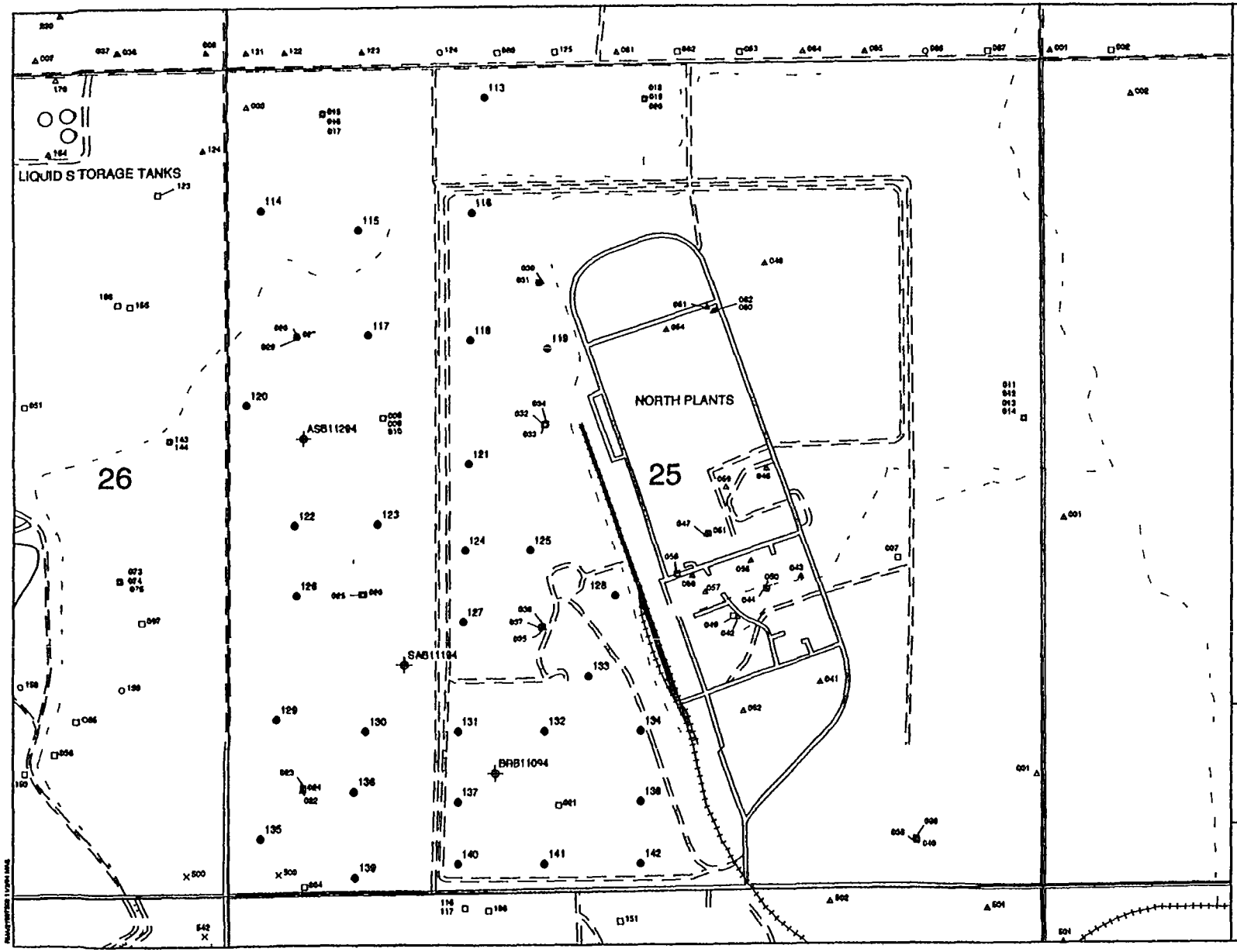
3.1.3 Borehole Coring Procedures

Before field work is started, the geologist will be responsible for assuring that personnel (1) read and sign the accident prevention safety plan, (2) are trained to operate the field equipment, and (3) understand the field procedures described in this Work Plan. All work will be performed in accordance with the Final Accident Prevention Plan (HLA. 1994b).

The boreholes are specifically located outside areas of known contamination; therefore, rigorous decontamination procedures normally followed when soil samples are collected for chemical analysis are not necessary for this program However, before starting and following completion of drilling operations, the drilling rig and associated downhole equipment will be decontaminated at the CERCLA Wastewater Treatment System (CWTS) Decontamination of downhole equipment between each borehole will only be necessary to maintain proper working order of the equipment.

A lithologic log will be prepared for split-spoon and core samples recovered at each borehole The samples will be logged immediately in the field and in more detail later using geophysical logs for comparison. These logs will include alluvium and bedrock descriptions, stratigraphic features, details of observed structural features, and other pertinent information. Sample recovery will be noted on the field logs, and the samples scanned with a photoionization detector (PID).

Colog, Inc (Colog), Golden, Colorado, will provide geophysical logging services during the coring program. Colog will geophysically log each completed borehole after coring has been completed.



Explanation

- Alluvial well with well number
- Unconfined Denver Formation well with well number
- Confined Denver Formation well with well number
- Proposed Soil Borings (30)
- Proposed Bore Holes (3)
- Unpaved roadway
- Surface drainage
- Section number

0 600
Scale in feet

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure 3 1

Proposed Boring Location Map
Section 25

Colog will use the following borehole geophysical techniques normal resistivity, spontaneous potential, single-point resistivity, gamma, full waveform sonic, neutron, and caliper. The geophysical logging tools will be calibrated for the methods specified above before logging operations are initiated and after logging operations are completed. The calibrations will be recorded and submitted to HLA for review. The depth indicators for the geophysical logging tools will be set so that zero corresponds with the ground surface before each run. The geophysical logging tools will be run twice over an interval in each borehole The results of both runs will be compared as a means of verifying the repeatability of results. The geophysical logging equipment will be decontaminated before and after working on this project. Field plots of the geophysical logs will be prepared with an expanded scale of 10 feet per inch. The final logs will be plotted on vellum

Upon arrival at individual boring sites, the following procedures will be implemented.

1 Water to be used in drilling and grouting will be obtained from a Contracting Officer's Representative (COR)-approved water source

2 The HLA geologist shall check the boring location stake against the site location map to verify the borehole location and perform borehole clearance for buried utilities and metallic objects

3 PID background readings will be taken before intrusive activities begin. Field documentation of all boring activities will begin at this time and include the following information. boring number; date, and pertinent observations such as weather, surface conditions, and field equipment identification numbers It is anticipated that the borings will be drilled in modified Level D personal protective equipment (PPE)

4 Once drilling starts, PID readings will be taken in the breathing zone and at the top of boring The PID readings are taken for health and safety monitoring and boring location evaluation. If the PID readings are above background levels, the rig geologist will notify the task manager immediately The level of PPE will be upgraded according to specific guidelines, and the boring will be backfilled and a new boring location identified.

5 The alluvium will be drilled with a solid-stem (8-inch-OD) auger and sampled with 2-foot split-spoon samplers Blow counts and sample recovery data will be recorded on preprinted boring logs and in bound field logbooks

6 After the alluvium has been split-spoon sampled and drilled, it will be cased with 5-inch-inside-diameter (ID) PVC casing, and pressure grouted in place

7 The PVC casing and grout will be left to set up for a minimum of 24 hours

8 The bedrock will be continuously cored at each borehole location to a consistent reference datum elevation of approximately 5085 feet. Therefore, one borehole will be less than

150-foot total depth and two boreholes will be greater than 150-foot total depth (see Table 3.1)

9 As the soil and rock core are recovered from the boring, they will be logged by the geologist on the lithologic log.

10 The core will be placed in core boxes with the top and bottom of depth labeled for each section of core The quantity recovered will also be marked on the core box. The outside of the core box shall be labeled with the boring number and core interval The core will be stored in Building 785 West until the core is no longer needed, at which time the core will be returned to the site and spread on the ground.

11 A metal mud tank will be used to recirculate the drilling mud during coring. Soil cuttings produced during drilling will be spread evenly around the drill site

12 Upon completion of the drilling and sampling, the boreholes will be geophysically logged by Colog using the following logging tools.

- Normal resistivity
- Spontaneous potential
- Single-point resistivity
- Gamma
- Full waveform sonic
- Neutron

13 After the boreholes have been geophysically logged, they will be grouted to the surface using a tremmie pipe and pumped with cement/bentonite grout.

14 A stake will be placed at the borehole location with the appropriate boring identification clearly marked The location and ground surface elevation of the borings will be surveyed by a licensed surveyor and the coordinates will be forwarded to RMA's data management subcontractor, D.P. Associates.

3.2 Soil Boring Program

Up to 30 shallow boreholes will be drilled and sampled in Section 25 of RMA to gather detailed geologic and geotechnical data for site characterization.

3.2.1 Soil Boring Locations

Geologic boring logs and cross sections from borings in Section 25 and northern Section 36 will be reviewed. The data review and cross sections will help locate the boreholes for the drilling program.

Table 3.1: Projected Borehole Drill Depths

Boring Number	Projected Thickness of Alluvium (feet)	Projected Total Depth (feet)	Projected Surface Elevation (feet)
BRB11094	22 5	175	5260
SAB11194	15 8	170	5254
ASB11294	27.2	145	5232

Borings will be terminated at approximately 5085 feet elevation above mean sea level.

The borehole locations will be cleared for utilities and other subsurface objects using utility maps and a metal detector before any drilling begins

Boring locations will be selected to optimize the density coverage within the proposed landfill siting area. The most desirable geologic areas for siting a landfill in Section 25 (based on the suitability criteria) will be targeted for study Figure 3.1 shows the proposed soil boring and coring locations

3.2.2 Drilling and Sampling Personnel, Equipment, and Procedures

This subsection presents soil boring and geotechnical soil sampling procedures Procedures for completing COC forms and shipping forms are also discussed.

Field Personnel

Soil boring activities will be accomplished by a two-person field team. The field team will consist of an HLA geologist and an engineering technician (ET). The rig geologist will log each boring in the field as it is drilled, and continuously collect soil samples The task manager (TM) will review the final field lithologic logs The ET will assist the rig geologist with sample collection and be responsible for sample handling, packaging, and shipment.

Field Equipment

Borehole drilling will be accomplished using 3-1/4-inch-ID hollow-stem augers and a Mobile drilling rig Split-spoon samplers and shelby tubes (when necessary) will be used to collect soil samples during drilling Layne Environmental Services, Inc., will provide a drilling rig, drill crew, water truck, and a vessel to mix grout in for borehole abandonment. HLA will have a truck to transport sample coolers, sample bottles, and sample equipment.

Soil Sampling Procedures

The rig geologist will be responsible for assuring that personnel (1) have read and signed the Site Safety and Health Plan, (2) are trained to operate the field equipment, and (3) understand the field procedures described in this Work Plan.

Each boring location must be cleared for utilities and metallic objects before drilling can begin. The TM will make sure that COC forms and labels are prepared for each borehole Information from previous boreholes in the areas being drilled will be provided to the rig geologist. Data from the boreholes will be recorded on preprinted boring logs and in bound field logbooks

Up to 30 borings will be drilled and sampled as part of the area feasibility subtask. The borings will be continuously sampled to a depth of approximately 50 feet or into bedrock. The alluvium will be logged for lithology and blow counts will be recorded to collect geotechnical information. Samples will be collected for geotechnical testing from every 5-foot interval. Undisturbed soil samples will be collected using split-spoon samplers and shelby tubes when necessary. It is anticipated that the borings will be drilled in Level D PPE. The borings have been located outside areas of known soil contamination, and if any sustained readings above background are detected in the field using a PID, drilling will be stopped and the level of PPE will be upgraded as necessary

Before starting and after completion of drilling operations, the drilling rig and associated downhole equipment will be decontaminated at the CWTS However, decontamination of downhole equipment between each borehole will not be necessary

Upon arrival at individual boring sites, the following procedures will be implemented.

1 Water to be used in drilling and grouting will be obtained from a COR-approved water source

2 The HLA geologist or technician shall check the boring location stake against site location maps and pertinent borehole clearance information to verify the boring location.

3 An HNu PID will be used to obtain background readings before intrusive activities begin. Field documentation of all boring activities will begin at this time and include the following information boring number; date, and pertinent observations such as weather, surface conditions, and field equipment identification numbers

4 Once drilling commences, PID readings will be taken in the breathing zone and at the top of boring The PID readings are taken for two purposes health and safety monitoring and boring location evaluation. If the PID readings are above background, the rig geologist will notify the TM immediately, and two actions will be taken. The level of PPE will be upgraded

according to specific guidelines, and the boring will be backfilled and a new boring location identified

5 Soil cuttings produced during drilling will be spread evenly around the drill site

6 As the soil core is recovered from the boring, it will be logged by the site geologist on the lithologic log Soil cuttings from the auger will also be monitored for lithologic changes and noted on the boring log

7 The samples will be continuously collected and those samples to be analyzed will be selected following completion of the borings and a review of the boring logs

8 Most samples will be collected in wide-mouth jars for geotechnical analysis Additional material will be collected in shelby tubes and 5-gallon buckets The 5-gallon bucket samples will be collected from the auger flights. Sampling technique, sample depth, and fractions collected will be recorded on the lithologic logs, COC forms, and sample tags.

9 The residual soil core will be packaged for storage at Building 785 West until no longer needed, at which time the residual soil cores will be returned to the site and spread on the ground.

10 The borings will be terminated at bedrock or at 50 feet, whichever is encountered first. If groundwater is encountered, the boring will be terminated at the groundwater level

11 Upon completion of the soil sampling, the boring will be backfilled with portland type I/II cement with 5 percent bentonite. Residual soil will be removed from the auger bits and soil sampling equipment.

12 A stake will be placed at the borehole location with the appropriate boring identification clearly marked The location of the boring will be surveyed by a licensed surveyor and the coordinates will be forwarded to D.P Associates

13 Samples will be labeled and stored onsite pending selection of samples for subsequent geotechnical analyses At the conclusion of the program, unused samples will be spread evenly over ground surface at a location approved by PMRMA.

3.3 Chain of Custody

The ET will place the correct COC forms within the designated sample cooler before relinquishing the cooler to the rig geologist. These forms include an inventory of the samples and a listing of those persons with access to the samples The forms will be transported with the samples at all times. Possession of the samples will begin with the sample collectors All subsequent sample transfers will require the relinquisher and the receiver to sign, date, and record the time of transfer on the COC forms

Data on final COC forms will be checked by the ET and will include the sample number, sampler's signature, collection date and time, fractions collected, and sample depth. The ET will check these data against the boring logs and field logbooks transmitted by the rig geologist.

At the end of each day, all samples will be brought back to the trailer for packaging The ET will complete the COC forms and review field logbooks and field data sheets for errors and omissions

Sample fractions will be repackaged with a layer of plastic bubble wrap below and above the samples, in heavy-duty coolers to ensure that the samples will not break during shipment COC forms will be placed in waterproof bags in their corresponding coolers. All coolers will be sealed and wrapped in accordance with PMRMA shipping requirements Evidence tape will be placed across each cooler to ensure that the contents are not violated during shipping The last person to sign the COC form for each cooler will sign and date the evidence tape. The COC forms will be signed over to PMRMA's transport courier PMRMA will ship the samples by air freight (Federal Express) to HLA's geotechnical laboratory

3.4 Geotechnical Testing

A series of laboratory geotechnical tests will be performed on soil samples collected during the soil boring program to evaluate the geotechnical characteristics of the soil in the preferred landfill area. The geotechnical testing will be performed by HLA's geotechnical laboratory in Houston, Texas

Samples for geotechnical testing will be selected at 5-foot intervals from the boreholes The following geotechnical tests will be performed·

- Geotechnical testing to include approximately 350 samples for the following tests·
  - Grain-size analysis (ASTM D422)
  - Atterberg limits (ASTM D4318-84)
  - Natural water content (ASTM 2216)

- Remolded compaction (ASTM D698)
- Remolded permeability (EM1110-2-19096) at 90 and 95 percent relative compaction
- Shrink swell (ASTM D427)
- Organic content (ASTM D2976)
- Flexible wall permeameter (ASTM D5084-90)
- Shear strength consolidated undrained (ASTM D4767-88)
- Shear strength unconsolidated undrained (ASTM D2850-87)

Approximately 100 percent of the samples will be analyzed for grain size, Atterberg limits, and natural water content. The remaining tests will be performed on approximately 10 percent of the samples

3.5 Data Evaluation and Reporting

The data from the borehole coring and geophysical logging, soil boring and sampling, and geotechnical laboratory testing subtasks will be included in the Site Feasibility Report. These data will be integrated into the area feasibility subtask and used to evaluate the feasibility of constructing a landfill using the existing foundation materials

The borehole coring and geophysical logging data will be used with existing geologic data to generate additional detailed geologic cross sections within Section 25 Drafted lithologic logs of each borehole will be produced. The geophysical logging data will be used to correlate between the boreholes and to compare with the geologic core. A map will be generated that includes the new and existing boreholes, and also shows the location of newly constructed cross sections

The soil boring geologic logs and geotechnical testing data will be used to generate shallower geologic cross sections and characterize the geotechnical properties of the soil in the western half of Section 25 The geotechnical test results will be submitted to PMRMA through the data management subcontractor, D.P Associates.

4.0 ACRONYMS AND ABBREVIATIONS

Army	U.S Department of the Army
ASTM	American Society for Testing and Materials
bgs	Below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/s	Centimeters per second
COC	Chain of custody
Colog	Colog, Inc
COR	Contracting Officer's Representative
CWTS	CERCLA Wastewater Treatment System
DAA	Detailed Analysis of Alternatives
DSA	Development and Screening of Alternatives
ET	Engineering technician
FFA	Federal Facilities Agreement
FS	Feasibility study
HLA	Harding Lawson Associates
ID	Inside diameter
K_v	Vertical permeability
K_h	Horizontal permeability
NCP	National Contingency Plan
OD	Outside diameter
PID	Photoionization detector
PMRMA	Program Manager for Rocky Mountain Arsenal
PPE	Personal protective equipment
RAOs	Remedial action objectives
RMA	Rocky Mountain Arsenal
ROD	Record of Decision

SARA	Superfund Amendments and Reauthorization Act of 1986
SDRI	Sealed double-ring infiltrometer
TEG	Temperature effect gauge
TM	Task manager
TSB	Two-stage borehole
USFWS	U S Fish and Wildlife Service
WES	Waterways Experiment Station

5.0 REFERENCES

EBASCO Services, Inc. 1994 *Final report, hazardous waste land disposal facility assessment*, September

Harding Lawson Associates. 1994a. *Draft final feasibility study soils support program report*, June

Harding Lawson Associates 1994b *Final accident prevention plan (site safety and health plan) for the feasibility study soils support program*, as amended June 1994.

Appendix A

INSTALLATION AND OPERATING INSTRUCTIONS FOR THE SEALED DOUBLE-RING INFILTROMETER

soil testing equipment
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INSTALLATION AND OPERATING INSTRUCTIONS FOR THE SEALED-DOUBLE RING INFILTROMETER

1.0 SUMMARY OF TEST METHOD

The Sealed-Double Ring Infiltrometer (SDRI) can be used to measure the vertical, one-dimensional infiltration rate of water through soil This device provides a means to measure low infiltration rates, those associated with fine-grained, clayey soils, and are in the range of 1x10-5 cm/sec to 1x10-8 cm/sec The SDRI is particularly useful for measuring liquid flow through soil moisture barriers such as compacted clay liner or covers used at waste disposal facilities, and amended soil liners such as those used for retention ponds or storage tanks.

A schematic of a typical test installation is shown in Fig. 1 The infiltrometer consists of an outer ring (12' x 12') and an inner ring (5' x 5'). The rings are grouted in trenches excavated in the test area. The outer ring is placed at a depth of 14 in. to 18 in., the inner ring to a depth of 4 in. to 6 in. Both rings are filled with water. The outer ring is filled to a depth of approximately 12 in., submerging the inner ring The top on the inner ring seals the water within it from the atmosphere.

Installation requires a level, obstruction free work zone approximately 24' x 24' A primary concern before and during installation of the infiltrometer is desiccation. Before installation, desiccation can be minimized by covering the test area with plastic. Plastic sheets for this purpose, 20' x 100', are readily available at most building supply stores. Spreading a thin layer of soil over the plastic will prevent it from blowing away During installation, desiccation can be minimized by removing plastic only in areas being worked, and recovering areas once work has been completed. Water should be sprayed on any soil that is exposed for long periods of time.

Measurement of flow is made by connecting a flexible bag, filled with a known weight of water, to a port on the inner ring. As water infiltrates the ground and leaves the sealed inner ring, it is replaced with an equal amount of water drawn in from the flexible bag. After a known interval of time, the flexible bag is removed and weighed. The weight loss, converted to a volume, is equal to the amount of water that has infiltrated the ground. An infiltration rate, usually expressed in cm/sec, is then determined using this volume of water, the area of the inner ring, and the interval of time that the bag was connected to the inner ring This process is repeated and a plot of infiltration versus time is constructed. The test is continued until the infiltration rate becomes steady or until it becomes equals to or less than a specified value

The advantage of the SDRI over other infiltrometers is the capability to measure low infiltration rates. This is accomplished by measuring the actual quantity of flow rather than a drop of elevation in the water level and by eliminating evaporation from the ring where measurements are made.

2.0 PARTS LIST

First check to see that the following parts were included with the Sealed Double Ring Infiltrometer .

a 4 - aluminum panels approximately 12' x 36"
b 1- fiberglass inner ring approximately 5' x 5'

c. 36 - of each of the following 3/8" round head bolts and nuts
d. 2 - flexible bags with pinch valves and barbed connectors
e. 1 - 1/2" NPT plug fitting
f. 1 - 1/2" NPT fitting with straight-barbed connector
g. 1 - 1/2" NPT fitting with elbow -barbed connector
h. 1 - 15' length of 3/8"od x 1/4"id clear plastic tubing
i. 1 - 1/4" brass plug fitting for sealing end of plastic tubing
j. 1 - tee fitting
k 4 - rubber gasket strips
l. 1 - tensiometer set (optional -.see Appendix A)
m. 1.- swell gage (optional - see Appendix B)

In addition to the list above, the following items will be needed to assemble and install the SDRI

a. 1 - flat bladed screw driver for assembling the outer ring
b. 1 - 9/16" wrench for assembling the outer ring
c. 1 - brick or mason's hammer for excavating trench for the inner ring
d. 1 - adjustable wrench for installing fittings on inner ring
e 1 - knife or scissors for cutting tubing
f. 1 - trenching machine for excavating outer ring trench
g. 5 - 5 gal. buckets to mix grout and place on inner ring
h. water supply - approximately 1200 gallons is needed to fill rings
i bentonite grout to place in trenches
j cover for rings (see Appendix C)
k 1 - thermometer to monitor temperature in outer ring
l surveyor's level and rod
m. 1 - scale to measure the depth of the water in the outer ring
n grout mixer, shovels, and wheelbarrows for preparing grout.
o cinder blocks to stand on when connecting fittings to inner ring and also to hold down platform for flexible bag
p trowel
q scale - 4000g capacity sensitive to 1g
r. 1 - 14' 2x4 to use as guide when excavating trench
s plywood (2'x3'x1/2") to use as splashboard and platform for flexible bags

3.0 ASSEMBLY OF OUTER RING

Installation starts with the assembly of the outer ring as follows

1. Carefully uncrate the aluminum panels. Save the crate for future shipping.

2. Carefully tilt up two panels and align edges and bolts holes (Fig 2) Support panels on both ends as they bend easily, particularly in windy conditions.

3. Wipe panel edges clean around bolts holes Also wipe rubber gasket strips clean.

4 Place a rubber gasket between the panel edges and insert bolts through the holes Turn nuts on bolts until finger tight.

5 Tilt up remaining panels, one at a time, and bolt edges together as described above

6 Position outer ring so that it is square Turn nuts on bolts until snug. Do not overtighten as this will cause panel edges to bow apart between bolts.

4.0 EXCAVATION OF TRENCHES

The area to be tested should be level with a slope no greater than 4" over 12' Slopes of this magnitude are difficult to detect by eye, so a surveyor's level should be used to check elevations. High and low areas should be noted so that trench depthin these zones can be adjusted to keep rings level.

Procedures for excavating trenches are described below.

4.1 OUTER RING

1. Set the outer ring on the area to be tested so that it is square

2. Scribe a mark on the ground along the lower edge of the ring.

3. Lift ring and place it aside while trench is being excavated.

4. Place the edge of a 2x4 along scribe marks and paint a line on the ground. Extend line approximately 5' beyond each corner. This will help in aligning trenching machine. .

5. Use a trenching machine to excavate the trench (Ditch Witch Model No 1010 or equivalent). Select a machine that makes as narrow a trench as possible, no more than 4" - 6" in width. The narrower the trench, the less grout needed to fill it. Align the trenching machine with the boom over the paint line. The side of the trencher which removes the excavated dirt should be pointed away from the test area. Offset a 2x4 so that it is parallel to the paint line and against the wheel of the trenching machine inside the test area. Paint a line along edge of 2x4 to mark its position. Use the 2x4 as a guide by keeping the wheel of the trencher against it while excavating the trench. Excavate so that the deepest point is 18". Limit the amount of over excavation at corners as this will only increase the volume of grout needed.

   In some soils, several passes may be needed to reach the required depth. Typically, the higher the plasticity index, the greater the

number of passes Loose soil in bottom of trench and packed in corners should be removed by hand.

6. Once trench has been excavated and loose material removed, carefully place outer ring in trench to check fit Make adjustments as needed The ring should be level (±1") After adjustments are made, lift ring out of trench and set aside Cover trench to keep soil from drying while grout is prepared.

4.2 INNER RING

1. Center fiberglass inner ring within outer ring. Scribe a mark on ground along lower edge of inner ring.

2. Note the orientation of inner ring and set it aside. Also lift outer ring and place it aside. Cover outer ring trench to keep from drying.

3. Use a brick hammer (mason's hammer) to excavate a narrow trench. Trench should be approximately 2" wide and 6" deep When using brick hammer, it is best to start by digging down several inches in one spot and advancing trench forward by chopping down on soil. Try not to pry soil up as this tends to lift up large wedges, open cracks, and causes the trench to be oversized .

4 Place the inner ring in the trench to check the fit. Excavate any areas where the ring does not fit. Use a surveyor's level to check elevation of the corners of the ring The inner ring should be level or tilted so that lower end is slightly below horizontal. If lower end of ring is above horizontal, air may be trapped in ring when ring is filled with water.

5 Set the ring aside and cover the trenches.

5.0 INSTALLATION OF THE RINGS

5.1 PREPARATION OF GROUT

A product sold by American Colloid called "Volclay Grout" works well for sealing the rings. Between 15 to 20 bags of Volclay Grout are needed for 4" wide by 18" deep trench. If this product is used, add between 15-20 gallons of water per 50 pound bag The most convenient way of mixing the grout is to use a 4 bag grout mixer. Two bags of grout can be prepared at a time. First add 15 gallons of water to the mixer and then slowly add the grout . Adding the grout too quickly will result in a mixture with large chunps. Add 15 more gallons of water and then add the second bag. Add additional water as needed until the grout flows easily

5.2 OUTER RING

1. Prepare enough grout to fill the outer ring

2 Remove the cover from the outer ring trenches and clean all loose dirt out of the trench.

3 Use a wheelbarrow to place grout in the outer ring trench Use a sheet of plywood from the outer ring crate as a splash board to guide grout into trench and from getting on ground inside the trenches

4. With one person at each corner of the outer ring, lift it and center it over the trench Slowly push the ring in place while keeping it level. Once in place, use a trowel to push the grout against both the inside and the outside of the ring , particularly at the corners, to obtain a good seal.

5. Pile loose soil (12" high) all around the outside edge of the outer ring (Fig. 3) This berm will prevent the ring from bowing and will keep grout from being pushed out of the trench when the ring is filled with water. The berm also serves to insulate the outer ring which minimizes temperature changes in the water.

5.3 INNER RING

1 Prepare a thicker mix of grout for the inner ring trench.

2. Remove the cover from the inner ring trench and clean all the loose dirt out of the trench. Also clean off the surface of the area surrounded by the inner ring trench.

3. Fill the trench to within 3/4" of the top. Rod the grout to remove any air pockets

4 Lift the inner ring and center it over the trench. Lower it into the trench and push it down into place Use a surveyor's level to check the elevation of the corners of the ring. Make sure that the lower end of the ring is not tilted or raised above horizontal as discussed before.

5 Use a trowel to press the grout against the outside wall of the ring in order to obtain a good seal.

6 Cover the grout to prevent desiccation.

6.0 TENSIOMETERS

If it is desired to know the position of the wetting front during infiltration, it is recommended that tensiometers be used. A description of tensiometers and installation procedures are given in Appendix A.

7.0 SWELL GAGES

If the soil has a high potential for swelling, it is recommended that swell be measured during the test. Swell can be measured by monitoring the vertical movement of the inner ring during the test. As the soil beneath the inner ring swells, it will lift the inner ring A procedure for monitoring swell is described in Appendix B

8.0 FILLING THE RINGS

It is best to fill the rings slowly so that the seal can be checked for leaks It is much easier to repair a leak when the water level is low than when it is high.

When filling the inner ring, it is important to realize that water causes an uplift force to act on the ring. If the ring is filled to too high a level, the uplift forces can lift the ring out of the ground. For this reason buckets of water are placed on the inner ring before water is is added to it.

The general procedure for filling the rings is as follows First, the inner ring is partially filled and let to sit to check its seal. Next, the outer ring filled. The ports on the inner ring are left open so it will fill as the water level in the outer ring rises

The fittings are attached to the inner ring after the outer ring is filled. The cinder blocks are used to provide a place to stand when attaching the fittings Place several cinder blocks on the ground in the vicinity of ports on the inner ring Also place several cinder blocks on the ground just inside the outer ring to provide a place to lay the flexible bag during the test.

Detailed instructions for filling the rings are given below

8.1 INNER RING

1 Fill two buckets with water and place one on each corners of the low edge of the inner ring Make sure that the buckets are placed on the edge of the ring and not in the center as this may cause the fiberglass to crack. Try not to spill any water around the inner ring as this will make it difficult to check for leaks around the seal later on.

2. Invert one bucket on the ground near the ports on the inner ring Fill a second bucket with water and place it on the inverted bucket.

3. Cut a length of the flexible tubing long enough to reach from the bucket to the top port. Use this tube to siphon the water from the bucket to the inner ring. Siphon a total of three buckets (15 gallons) of water into the inner ring.

4 Let the water in the inner ring stand for at least 30 min. Check for leaks in the inner ring seal and repair any that are found.

8.2 OUTER RING

1 Place a piece of plywood from the outer ring crate on the ground between the inner and outer ring Place a bucket on the plywood. Put the end of the hose that is to used to fill the rings into the bucket.

2. Slowly fill the rings at a rate that will not scour the soil

3. Should a leak occur, repair it by pushing down on the grout on the inside edge of the outer ring first, then pressing down on the grout along the outer edge.

5. When the water level is at the top port on the inner ring, stop filling and allow the water level in the inner ring equilibrate with the water in the outer ring.

6. Continue to fill the outer ring until the water level is approximately four inches above the top port on the inner ring (a depth of approximately 12"). Use a board or shovel handle to gently tap the inner ring to dislodge air bubbles that are trapped inside. Continue tapping on the inner ring until bubbles cease to emerge from the top port.

7. Remove the buckets from the top of the inner ring

9.0 INSTALLATION OF FITTINGS

Before installing any fittings into the ports of the inner ring, check that all the threads are wrapped with teflon tape. Screw fittings in slowly at first and check that they are not cross-threaded. The threads in the fiberglass can be stripped easily. Also, do not overtighten the fittings as this may crack the fiberglass.

Detailed instructions for installing the fittings are given below.

1. Find the plug fitting and install it in one of the lower ports.

2. Find the two fittings with the barbed hose connectors. The straight fitting goes in the lower port and the elbow fitting goes into the top port. Saturate the fittings before connecting them to the inner ring.

3. Cut two lengths of tubing, one 3' long and the other 7' long

4. Place the two pieces of tubing under water to saturate them. Be sure that all the air is removed from the tubing before connecting it to the inner ring Any air remaining in the tube will be drawn into the inner ring.

5. Push one end of the long piece of tubing onto the top port fitting Find the small brass plug fitting and insert it into the other end of

the tubing This tube is the flush tube and is used to purge air that has become trapped in the inner ring

6. Connect the short piece of tubing to the lower port fitting This is the inlet tube through which flow measurements are made Fix the open end of the tube to one of the cinder blocks near the wall of the outer ring. Be sure the end of the tube does not float to the surface and suck in air or fall to the bottom and suck in mud.

10.0 COVERING THE RINGS

The rings should be covered throughout the test. Its best to construct a cover of plywood, 2x4's, and insulation. The primary purpose of the cover is to minimize temperature change of the water in the rings, block sunlight, and prevent from wind blowing over the water surface. Supplies and material for building a cover are given in Appendix C.

11.0 DATA COLLECTION

The data collected during the test includes flow measurements, water temperature, water level measurements, swell measurements, and tensiometer readings Sample data sheets are attached to these instructions. The procedures used to collect these measurements are discussed below.

11.1 FLOW MEASUREMENTS

Measurement of flow during an SDRI test is made using a flexible bag The bag is filled water, weighed, connected to a port on the inner ring, and submerged in the water of the outer ring. Any water that flows out of the inner ring into the ground will be replaced by an equal amount of water from the bag. Periodically, the bag is removed and weighed to determine the amount of water that was lost.

Besides convenience and simplicity, a key feature of using a flexible bag to measure flow is that a constant pressure difference is maintained across the wall of the inner ring. Consequently, the inner ring does not expand or contract when the water level changes in the outer ring.

The flow measurement data is used to construct a plot of infiltration versus time. For unsaturated soils such as compacted clay liners and covers, infiltration decreases with time at first, changing rapidly at the beginning of the test, and then eventually becoming constant with time as the soil becomes saturated. Consequently, more frequent readings are needed at the beginning of the test and less frequent readings are need as the flow rate becomes steady

Typically, flow rates at the beginning of the test (< three weeks) range from 1000 ml to 3000 ml per day. One reading per day has been found to be sufficient during this time. When infiltration starts to level out (three to four weeks) one reading in several days is all that is necessary.

Temperature changes of the water in the inner ring can introduce significant error in the flow measurements A 1 change in water temperature can result in a flow of 50 ml due to volume change of the water in the inner ring as well as in the inner ring itself. To avoid this problem, the bag should be disconnected from the inner ring when the water temperature is within ±1 °C of the water temperature when the bag was connected. This is particularly important if the flow rate is less than 500 ml/day

Experience has shown that if the rings are covered and a layer a polystyrene is used for insulation under the cover, the temperature of the water from one morning to the next does not vary by more than 1°C. More consistent readings are obtained if they are taken on a 24 hour basis and the bag is connected and disconnected between 7am and 9am. It should be noted that the water temperature may change by several degrees during the day but that these cyclic variations are only a problem if readings are made at different temperatures Allowing the bag to remain connected until at least 1500 ml of flow has occurred also helps to minimize the effect of temperature changes on the measurement of infiltration rate

The bag should never be allowed to empty when connected to the inner ring When the bag empties, a suction will develop in the inner ring and it may jepoardize the seal. The most likely time that the bag will empty is at the beginning of the test when flow rates are not known. For this reason, the bag should be checked often when first connected. An initial reading should be made after several hours so that a flow rate can be calculated and an estimate of when the bag will empty can be made

It should be noted that it is not necessary to have the bag connected to the inner ring continuously. If the flow rates are high, (>3000 ml/day) it may be more convenient to connect the bag up to the inner ring for several hours a day and let the inlet tube open in the outer ring for the remainder of the time. Whether the inlet tube is connected to the bag or open to the outer ring does not affect the infiltration rate. Just be sure if the tube is left open that it is propped in such a way that it does no suck in air or soil. If it is desired to measure flows greater than 3000 ml/day, a tee fitting has been provided so that two bags can be connected to the inlet tube at once.

Detailed instructions for using the bag given below

11.1.1 <u>Filling the bag.</u>

1 Fill a bucket or a 5 gallon water jug with water and allow to stand for 24 hours to degas.

2. Cut a piece of flexible tubing long enough to reach from the bottom of the jug or bucket to a flexible bag laying next to it.

3. Connect the tube to the valve on the bag and siphon water from the jug into the bag until it is filled.

4. Lift the bag above the water surface in the jug. Hold the bag with the inlet port at the top and squeeze it to remove all the air. Squeeze the bag long enough to force the air out of the tube and then lower the bag so that water will flow back into it. Repeat this process until all the air is removed.

5 Once all the air is removed, fill the bag slightly less than full and shut the valve. Avoid completely filling the bag so that the water in it is under pressure.

6. Dry the bag and valve thoroughly If small amounts of flow are expected (20 ml or less) then be sure that the tube connector remains full of water.

7 Weigh and record the initial weight of the bag to the nearest gram

11.1.2 Connecting the bag to the inner ring.

1. Connect the bag to the inlet tube as follows. Lower the bag into the water of the outer ring Orient the valve so that the tube connector is pointed up Flick the tube connector so that any entrapped air bubbles will be removed from it. It is important that no air bubbles are present in the tube connector or bag as they will be drawn into the inner ring or may even block the flow of water from the bag to the inner ring With the bag completely submerged push the tube connector into the inlet tube Lay the bag flat on the cinder blocks Be sure to position the valve so that it is not folded back onto the bag and possibly pinching off the flow path.

2. Start flow measurements immediately as follows. Use the attached data sheet and record the date and time next to the initial weight of the bag Carefully open the valve and allow flow to occur.

3. Periodically determine the amount of flow that has occurred as follows. Carefully close the valve and disconnect it from the inlet tube. Be sure to close the valve before handling the bag. Also, be sure to prop up the open end of the inlet tube for the reasons mentioned previously. Record the date and time that the valve was closed . Remove the bag from the inner ring, dry it thoroughly, and record its weight. As before, make sure that the tube connector is filled with water to be consistent. Subtract the final weight from the initial weight to obtain the amount of flow that has occurred.

4 Refill and reweigh the bag if necessary and connect it to the inner ring. Always check to see that the valve on the bag or the inlet tubing has not become clogged. With time, algae may grow in the tube. If this is the case then the tube should be cleaned or replaced.

Two bags have been supplied. If flow rates are greater than 3000 ml/day, both bags can be connected to the inner ring at the same time by using the tee fitting(Fig 4) that has been supplied. If the flow rate is less than 3000 ml/day, the extra bag can be filled and weighed in advance so that it can be connected to the inlet tube when the other is removed. By doing this, only one trip to the ring is needed to take a reading

When connecting a bag to the inner ring, be sure that the valve is closed. If the bag is accidentally lifted out of the water with the valve open, it is possible to lift the inner ring out of the ground or rupture the seal. Each inch of head of water produces an uplift force of about 125 pounds on the inner ring, so holding the bag several inches above the water level with the valve opened can easily lift the inner ring out of the ground.

11.2 WATER LEVEL

The infiltration rate varies with the depth of the water level in the outer ring. For this reason, the water level should be recorded each time a flow measurement is made. Water should be added to the outer ring occasionally in order to keep the water level to within ±1/2 inch of the initial level. A scale taped to the inside wall of the outer ring makes it convenient to monitor the water level.

11.3 TEMPERATURE

The temperature of the water in the rings should be monitored closely for reasons discussed previously. If temperature is monitored with a thermometer, then measurements need to be made as close to the inner ring as possible The recommended procedure is to put the thermometer in a soda can and then place the can on the ground next to the inner ring. Remove both the can and the thermometer to take a reading. The water in the can should remain at the same temperature as the water near the inner ring long enough to take a reading.

11.4 PURGING AIR FROM INNER RING

During the test, it is possible that air may rise out of the soil and become trapped in the inner ring This air should be purged from the inner ring and an estimate of its volume made. If the volume is significant (>20% of flow since the last time the ring was purged) the infiltration rate should be corrected to account for it.

The procedure for purging the inner ring of air is described below.

1 Disconnect bag inlet tube. Use a board or shovel handle and gently tap on the inner ring to get the air bubbles to rise to the flush port.

2. Lift the flush tube out of outer ring and lay end of tube on the ground. The end of the tube needs to be below the water level so that water can be siphoned out of inner ring.

3 Remove plug from end of flush tube. Water and air if present will start to flow out of inner ring. If air completely fills the tube, the syphon will be lost. If this happens, submerge end of tube in water of outer ring and work air out of tube. Once the

tube is saturated, place plug in end of tube, lift tube out of ring and place on ground. Remove the plug and allow water to flow from end of tube (if tensiometers are being used, the hand pump can be used instead to restart the siphon by pulling a vacuum on the end of the tube)

4. Allow water to flow from end of tube until air ceases to emerge from inner ring. Replace plug in end of flush tube and place tube back into outer ring.

5. Wait at least 30 min. before taking any flow measurements.

Purge the inner ring on a weekly basis until no significant amount of air is found.

12.0 DATA REDUCTION

12.1 INFILTRATION

Infiltration (I) can be determined as follows:

$$I = Q/(At)$$

where:

I = infiltration (cm/sec)
Q = volume of flow (cm^3)
A = area of flow (cm^2)
t = time interval in which Q was determined (sec)

Two factors that can have a significant effect on the infiltration rate are temperature changes and swelling of the soil. If either are significant, the infiltration rate should be corrected to account for it. The total flow (Q) that is measured is the sum of the following.

$$Q = Q_i + Q_s + Q_t$$

where

Q_i = flow due to infiltration

Q_s = flow due to swell

Q_t = flow due to temperature changes

The infiltration rate corrected for swell and temperature changes is.

$$I = Q_i / At$$

where:

$$Q_i = Q - Q_s - Q_t$$

Temperature changes can be minimized as discussed previously and consequently, Q_t is seldom significant.

The remaining portion of flow to consider is Q_s, the flow due to soil swell. The process of water infiltrating an unsaturated swelling soil is complex and difficult to analyze Presently, there is not an accepted procedure to account for the effect of soil swell on the infiltration rate. The author is of the opinion however, that a close estimate of Q_s can be obtained as follows First, it is assumed that any volume change that occurs is vertical. Second, it is assumed that all of the additional volume generated by the swelling soil is filled with water that infiltrated the soil. Based on these two assumptions:

$$Q_s = \Delta h \times A$$

where

Δh = vertical swell of soil beneath inner ring

A = area of inner ring

12.2 HYDRAULIC CONDUCTIVITY

Hydraulic conductivity (k) in the saturated zone can be determined as follows:

$$k = Q/(iAt)$$

where:

Q = volume of flow (cm^3)
A = area of flow (cm^2)
t = time interval in which Q was determined (sec)
i = gradient
= $\Delta h / \Delta s$
Δh = head loss
Δs = length of flow path for which Dh is measured

since.

$$I = Q/(At)$$

then

$$k = I/i$$

The determination of k depends on calculating a value for the gradient (i). Unlike the calculations for I and k, the determination of i is not straight forward. The parameters used to calculate i for a typical infiltration test are shown in Fig. 5. These parameters are used to calculate the gradient as follows:

$$i = (H + D + Hs) / D$$

where

H = depth of water ponded in rings
D = depth to the wetting front
Hs = suction at the wetting front

There are differing opinions on what value should be used for Hs One view is that Hs should be equal to the ambient suction in the soil below the wetting front. The ambient suction can be measured with tensiometers can be quite high, yielding values of Hs as high as 700 cm of water. Another view is that Hs should be equal to zero, ie the suction in the soil at the wetting front has no influence on the infiltration rate. Hence, if the position to the wetting front is known, the gradient is simply (H + D) / D.

The author feels that the second view (Hs = 0) yields a close approximation to the actual gradient Measurements made at several sites have shown that the drop in infiltration rate versus time can be accounted for by the increase in D as the wetting front moves through the soil. If suction had an influence, a much larger decrease in the infiltration rate would have occurred.

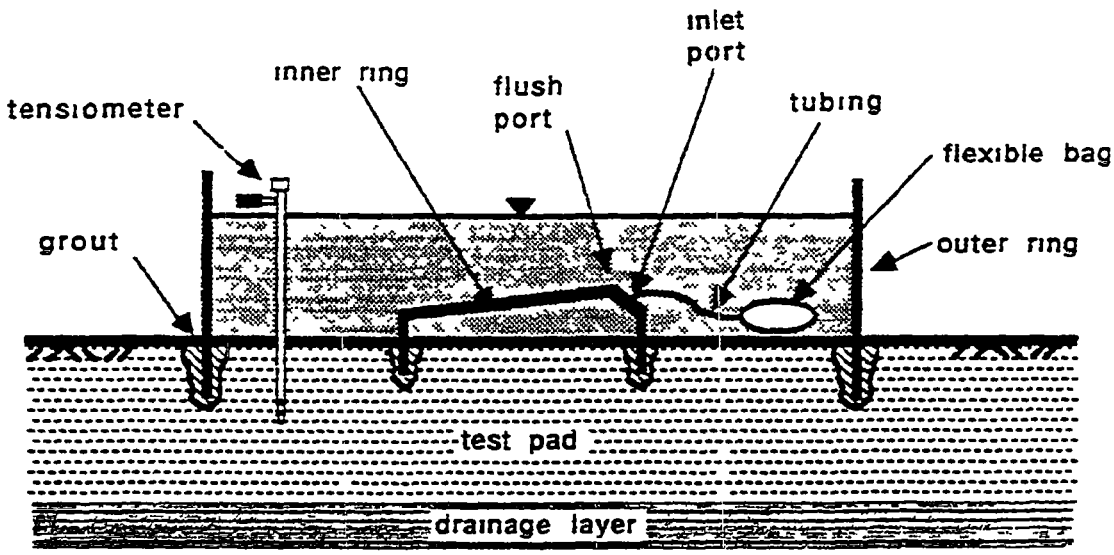


Figure 1. Schematic Of A Sealed-Double Ring Infiltrometer Installed On Test Pad

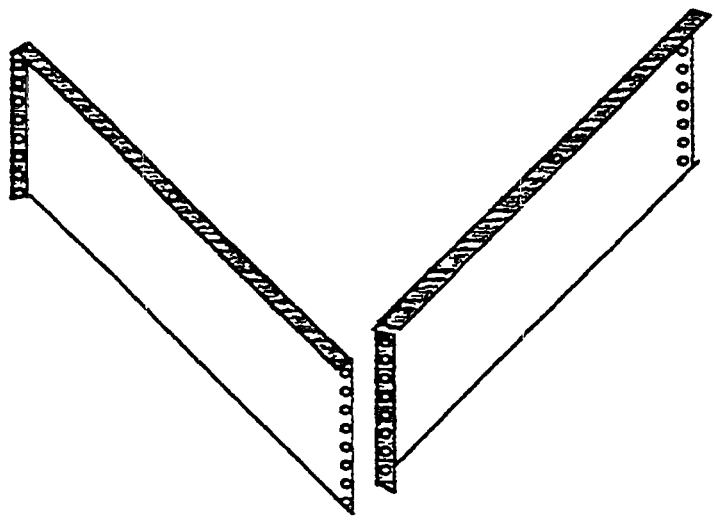


Figure 2. Orientation Of Panels For Assembly Outer Ring.

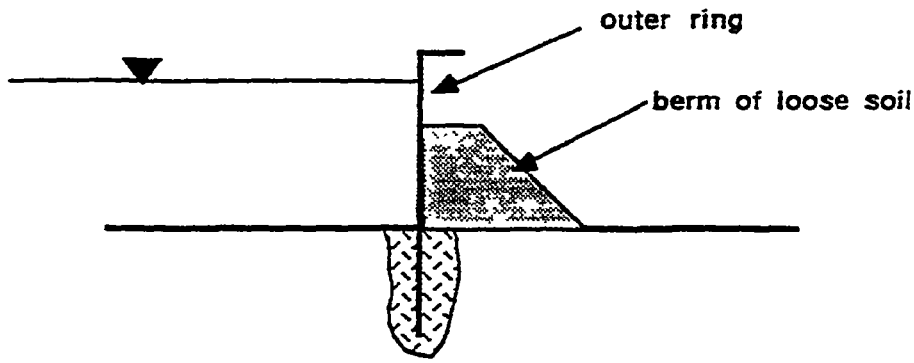


Figure 3. Berm Of Soil On Outside Of Outer Ring

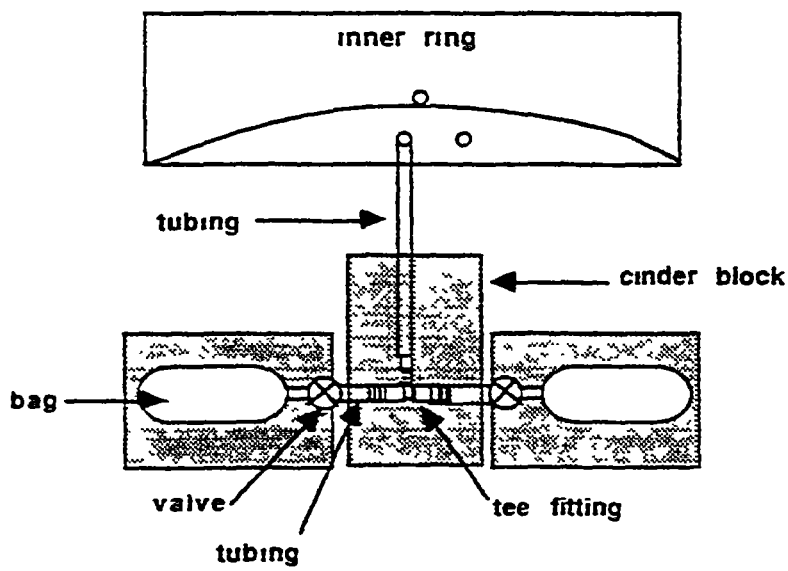


Figure 4. Arrangement Of Two Bags Connected To Inner Ring

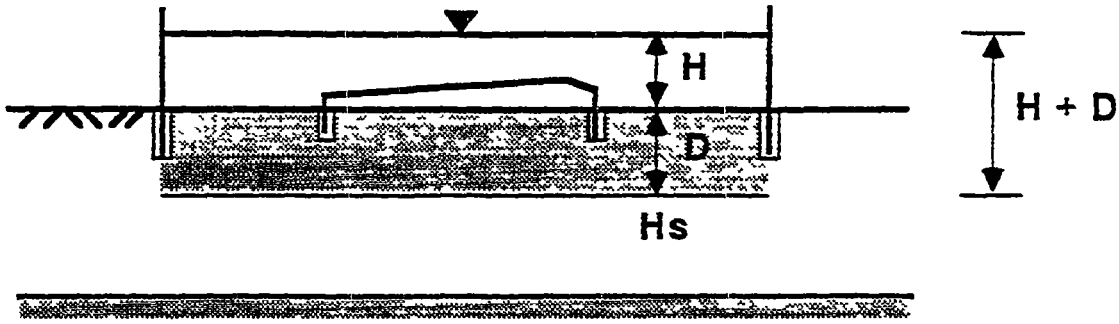


Figure 5. Diagram With Parameters Needed To Calculate Gradient

APPENDIX A

TENSIOMETER DESCRIPTION AND INSTALLATION INSTRUCTIONS

A schematic of a tensiometer is shown in Fig. 6. It consists of a sealed plastic tube with a porous tip on one end and a vacuum gage on the other The tube is filled with water and then sealed. Operating instructions have been included with the tensiometers A preferred method of installation however is described on Fig 6. Disregard the installation procedure described in the manufacturer's instructions. Driving a pipe may crack the soil and open up flow channels.

Tensiometers work as follows If the soil is unsaturated and there is good contact between the tip and the surrounding soil, water will be drawn out of the tube and the gage will register a suction. As the wetting front passes the the tip, the suction will decrease and water will reenter the tensiometer until the suction goes to zero Good performance of tensiometers depends on saturating the tensiometer and achieving good contact between the tensiometer and the surrounding soil.

It is recommended that nine tensiometers be used, three at each depth of 6", 12", and 18". A suggested layout for the tensiometers is shown in Fig. 7. Auguring a hole and pushing the tensiometer in place is preferred to forming a hole by driving a pipe into the ground.

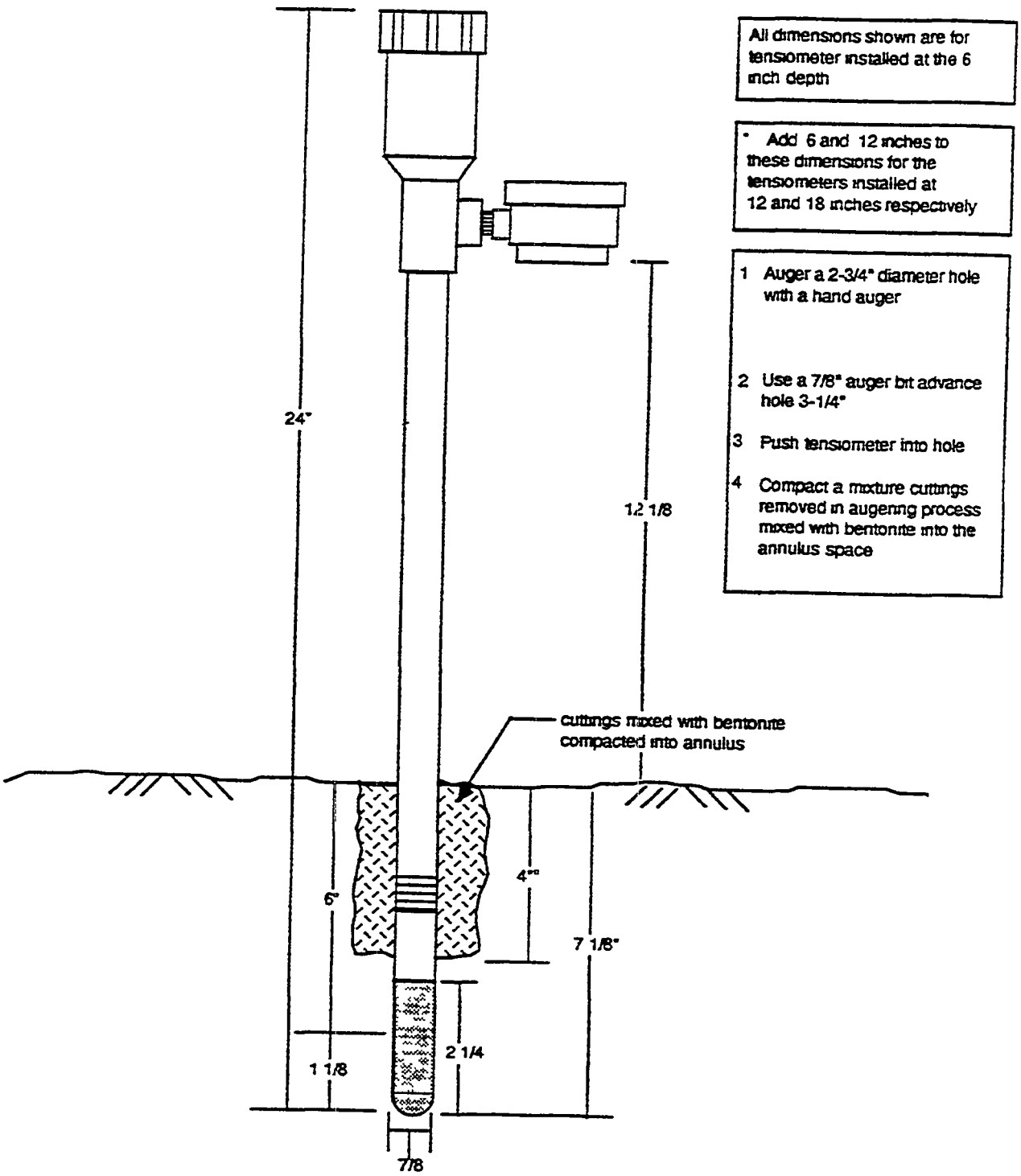


Figure 6. Schematic of a Typical Tensiometer Installation

APPENDIX B

SWELL MEASUREMENTS

An arrangement that can be used to measure swell is shown in Fig. 8. This arrangement consists of stretching thin wire between two fence stakes that have been driven into the ground close to the outer ring. The stakes are aligned so that the wire is positioned directly above two handles on the inner ring. The wire serves a a reference elevation to monitor upward movement of the inner ring. A swell gage is used to establish a reference distance between a reference mark on a handle and the wire. The swell gage consists of a dial gage mounted to a rod. The position of the dial gage on the rod is fixed.

It is recommended that two wires be used so that the elevation of all four handles on the inner ring can be monitored. A olt can be attached to the handle by drilling a 3/8" hole through the handle The bolt head can serve a reference point for the end of the swell gage rod. Initial readings are taken before the rings are filled to serve as a reference It is also recommended that the elevation of the wires be surveyed and referenced to a benchmark located away from the rings. If a discrepancy occurs in the readings, the wire can be surveyed to check that its position has not changed.

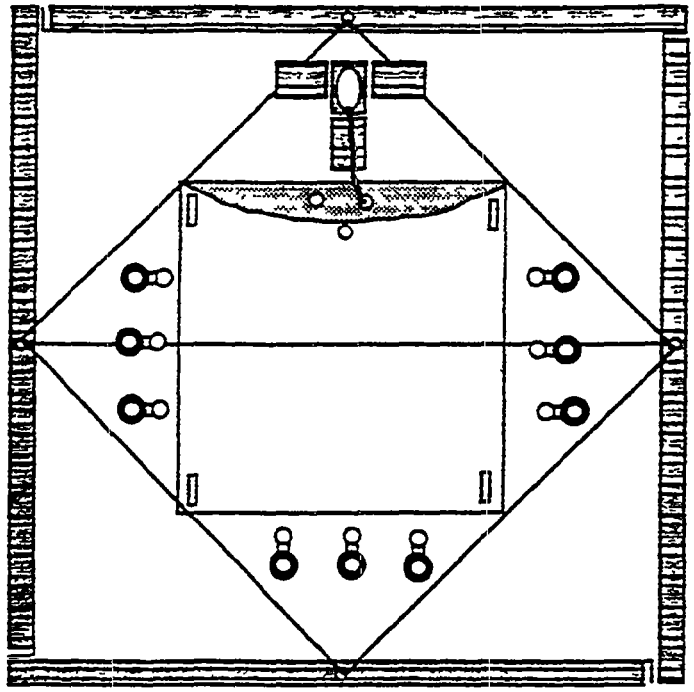


Figure 7. Top View Of SDRI Showing Layout Of Tensiometers

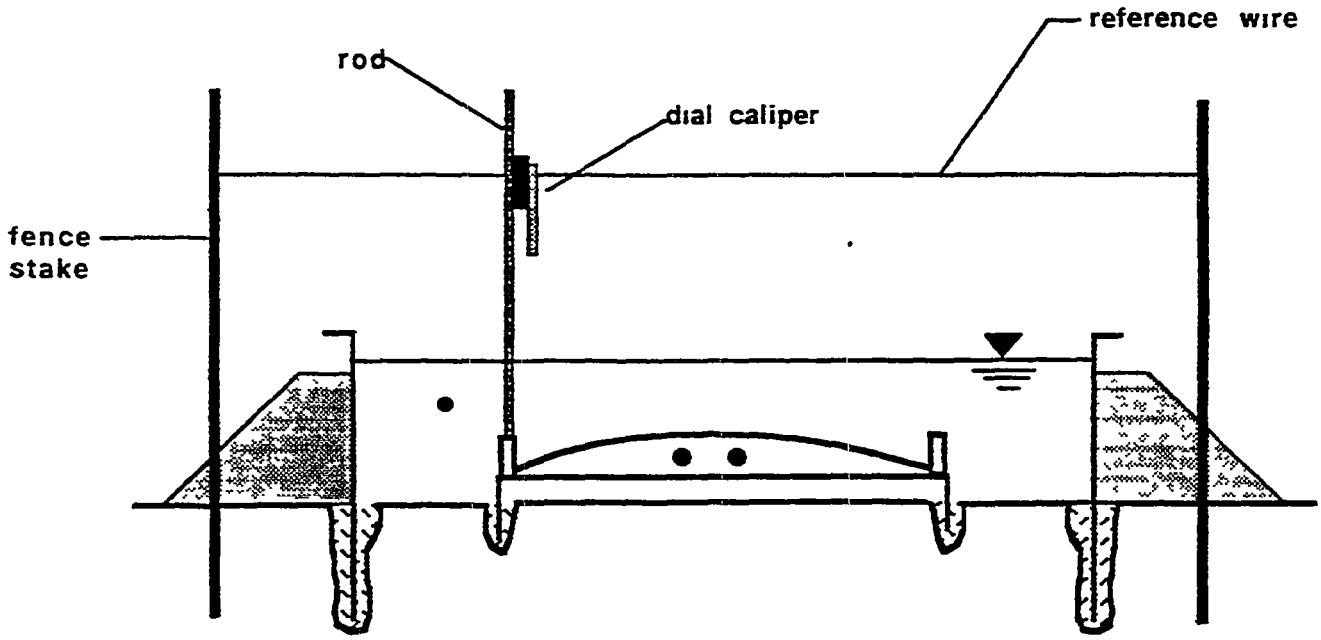


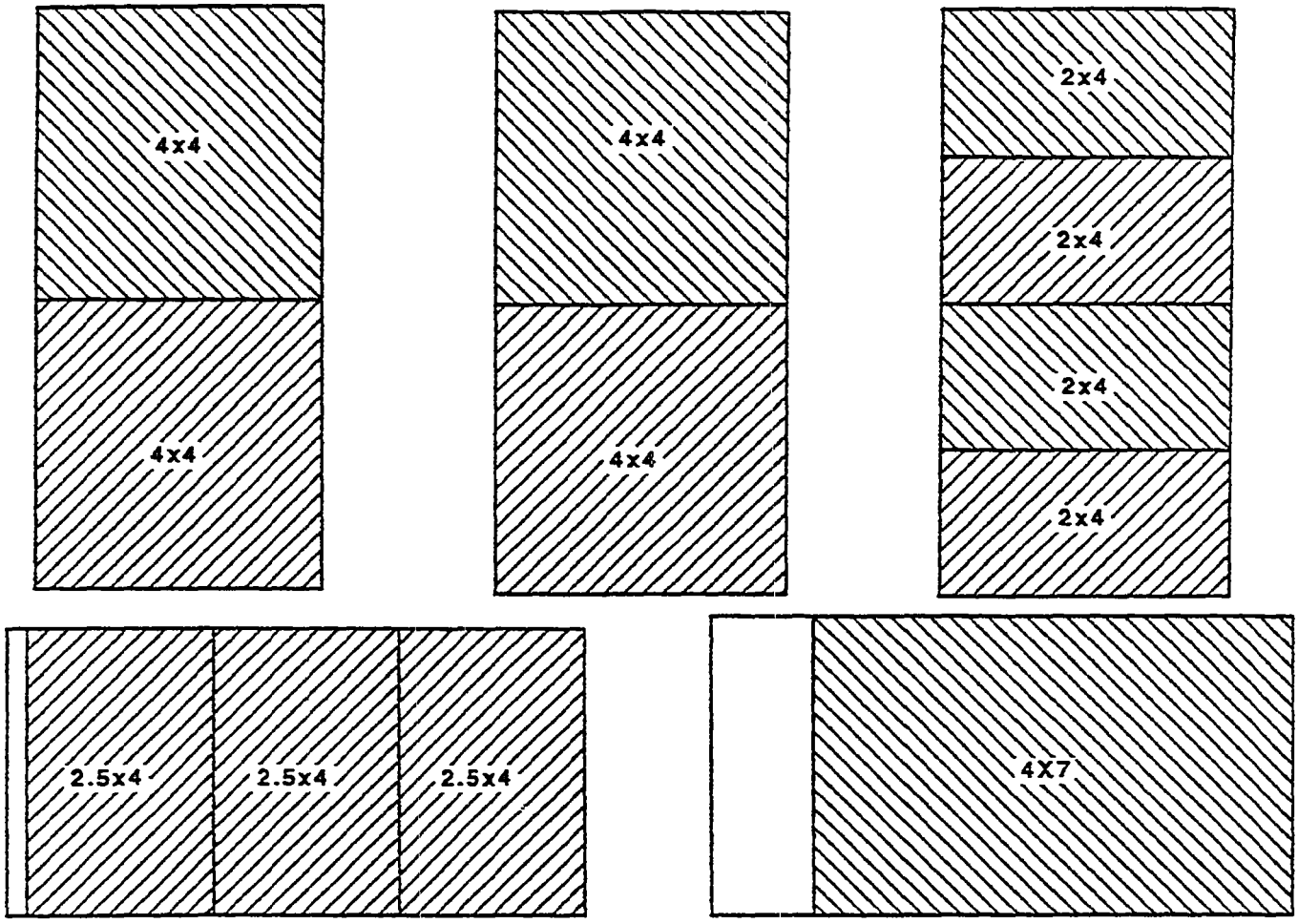
Fig. 8. Arrangement For Monitoring Swell

APPENDIX C

COVER DESCRIPTION

It is highly recommended that a cover which insulates the rings and blocks sunlight is be used during the test. A cover consisting of plywood, 2 x 4's, and insulation is shown in Fig. 9.

COVER MATERIAL LIST



MATERIALS

nails	2x4's	1/2" plywood	insulation
# 16 common 2" roofing	13 - 12'	(5) sheets cut as follows. 4 - 4x4 4 - 2x4 1 - 7x4 3 - 2.5x4	5 - 4x8x1/2 sheets (foil backed insulation- the type used on ext. walls of houses)

Fig. 9a. SDRI Cover

TOP VIEW OF SDRI COVER
WITH 2X4'S IN PLACE

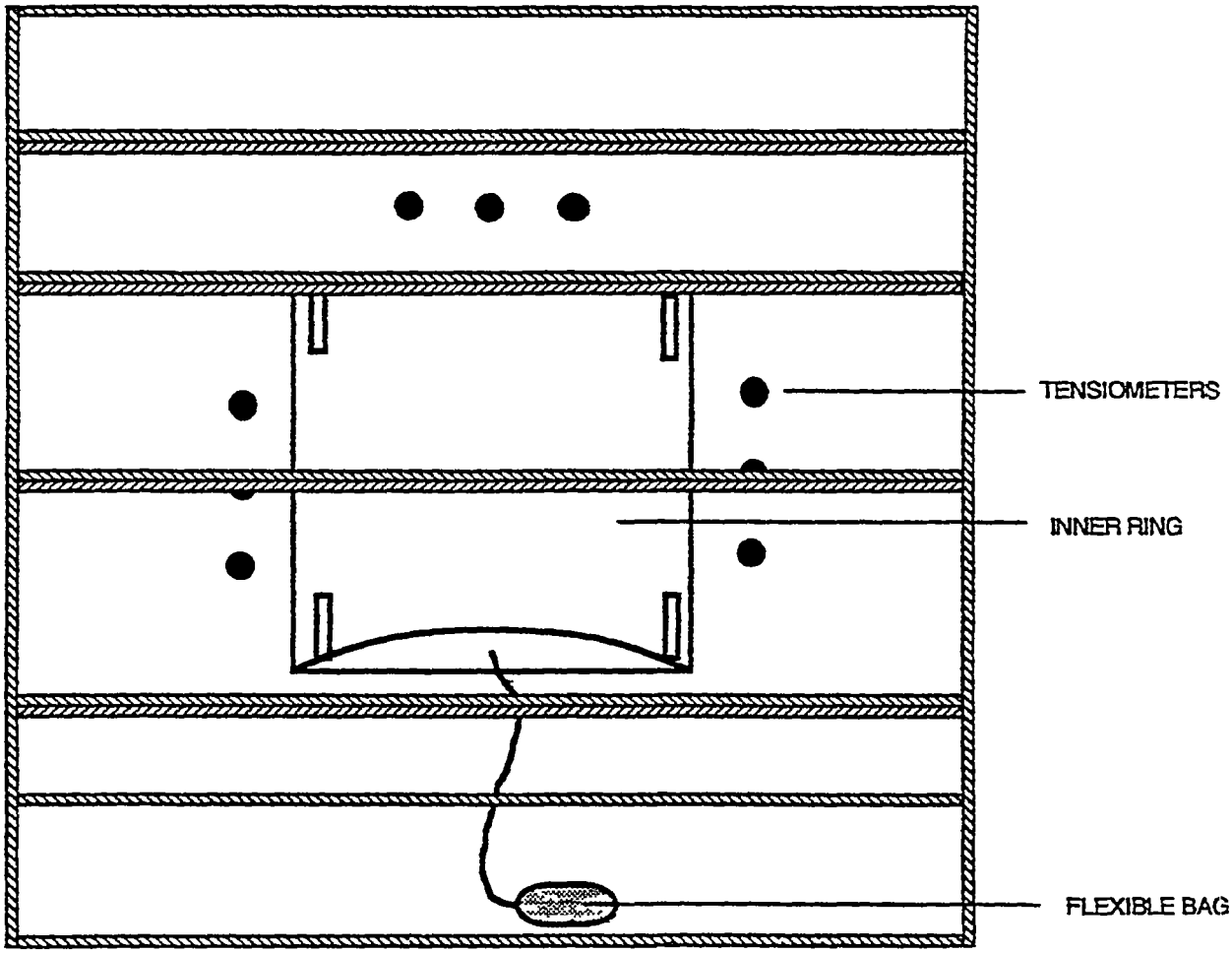


Fig. 9b. SDRI Cover

TOP VIEW OF SDRI COVER
WITH PLYWOOD IN PLACE

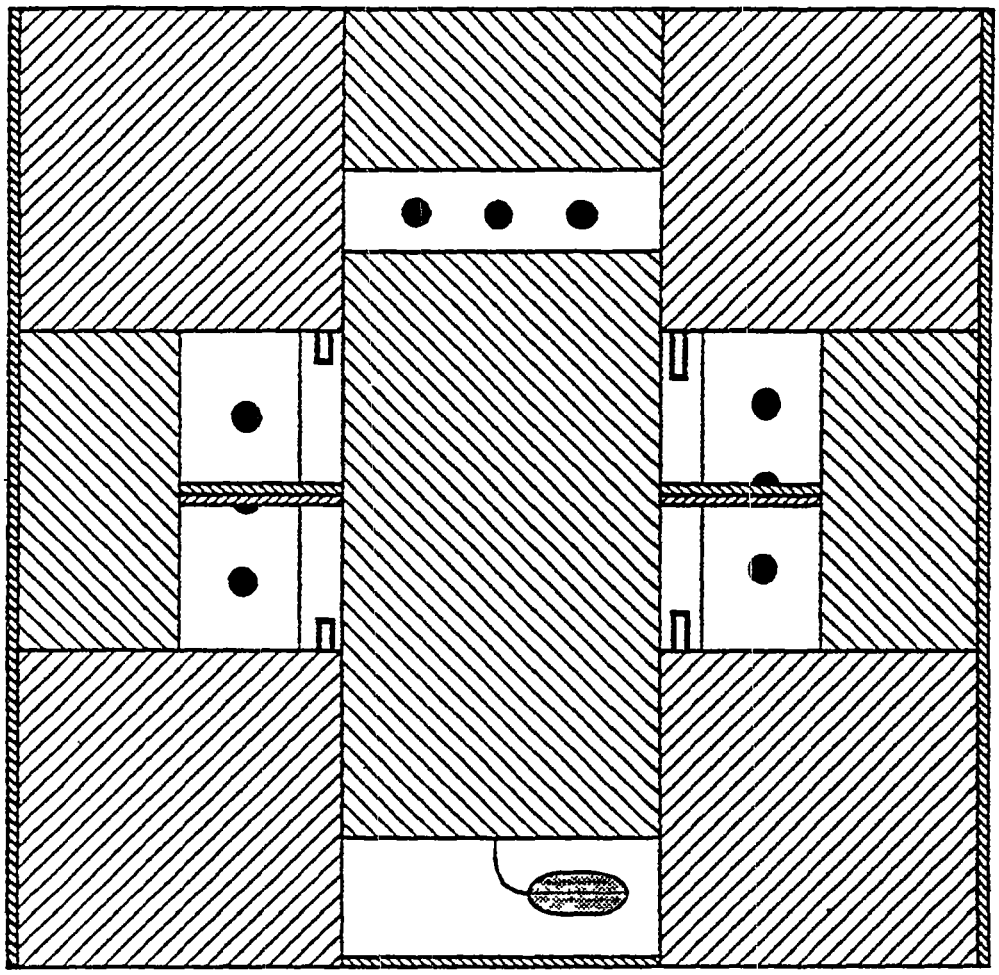
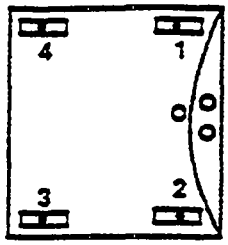


Fig. 9c. SDRI Cover

APPENDIX D

DATA FORMS

SWELL DATA



DATE	TIME	1	Δh	2	Δh	3	Δh	4	Δh	Δh_{avg}

NOTES

		TENSIOMETER READING - CENTIBARS											
		DEPTH - 6"				DEPTH - 12"				DEPTH - 18"			
DATE	TIME	GROUP 1	GROUP 2	GROUP 3	AVG	GROUP 1	GROUP 2	GROUP 3	AVG	GROUP 1	GROUP 2	GROUP 3	AVG

PROJECT: _____

TENSIOMETER TYPE: _____

NOTES:

DATA FORM FOR SDRI TEST

Project: _____

Inner ring info: _____

Outer ring info: _____

Liner thickness (cm) : _____

$I = Q/(At)$

I = infiltration (cm/sec)

Q = quantity of flow (ml)

t = interval of time (sec)

A = area of inner ring (cm 2) _____

Date	Initial time (sec)	Final Time (sec)	t Interval of ** Time (sec)	Initial Wt of Bag (grams)	Final Wt of Bag (grams)	Q Quan of Flow (ml)	I Infiltra-tion (cm/sec)	Temp (C)	Water Depth (in)
on / off								on / off	on / off

NOTES:

Appendix B

THE STEI TWO-STAGE BOREHOLE FIELD PERMEABILITY TEST

THE STEI TWO-STAGE BOREHOLE FIELD PERMEABILITY TEST

by: Gordon P. Boutwell, PhD, P.E.

Presented to
"CONTAINMENT LINER TECHNOLOGY AND SUBTITLE D"
Seminar Sponsored by
Geotechnical Committee
Houston Branch, ASCE
Houston, Texas - March 12, 1992

SYNOPSIS

In 1991, the Texas Department of Health began requiring field verification of the hydraulic conductivity for the waste-retention barriers under its jurisdiction. The TDH has approved two procedures: the Two-Stage Borehole (TSB) method and the Sealed, Double-Ring Infiltrometer (SDRI) method. The TSB method is discussed herein.

It is a falling-head infiltration test conducted in a cased borehole, typically 4 inches in diameter. The first stage is performed with the bottom of the hole flush with the bottom of the casing for maximum effect of vertical permeability (k_v). After steady-state is achieved, the hole is advanced some 6 to 8 inches below the bottom of the casing so that horizontal permeability (k_h) has a greater effect. The two stages yield the following:

Stage 1 - The maximum possible value for (k_v).
Stage 2 - The minimum possible value for (k_h).
Stage 1 + Stage 2 - Constants for two equations which can then be solved for the real (k_h, k_v).

Procedures are available for reduction of the data in the cases of both above and below water table testing, and for the bottom boundary conditions of a material far more permeable, equally permeable, or far less permeable than the medium being tested. The test has been successful in evaluating both compacted and natural materials with permeabilities as low as 1x10(-9) cm/sec.

The major test precautions include proper sealing of the casing along the outside, accounting for temperature effects, and correcting for sidewall smear during the second stage. The test is quick, simple, and relatively inexpensive. It allows results in days, rather than months. Multiple installations are feasible so that statistical confidence can be achieved. It is recognized in the literature, including U.S. EPA publications, and accepted by many State regulatory authorities.

I. INTRODUCTION

Clay barriers are an important component of waste retention structures. Their primary geotechnical characteristic for this use is hydraulic conductivity, which must be verified during the Construction Quality Assurance program. Until recently, practice relied on laboratory testing of small (7 to 10 cm diameter) undisturbed samples taken from the barrier or a similarly constructed test pad. Day and Daniel (1985) reported conductivities measured in the field which were 3 to 4 orders of magnitude higher than they obtained with laboratory tests. While that study was justly criticized, the horse was out of the barn and regulators all over the country galloped into field testing for hydraulic conductivity evaluation at waste facilities.

From the regulatory standpoint, a test procedure should be accurate and avoid false positives, i.e., not indicate compliance with the specified conductivity when the liner or pad truly has a higher value. This normally means testing a large soil volume searching for the elusive "macropores" which are thought to evade, somehow, even numerous laboratory tests. The regulated community wants the accuracy and avoidance of false positives for their own protection, but also wants to minimize testing times (and costs), and to avoid false negatives, both for economy.

In about the last two years, two methods have become accepted as meeting these criteria to a satisfactory degree: the Sealed, Double-Ring Infiltrometer (SDRI) and the Two-Stage Borehole (TSB) procedure. Each has its stronger and weaker points (see Daniel, 1989).

II. BASIC CONCEPTS

The vertical conductivity (k_v) governs flow, even in sidewall liners if built in the preferred manner: lifts parallel to the slope. However, the horizontal conductivity (k_h) is greater than the vertical. All field tests are affected by this anisotropy, unless flow in the horizontal direction is artificially blocked; the effect is to increase the test conductivity by factors of 2 to 5 over the real (k_v) value. Equations for flow from various source geometries in a cross-anisotropic medium are available in Hvorslev (1951). However, each equation has two unknowns: (k_v) and ($m^2 = k_h/k_v$).

The TSB procedure combines four old concepts into one new idea to find (k_v). The field procedure is taken from long-established US Bureau of Reclamation methods: their flush-bottom borehole test (E-18) and borehole packer test (E-19). Computations are based on the Hvorslev equations adapted for various bottom boundary conditions by the three-dimensional Image Potential Technique (Carslaw and Jaeger, 1959). The new idea is performing both USBR tests in the same borehole, yielding two equations which can be solved for the two unknowns, (k_h) and (k_v).

The TSB is a field infiltration test, conducted in a cased borehole so that the geometry of the infiltrating zone can be controlled. It is normally conducted as a falling-head test. The basic idea is to vary the geometry of the infiltrating area so as to vary the relative effects of (k_h) and (k_v). In the first stage, the geometry is chosen so that (k_v) has its maximum effect. The second stage geometry is such that (k_h) has its maximum effect. The results of the two stages yield two equations in two unknowns (k_h, k_v), which can then be solved. This concept is illustrated on Figure 1, below:

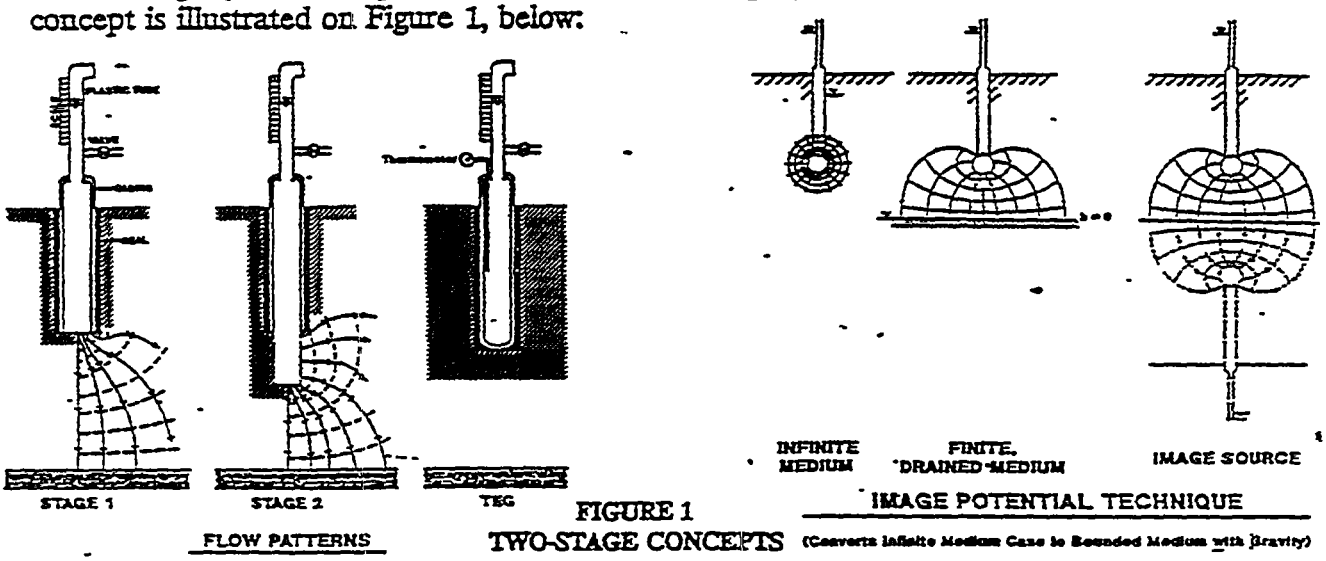


FIGURE 1
TWO-STAGE CONCEPTS

Stage 1 is normally conducted using a flat bottom flush with the base of the casing. Infiltration proceeds until a steady-state flow condition is achieved. Then, the borehole is advanced some 1.5 to 2 casing diameters (6 to 8 inches) below the bottom of the casing. The apparatus is refilled, and infiltration in this Stage 2 continues until it achieves steady-state flow.

During the test, the soil is assumed isotropic ($k_v = k_h$). Stage 1 then yields an apparent permeability (K1), and Stage 2 a different value (K2). The unknown ratio (k_h/k_v) is a unique function of the known test geometry and the known test ratio (K2/K1). When the former is determined, the real (k_v, k_h) can be computed from (K1) or (K2).

III. FIELD PROCEDURES

As is the case with virtually all field tests, and especially field permeability tests, the field procedures are of paramount importance. The most diligent office analyses cannot overcome all of the problems resulting from improper installation, inadequate monitoring, premature test termination, and the like.

3.1 Test Program Design. The test program should be designed to meet the conditions assumed in deriving the data reduction equations so that meaningful results can be obtained.

3.1.1 Vertical Boundaries. Certain clearances are required between the infiltrating surface and any boundaries, pervious or impervious. These can be summarized as:

a. **Minimum casing embedment below ground surface** = 2.5D
(Prevents uplift, minimizes hydraulic fracturing)

b. **Minimum thickness of tested material below bottom of Stage 2** = 2.0D
(Avoids violating boundary conditions of equations)

c. **Minimum recommended Stage 2 extension** = 1.5D
(Avoids theoretical problems at finite but small L/D)

D = Casing inside diameter
L = Length of Stage 2 extension

3.1.2 Horizontal Spacings. It is intuitively obvious that the tests must be spaced "far enough" apart so that their flows do not interfere with each other causing a falsely low permeability. Also, the presence of a drainage boundary (such as the edge of a test pad) which is "too close" to the test will increase the flow, yielding a falsely high permeability.

This can be avoided by maintaining at least the following clearances:

a. **Minimum horizontal distance between tests** = 30D
b. **Minimum horizontal distance to free surface** = 30D

3.1.3 Number and Size of Tests. The number of tests required for evaluation depends on the project, the acceptance criteria, and the variability of the stratum/fill being evaluated. As in virtually any other geotechnical testing, "the bigger the better".

However, the general practice has been to use 4-inch (ID) tests, with 5 tests for the typical liner or test pad.

The scale effect, if any, of test size has not been fully researched. Virtually all of the known tests have been conducted using 4-inch (10 cm) ID casings. These tests typically permeate a volume of some 0.4 - 1.1 cubic feet each, or 2 to 5 cubic feet for a 5-test group. Benson (pers. comm., 1991) indicates that the minimum representative volume for a permeability determination is on the order of 0.5 - 1.0 cubic foot. This is about the volume permeated by a typical TSB test.

3.1.4 Other Details. There are a few other details in test planning which should be considered. Among these are:

a. Protect the test area surface from desiccation, usually with clear or white plastic.
(Avoids heat-induced problems).

b. Use a "sock" to prevent collapse of the Stage 2 open hole in susceptible materials. The sock is a rigid cylinder of open-mesh plastic, lined with a filter geofabric. The cylinder is somewhat smaller in diameter than the casing ID (and thus the Stage 2 hole), and an inch or so longer than the extension for Stage 2. It is fitted with retrieving lines and not left in the hole after the test.

c. Minimize the distance (R_2) from the ground surface to the bottom of the measuring scale, especially for shallow tests. This also aids in having the longest possible reading time between standpipe refills and avoiding hydraulic fracturing.

d. Match the standpipe size to the flow rate so that accuracy is achieved but overnight readings are possible. For a 4-inch casing, this usually means a 0.5 - 0.75 inch ID standpipe.

3.2 Permeameter Installation. Proper installation and checking the permeameters are vital to obtaining a valid test. Various field techniques have been developed through experience which minimize problems. These techniques are discussed in this section.

3.2.1 Permeameter. A typical permeameter is illustrated on Figure 2. The apparatus is simple; the permeameter can be assembled with a visit to a water-well driller and a hardware store. The elements for a falling-head system are:

a. Casing. Typically 4-inch ID Schedule 40 PVC monitoring well pipe, flush-threaded, with "O"-Ring joint. Other casings can be used.

b. Cap. To fit casing, preferably domed, and drilled and/or tapped to receive the standpipe apparatus.

c. Standpipe. *Clear* Schedule 40 PVC or acrylic tube, 0.5 to 1.0 inch ID, with scale. Include elbow with cover (having air-vent) to prevent rain entry and minimize evaporation.

d. Fittings. The small fittings necessary to assemble the apparatus.

All joints which are not glued are assembled with PTFE Plumber's Tape and silicone grease (not sealant).

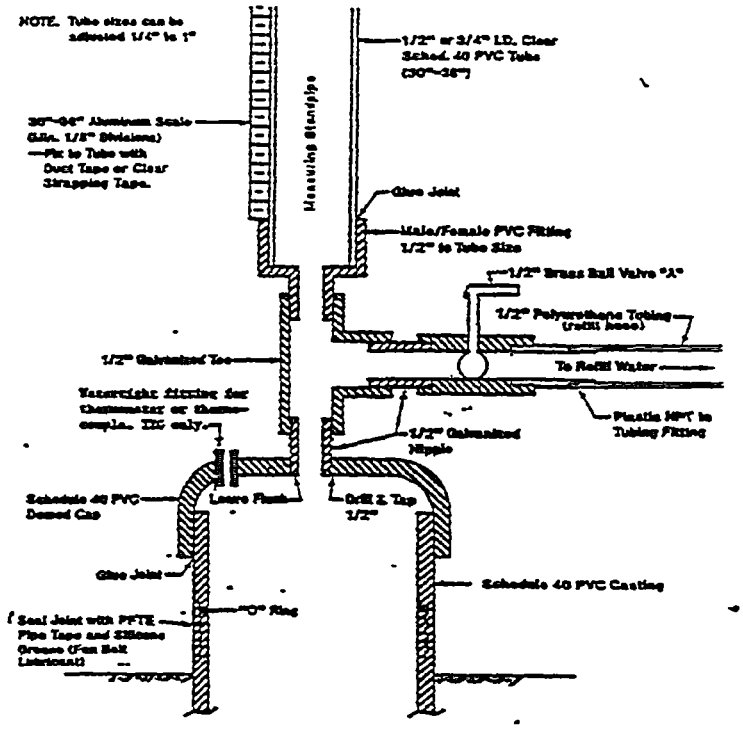


FIGURE 2
TYPICAL PERMEAMETER

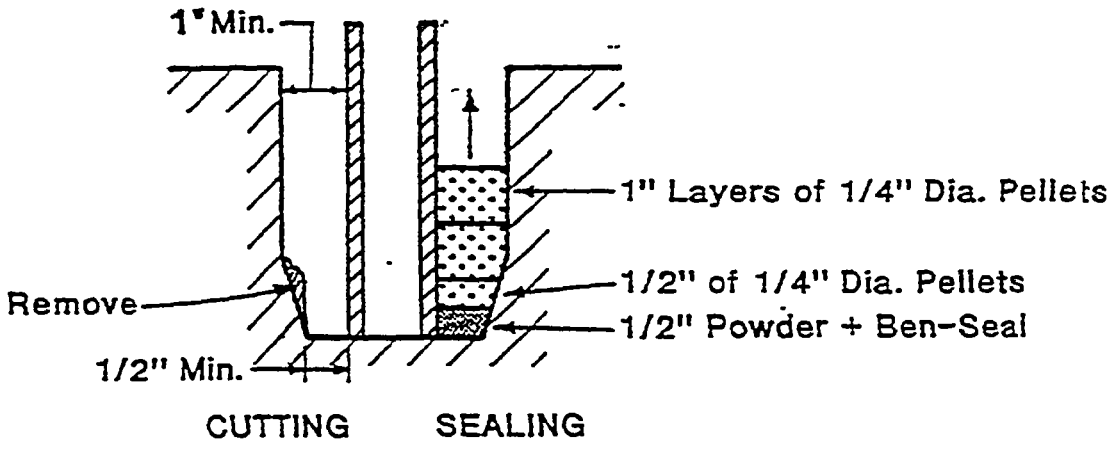


FIGURE 3
SEALING PROCEDURE

3.2.2 Borehole. The casing is set into a borehole. The holes have been drilled using rigs, power-operated hand equipment, and hand augers. The device depends on depth and hardness of material. The hole must have a large enough diameter to allow sealing the annular space between the borehole wall and the casing. Also, it must not disturb the soils below the casing bottom. The bottom must also be flat. Experience has shown the following to be acceptable:

a. **Borehole diameter at least 2 inches greater than the casing OD.** (To allow sealant to reach the bottom and for tamping).

b. **Stop point of auger about 1 inch above proposed casing bottom.** (To avoid testing in a disturbed material)

c. **Ream bottom of borehole to final depth with a flat auger.**

The bottom of the borehole should be flat and flush with the bottom of the casing in order to correspond with Hvorslev's (or H-I) Case "B" or "C" for Stage 1.

3.2.3 Sealing. This is the single most important step in installation. A poorly sealed test cannot be salvaged. The annular space between the casing and the wall of the borehole is sealed with bentonite. Best results have been attained using 1/4" (not 3/8" or larger) bentonite pellets or crushed bentonite (Baroid "Hole-Plug" or equivalent). The procedure, illustrated on Figure 3, is:

a. **Crush sufficient pellets, "Ben-Seal", or "Hole-Plug" to fill about 1/2 inch of the annulus. This should have about 1/16" size fragments with some powder.**

b. **Place this material into the annular space.**

c. **Place about 1/2 inch of bentonite pellets or "Hole-Plug" into hole,**

d. **Tamp the bentonite pellets or "Hole Plug",**

e. **Add water until it shows above the bentonite,**

f. **Repeat the process (but using only the pellets or "Hole Plug") in 1 inch increments to the ground surface or a minimum of 6D above the casing bottom, whichever occurs first. Grouting above the 6D level is allowable.**

g. **Allow the bentonite (and grout) to hydrate at least overnight.**

The casing must be steadied to prevent lateral motion while sealing. The bentonite seal is then allowed to hydrate overnight before any head is applied to the system.

3.2.4 Advancing for Stage 2. Upon completion of Stage 1, a borehole is advanced below the bottom of the casing to form the cylindrical infiltrating surface for Stage 2. The important points are:

a. **Do not disturb the casing - that can affect the seal.**

b. **Borehole diameter should equal casing ID.**

c. **Stop point of auger about 1 inch above proposed Stage 2 bottom. Ream flat and measure depth.**

d. **Roughen the sidewalls to minimize smear.**

This portion of the work is normally handled with hand equipment. The first step after removing the cap is to empty the casing of water (tests above groundwater level or where no seepage was noted during Stage 1 drilling and/or sealing). It is frequently useful to obtain an undisturbed sample during this process, using ASTM D2937 or D1587. However, undisturbed sampling should not be performed if the material being tested contains gravel-sized particles; they can disturb the sidewalls during the push or driving. After or in lieu of undisturbed sampling, the boring is augered until the point of the auger is about 1 inch above the desired bottom for Stage 2. The auger should be at least 1/2 inch in diameter smaller than the casing ID. The boring is then completed to depth and diameter with a flat-bottomed reamer.

The reamer is designed to minimize sidewall smear, having full casing ID only at the cutting edge. The sidewalls are then roughened with a wire brush or similar device, a procedure also recommended in USBR E-18. This step must not be omitted, since one of the significant problems encountered in Two-Stage testing has been artificially low values for Stage 2 due to smear. Equations to handle smear are included herein, but require some idea of the degree of smear.

After the borehole is completed and cleaned of cuttings, the depth is measured so that the correct length of the Stage 2 cylinder is known. For a typical test, a 1-inch depth error will yield the wrong Stage 2 permeability value by 7 to 8%. The cap is then reseated, and Stage 2 begins.

3.3 Ambient Condition Effects. Temperature changes cause the dominant effects of ambient conditions on this test, although there may be some contribution from barometric pressure changes. Temperature changes affect the test by:

* Volumetric changes in the water and apparatus.
* Viscosity changes with temperature.
* Freezing the test water.

The procedures for overcoming these effects are given below.

3.3.1 Volumetric Effects (TEG). At slow rates of flow, the field readings are affected by temperature, as has been noted on many such projects. Rising temperature causes the water column in the pressure/measurement standpipe to expand, so that the drop in water level is less than flow alone would produce. The net effect is a lower apparent permeability. Conversely, falling temperature produces a higher apparent permeability. A normal day's temperature variations can easily cause a 0.5 to 1 order of magnitude change in the apparent permeability of low-permeability materials.

Therefore, a complete "dummy" test setup is installed but with the bottom of the casing sealed with a cap which is normally glued on and pressure-tested. This dummy, or temperature effect gauge (TEG) is of the same construction and embedded to the same depth as the regular test setups. Since there is no flow from the TEG, any change in its readings must be due to changes in the ambient conditions (temperature and/or barometric pressure). Such changes would affect the regular test setups to exactly the same degree.

This correction is applied to the regular tests by:

* Reading the TEG at the same times as readings are taken on the regular tests.

* Determining any increase (decrease) in water levels in the TEG between regular test readings.

* Subtracting any increase (adding any decrease) at the TEG from the readings at the regular tests for the ends of the same time increments.

3.3.2 Viscosity Effects of Temperature. Permeability is normally reported as the value for water at 20°C (68°F). The density and viscosity of liquids, including water, are affected by temperature. The effect on permeability is in direct ratio to the kinematic viscosity (U), which is the viscosity divided by the density. The kinematic viscosity decreases at higher temperatures. The net effect is that the apparent permeability is greater than the 68°F value at low temperatures. The reverse occurs with decreasing temperatures. The effects for ordinary conditions can be from -50% to +15% on the permeability value. The normal correction to the standard condition is given in ASTM D5084:

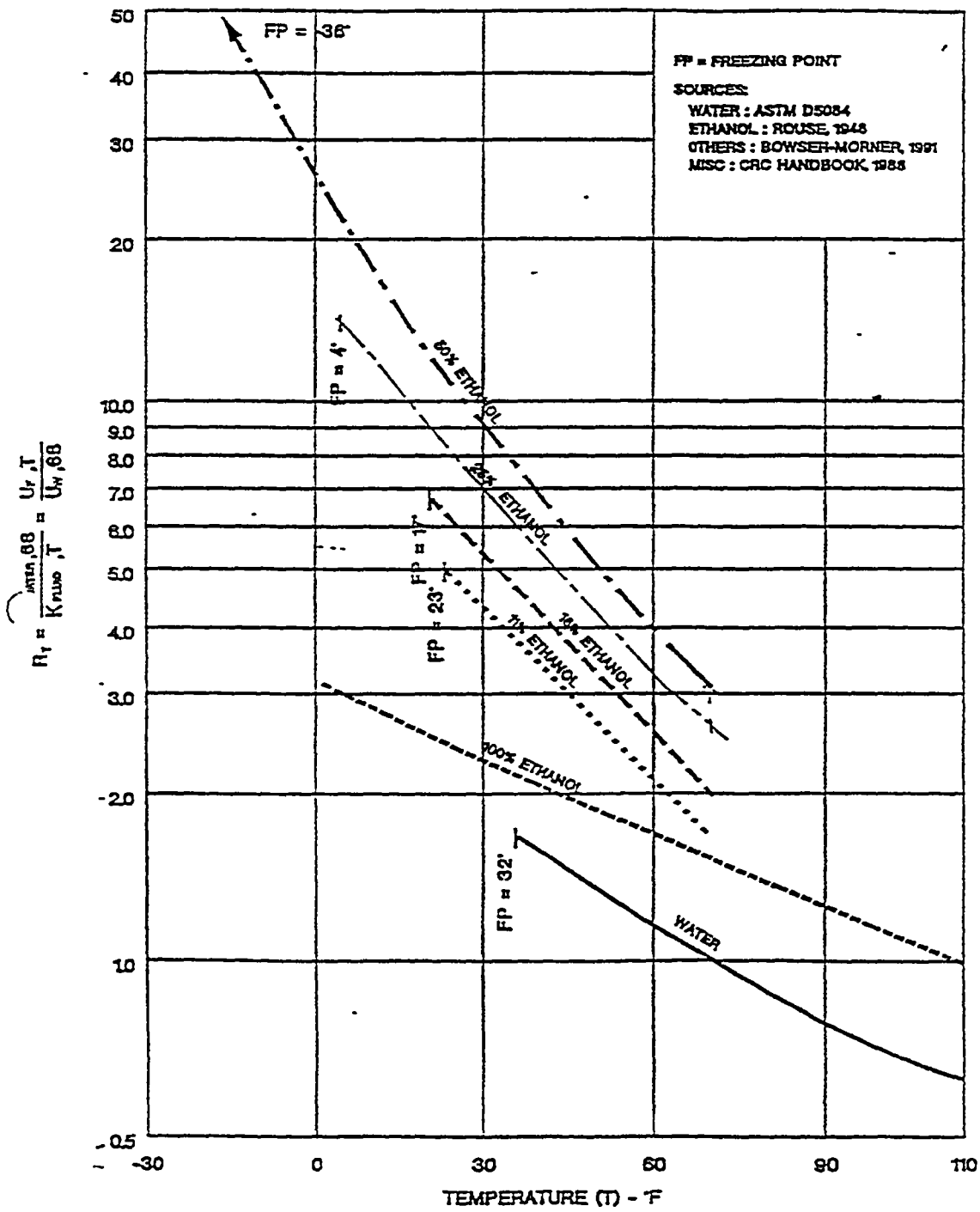


FIGURE 4
KINEMATIC VISCOSITY FACTORS

$$k_s/k_T = R_T = U_T/U_s \qquad (3.3.-1)$$

where:
k_s = Permeability for water at 68°F
k_T = Permeability observed in test
R_T = Correction Factor
U_T = Kinematic viscosity for test fluid at test temperature
U_s = Kinematic viscosity for water at 68°F

The factors (R_T) are given for water at temperatures between freezing and 120°F (0 to 49°C) in ASTM D5084. See also Figure 4 which reproduces that data.

The temperature of the exfiltrating water is measured by a thermometer or thermocouple in the TEG. It should extend to roughly the bottom of the casing. The thermometer or the leads for the thermocouple should have its own (sealed) port into the TEG cap or casing. Running either through the TEG standpipe could easily affect its function of volumetric correction.

3.3.3 Freezing Conditions. Unfortunately, field testing must sometimes proceed when the air temperatures are below freezing. Landfill operators often complete a test pad in late fall, so that they will have approval from the regulators for construction in the spring. Even if the ground temperatures stay above freezing, one cannot get decent readings from a frozen standpipe. Three procedures have been used:

a. Insulate the exposed test equipment, exposing only to make readings. (Only if mean daily air temperature exceeds freezing)

b. Use an antifreeze.
(Ethanol as Vodka is good, but needs its own R_T vs temperature graph. Does not attack clay at 25% or less alcohol).

c. Heat the test units.
(Potential for different temperatures - can invalidate the TEG).

3.4 Conducting the Test. The following discussion is applicable to both Stage 1 and Stage 2. Basically, the procedure is:

a. Fill and assemble permeameters.
(Use PTFE tape and silicone grease. Pour slowly to avoid bottom erosion).

b. **Read standpipe levels over time at the permeameter, plus level and temperature at the TEG.**
(Levels: to 1/16", temperature to 1°F).

c. **Convert these readings to apparent permeabilities.**

d. **Continue the test until these permeabilities remain steady.**

3.5 Field Calculations - Apparent Permeability. The data from each reading is converted into an apparent permeability, termed (K1) for Stage 1 and (K2) for Stage 2. Keeping up with the data in terms of a permeability has a physical meaning, and also yields a better "feel" for the behavior of the medium being tested. If that medium were isotropic ($k_h = k_v$), then (K1,K2) would be "the" permeability. Remember that the objective of most field permeability tests on regulated facilities is to determine that the vertical permeability (k_v) of the liner is not greater than some value, usually 1x10(-7) cm/sec, or to show that the horizontal permeability (k_h) of a drainage material is not less than some value, typically 1x10(-2) cm/sec. It can be shown that (K1) is the maximum possible value for (k_v) and that (K2) is the minimum possible value for (k_h). Hence, using these apparent permeabilities (K1,K2) frequently allows "pass-or-fail" determination early in the testing process. For example, (K1<Spec) within 24 hours in 90% of tests where (k_v/Spec<0.6), and 70% of all tests.

The equations for both Stage 1 and Stage 2 follow the generic falling-head test format:

$$k = R_T G \, Ln(H_1/H_2)/(t_2-t_1) \qquad (3.5\text{-}1)$$

where:

k	=	Permeability
H_1	=	Initial head (at $t=t_1$)
H_2	=	Final head (at $t=t_2$)
t_1	=	Initial time
t_2	=	Final time
G	=	Geometric Constant, depends on test geometry
R_T	=	Kinematic viscosity correction to water at 68°F

In both Stages, the head is taken as the distance from the level in the standpipe to the groundwater level. The distance from the bottom of the casing to the groundwater level is limited for calculation purposes (only) to no more than 20 times the casing ID. If the depth to groundwater is less than 20 times the casing ID, the true depth is used in the calculations. However, where the depth to groundwater exceeds this criterion, it is considered to be at this 20-diameter depth in the calculations. This limitation is derived by 3-dimensional analogy with the two-dimensional "effective radius" of a well. The volumetric effects of temperature are accounted for using a corrected final head, replacing (H_2) by (H_2'), where:

$$H_2' = H_2 - c \qquad (3.5\text{-}2)$$

where: c = Increase in TEG standpipe water level during time period from t_1 to t_2

If the TEG standpipe water level goes up between readings, (c) is positive and ($H_2'<H_2$). Conversely, (c) is negative and ($H_2'>H_2$) if the TEG standpipe level drops between readings. This step is not theoretically precise, but is close enough for test purposes. The theoretical solution yields a complex implicit equation in which the true permeability is a function of its own logarithm. However, for the geometry of the test setups and the observed magnitudes of increases/decreases, the apparent permeabilities calculated in this manner differ from the true permeabilities by no more than 2 to 5 percent. The net result is to "smooth" the apparent permeabilities. This smoothing is most apparent (and most useful) when the soil's apparent permeability is less than about 2 to 5x10(-7) cm/sec and especially for small-diameter standpipes.

The kinematic viscosity factor (R_T) used in the calculation is that for the <u>average</u> test water temperature during the period from (t_1) to (t_2).

<u>3.5.1 Stage 1.</u> The nomenclature for the various terms of the Stage 1 calculations is illustrated on Figure 5. The proper equation is given below; it is the solution for (k_v) for an isotropic medium ($k_h/k_v=1$).

$$K1 = R_T(\pi d^2/11D_1)[1+a(D_1/4b_1)]Ln(H_1/H_2')/(t_2-t_1) \qquad (3.5\text{-}3)$$

where:
- d = ID of Standpipe
- D_1 = Effective diameter of Stage 1 (Casing ID or OD)
- b_1 = Depth of tested medium below bottom of casing
- a = +1 for impervious lower boundary
- a = 0 for infinite depth of tested medium ($b_1=\infty$)
- a = -1 for pervious lower boundary

And the other terms are as defined above. For field use, the geometric terms are combined into a single constant:

$$K1 = R_T\, G1\, Ln(H_1/H_2')/(t_2-t_1) \qquad (3.5\text{-}4)$$

where: $G1 = (\pi d^2/11D_1)[1+a(D_1/4b_1)]$

A complete example is given in the Sample Calculations, Appendix A.

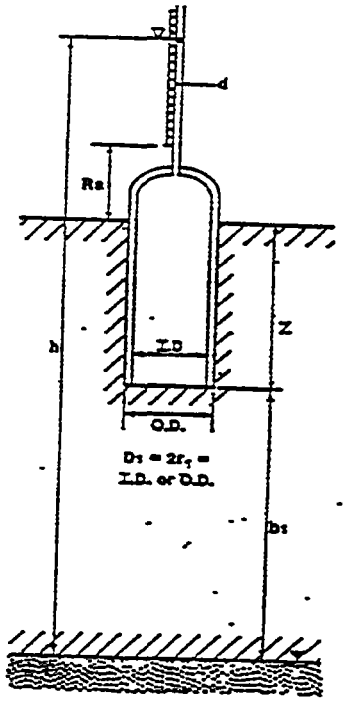


FIGURE 5
STAGE 1 NOMENCLATURE

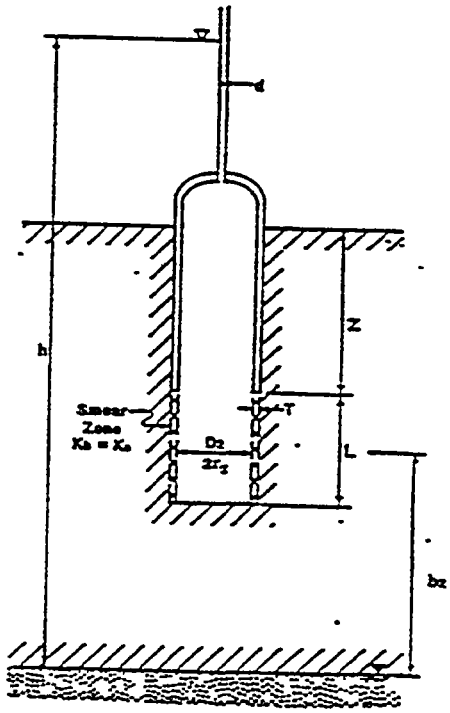


FIGURE 6
STAGE 2 NOMENCLATURE

3.5.2 Stage 2. The nomenclature for the various terms of the Stage 2 calculations is illustrated on Figure 6. The proper equation is that given below; it is the solution for (k_v) with the assumption that (k_h/k_v=1).

$$K2 = R_T\,(d^2/16Lf)\,\{Ln[u(1,r_o,o)] + a\,Ln[u(1,r_o,2b_2)]\}\,Ln(H_1/H_2')/(t_2-t_1) \qquad (3.5\text{-}5)$$

where:

f	=	$1-0.5623\,Exp(-1.566\,L/D)$
L	=	Length of Stage 2 cylinder below casing
$u(1,r_o,o)$	=	$\{L/D_2 + \sqrt{1+(L/D_2)^2}\}^2$
$u(1,r_o,2b_2)$	=	$\dfrac{4b_2/D_2+L/D_2+\sqrt{1+(4b_2/D_2+L/D_2)^2}}{4b_2/D_2-L/D_2+\sqrt{1+(4b_2/D_2-L/D_2)^2}}$
D_2	=	Diameter of Stage 2 extension (normally casing ID)
b_2	=	Distance from center of Stage 2 extension to underlying boundary

And the other terms are as defined previously. The factor (f) was introduced to account for the non-convergence of the Hvorslev equations as ($L \rightarrow 0$). For field use, the geometric terms are combined into a single constant:

$$K2 = R_T\,G2\,Ln(H_1/H_2')/(t_2-t_1) \qquad (3.5\text{-}6)$$

where: $G2 = (d^2/16Lf)\,\{Ln[u(1,r_o,o)] + a\,Ln[u(1,r_o,2b_2)]\}$

A complete example is given in the Sample Calculation, Appendix A.

3.5.3 Time-Weighted Averaging. Whether one uses the Laplacian or the Green-Ampt model for groundwater flow, there are still transient effects at the beginning of every type of field or laboratory permeability test. The observed effect is to indicate a high permeability, gradually decreasing to some relatively constant value corresponding to a steady-state flow condition. Such an effect is usually noted in the TSB. Therefore, the test must be conducted "long enough" to achieve virtually the steady-state condition or the results will be not only too high but also erratic. In addition, a single value each of (K1) and (K2) must be used in the final data reduction (Section IV).

There is no reliable method for pre-calculating the length of time required to achieve steady-state. Rather, the observational method is used. The appropriate apparent permeability (K1 or K2) is calculated for each time increment, and/or over longer periods of time; when these appear to be stable, they are checked using arithmetic time - weighted averages, e.g.,

$$K' = \Sigma\ (TiKi)/\Sigma\ (Ti) \qquad (3.5\text{-}7)$$

where: K' = Arithmetic Time-Weighted Average (ATWA) Permeability
Ti = Time Duration of Test Increment (i)
Ki = Permeability Measured during Test Increment (i)

This is theoretically exact for a single run (between refills). Time - weighted averaging also provides a rational basis for smoothing the (often) slightly erratic individual (K1,K2) values from the various time increments. An example of time-weighted averaging is given in the Sample Calculations, Appendix A.

3.5.4 Termination Criteria. Infiltration theory indicates that the apparent permeabilities (K1,K2) should forever decrease at an ever-and-ever decreasing rate. Observations in over 200 of these tests show that a steady-state condition or a close approximation of it is achieved in reasonable testing periods. A log-log plot of apparent permeability versus time is useful in determining when steady-state is achieved. Eventually, the (K1,K2) plots fluctuate about stable values. An example of such a plot is given in the Sample Calculation, Appendix A. This plot illustrates the importance of fairly closely spaced readings at the beginning of each stage, which allow separating the long-term behavior from the short-term fluctuations, i.e., enhance the "signal-to-noise" ratio.

In most tests, time-weighted averages become quite stable, often to within 1 to 5%. A reasonable set of criteria for terminating a stage is as follows:

* The time-weighted averages do not show an upwards or downwards trend with time,

and

* Do not fluctuate more than 10 to 20% among themselves,

and

* Maintain this behavior over a "sufficiently long" time, 12 - 72 hours depending on permeability.

IV. DATA REDUCTION

4.1 Basic Procedure. In some cases, the (K1') or (K2') values may be adequate for the purpose of the test. More generally, the test is performed to determine the actual (k_h,k_v). This section outlines how to convert the (K1',K2') values calculated as outlined in Paragraphs (3.5.1) and (3.5.2) into the real permeabilities (k_h,k_v). Details for the common case are covered below.

4.1.1 Simultaneous Equations. The equations presented earlier for determining (K1,K2) are special cases of more general relationships. These more general equations define the degree of anisotropy by the parameter:

$$m = \sqrt{k_h/k_v} \tag{4.1-1}$$

This parameter affects the geometric terms of the various equations. Each stage has its own equation with a different effect of (m). In a general sense, these can be written as:

Stage 1: $k_v = G1_m \, Ln(H_1/H_2')(t_2-t_1)$
$K1 = G1 \, Ln(H_1/H_2')(t_2-t_1)$

or $$k_v = K1 \, (G1_m/G1) \tag{4.1-2}$$

where: $G1_m$ = Geometric factor including (m)

Similarly, for Stage 2,

$$k_v = K2' \, (G2_m/G2) \tag{4.1-3}$$

If the soil medium being tested is homogeneous (although cross-anisotropic and possibly bounded), the vertical permeability (k_v) must be the same in both stages. Hence, (4.1-2) and (4.1-3) provide two equations in the two unknowns ($m = \sqrt{k_h/k_v}$) and (k_v). The resulting equation is:

$$K1'(G1_m/G1) = k_v = K2'(G2_m/G2)$$

or $$K2'/K1' = (G1_m/G1)(G2/G2_m) \tag{4.1-4}$$

The standpipe area (A_p) cancels for each individual stage in (4.1-2 and 4.1-3), even though different (A_p) values may have been used for Stage 1 and Stage 2, and even for different portions of either stage. The actual equations for the geometric constants involving (m) are given in Paragraph (4.2).

The ratio (K2'/K1') is known from the test; the actual values introduced are the long-term time-weighted averages, (K1' and K2'). The geometric terms are also known. Therefore, Equation (4.1-4) is satisfied only for one value of (m). Due to the complex nature of (4.1-4), trial-and-error or graphical solution works best for specific problems.

4.1.2 Calculating (k_h) and (k_v). The value for (m) is obtained as outlined above in Paragraph (4.1.1). When (m) is known, (k_v) can be calculated directly from Equation (4.1-2), and, by the definition of (m) in Equation (4.1-1).

$$k_h = m^2 k_v \tag{4.1-5}$$

4.1.3 Stage 1 Only Method. In some individual tests, the ratio (K2'/K1') is so low that Equation (4.1-4) fails to converge. Others may have so large a (K2'/K1') ratio that the permeability values are obviously in error: (k_v) is far too low and (k_h) is far too high. This is usually due to inhomogeneity of the tested material. Advancing Stage 2 into a zone of lower permeability will cause a low (K2'/K1'). Conversely, advancing into a zone of higher permeability (such as a poor lift joint in fill or a silt/sand seam in natural materials) yields a very high (K2'/K1').

These events are handled by using a conservative (m) from the best-behaved tests and introducing that value into Equation (4.1-2).

4.2 Image Equation with Smear. The basic Hvorslev equations apply most directly to masses of infinite depth and below the groundwater level. Neither test pads nor liners often meet these criteria. Therefore, results calculated by using the Hvorslev equations directly for such cases will not be correct. For a given permeability, both proximity to a drainage zone and the vertical gradient due to gravity cause the flow to be greater than the basic Hvorslev equations would predict. The basic Hvorslev equations therefore predict a higher permeability than the material really has. The vertical gradient effect can be overcome by using the head as from the top of the standpipe to the groundwater level. A method for accounting for the proximity effect and proving the previous assertion was needed.

The method of image wells has been used in geohydrology for years. The classic example is the solution for a well near a river, found in many textbooks. However, the method is not limited to two-dimensional situations such as this illustration. Any solution for an infinite or semi-infinite medium which describes the potential field (head distribution) can be converted to a solution for a finite medium bounded by a plane by using the Image Potential technique (Carslaw & Jaeger, 1959).

The basic idea is that halfway between a source and a sink of equal but opposite strength will be a plane of zero potential. So, if there is a plane of zero potential (head), its effect can be replaced by an "image" source/sink located twice as far away from the sink/source as is the midway plane. If the test (source) is set a distance (b) above the drainage blanket, the flow field will be the same as if there were no blanket but there was an image test (sink) with negative head at a distance of (2b) below the real test. Since the drainage blanket is at zero head, the head at the test is taken as the total head lost: (b) plus the excess pressure (ht) applied at the infiltration point of the test.

Consider also the case where both the real and image sources have equal strengths and both are sources (positive head) or both are sinks (negative head). By the same logic as given above, the midway plane will be a no-flow boundary, corresponding to an impermeable bottom boundary located at a depth (b) below the real test.

4.2.1 Stage 1. The Hvorslev-Image equation (Case "C") for the flush-bottomed portion of the test is given by:

$$k_v = (\pi d^2/11mD_1)[1+a(D_1/4mb_1)]Ln(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}1)$$

where:

d	=	ID of Standpipe
D_1	=	Test diameter for Stage 1
b_1	=	Thickness of test medium below base of casing
H_1	=	Initial head ($t=t_1$)
H_2'	=	Corrected final head = H_2-c (see Paragraph 3.5)
t_2	=	Final time
t_1	-	Initial time
a	=	-1 for permeable bottom boundary
a	=	0 for infinite depth to bottom boundary
a	=	+1 for impermeable bottom boundary

Equation (4.2-1) can also be written as:

$$k_v = G1_m\, Ln(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}2)$$
$$G1_m = (\pi d^2/11mD_1)[1+a(D_1/4mb_1)]$$

4.2.2 Stage 2. Similarly, for the cylindrical case (Hvorslev "G"), the Image equation (with sidewall smear) is that given by:

$$k_v = (d^2/16Lfm^2)\,\{Ln[u(m,r_o+T,o)] + a\,Ln[u(m,r_o,2b_2)] + p\,Ln[u(m,r_o,o)/u(m,r_o+T,o)]\}\,Ln(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}3)$$

where:

L	=	Length of Stage 2 extension
f	=	$1-0.5623\ \mathrm{Exp}(-1.566\ L/D)$
$u(m,r_o,o)$	=	$[mL/D_2 + \sqrt{1+(mL/D_2)^2}]^2$
$u(m,r_o,2b_2)$	=	$\dfrac{4mb_2/D_2+mL/D_2+\sqrt{1+(4mb_2/D_2+mL/D_2)^2}}{4mb_2/D_2-mL/D_2+\sqrt{1+(4mb_2/D_2-mL/D_2)^2}}$
$u(m,r_o+T,o)$	=	$\{mL/(D_2+2T) + \sqrt{1+[mL/(D_2+2T)]^2}\}^2$
p	=	k_b/k_s
k_s	=	Permeability of smeared zone
T	=	Thickness of smeared zone (0.6cm=0.25in)
D_2	=	Diameter of Stage 2 extension
b_2	=	Distance from <u>center</u> of Stage 2 cylinder to underlying boundary

And the other terms are as defined above for Stage 1. Equation (4.2-3) can be written in the generic format as:

$$k_v = G2S\ \mathrm{Ln}(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}4)$$

where:

$$G2S = (d^2/16Lfm^2)\{\mathrm{Ln}[u(m,r_o+T,o)] + a\ \mathrm{Ln}[u(m,r_o,2b_2) + p\ \mathrm{Ln}[u(m,r_o,o)/u(m,r_o+T,o)]\}$$

The generic expression for (K2'/K1') as a function of the test geometry is Equation (4.1-4). Following the steps outlined in Paragraph (4.1.1),

$$K2'/K1' = (G1_m/G1) \cdot (G2/G2S) \qquad (4.2\text{-}5)$$

where:

$$(G1_m/G1) = (1/m)\ [1+a(D_1/4mb_1)]/[1+a(D_1/4b_1)]$$

$$(G2/G2S) = \frac{m^2\{\mathrm{Ln}[u(1,r_o,o)]+a\mathrm{Ln}[u(1,r_o,2b_2)]}{\mathrm{Ln}[u(m,r_o+T,o)]+a\mathrm{Ln}[u(m,r_o,2b_2)]+p\mathrm{Ln}[u(m,r_o,o)/u(m,r_o+T,o)]}$$

Equation (4.2-5) is solved by taking an appropriate (p) and determining (m) by trial-and-error or by a graphical solution such as Figure 7.

The value of (p) is not determined in the test. The normal range of (p) is from 2 to 20; (p=1) indicates no smear. The following values for (p) have yielded satisfactory results, consistent with apparently non-smeared tests on the same tested units:

K2'/K1'	p
>1.1	1
0.9 - 1.1	1,2
0.8 - 0.9	2,5
0.7 - 0.8	5,10
0.6 - 0.7	10,20
0.4 - 0.6	15,20
0.4>	*

* Use Stage 1 Only Approach - Paragraph (4.1.3).

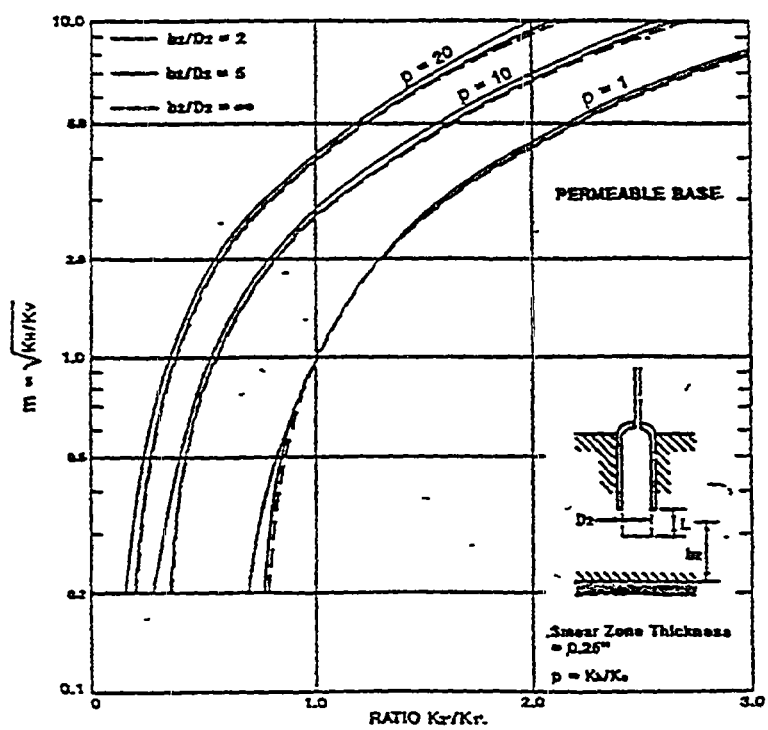


FIGURE 7
GRAPH FOR (m) - (L/D=1.5)

4.3 Non-Saturated Media. Field permeability tests are frequently performed on materials which are not fully saturated. Such materials affect the tests in two ways:

* The hydraulic head is dissipated over the (changing) distance from the point of inflow into the soil to the "wetting front", where the soil is considered fully saturated (Green-Ampt Model).

* Unsaturated clays exhibit "soil suction", which effectively adds to the hydraulic head.

In the Two-Stage test, infiltration into the soil is three-dimensional. The majority of the head loss occurs close to the inflow surface, even in a fully saturated material. About 50% of the loss occurs within one test radius of the inflow surface. For a typical Two-Stage test, disregarding wetting front distance theoretically yields a permeability 10 to 50% too high.

The effect of soil suction is roughly proportional to the ratio of suction to applied head. The effect of suction alone on a permeability test can be expressed as:

$$k_a/k_t = (1 + S/h_o) \qquad (4.3\text{-}1)$$

where:

k_a	=	Observed permeability
k_t	=	True saturated permeability
S	=	Soil suction
h_o	=	Applied head

The Two-Stage test normally operates with heads 3 to 6 times those of other test methods, minimizing the relative effect of suction.

These two effects can be handled using the graph presented on Figure 8. That figure is based on numerical solutions for the equipotential surfaces in an infinite medium (a=0). However, for the typical real test, the dimensionless flow volume is such that the equipotentials do not vary significantly from the ellipsoids in either the permeable-base (a=-1) or impermeable-base (a=+1) cases. The actual volume, which includes an allowance for the impermeable casing, has been included on Figure 8.

When using Figure 8, the initial volume (V_o) is taken as:

* Stage 1 - The volume of a hemi-ellipsoid having the diameter (D_1) and height ($D_1/4$).

$$V_{o1} = (\pi/24)\, D_1^3 \qquad (4.3\text{-}2)$$

* Stage 2 - The volume of the Stage 2 cylinder.

$$V_{o2} = (\pi/4)\, D_2^3\, (L/D_2) \qquad (4.3\text{-}3)$$

The term (V_w) is the total volume of water which has infiltrated into the soil through the end of each stage, allowing for that removed in the Stage 2 extension. The (n_a) term is the soil's air porosity.

Figure 8 is applied first to the individual (K1) values from Stage 1:

$$K1_t = K1/[R(1+s/H_o)] \qquad (4.3\text{-}4)$$

where: $K1_t$ = K1 corrected for suction and wetting front
R = Permeability ratio from Figure 8

Then, Figure 8 is similarly applied to the individual (K2) values from Stage 2:

$$K2_t = K2/[R(1+s/H_o)] \qquad (4.3\text{-}5)$$

where: $K2_t$ = K2 corrected for suction and wetting front

Thereafter, ($K1_t$,$K2_t$) are used in Equation (3.5-7) for the average values ($K1'_t$,$K2'_t$). These are then introduced into Equations (4.2-5) for (m) then (4.1-2) for (k_v), and finally (4.1-5) for (k_h).

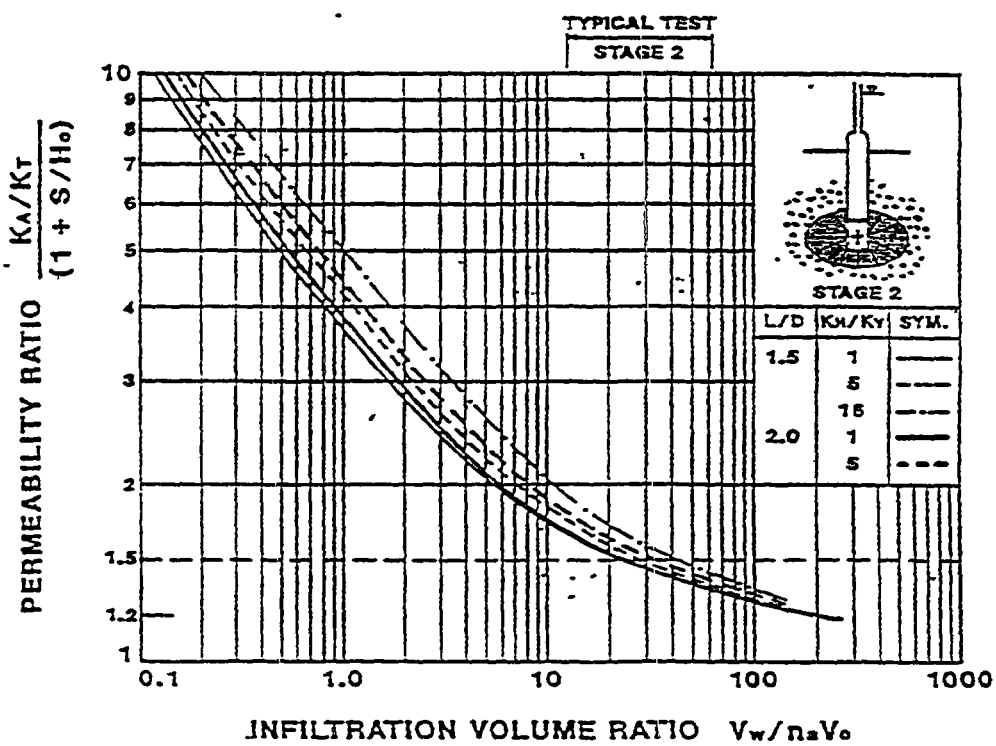


FIGURE 8
NON-SATURATION EFFECTS

V. EXPERIENCE WITH TSB TESTS

As of January, 1992, STEI alone has been involved in some 200 tests (40+ projects) on recompacted materials and 90 tests (6 projects) in natural materials. These have generally been of relatively low permeability [10(-6) to 10(-9) cm/sec]. Some conclusions from this experience are given below.

5.1 Types of Projects. The test has been successful in many types of soils:

5.1.1 Test Pads and Liners. It has been used in such conditions for test units from 20 to 60 inches thick. Materials have ranged from CH-OH (Liquid Limit 100+, clay content 70%+) to SC/GC (Liquid Limit 30-, gravel content up to 30%, clay content 12%). Vertical permeabilities have been successfully measured from the mid 10(-7)'s to the low 10(-9)'s (values in cm/sec).

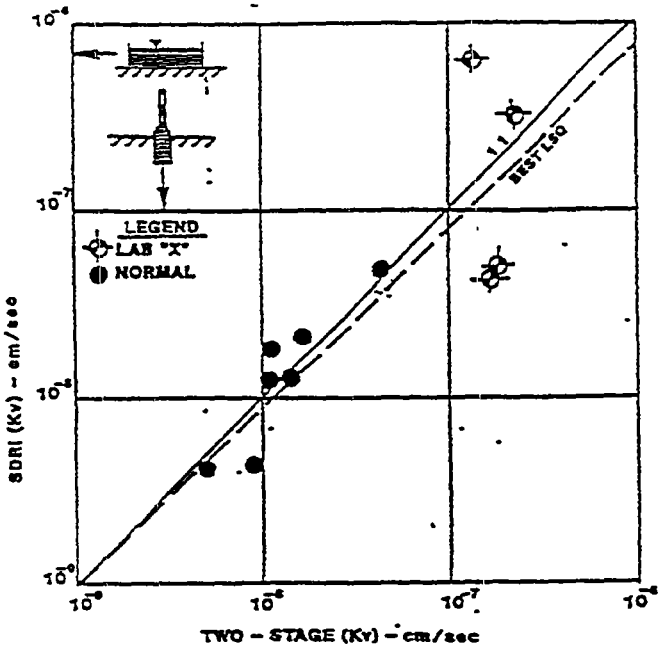
5.1.2 "Natural" Deposits. It has been very successful in clays to depths of 10 to 15 feet. Where the clay does not make water, it has also been successful to about 20 to 25 feet. The test was moderately successful in soft, highly layered mine tailings clay at depths up to 30 feet. It has been used up to 7 feet deep in shales. Measured vertical permeabilities have been in the same ranges mentioned above.

5.2 Comparisons with Other Methods. The accuracy and lack of false negatives of the TSB can be evaluated by the comparisons with SDRI data shown on Figure 9 and with laboratory data from undisturbed samples given on Figure 10. Of the 11 known cases where both field methods were used on the same test pads/liners the mean ratio of their conductivities was 1.1 (TSB higher). In three known cases, the TSB proved failure defects in test pads that laboratory tests did not show, indicating the TSB avoids false positives. Experience to date can be summarized as:

5.2.1 Recompacted Clays. The vertical permeability (k_v) as obtained from laboratory tests, the TSB, and the SDRI generally agree quite well on test pads/liners (11 cases) which have had proper CQA. The laboratory tests tend to underestimate the horizontal permeability.

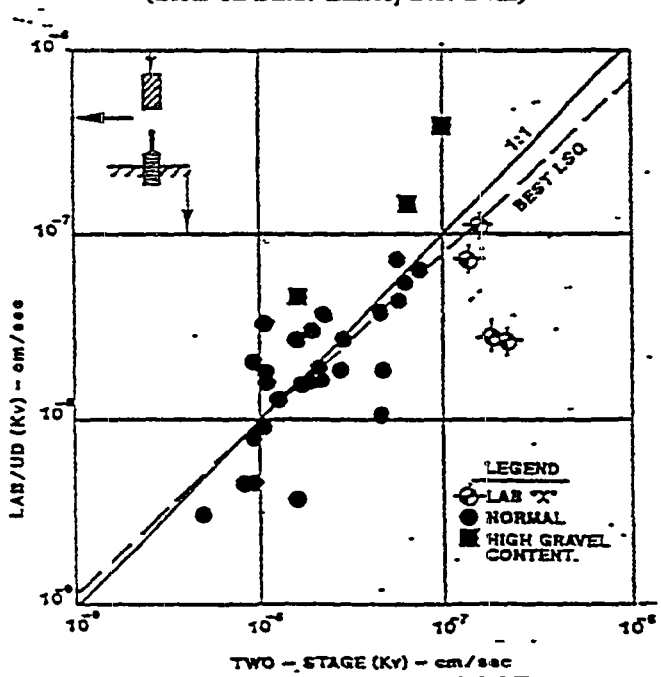
5.2.2 Natural Clays. Comparisons have only been made with small-scale laboratory tests. In general, there is good agreement with the TSB for vertical permeability, while laboratory tests again underestimate the horizontal permeability.

5.3 Speed. As soon as the test begins, so does the question from the client, "Does it Pass?" It is usual that (k_v) must be less than some specified value (Spec), or that (k_h) must be greater than a different (Spec). Since the maximum possible value for (k_v) is (K1), as soon as (K1<Spec), one knows the test for (k_v) must pass. Likewise, since (K2) is the minimum possible value for (k_h), if the long-term (K2) is greater than (Spec), the test for (k_h) must pass.



SDRI vs TWO STAGE

FIGURE 9
TSB AND SDRI RESULTS
(Tests on Same Liners/Test Pads)



LAB/UD vs TWO STAGE

FIGURE 10
TSB AND LAB (k_v) RESULTS
(Tests on Same Liners/Test Pads)

Most of the TSB tests to date in test pads/liners have been for (k_v). The better the pad, i.e., the higher the (Spec/k_v) ratio, the sooner (K1<Spec). In 90% of the tests where (Spec/k_v>1.7), passing was indicated in 24 hours or less. Some 75% of all tests have indicated passing within 72 hours. A marginal test unit, whose (k_v) is just below (Spec), will require completing Stage 2. In general, each Stage lasts 4 to 14 days, the longer times being required to complete a test in lower permeability materials.

5.4 Volume Tested. A single typical TSB test permeates a volume around 0.6 to 1.1 cubic feet, or 60 to 200 times the volume of a typical plug tested in the laboratory (3 inch diameter, 3 inch height). The usual 5-test program thus tests about 10 to 20% the volume of an SDRI, yet yields about the same values. The TSB has a good balance of soil volume tested and speed.

REFERENCES

Benson, C.H. (1991) - personal communication.

Boutwell, G.P., and C.N. Tsai (1992), "The Two-Stage Test - Measuring Field Hydraulic Conductivity Rapidly", Geotechnical News, June, 1992 (in press).

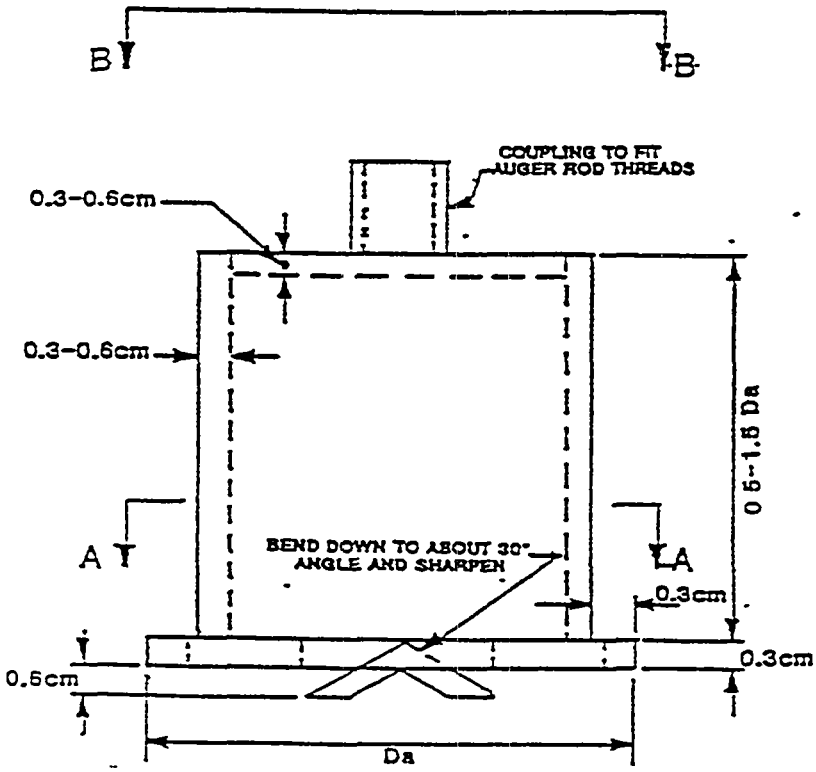
Carslaw, H.S. and J.C. Jaeger (1959), Conduction of Heat in Solids, 2nd. Ed., Oxford University Press, London, UK.

Daniel, D.E. (1989), "In-Situ Hydraulic Conductivity Tests for Compacted Clay", Journal of Geotechnical Engineering, ASCE, Vol. 115, No. 9, Sept. 1989, pp. 1205-1226.

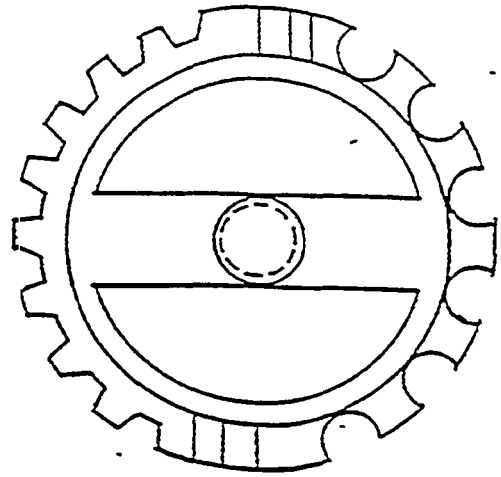
Day, S.R., and D.E. Daniel (1985), "Hydraulic Conductivity of Two Prototype Clay Liners", Journal of Geotechnical Engineering, ASCE, Vol. 111, No. 8, pp. 957-970.

Hvorslev, M.J. (1951), Time Lag and Soil Permeability in Ground-Water Observations, Bulletin No. 36, USA/COE WES Vicksburg, MS.

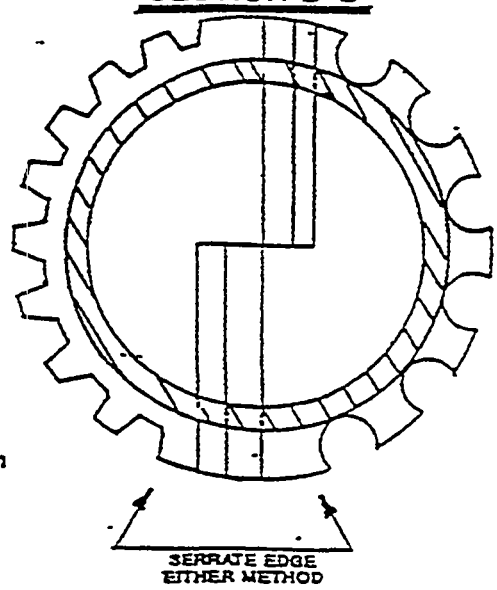
U.S Bureau of Reclamation, The Earth Manual, Second Edition, 1974, pp. 573-578.



ELEVATION



SECTION B-B



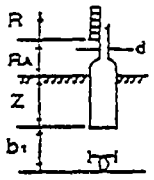
SECTION A-A

not to scale

NOTE: FOR FLAT AUGER, Da=D+5cm
FOR REAMER, Da=D-0.1 cm

FLAT BOTTOM REAMING AUGER

STAGE 1 CALCULATIONS



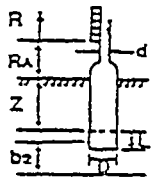
d = 1.27 cm
D = 11.43 cm
Z = 61.0 cm
RA = 22.9 cm
b1 = 61.0 cm

ΔV = 1.27 Δhc
H = 144.8 +R
K1 = 0.0384 / Ln (H1/H2) / (t2−t1)

Ground Elev.: _____ Project: _____
TOC Elev.: _____ (before) File No.: _____
_____ (after)
Site Coords: _____ Test No.: _____
_____ Page: _____

Date	Time	Δt (hrs.)	Δt (sec.)	R (cm)	H1 (cm)	H2 (cm)	K1 (cm/sec)	C (cm)	H2' (cm)	K1' (cm/sec)	Temp. (°C)	Rt Factor	K1't (cm/sec)	Cum Vol. (cc)	Cum. Hrs.	Remarks
8/01	0800	—	—	64.8	—	209.6	—	0.0	—	—	21	—	—	0.0	0.0	START
	0830	0.50	1800	47.8	209.6	192.6	1.80E-06	0.0	192.6	1.80E-06	21	0.97	1.76E-06	21.5	0.5	
	0900	0.50	1800	36.3	192.6	181.1	1.31E-06	0.0	181.1	1.31E-06	21	0.97	1.27E-06	36.0	1.0	
	1000	1.00	3600	19.7	181.1	164.5	1.03E-06	0.2	164.3	1.04E-06	22	0.96	9.99E-07	57.1	2.0	END RUN
	1001	-	—	66.7	—	211.5	—	0.0	—	—	22	—	—	—	2.0	REFILL
	1200	1h+59m	7140	47.0	211.5	191.8	5.26E-07	0.6	191.2	5.44E-07	23	0.94	5.09E-07	82.0	4.0	
								etc.								
8/05	1700			50.0		194.8					26				105.0	
8/06	0800	15.00	54000	38.1	194.8	182.9	4.49E-08	-2.8	185.7	3.39E-08	19	0.94	3.20E-08	205.5	120.0	STOP

STAGE 2 CALCULATIONS



d = 1.27 cm
D = 10.16 cm
Z = 61.0 cm
RA = 22.9 cm
b2 = 53.3 cm

L = 152 cm
ΔV = 1.27 Δhc
H = 144.8 +R
K2 = 0.01570 Ln (H1/H2) / (t2−t1)

Ground Elev.: _____ Project: _____
TOC Elev.: _____ (before) File No.: _____
_____ (after)
Site Coords: _____ Test No.: _____
_____ Page: _____

Date	Time	Δt (hrs.)	Δt (sec.)	R (cm)	H1 (cm)	H2 (cm)	K2 (cm/sec)	C (cm)	H2' (cm)	K2' (cm/sec)	Temp. (°C)	Rt Factor	K2't (cm/sec)	Cum Vol (cc)	Cum. Hrs.	Remarks
8/06	0930	—	—	65.4	—	210.2	—	—	—	—	20	—	—	0.0	0.0	START
	1000	0.5	1800	59.4	210.2	204.2	2.52E-07	0.0	204.2	2.52E-07	21	0.99	2.49E-07	7.6	0.5	
	1030	0.5	1800	54.3	204.2	199.1	2.21E-07	+0.2	198.9	2.28E-07	22	0.96	2.19E-07	14.1	1.0	
	1130	1.0	3600	45.7	199.1	190.5	1.92E-07	+0.3	190.2	2.00E-07	23	0.94	1.87E-07	24.9	2.0	
	1330	2.0	7200	33.3	190.5	178.1	1.47E-07	+1.3	176.8	1.62E-07	24	0.91	1.48E-07	40.6	4.0	
							etc									
8/09	0730			21.3		166.1					16			-	70.0	
	1600	8.5	30600	9.2	166.1	154.0	3.88E-08	+1.1	152.9	4.25E-08	19	1.07	4.56E-08	267.9	78.5	STOP

FIGURE 3

APPENDIX A

SAMPLE CALCULATION
FOR
2-STAGE FIELD PERMEABILITY TEST

NOTE: This is an idealized case exhibiting virtually perfect behavior, and is not to be considered representative of field behavior.

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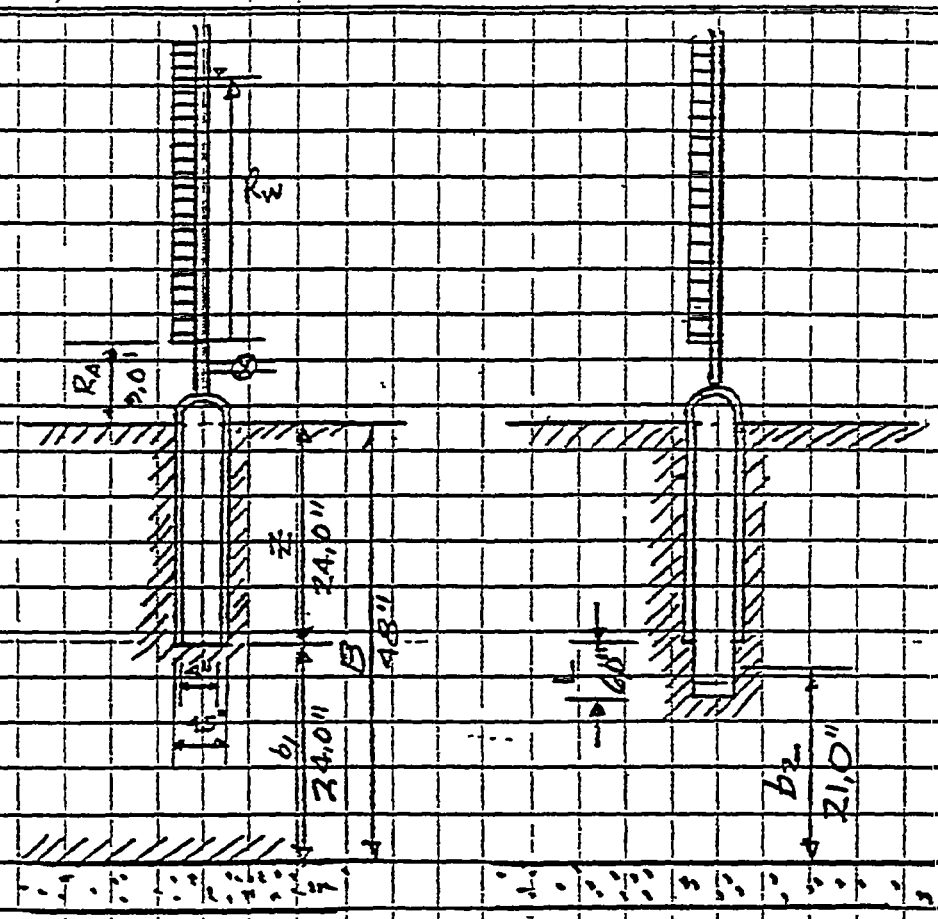
JOB SAMPLE — "A"
SHEET NO. 1 OF
CALCULATED BY [illegible] DATE 08 Aug
CHECKED BY DATE
SCALE

SAMPLE 2-STAGE CALCULATION - HYPOTHETICAL TEST "A"

1. TEST SETUP



Note: Water seeped into casing during bentonite sealing. Therefore, use casing OD = 4.5" for Stage 1 Only.

TO AVOID HYDRAULIC FRACTURING:

HEAD < 1.25 × OVERBURDEN AT CASING BOTTOM

$62.4 \frac{LB}{FT^3} H_{FT} < 1.25 \times 2.0^{FT} \times 124.8 \, LB/FT^3$

$H^{FT} < 5.0 \, FT$

OR $R_W < 5.0 - 2.0 - 0.75 = 2.25 \, FT = 27.0^{IN}$

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JOB: SAMPLE - A
SHEET NO. 2 OF
CALCULATED BY DATE
CHECKED BY DATE
SCALE

2. TEST DATA

STAGE 1 DATA

Date	Time	RW (in.)	ΔC (in.)	Temp. (°F)	TEG (in.)
8/01	08:00	25.50	—	70	13.00
	0830	18.81	0	70	13.00
	0900	14.31	0	70	13.00
	1000	7.75	+0.06	72	13.06
Rd.	1001	26.25	—	72	13.06
	1200	18.50	+0.25	74	13.31
	1600	13.88	+1.00	80	14.31
Rd.	1601	26.00	—	80	14.31
8/02	0800	15.81	-1.50	65	12.81
	1700	14.06	+1.31	74	14.12
8/03	0800	9.06	-1.25	68	12.87
	1600	8.38	+1.06	76	13.93
8/04	0800	3.75	-1.44	62	12.49
Rd.	0801	26.50	—	62	12.49
	1701	24.88	+0.50	71	13.00
8/05	0700	20.88	-0.62	66	12.37
	1700	19.69	+1.25	78	13.62
8/06	0800	15.00	-1.12	67	12.50

STAGE 2 DATA

Date	Time	RW (in.)	ΔC (in.)	Temp. (°F)	TEG (in.)
8/06	0930	25.75	—	68	12.56
	1000	23.39	0.00	70	12.56
	1030	21.38	+0.06	72	12.62
	1130	18.00	+0.13	74	12.75
	1330	13.12	+0.50	76	13.25
	1700	7.12	+0.69	80	13.94
R	1701	26.56	—	80	13.94
8/07	0700	6.06	-1.12	70	12.82
R	0701	25.25	—	70	12.82
	1200	19.88	+0.31	74	13.03
	1700	15.94	+0.56	78	13.59
8/08	0800	3.81	-1.50	62	12.09
R	0802	26.31	—	62	12.09
	1700	20.56	+1.69	74	13.78
8/09	0730	8.38	-1.56	60	12.22
	1600	3.62	+0.44	66	12.66

READ FROM TEG

CALCULATED FROM TEG LEVELS

READ FROM TEG

Calculate from TEG Levels

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JOB SAMPLE – A
SHEET NO 3 OF
CALCULATED BY DATE
CHECKED BY DATE
SCALE

3. STAGE 1

A. CALCULATE FACTOR [Eq. 3.5-4]

$$K1 = F_1 \frac{\ln(H_1/H_2)}{t_2 - t_1} \quad \text{where } F_1 = \frac{\pi d^2}{11 D}\left(1 - D/4b_1\right)$$

$d = 0.50'' = 1.27$ cm (See Sketch on p. 1)
$D = 4.50'' = 11.43$ cm (See note on p. 1)
$b_1 = 24.0'' = 60.96$ cm (See sketch on p. 1)

$$F_1 = \frac{\pi (1.27)^2}{11 \times 11.43}\left(1 - \frac{11.43}{4 \times 60.96}\right)$$

$$\boxed{F = 0.03841 \text{ cm}}$$

B. CALCULATIONS:

i. $H1 = B + R_A + R_{W1} = 48.00 + 9.00 + R_{W1} = 57.00 + R_{W1}$
$H2 = B + R_A - R_{W2} - C = 48.00 + 9.00 + (R_{W2} - C) = 57.00 + (R_{W2} - C)$

i. Period 1700 08/02 – 0800 08/03

$$K1 = .03841 \frac{\ln[(57.00 + R_{W1}) / (57.00 + R_{W2} - C)]}{\Delta t \text{ (sec)}}$$

$H1 = 57.00 + 14.06 = 71.06$
$H2 = 57.00 + 9.06 + 1.25 = 67.31$

Note: TEG fell 1.25" in this period, ∴ 1.25' of the Test drop is purely temp.

$\Delta t = 15 \text{ hrs} \times 3600 \text{ s/hr} = 54000$ sec.

$$K1 = 0.03841 \text{ cm} \frac{\ln(71.06/67.31)}{54000 \text{ sec}} = 3.86 \times 10(-8)$$

Now, apply viscosity correction
Temp $= \frac{1}{2}(74 + 68) = 71°$
From chart, Viscosity Factor $= 0.96 = R_T$

$$K1_c = R_T \cdot K1 = 0.96 \times [3.86 \times 10(-8)] = 3.71 \times 10(-8) \frac{\text{cm}}{\text{sec}}$$

See p. 16 for tabulation of all points

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CHECKED BY DATE
SCALE

4. STAGE 2

A. CALCULATE FACTOR [Eq. 3.5-5, with a = -1]

$$K2 = F \frac{L_N(H_1/H_2)}{H_2 - H_1}$$

where: $F = \left(\frac{1}{f}\right)\left(\frac{d^2}{16L}\right) L_N \left[\frac{U(D, 0)}{U(D, 2b_2)}\right]$

$f = 1 - 0.5623\, e^{-1.566(L/D)}$

L = Extension below Casing (6 inches = 15.24 cm)

D = Borehole diameter = ID of Casing (4 inches)

$r_2 = D/2$

$b_2 = B - Z + L/2 = 48.00'' - 24.00'' - 6.00''/2 = 21.00''$

$$U(1, D, z) = \frac{(z/D + L/D) + \sqrt{1 + [z/D + L/D]^2}}{z/D - L/D + \sqrt{1 + [z/D - L/D]^2}}$$

$\therefore f = 1 - 0.5623\, e^{-1.566(1.5)}$ ... $L/D = 6''/4'' = 1.5$

$= 0.9463$

$$U(1, r_0, 0) = U(1, D, 0) = \frac{(0 + 1.5) + \sqrt{1 + [0 + 1.5]^2}}{(0 - 1.5) + \sqrt{1 + [0 - 1.5]^2}} = \frac{1.5 + \sqrt{1 + 1.5^2}}{-1.5 + \sqrt{1 + 1.5^2}} = \left[1.5 + \sqrt{1 + 1.5^2}\right]^2$$

[U(1, r0, 0) Eq. 3.5-5]

$= 10.9083$

$2b_2 = 2 \times 21 = 42''$

$$U(1, r_0, 2b_2) = U(1, D, 42) = \frac{(84/4 + 1.5) + \sqrt{1 + [84/4 + 1.5]^2}}{(84/4 - 1.5) + \sqrt{1 + [84/4 - 1.5]^2}} = \frac{22.5 + \sqrt{1 + 22.5^2}}{19.5 + \sqrt{1 + 19.5^2}}$$

$= 1.1537$

[U(1, r0, 2b2) Eq. 3.5-5]

$$\therefore F = \frac{1}{0.9463} \times \frac{127^2\ cm^2}{16 \times 15.24\ cm} L_N(10.9083/1.1537)$$

$$\boxed{F = 0.01570\ m}$$

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JOB SAMPLE — A
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= 57.00 + R_{w1} , $H_2' = 57.00 + (R_{w2} - c)$

17:00 R/OB

= 83.31 IN

= 1.60 = 75.87"

Note: During this period water rose 1.60"; due only to temp. ∴ subtract 1.60" to get corrected level in test

= (3600) + 55(60) = 32280 sec.

$$= \frac{\ln(83.31/75.87)}{32280 \text{ sec}}$$

= 3.5 × 10(-8) cm/sec

= 1/(62+74) = 68.0°

viscosity factor = 1.00 = R_T

= 1.00 × [3.55 × 10(-8) cm/sec] = 4.35 × 10(-8) cm/sec.

/o Tabulation of all data points

SAMPLE - A
STAGE 1

DATE	TIME	READING (in)	TIME (sec)	H1 (in)	H2 (in)	K1 (cm/sec)	TC (in)	H2' (in)	K1c (cm/sec)	Temp	Temp Factor	K1tc (cm/sec)	Cum. Hrs.	Cum. Volume (cu. cm.)	Remarks
8/1	8 00	25 50	-	-	82 50	-	0 00	82 50	-	70	-	-	0 0	0 0	START
	8 30	18 81	1800	82 50	75 81	1 80E-06	0.00	75.81	1.80E-06	70	0.97	1.76E-06	0.5	21 5	
	9 00	14 31	1800	75 81	71 31	1.31E 06	0 00	71 31	1 31E-06	70	0 97	1 27E-06	1 0	36 0	
	10 00	7 75	3600	71 31	64 75	1 03E-06	-0 06	64 69	1 04E 06	72	0 96	9 99E-07	2 0	57 1	end run
	10 01	28 25	60	64 75	83 25	-	0 00	83 25	-	72	-	-	2 0	57 1	Refill
	12 00	18 50	7140	83 25	75 50	5 26E 07	-0 25	75 25	5 44E-07	74	0 94	5 09E 07	4 0	82 0	
	16 00	13 88	14400	75 50	70 88	1 68E-07	-1 00	69 88	2 06E-07	80	0.89	1 84E 07	8 0	96 9	end run
	16 01	26 00	60	70 88	83 00	-	0 00	83 00	-	80	-	-	8 0	96 9	Refill
8/2	8 00	15 81	57540	83 00	72 81	8 74E-08	1 50	74 31	7 38E-08	65	0 94	6 96E 08	24 0	129 7	
	17 00	14 06	32400	72 81	71 06	2 88E-08	-1 31	69 75	5 09E-08	74	0 98	4 99E-08	33 0	135 3	
8/3	8 00	9 06	54000	71 06	66 06	5 19E-08	1.25	67.31	3 86E-08	68	0 96	3 71E-08	48 0	151.4	
	16 00	8 38	28800	66 06	65 38	1.38E-08	-1.06	64 32	3 56E-08	76	0 95	3 38E-08	56 0	153 6	
8/4	8 00	3 75	57600	65 38	60 75	4 90E-08	1 44	62 19	3 34E-08	62	0.99	3 29E-08	72 0	168.5	end run
	8 01	26 50	60	60.75	83.50	-	0 00	83 50	-	62	-	-	72 0	168 5	Refill
	17 01	24 88	32400	83 50	61 88	2 32E-08	-0.50	81 38	3 05E-08	71	1 02	3 11E-08	81 0	173.7	
8/5	7:00	20.88	50340	61.88	77 88	3 82E 08	0.62	78 50	3 22E-08	66	0 99	3 20E-08	95 0	186 6	
	17:00	19 69	36000	77 88	76 69	1 84E-08	-1.25	75 44	3 40E 08	78	0 95	3 22E-08	105 0	190 4	
8/6	8 00	15 00	54000	76 69	72 00	4 49E-08	1.12	73 12	3 39E-08	67	0 94	3 20E 08	120 0	205 5	STOP

p. 6

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5.B. Calculation for K2' - (See p. 7 for the data points)

This is virtually the same calculation as on p. 8

Period (hrs)	CALCULATION	K2'c
0.0–2.0	$\frac{24.9\times1.80+21.9\times1.80+18.7\times3.60}{1.80+1.80+3.60} = \frac{151.56}{7.20} = 21.05\times10(-8)$	$2.11\times10(-7)$
2.0–21.5	$\frac{14.8\times7.20+11.0\times12.60+1.52\times50.34}{7.20+12.60+50.34} = \frac{623.12}{70.14} = 8.89\times10(-8)$	$8.89\times10(-8)$
21.5–31.5	$\frac{5.94\times17.94+4.14\times18.00}{17.94+18.00} = \frac{191.88}{35.94} = 5.34\times10(-8)$	$5.34\times10(-8)$
31.5–55.5	$\frac{4.46\times54.00+4.55\times32.28}{54.00+32.28} = \frac{387.11}{86.28} = 4.49\times10(-8)$	$4.49\times10(-8)$
55.5–78.5	$\frac{4.49\times52.20+4.56\times30.60}{52.20+30.60} = \frac{373.91}{82.80} = 4.52\times10(-8)$	$4.52\times10(-8)$

The last two periods are virtually identical and last some 24 hours each (appropriate for the permeability level)

i.e. $K2' = \frac{387.11+373.91}{86.28+82.80} = \frac{761.02}{169.08} = 4.50\times10(-8)$

$$\boxed{K2' := 4.50\times10^{-8}\ cm/sec}$$

6.0 Calculate Kv and KL

A. Smear

Check by K2/K1 ratio needed for next step

$K2'/K1' = \frac{4.50\times10(-8)}{3.21\times10(-8)} = 1.40$

Probably no smear since > 1.0

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B. EQUATION (FOR SHORTCUT, SEE p. 12)

$$K2'/K1' = \left(\frac{G1m}{G1}\right)\left(\frac{G2}{G2S}\right) \qquad [\text{Eq. } 42\text{-}5]$$

where $G1m/G1 = (1/m)\left[1 + a(D_1/4mb_1)\right] / \left[1 + a(D_1/4b_1)\right]$

but, $D_1 = 11.43$ cm (p. 3) $\quad a = -1$ (Perm. Base)

$b_1 = 20.96$ cm (p. 3)

$$G1m/G1 = (1/m)\left[1 - \frac{11.43}{4(m)(20.96)}\right] / \left[1 - \frac{11.43}{4(20.96)}\right]$$

$$= (1/m)\left(\frac{1}{0.9464}\right)\left(1 - \frac{1}{21.33m}\right)$$

$$G2/G2S = \frac{m^2 \{ \ln[U(1, r_0, 0)] + a \ln[U(1, r_0, 2b_2)] \}}{\ln[U(m, r_0+1, 0)] + a \ln[U(m, r_0, 2b_2)] + p \ln[U(m, r_0, 0)/U(m,$$

$a = -1$

$p = 1$

$$\text{Thus } G2/G2S = \frac{m^2 \ln[U(1, r_0, 0)/U(1, r_0, 2b_2)]}{\ln[U(m, r_0, 0)/U(m, r_0, 2b_2)]}$$

$$U(1, r_0, 0) = \left[L/D + \sqrt{1 + (L/D)^2}\right]^2 = \left[1.5 + \sqrt{1 + 1.5^2}\right]^2 = 10.90833$$

$$U(1, r_0, 2b_2) = \frac{4b_2/D_2 + L/D_2 + \sqrt{1 + (4b_2/D_2 + L/D_2)^2}}{4b_2/D_2 - L/D_2 + \sqrt{1 + (4b_2/D_2 - L/D_2)^2}}$$

$b_2 = 21''$ (See p. 1)

$D_2 = 4.0''$ (See p. 1)

$$= \frac{4(21/4) + 6/4 + \sqrt{1 + (4 \times 21/4 + 6/4)^2}}{4(21/4) - 6/4 + \sqrt{1 + (4 \times 21/4 - 6/4)^2}} = \frac{45.0222}{39.0256}$$

$U(1, r_0, 2b_2) = 1.15366$

$$G2/G2S = \frac{m^2 \ln[10.90833/1.15366]}{\ln[U(m, r_0, 0)/U(m, r_0, 2b_2)]} = \frac{2.24652\, m^2}{\ln[U(m, r_0, 0)/U(m, r_0, 2b_2)]}$$

$$K2'/K1' = \frac{1}{m}\frac{1}{0.9464}\left(1 - \frac{1}{21.33m}\right) \cdot \frac{2.24652\, m^2}{\ln[U(m, r_0, 0)/U(m, r_0, 2b_2)]}$$

$$= 2.3738\, m \left(1 - \frac{1}{21.33m}\right) \frac{1}{\ln[U(m, r_0, 0)/U(m, r_0, 2b_2)]}$$

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(i) Try $m = 2.0$

$$u(m, r_o, 0) = \left[mL/D_2 + \sqrt{1 + (mL/D_2)^2} \right]^2$$
$$= \left[1.5m + \sqrt{1 + (1.5m)^2} \right]^2$$
$$u(2, r_o, 0) = \left[1.5 \times 2 + \sqrt{1 + (1.5 \times 2)^2} \right]^2 = 6.1623^2$$
$$= 37.9737$$

$$u(m, r_o, 2b_2) = \frac{4mb_2/D_2 + mL/D + \sqrt{1 + (4mb_2/D_2 + mL/D_2)^2}}{4mb_2/D_2 - mL/D + \sqrt{1 + (4mb_2/D_2 - mL/D_2)^2}}$$
$$= \frac{4m\,2/4 + m\,6/4 + \sqrt{1 + (4m\,2/4 + m\,6/4)^2}}{4m\,2/4 - m\,6/4 + \sqrt{1 + (4m\,2/4 - m\,6/4)^2}}$$
$$= \frac{22.5m + \sqrt{1 + (22.5m)^2}}{19.5m + \sqrt{1 + (19.5m)^2}}$$
$$u(2, r_o, 2b_2) = \frac{22.5 \times 2 + \sqrt{1 + (22.5 \times 2)^2}}{19.5 \times 2 + \sqrt{1 + (19.5 \times 2)^2}} = \frac{90.0111}{78.0128} = 1.1538$$

$$K_2'/K_1' = 1.40 \overset{?}{=} 2.3738(2.0)\left(1 - \frac{1}{21.33 \times 2}\right) \frac{1}{\ln\left[37.9737/1.1538\right]}$$
$$= 4.7476\,(.9766)\,\frac{1}{3.4938}$$
$$1.40 > 1.327$$

∴ need larger m

ii. Try $m = 2.4$

$$u(2.4, r_o, 0) = \left[1.5 \times 2.4 + \sqrt{1 + (1.5 \times 2.4)^2} \right]^2 = 53.8214$$

$$u(2, r_o, 2b_2) = \frac{22.5 \times 2.4 + \sqrt{1 + (22.5 \times 2.4)^2}}{19.5 \times 2.4 + \sqrt{1 + (19.5 \times 2.4)^2}} = 1.1538$$

$$K_2'/K_1' = 1.40 \overset{?}{=} 2.3738(2.4)\left[1 - \frac{1}{21.33 \times 2.4}\right] \frac{1}{\ln\left[53.8214/1.1538\right]}$$
$$= 5.6972\,(.9805)\,(1/3.8426)$$
$$1.40 < 1.454$$

∴ need smaller m

Successive trial-and-error yields $m = 2.27$

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C. CALCULATE K_v, K_h

Note: One can avoid the calculations of pp. 10 and 11 by using the attached nomograph (Fig. 7-Text)

The easiest calculation is using the Stage 1 equation:

$$K_v = \frac{G_{lm}}{G_{l1}} K_1 = \qquad [Eq. 41-2]$$

$$= \frac{1}{m}\left[\frac{1 - D_1/4m b_1}{1 - D_1/4 b_1}\right] K_1$$

with $D_1 = 4.50$"
$b_1 = 24.0$"
$m = 2.27$

$$K_v = \frac{1}{2.27}\left[\frac{1 - \frac{4.5}{4(2.27)(24)}}{1 - \frac{4.5}{4(24)}}\right] \times [3.21 \times 10(-8)]$$

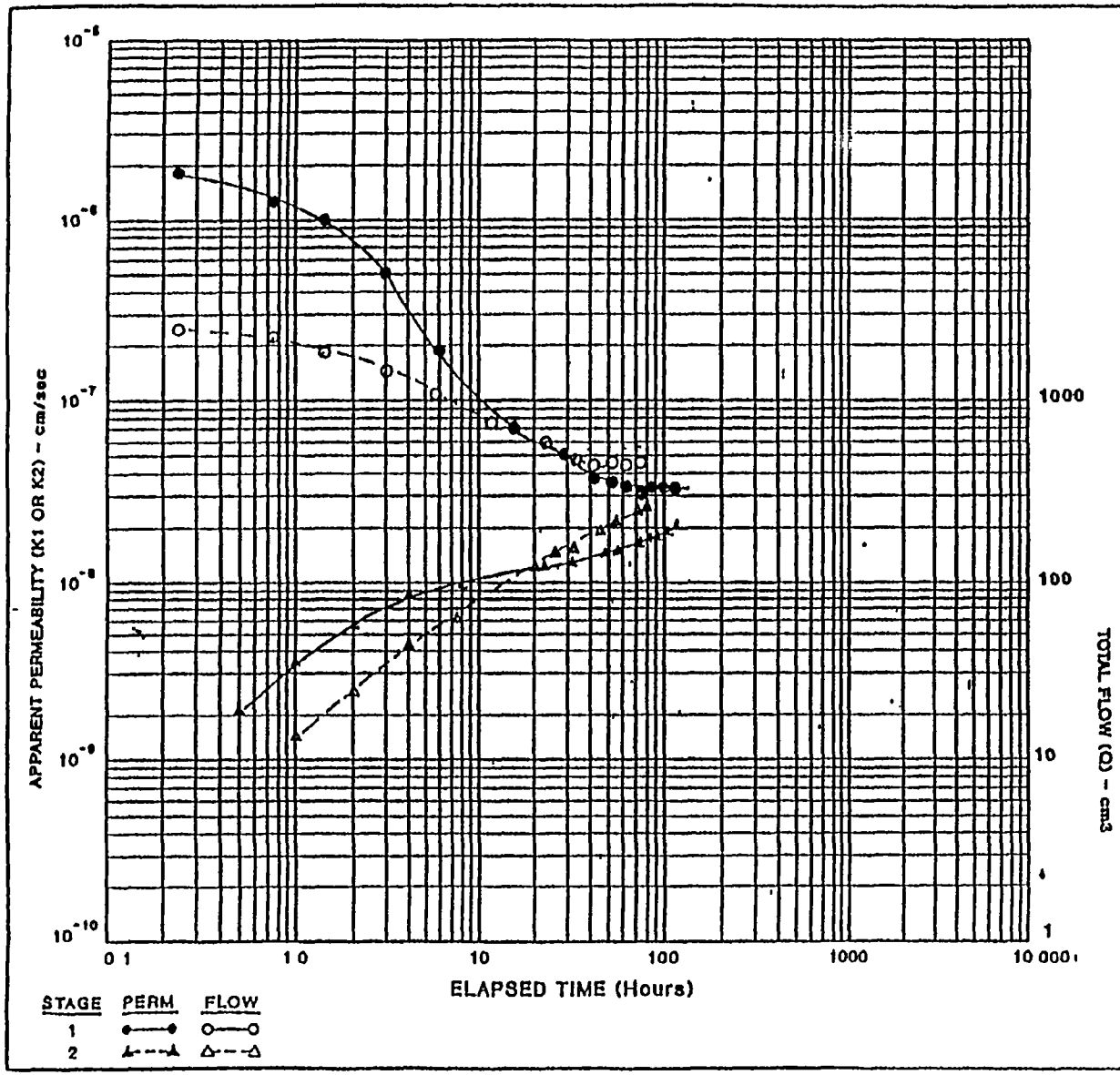
$$= \frac{1}{2.27}\left[\frac{.9762}{.9464}\right] 3.21 \times 10(-8)$$

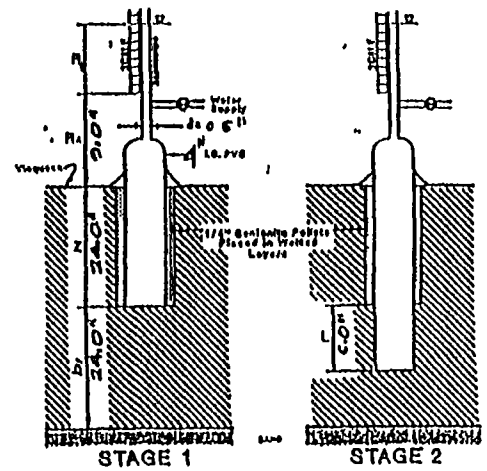
$$\boxed{K_v = 1.45 \times 10(-8) \text{ cm/sec}}$$

$$K_h = m^2 K_v \qquad [Eq. 41-5]$$

$$= 2.27^2 [1.45 \times 10(-8)]$$

$$\boxed{K_h = 7.47 \times 10(-8)}$$





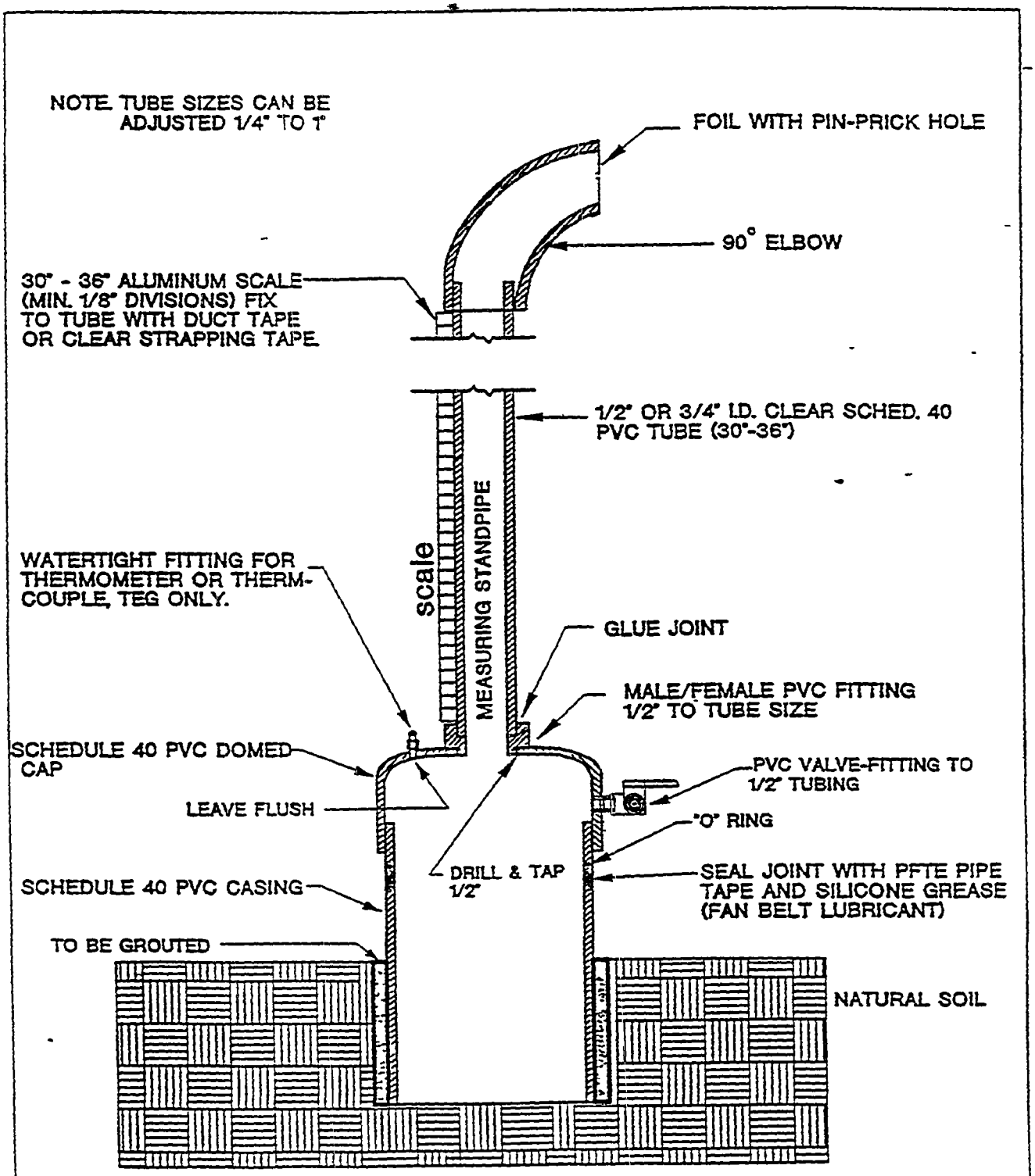
TWO - STAGE
FIELD PERMEABILITY TEST
SUBBASE TEST PAD

1. SAMPLE TEST "A"
EREWHON, CALIFORNIA

GEOTECHNICAL SERVICES BY
SOIL TESTING ENGINEERS, INC.
Baton Rouge LA Lake Charles LA

Project Engineer:	Drawn by:	Checked by:
G P BOUTWELL	SJT	C N TSAI
File No.: 91-061	Date:	Figure No.:

Title:
BEHAVIOR OF TEST FP- "A"



TYPICAL PERMEAMETER

Attachment 1

STATE COMMENTS ON THE FINAL LANDFILL SITE FEASIBILITY REPORT

STATE OF COLORADO

Roy Romer, Governor
Patti Shwayder, Acting Executive Director

Dedicated to protecting and improving the health and environment of the people of Colorado

HAZARDOUS MATERIALS AND WASTE MANAGEMENT DIVISION

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Colorado Department
of Public Health
and Environment

August 30, 1995

Mr. Charlie Scharmann
Office of the Program Manager
AMXRM-PM, Building 111
Rocky Mountain Arsenal
Commerce City, CO 80022-2180

Dear Mr. Scharmann

The state has reviewed the Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program. The report was generally well done. Enclosed please find comments on both the technical aspects of this report and the state's analysis of the regulatory aspects that need to be addressed in the CAMU Designation process for the hazardous waste landfill.

Now that a Conceptual Remedy exists for RMA, the Army can become very specific with respect to configuration and design of the landfill. The CAMU regulations require compliance with Part 264, Subparts B, C, D, E, and N as well as the siting requirements contained in 6 CCR 1007-2, Part 2 The CAMU must also meet regulatory requirements for applicable design, operation and closure requirements including ground water monitoring. The specific requirements needed for the CAMU Designation Document can be discussed at our meeting tomorrow; some items should be described in detail by the Army in its proposed designation document, while other items could be outlined with a corresponding schedule for future submittals of the required information.

The state would like to request a copy of the HELP inputs used by the Army for the Feasibility Study in a digital format If you have any questions, please feel free to call.

Sincerely,

Barbara Nabors

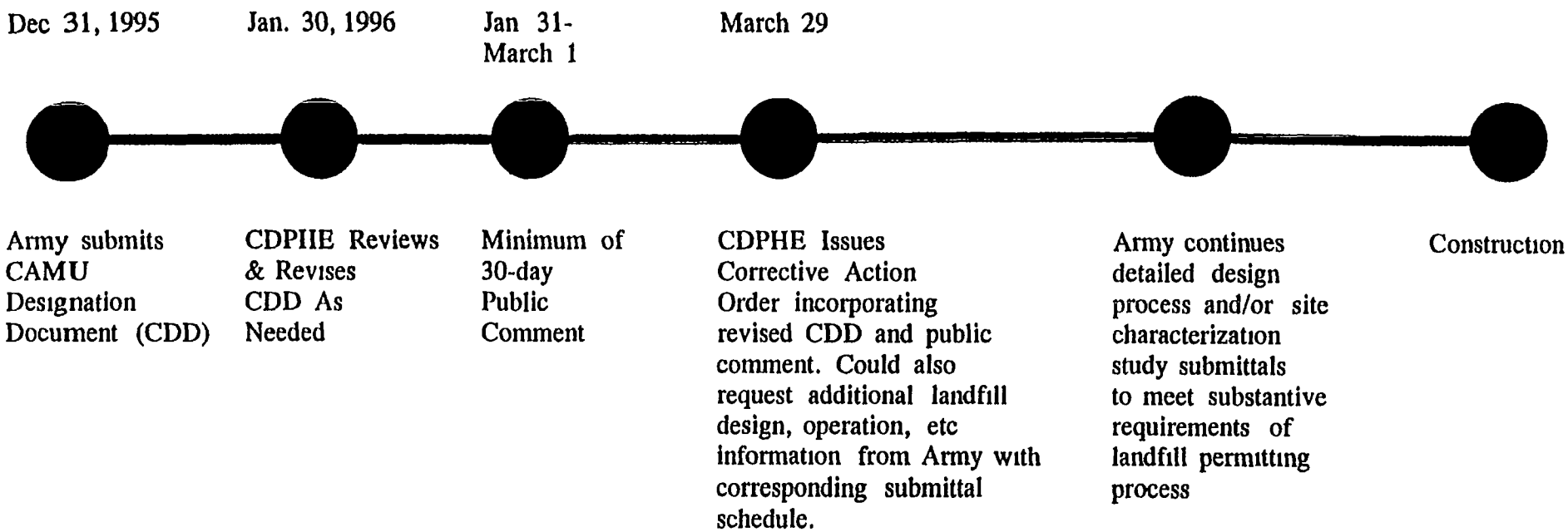
for Jeff Edson
RMA Project Manager
Hazardous Materials and
Waste Management Division

cc:	Connally Mears, EPA	Ken Conright, TCHD	Eduardo Quintana, EPA
	William Adcock, Shell	Ronel Finley, USF&W	Craig Tessmer, Adams County
	Robert Foster, DOJ	Edward McGrath, HRO	Ronel Finley, USF&W
	Jonathan Potter, JAG	Vicky Peters, AGO	Ira Star, GT

CDPHE Review of Landfill Siting Criteria

Siting Criteria	Adequately Addressed by Site Feasibility Report?
Faults (1,000 year)	Yes
Floodplain (100 year)	Yes, but provide more info on source of map
Salt Formations	Yes
Surface Water/Ground Water	Yes
Airport Safety	Yes, please provide a map for ease of public review showing location of landfill with surrounding land uses including DIA
Wetlands	Yes
Seismic Impact Area	No, please provide citation for source
Unstable Area (onsite soil conditions)	No, no discussion provided
Topography (protection against winds and minimize precip catchment)	No, not discussed
Isolation (isolate wastes)	No, but seems like more of a design issue
Hydrogeology/Geology 1,000 siting criteria	No, have questions
Location (controlled by operator)	Yes
Buffer Zone (noise)	Yes

Proposed RMA Landfill CAMU Designation Time Line
CDPHE - August 30, 1995



* Corrective Action Order needs to be issued in advance of the Record of Decision

Colorado Department of Public Health and Environment
Comments on Final Landfill Site Feasibility Report and Requirements
for the CAMU Designation
August 30, 1995

Summary:

CAMU regulations specifically dictate compliance with Subpart B, C, D, E and N of Part 264 of the state's Hazardous Waste Regulations and compliance with the state's regulations for siting of hazardous waste disposal sites, 6 CCR 1007-2, Part 2. CAMU regulations (264.552E) also specify requirements that address design, operation, closure, post-closure, and ground-water monitoring. Prior to the issuance of the CAMU Designation Document (CDD), the Army should provide information necessary to satisfy the state siting criteria (particularly the 1,000 year protection criterion), identify and technically support a preliminary liner and cover design, and submit a Construction Quality Assurance document and specifications that are consistent with the construction methods used in the test fill Other regulatory requirements should be addressed directly in the proposed CDD or by schedule and provided for state approval during development of the landfill design.

The discussion below indicates some of the preliminary technical concerns of the state and indicate appropriate regulations. Reference is also made to the July 1995 Site Feasibility Report (Report) Regulatory citations are noted in *italics*.

Part 264, Subpart B -- General Facility Standards

Section 264 13, General waste analysis

Addressed in the Report but not fully developede Chemical and physical analyses of hazardous waste and hazardous debris must contain all information which must be known to treat, store, or dispose of wastes properly in accordance with Part 264 A waste analysis plan is required. This plan can take into account the sampling that has occurred at most sites during the Remedial Investigation This information should be provided or addressed in a schedule by issuance of the CDD

Section 264 14 Security

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD

Section 264 15, General inspection requirements

Addressed in the Report but not fully developed. This information should be provided or

addressed in a schedule by issuance of the CDD

Section 264 16, Personnel training

Addressed in the Report but not fully developed This information should be provided or addressed in a schedule by issuance of the CDD

Section 264 17, General requirements for ignitable, reactive, or incompatible wastes

Not addressed in the Report. This information should be provided or addressed in a schedule by issuance of the CDD. This plan will interface with the waste analysis plan This issue is important considering UXO debris and Basin F materials

Section 264 18, Installation standards, were addressed by the Army in the Report in Section 4-- Area Feasibility Study. Additional information is needed with respect to the flood plain analysis, which was based on an Army Corps reference The groundwater protection regulation is further developed in the state's siting regulations

Section 264.19, Construction quality assurance program, is a requirement of the state for construction of foundations, dikes, liners, leachate collection and detection and cover systems A formal written CQA plan is required. The plan should be completed in conjunction with the final designs

Test Fill

The Army has already undertaken a major step in the CQA program by developing specifications and constructing a test fill. The general concern of the state is that specifications for the full-scale liner construction be consistent with the findings of the field program or with the original specifications-- whichever is more conservative

The test fill did not meet several technical specifications (e g., the contractor did not use the equipment specified) Specific concerns are noted below

Lift Thickness --

The specifications (Appendix A) state that loose lifts of 9" of soil will be placed on the pad in order to achieve 6" of compacted material In the final results, as recorded in Figure 3.2, both test pads only achieved 3" and 4" of compacted soil This may suffice for a test pad attempting to prove only low permeability, but it is not the most optimum lift thickness for future construction, which was one of the objectives of this part of the report, as stated in Section 2.1 of the Material Feasibility Study The full-scale construction specification should be revised to reflect that smaller lift thickness

was obtained in the field.

Clod size --

A 3" maximum size was specified in the contract specifications (Appendix A, page 11-4 of the Report) This is a large clod size and the state reserves the right to review this potential criterion based current state-of-the-art practice The number of moisture failures observed during the test fill may have resulted from inadequate soil conditioning Specifications should be written on equipment and methods to condition soil moisture and clod size The specifications as written did not specify the equipment to achieve this end. A pulvamixer was ultimately used on the test fill and should be so-specified for full-scale.

Moisture and Curing --

In Appendix I, Section 2.2 4, there is a statement regarding the soil processing function. It states that there is a need to "allow adequate time for clod reduction, moisture addition, blending, curing and testing to verify the optimal moisture content range has been achieved " There is further EPA QA/QC guidance (Sept 93) recommending at least 24 - 48 hours curing time for uniform absorption and hydration of soil particles when the moisture variance is increased by more than 3 percentage points. It is also recommended in guidance that if this moisture variance is observed during the test pad construction, test soil should be removed from the test pad and brought back to the soil processing area for reworking The removing and reprocessing of the soil is also required in the specifications of Appendix A, page 11-5. However, as evidenced by the soils test reports in Tables 3.2 and 3.3 of this document, soils failing moisture tests by much greater variances than those discussed above, were neither allowed adequate time to absorb added moisture nor were they removed from the test pad to be re-processed in a separate processing area, or at least no details were provided to verify such. No such variation from the specifications should be allowed in the full-scale specifications

Depth of compaction and type of compactor --

The depth of compaction is measured by the length of the compactor's foot. EPA QC/QA guidance makes it clear that the minimum length of the roller foot should be the length of the loose lift of soil. The specifications, however, (Appendix A, pg 11-4) state that the foot is to be as long as the compacted lift thickness (6"). This is short of the desired length resulting in lack of bonding between lifts This is critical for adequate mixing and kneading of the soil to insure proper homogeneity and even moisture control The shorter feet on this test fill may have resulted in problems with achieving compaction, as evidenced in the test results shown in Tables 3.2 and 3.3

The type of compactor is also very important, as noted in the Work Plan for this project in Section 2 2.6, of Appendix I. It states a "Caterpillar Model 825 or equal" is to be used for this project. The actual model used was an 815B, per Section 3.22 of the Material Feasibility Study This compactor is nearly one half the size of the 825 Model and definitely not the most desirable piece of equipment for construction of this large of a landfill (see Appendix C for details)

Recompaction and Moisture Adjustment --

Significant moisture adjustments in the test fills were required, as reported in Tables 3.2 and 3.3 Most results appeared to have been corrected on the same day, without adequate saturation time, and repaired on the test pad itself, without moving the failing soil back to the processing area. Both of these conditions violate the specifications written for this project in Appendix A For example, Appendix A, Section 11, Part 3.02 -H, page 11-5, states "No more than 2 percent moisture may be added to the test fill during construction. If the moisture content is greater than 2 percent.. , the test fill soil shall be removed from the test fill..." No evidence of the correct procedure was recorded or so stated in the document when moisture tests failed on the test pad by this margin

Test fill #2 recorded a moisture test, Test Number 34, of 6 percentage points above optimum moisture On the same day, a second passing test was recorded (Test Number 37), that stated in the comments, "Retest of No. 34, after *wetting* of dry areas pulverizing and compacting"

This would not be significant if not for the fact that in two test fills containing 55 and 70 tests each, a failure rate of 20% - 30% was experienced. Also, there were soil moisture variations on the test fills of 5 points below to 6 points above optimum moisture Both observations lead to the acceptability and reliability of the test fill construction program methods The full-scale specifications should concur with the original test fill specifications with regard to reconditioning failed lifts

Part 264, Subpart C -- Preparedness and Prevention

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD.

Part 264, Subpart D -- Contingency Plan and Emergency Procedures

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD

Part 264, Subpart E -- Manifest System, Record keeping and Reporting

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD (State agrees that manifest system is not applicable).

Part 264, Subpart F -- Ground Water Protection

Development of a ground water monitoring plan is needed for the CDD and not addressed in the Report.

Part 264, Subpart G -- Closure and Post-Closure
Part 264, Subpart S, (d)(4) addresses in general terms the closure and post-closure requirements for CAMUs Substantive sections of Subpart G will be applicable.

Part 264, Subpart N -- Landfills

Development of landfill design, specifications, construction, response actions, record keeping, and closure and post closure care, will be consistent with this Subpart.

Rules and Regulations pertaining to Solid Waste Disposal Sites and Facilities 6 CCR 1007-2

CAMU Regulations specifically address siting of hazardous waste disposal sites, 6 CCR 1007-2, Part 2 The Army also considered the solid waste regulations. The state's regulations governing solid waste disposal sites were addressed in the Report and adopted as criteria, specifically *Location Restrictions and Site Standards, Section 3 1* The demonstration that these criteria are met is lacking in some instances, as noted by the Army (e.g., topographic protection and hydrogeologic isolation, Page 4-15) The isolation criteria is actually more fully developed under the Part 2 rules. below

Rules and Regulations pertaining to Solid and Hazardous Wastes 6 CCR 1007-2, Part 2 Requirements for Siting of Hazardous Waste Disposal Sites

These regulations are adopted under the CAMU regulations *Section 264 552*

6 CCR 1007-2, Part 2, Section 2 4, Minimum Design Performance Criteria

These regulations consider: 2 4 1, Protection of human health and the environment, 2 4 2, Protection of groundwater quality, 2 4.3, Protection of surface water quality, 2 4.4, Protection of Air Quality, 2 4.5, Long-term impact to public health and the environment, 2 4.6, Liner

integrity, 2 4 7, Leachate and runoff control, 2 4 8, Closure, 2 4 9, Surface and groundwater water monitoring; and 2.4 10, Post-construction certification, 2.5 Requirements for Siting and Design. General comments follow

The Army should provide cross-reference to these regulations for agency reviewers, as many of these requirements are partially addressed in various sections of the Report.

A major design consideration, the potential for migration through liners (and impact to groundwater) should be addressed using mass transport modeling, not just by HELP The Army used RITZ for unsaturated flow estimates. The estimate of travel time to demonstrate the 1,000 year protectiveness criterion requires additional evaluation

The Army should consider other liner performance criterion besides cost and constructability, such as mass transport considerations, before selecting a liner design. The state is particularly concerned with the use of GCL in the primary liner The state is also concerned with using sand in the leachate collection layers (See page 5-10, second paragraph of the Report) Coarse granular material or geogrid is more effective than sand (coarse granular is preferred over geogrid) The state would like to discuss the use of 80-mil geomembrane versus 60-mil

The prevention of impacts to air and surface-water quality should be addressed at the issuance of the CDD

6 CCR 1007-2, Part 2, Section 2 5, Requirements for Siting and Design
Sections 2 5 1,2
These sections consider conformance with the minimum design criteria, odor-threshold levels, safety and contingency issues, materials for liners and covers, and resources necessary to guarantee long-term protection of the environment. The Army should address these issues directly, referencing the appropriate regulation. Odor, in particular, has not been addressed in the Report Material availability for liners and covers has been addressed in this report and the Final Feasibility Study Soils Support Program Report.

Section 2 5 3, addresses the 1,000 year criterion for exposure of waste to the public This criterion was addressed in previous RMA studies using a time of travel argument to show that a depth to groundwater greater than 40 feet below the liner system was adequate to prevent impact to groundwater for close to 1,000 years. The current Report approaches the issue in Section 4-- Area Feasibility by citing the requirements directly from the regulations (see page 4-16, first complete paragraph) without evaluating how the criterion is met. The selected depth criterion (ground surface to groundwater) ranges from 40 to 70 feet (See Page 4-21, First Paragraph)

In Section 5-- Site Feasibility Study, the Army notes that the effective depth to groundwater from the bottom of the liner can be as shallow as 10 feet (Page 5-37, First Complete Paragraph) This shallow depth is presumed to provide in excess of 1,000 years travel time to

groundwater. Thus the current report reduces the minimum depth to groundwater significantly below the 40 foot depth presumed in earlier siting documents

The model runs, including HELP and RITZ should be further documented to justify not only the cover and liner designs, but to justify the Army's conclusion that soil water movement through the vadose zone could require 1,000 to 1,200 years to travel one foot. This rate is over 50 times slower than previous calculations shown in the 1988 Ebasco report. Mass transport modeling, in lieu of HELP modeling may be more appropriate to account for diffusion of volatiles

The report figures showing geologic cross-sections and sites should be modified to show groundwater elevations (Figures 5 6 to 5.8). The state infers that an excavated landfill in the Army's model would have a depth to groundwater much less than the 40 to 70 foot range discussed in the Report (page 4-21, second complete paragraph)

Sections 2.5 4,5 states that designs are to be consistent with requirements of section 2.4 in order to be sited.

Section 2 5 6 of the regulations addresses the location of a facility with respect to acceptable means to prevent adverse effects on public health in the event of discharges of hazardous waste (See page 4-16, last paragraph of the Report). The Army should note the appropriate plans (e g , contingency, operations) which will address this regulation

Part A requirements of 6 CCR 1007-3, Section 100.40 (See Appendix A)

This section of a state permit for siting a hazardous waste disposal facility, *Permit Requirements and Conditions*, covers thirteen items of general information, status of other environmental permits and approvals, and some specific information on the processes and wastes to be handled A formal permitting process will not be required for the landfill since the CAMU process is being used. However, substantive technical information that should be provided by the Army, are noted below (appropriate sections are italicized)

> *Section 100 40 (a), (8)* requires a "description of the processes to be used for treating, storing, and disposing of hazardous waste, and the design capacity of these items "
>
> *Section (a), (9)* requires a specification of the hazardous wastes listed. quantities, and processes to be used for such wastes
>
> *Section (a), (13)* covers hazardous debris and the categories

The Final Landfill Site Feasibility Report (Report) defines only general waste categories, e g., contaminated soils, treated soil, structural debris Additional detail on the hazardous waste sources and character, list category, and their respective volumes, based on the conceptual

remedy, will be needed with the CAMU Designation Document (CDD) Detail on any processes and material handling at the landfill are also required. The waste generation rates and schedule in the Report are broad enough to cover a range of potential remedial alternatives; however, these should be refined to reflect the current conceptual agreement and the new version of the DAA.

Part B requirements of 6 CCR 1007-3, Section 100.41 (See Appendix A)

Part B requirements are used to demonstrate compliance with standards promulgated in Part 264. Additional substantive technical information should be provided by the Army, as noted below-

Section 100.41 (a) (2,3) Chemical and physical analyses of hazardous waste and hazardous debris must contain all information which must be known to treat, store, or dispose of wastes properly in accordance with Part 264. A waste analysis plan is required.

This information, which was not included in the Report, is needed to support a liner design compatible with the wastes to be disposed (See 264 301) This information should be provided or addressed in a schedule by issuance of the CDD. The issue of waste analysis was briefly discussed in the Report. Further detail is needed.

Sections (a) (4), (5), (6), (7), (8)

These reports have been briefly addressed in the Report. These plans should be developed in detail and submitted or addressed in the schedule at the time of the CDD.

Section (a), (11)

This section, which relates to facility location information has been addressed, in part, in the Report. The following additional information is required

Section (a) (11) (B) (iii) The Army provides a 100-year flood plain map with a vague citation to a 1983 Army Corps study Please elaborate on this source of floodplain information.

Section (a), (18) A detailed topographic map showing a distance of 1,000 feet around the facility at a scale of one inch equal to not more than 200 feet is required. Inadequate topographics for the conceptual landfill footprints were provided in the Report.

Section 100 41 (b) (7) consists of additional detailed information requirements for landfills to illustrate compliance with Part 264, Subpart N

Appendix S

COLORADO DEPARTMENT OF HEALTH AND ENVIRONMENT'S MODIFICATIONS TO DRAFT FINAL CORRECTIVE ACTION MANAGEMENT UNIT DESIGNATION DOCUMENT

Colorado Department of Health and Environment's
Modifications to

Draft Final Corrective Action Management Unit
Designation Document
Rocky Mountain Arsenal
Commerce City, Colorado

The following modifications and/or additions are to be included in the Final Corrective Action Management Unit Designation Document, Rocky Mountain Arsenal

Text, Section 2.1, Facilitation of the Remedy

In the fourth paragraph, third bullet, replace "toxicity" with "mobility."

Text, Table 2 1, Description of Preferred Sitewide Soil Remedy

Toxic Storage Yards - The cubic yardage should be **2,700 BCY** instead of 2,600 BCY.

Chemical Sewers - The cubic yardage should be **64,000 BCY** instead of 62,000 BCY

Hex Pit - The cubic yardage listed under the 'Components of the Preferred Remedy' should be in bold type to indicate that remediation waste from that unit may go into the landfill.

Buried M-1 Pits - The cubic yardage (**26,000 BCY**) should be in bold type to indicate the volume of remediation waste that will be placed into the landfill

South Plants Balance of Areas - The cubic yardage should be **135,000 BCY** instead of 130,000 BCY

Section 36 Balance of Areas - The cubic yardage should be **142,000 BCY** instead of 140,000 BCY

'Principal' is misspelled through the table as 'principle '

Text, Table 4 2, Cross-References of Regulatory Requirements

Include Subpart N in the Table's title

Text, Figure 3, Schedule of CAMU Activities

Revise the table to indicate actual dates, i e

- 30-Day Public Comment period dates should be March 16, 1996 through April 19, 1996;
- Add - **30-Day Extension to Public Comment Period, starting April 20, 1996, finishing May 20, 1996.**
- CDPHE Issues CDD Designating CAMU - **June 11, 1996**

Appendix B, Section 3.1 2, Site Investigation and Laboratory Testing

In the last sentence of the section, replace "should" with "will "

Appendix B, Section 4 2.3, Vegetation

Delete "CERCLA" from the first sentence of the first paragraph

Appendix D, Section 4 ~~2~~ 4, Compatibility Screening Analysis

Add "Observable reactivity with liner components" to the list of exhibited waste characteristics which may entail segregation and/or pretreatment based on screening results.

Appendix D, Section 8 0, Acronyms

Define S^{2-} as Sulfide

Appendix K, Section 3.1.3, Monitoring Well Installation

Add a reference to ASTM D 5092 in item number 3. of this section

Appendix K, Section 8 1, Data Evaluation Including Statistical Analysis of Results

To be consistent with the text in Section 2.1, modify the first sentence of the second paragraph of Section 8 1 to read

> Groundwater analytical data collected as part of the pre-operational monitoring program will be reviewed initially to identify the background water quality conditions within the landfill CAMU areal configuration, including the CFS and the UFS.

Appendix L, Section 3.0, Closure Procedures

In the last sentence of the second paragraph, replace "may" with "will." The sentence will read
> Specific procedures for closure of these facilities will be developed during design and **will** include confirmation sampling and verification of decontamination.

Appendix P, Section 02721, Compacted Clay Liner

Section 3 02, A. - Revise the third sentence to read "The compacted clay liner shall be a minimum of three (3) feet thick over the bottom and perpendicular to sideslopes of the landfill cell "

Figures B1, K1, and L2

The label in the upper left corner should read Facilities within Corrective Action Management Unit (CAMU) areal configuration.