APPENDIX A

Infiltration Testing

APPENDIX A - INFILTRATION TESTING

Infiltration BMPs use the interaction of chemical, physical, and biological processes between soil and water to filter out sediments and constituents from stormwater. Infiltration BMPs require a maximum drawdown time to avoid nuisance issues. Since drawdown time is contingent on the infiltration rate of the underlying soil, tests are used to help establish the vertical infiltration rate of the soil below a proposed infiltration facility. The tests attempt to simulate the physical process that will occur when the facility is in operation.

Section 1 - General Requirements

1.1 - Summary of Requirements

The following is a brief summary of the requirements for all infiltration test reports submitted to the Engineering Authority (EA)[1] for the purpose of water quality BMP design. A checklist form is included at the end of this document.

1. Where infiltration testing is to be performed (as directed by the EA or in the WQMP), the measured infiltration rate of the underlying soil must be determined using either the single ring infiltrometer test (as described in ASTM D 5126, Section 4.1.2.1), the double ring infiltrometer test (ASTM D 3385), the well permeameter method (USBR 7300-89), or a percolation test per County of Riverside Department of Environmental Health (RCDEH) test procedures. A general explanation of these test methods can be found in Section 2 of this appendix. The minimum number of tests required can be found in Table 1 and is dependent upon the type of infiltration test performed.

2. Test pits and borings (ASTM D 1452) may be used to determine the USCS series and textural class (SM, CL, etc.) of the soil horizons, the thickness of soil and rock strata, and to estimate the historical high groundwater mark[2]. Test pits or boring logs must be of sufficient depth to establish that a minimum of 5 feet of permeable soil exists below the infiltration facility and that there is a minimum of 10 feet between the bottom of the infiltration facility and the historical high groundwater mark (Sections 1.7 and 2.5). The required number of test pits or borings are listed in Table 1.

3. A final report, prepared by a registered civil engineer, geotechnical engineer, certified engineering geologist or certified hydrogeologist shall be provided to the EA which demonstrates through infiltration testing and/or soil logs that the proposed facility location is suitable for the proposed infiltration facility and an infiltration rate shall be recommended. In addition, any requirements associated with impacts to a landslide, erosion or steep slope hazard area should also be addressed in the final report. (Section 1.7)

[1]*County Transportation, Coachella Valley Water District and the City Engineer for incorporated cities within the County may choose to alter these guidelines and may have different/additional requirements. These entities, along with the District, will be referred to as the Engineering Authority (EA).*

[2]*The "historical high groundwater mark" is defined as the groundwater elevation expected due to a normal wet season and shall be obtained by boring logs or test pits.*

4. Tests may be performed only by individuals trained and educated to perform, understand and evaluate the field conditions. The individual(s) supervising the field work must be named in the final report as described in Item 3. (Section 1.7)

5. Preliminary site grading plans shall be provided to the EA showing the proposed BMP locations along with section views through each BMP clearly identifying the extents of cut/fill relative to native soil. (See Section 1.1)

6. For sites where infiltration BMPs have been determined to be feasible and will be used, infiltration tests shall be performed within the boundaries of the proposed infiltration BMP and at the bottom elevation (infiltration surface) of the proposed infiltration BMP to confirm the suitability of infiltration. (See Photo 5)

A Note on "Infiltration Rate" vs. "Percolation Rate"

A common misunderstanding exists that the "percolation rate" obtained from a percolation test is equivalent to the "infiltration rate" obtained from a single or double ring infiltrometer test. While the percolation rate is related to the infiltration rate, percolation rates tend to overestimate infiltration rates and can be off by a factor of ten or more. However, as is discussed in Section 2.3, the percolation rate can be converted to a reasonable estimate of the infiltration rate using the Porchet Method.

1.2 Applicability of Infiltration BMPs

The WQMP guidance applicable to a project (based on the watershed location of the project), may include specific criteria for evaluating whether infiltration BMPs are feasible for a particular project. Where the WQMP requires that infiltration testing be performed as part of an infiltration feasibility evaluation, a testing method approved by the EA shall be used. The District requires the use of the methods described in Section 2 herein. The remainder of Section 1 herein describes requirements that must be implemented whenever an infiltration BMP is to be implemented.

1.3 - Grading Plans

Many projects require a significant amount of grading prior to their construction. It is important to determine if the BMP will be placed in cut or fill since this may affect the performance of the BMP or even the soil. As such, preliminary site grading plans showing the proposed BMP locations are required along with section views through each BMP clearly identifying the extents of cut or fill. In addition, since it is imperative that any testing be performed at the proper elevations and locations, it is highly recommended that the preliminary site grading plans be provided to the engineer/geologist prior to any tests being performed.

1.4 - Cut Condition

Where the proposed infiltration BMP is to be located in a cut condition, the infiltration surface level at the bottom of the BMP might be far below the existing grade. For example, if the infiltration surface of a proposed BMP is to be located at an elevation that is currently beneath 15 feet of cut, how can the proposed infiltration surface be tested?

In order to determine an infiltration rate where the proposed infiltration surface is in a cut condition, the following procedures may be used:

1. The USBR 7300-89, "Procedure for Performing Field Permeability Testing by the Well Permeameter Method" (Section 2.4). Note: the result must be converted to an infiltration rate.
2. The Percolation Test per RCDEH (Section 2.3) may be used. Note: the result must be converted to an infiltration rate.

Refer also to the WQMP guidance document applicable to the project, which may identify applicability criteria for infiltration BMPs in cut conditions.

1.5 - Fill Condition

If the bottom of a BMP (infiltration surface) is in a fill location, the infiltration surface may not exist prior to grading. How then can the infiltration rate be determined? For example, if a proposed infiltration BMP is to be located in 12 feet of fill, how could one reasonably establish an infiltration rate prior to the fill being placed?

Unfortunately, no reliable assumptions can be made about the in-situ properties of fill soil. As such, the bottom, or rather the infiltration surface of the BMP, must extend into natural soil. The natural soil shall be tested at the design elevation prior to the fill being placed.

In some cases, the extension of the BMP down to natural soil may prove infeasible. In that case, another BMP must be selected.

1.6 - Factors of Safety

Long term monitoring has shown that the performance of working full-scale infiltration facilities may be far lower than the rate measured by small-scale testing. There are several reasons for this:

- Over time, the surface of infiltration facilities can become plugged as sedimentary particles accumulate at the infiltration surface.
- Post-grading compaction of the site can destroy soil structure and seriously impact the facility's performance.

- Soils and soil strata are rarely homogenous, and variations across a site, and sometimes even within a BMP footprint, can cause tested infiltration rates to vary widely.
- Testing procedures in general are subject to natural variations and errors which can skew the results.

As such, to obtain an appropriate level of confidence in the final design infiltration rate, factors of safety shall be applied to the tested infiltration rate, I_t, in order to determine the design infiltration rate, I_d. These factors are based on such considerations as the type of tests used, the number of tests performed and whether testing is performed at all. Table 1 provides a complete matrix of testing requirements versus factors of safety.

1.7 - Infiltration Testing Requirements

Table 1 is a list of infiltration BMPs with test regime options and their corresponding design factors of safety. The options are summarized below:

Option 1- This test regime includes ring infiltrometer type tests, test pit or boring logs and a final report. The minimum required number of tests is as described in Table 1. The minimum required factor of safety for this option is FS=3.

Option 2- This test regime includes percolation type tests, test pit or boring logs and a final report. The minimum required number of tests is as described in Table 1. The minimum required factor of safety for this option is FS=3.

Option 3- This test regime includes test pit or boring logs only and a final report. The minimum required number of tests is as described in Table 1. An expected infiltration rate shall be included in the final report based on the specifics of the borings or test pits. The minimum required factor of safety for this option is FS=6. This option may be used for projects with a maximum tributary area of 5 acres only.

Option 4- This test regime includes a single test pit or boring log at any representative location on the project site. Plates E-6.1 and E-6.2 of the Riverside County Flood Control and Water Conservation District's (RCFCD) Hydrology Manual shall then be used to establish an approximate infiltration rate based on the appropriate Runoff Index and the Antecedent Moisture Content (AMC) as defined on page C-3 of the Hydrology Manual. The minimum required factor of safety for this option is FS=10.

Table 1 - Infiltration Testing Requirements							
Infiltration BMP	Testing Options	Ring Infiltrometer Tests[1]	Percolation Test[2]	Test Pits or Boring Logs[3]	Final Report[4]	Hydrology Manual[5]	Factor of Safety
Infiltration Trench	Option 1►	2 tests min. with at least 1 per trench	not used	1 boring or test pit per trench	Required	not used	FS = 3
	Option 2►	not used	4 tests min. with at least two per trench	1 boring or test pit per trench	Required	not used	FS = 3
	Option 3[7]►	not used	not used	1 boring or test pit per trench	Required	not used	FS = 6
	Option 4►	not used	not used	1 boring or test pit per site	not used	only	FS = 10
Infiltration Basin	Option 1►	2 tests min. with at least 1 per basin[6]	not used	1 boring or test pit per basin	Required	not used	FS = 3
	Option 2►	not used	4 tests min. with at least 2 per basin[6]	1 boring or test pit per trench	Required	not used	FS = 3
	Option 3[7]►	not used	not used	1 boring or test pit per basin	Required	not used	FS = 6
	Option 4►	not used	not used	1 boring or test pit per site	not used	only	FS = 10
Permeable Pavement	Option 1►	2 tests min. with at least 1 every 10,000 ft^2	not used	1 boring or test pit every 10,000 ft^2	Required	not used	FS = 3
	Option 2►	not used	4 tests min. with at least 2 every 10,000 ft^2	1 boring or test pit every 10,000 ft^2	Required	not used	FS = 3

Table Footnotes:

(1) Ring Infiltrometer tests per Section 2.2

(2) Percolation tests per Section 2.3 and Well Permeameter Test per Section 2.4

(3) Test pits or boring logs per Section 2.5

(4) Final Report per Section 1.7

(5) See Plate E-6.2 of the District's Hydrology Manual

(6) For basins in excess of 10,000 ft^2, provide one (1) ring infiltrometer test or two (2) percolation tests for each additional 10,000 ft^2

(7) This option may be used for projects with a maximum tributary area of 5 acres only.

1.8 - Final Report

Where a final report is required, a civil engineer, geotechnical engineer, certified engineering geologist or certified hydrogeologist shall establish whether the location is suitable for the proposed infiltration facility. At least 5 feet of permeable soil must be present below the infiltration facility and a minimum of 10 feet between the bottom of the infiltration facility and the historical high groundwater mark[1] is required. The signed/stamped report shall include discussion and records of the infiltration testing as well as boring log findings. Based on the results of these tests, the report shall provide an estimate of the infiltration rate found at the location of each proposed infiltration BMP in units of inches per hour. The factor of safety specified in Table 1 will be applied to the interpreted test results to determine the design infiltration rate for each infiltration BMP. Any requirements associated with impacts to an erosion hazard area, steep slope hazard area, or landslide hazard area should also be addressed in the report. In addition, the report shall include complete field records with the following information:

- Location of the test site.
- Dates of test, start and finish.
- Weather conditions, start to finish.
- Names(s) of technician(s).
- Description of test site, including assessment of boring profile and USCS soil classification.
- Depth to the water table and a description of the soils to a depth of at least 10 feet below proposed infiltration surface.
- Type of equipment used to construct the boreholes or test holes (such as backhoe, hollow stem auger, etc.)
- Areas of the rings (if used) or test hole diameter.
- Volume constants for graduated cylinder or Mariotte tube (if used).
- Complete field results in tabular format. Sample test data forms, as well as examples, have been provided following the description of each test in Section 2.
- A plot of the infiltration rate versus total elapsed time. An example is provided following the description of each test in Section 2.
- A labeled keymap showing test and boring locations.
- Confirmation that the soil was pre-saturated in accordance with the testing methods described herein.

Section 2 - Accepted Testing Methods

There is a wide range of different methods for measuring the infiltration rate of a given soil with varying degrees of accuracy and reliability. However, the District will accept only the following test methods:

1. Single Ring Infiltrometer (Per ASTM D 5126), Section 2.1.1
2. Double Ring Infiltrometer (Per ASTM D 3385), Section 2.1.2
3. Well Permeameter Method (USBR 7300-89), Section 2.4
4. Percolation Test (per County of Riverside Department of Environmental Health procedure), Section 2.3

[1]The "historical high groundwater mark" is defined as the groundwater elevation expected due to a normal wet season and shall be obtained by boring logs or test pits.

The following pages of this document provide an overview of these tests. It is recommended that the original Standards be referenced.

2.1 - Constant Head vs. Falling Head Method

There are two operational techniques used with all four of the testing techniques herein: the *constant head method* and the *falling head method*. With the *constant head method*, water is consistently added to both the outer and inner rings (ring infiltrometers) or to the test hole (pecolation test and well permeameter) to maintain a constant level throughout the testing. The volume of water needed to maintain the fixed level of the inner ring is measured. Conversely, in the *falling head method*, the water level is allowed to fall and the time that the water level takes to decrease is measured.

2.2 - Overview of Ring Infiltrometer Test Methods

Ring infiltrometers measure the rate of infiltration at the soil surface. Infiltration is influenced by both saturated hydraulic conductivity as well as capillary effects. The term *capillary effects* refers to the ability of dry soil to pull, or wick away, water from a zone of saturation faster than would occur if the soil were uniformly saturated. The magnitude of the capillary effect is determined by initial moisture content at the time of testing, the pore size, soil properties (texture, structure) and a number of other factors. The effects of capillarity are short lived and can greatly skew test results. As such, it is critical to obtain steady-state infiltration so that capillary effects are minimized. (ASTM 5126)

The ***single ring infiltrometer*** and ***double ring infiltrometer*** methods both employ the use of metal cylinders driven to shallow depths into the test soil. The rings are filled with water and the rate at which the water moves into the soil is measured. This rate becomes constant when the saturated hydraulic conductivity for the particular soil has been reached. This is reflected by the flattening out of the curve generated by sample test data as shown in Figure 2, "Plot of Infiltration Rate vs. Time". While we note that infiltration rate is not exactly the same as saturated hydraulic conductivity, for the purposes of this guidance document they are synonymous.

2.2.1 - Single Ring Infiltrometers

Single ring infiltrometer tests using a ring 40 inches or larger in diameter have been shown to closely match full-scale facility performance (Figures 1 and 2, Photo 1). The cylindrical ring is driven approximately 12 inches into the soil. Water is ponded within the ring above the soil surface. The upper surface of the ring is often covered to prevent evaporation. Using the constant head method, the volumetric rate of water added to the ring, sufficient to maintain a constant head within the ring is measured. The test is complete and the tested infiltration rate, I_t, is determined after the flow rate has stabilized. (ASTM D 5126)

Photo 1 – Simple Single Ring Infiltrometer

To help maintain a constant head, a variety of devices may be used. A hook gauge, steel tape or rule, length of steel, or plastic rod pointed on one end can be used for measuring and controlling the depth of liquid (head) in the infiltrometer ring. If available, a graduated Mariotte tube or automatic flow control system may also be used. Care should be taken when driving the ring into the ground as there can be a poor connection between the ring wall and the soil. This poor connection can cause a leakage of water along the ring wall and an overestimation of the infiltration rate.

The volume of liquid used during each measured time interval may be converted into an incremental infiltration velocity (infiltration rate) using the following equation:

$$I_t = \Delta V/(A*\Delta t)$$

Where:

I_t = tested infiltration rate, in/hr

ΔV = volume of liquid used during time interval to maintain constant head in the ring, in^3

A = internal area of ring, in^2

Δt = time interval, hr.

Final Report - Ultimately, as discussed in Section 1.7, a final report shall be provided and, based on the test results, an infiltration rate shall be recommended.

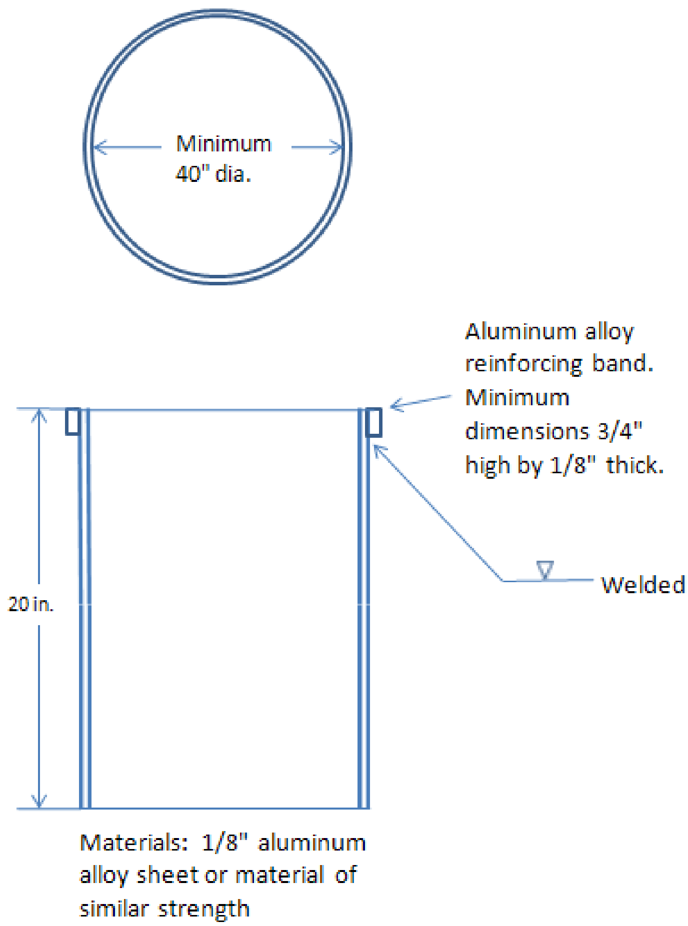


Figure 1- Single Ring Infiltrometer Construction

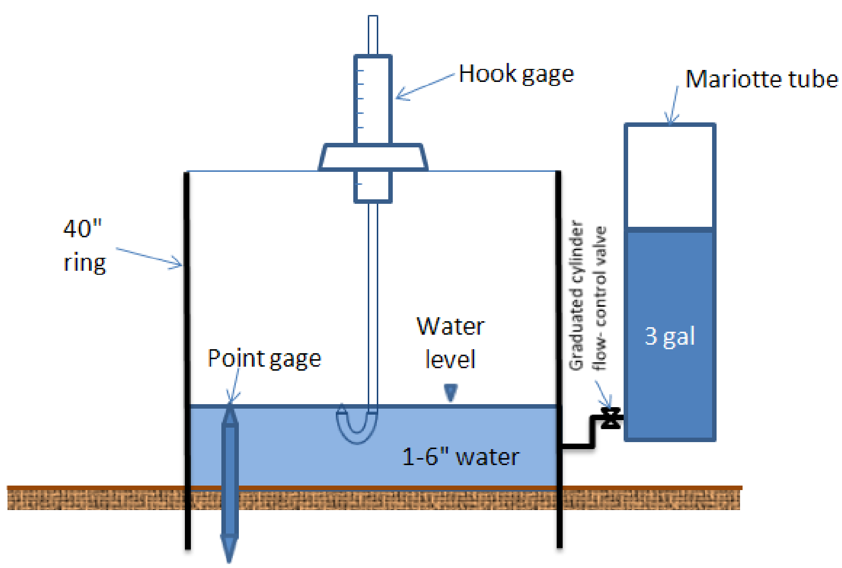


Figure 2- SIngle Ring Setup with Mariotte Tube

SINGLE RING INFILTROMETER TEST DATA						
Project Name and Test Location:		Constants-	Ring Data		Liquid Containers	
			Ring Area, A_r (in^2)	Depth of Liquid (in)	Reservoir Container Volume, V_r (in^3/in)	
Test By:		USCS Class:		Penetration of Ring into Soil (in.):		
Liquid Used:		pH:		Ground Temp (°F):		at Depth:
Date of Test:		Depth to Water Table:				
Liquid Level Maintained by using:	( ) Flow Valve ( ) Float Valve ( ) Marriotte Tube ( ) Other:					
Additional Comments:						

Time interval	Time (hr:min)	Dt (min) & Total	Flow Readings: Elev., H (In)	Flow Readings: ΔH (in) & Q_f* (in^3)	Liquid Temp (°F)	Infiltratn Rate, I**(in/hr)	Remarks
1 - Start							
End							
2 - Start							
End							
3 - Start							
End							
4 - Start							
End							
5 - Start							
End							
6 - Start							
End							
7 - Start							
End							
8 - Start							
End							
9 - Start							
End							
10 - Start							
End							
11 - Start							
End							
12 - Start							
End							
13 - Start							
End							
14 - Start							
End							
15 - Start							
End							

***Flow, $Q_f = \Delta H \times V_r$ **Infiltration Rate, $I = (Q_f/A_r)/$**

Table 2 – Sample Test Data Form for Single Ring Infiltrometer Test

SINGLE RING INFILTROMETER TEST DATA

Project Name and Test Location:	Constants-	Ring		Liquid Containers
		Ring Area, A_r (in^2)	Depth of Liquid (in)	Reservoir Container Volume, V_r (in^3/in)
ACME IND. SITE 24166 ELM, RIVERDALE * WESTERN CORNER OF SITE (NEAR WAREHOUSE)		12.56	4.0	78.54

Test By:	CMD	USCS Class:	SM	Penetration of Ring into Soil (in.):	3.0
Liquid Used:	TAP WATER	pH:	8.0	Ground Temp (°F): 57	at Depth: 16"
Date of Test:	3-21-09	Depth to Water Table:	40 FEET		

Liquid Level Maintained by using: ( ) Flow Valve ( ) Float Valve (X) Marriotte Tube ( ) Other:

Additional Comments: DRY GROUND

Time interval	Time (hr:min)	Dt (min) & Total	Flow Readings: Elev., H (In)	Flow Readings: ΔH (in) & Q_f* (in^3)	Liquid Temp (°F)	Infiltratn Rate, I**(in/hr)	Remarks
1 - Start	10:00	15	3.0	1.45	59	0.36	CLOUDY, SLIGHT WIND
End	10:15	(15)	4.45	114	59		
2 - Start	10:15	15	4.45	2.7	59	0.68	
End	10:30	(30)	7.15	212	59		
3 - Start	10:30	15	7.15	3.35	59	0.84	
End	10:45	(45)	10.5	263	59		
4 - Start	10:45	15	10.5	3.9	59	0.97	
End	11:00	(60)	14.4	306	60		
5 - Start	11:00	30	14.4	9.65	60	1.2	
End	11:30	(90)	24.05	758	61		
6 - Start	11:30	30	24.05	10.8	61	1.4	
End	12:00	(120)	34.85	848	62		
7 - Start	12:10	60	3.5	24.7	62	1.5	REFILLED TUBES
End	13:10	(180)	28.25	1944	63		
8 - Start	13:20	60	2.4	23.9	64	1.5	"
End	14:20	(240)	26.3	1877	64		
9 - Start	14:30	60	4.3	21.6	64	1.4	"
End	15:30	(300)	25.9	1696	64		
10 - Start	15:40	60	2.2	20.2	64	1.3	"
End	16:40	(360)	22.4	1586	64		CLOUDY, SLIGHT WIND
11 - Start							
End							
12 - Start							
End							
13 - Start							
End							
14 - Start							
End							
15 - Start							
End							

*Flow, $Q_f = \Delta H \times V_r$ **Infiltration Rate, $I = (Q_f/A_r)/\Delta t$

FIGURE 3 – Sample Test Data

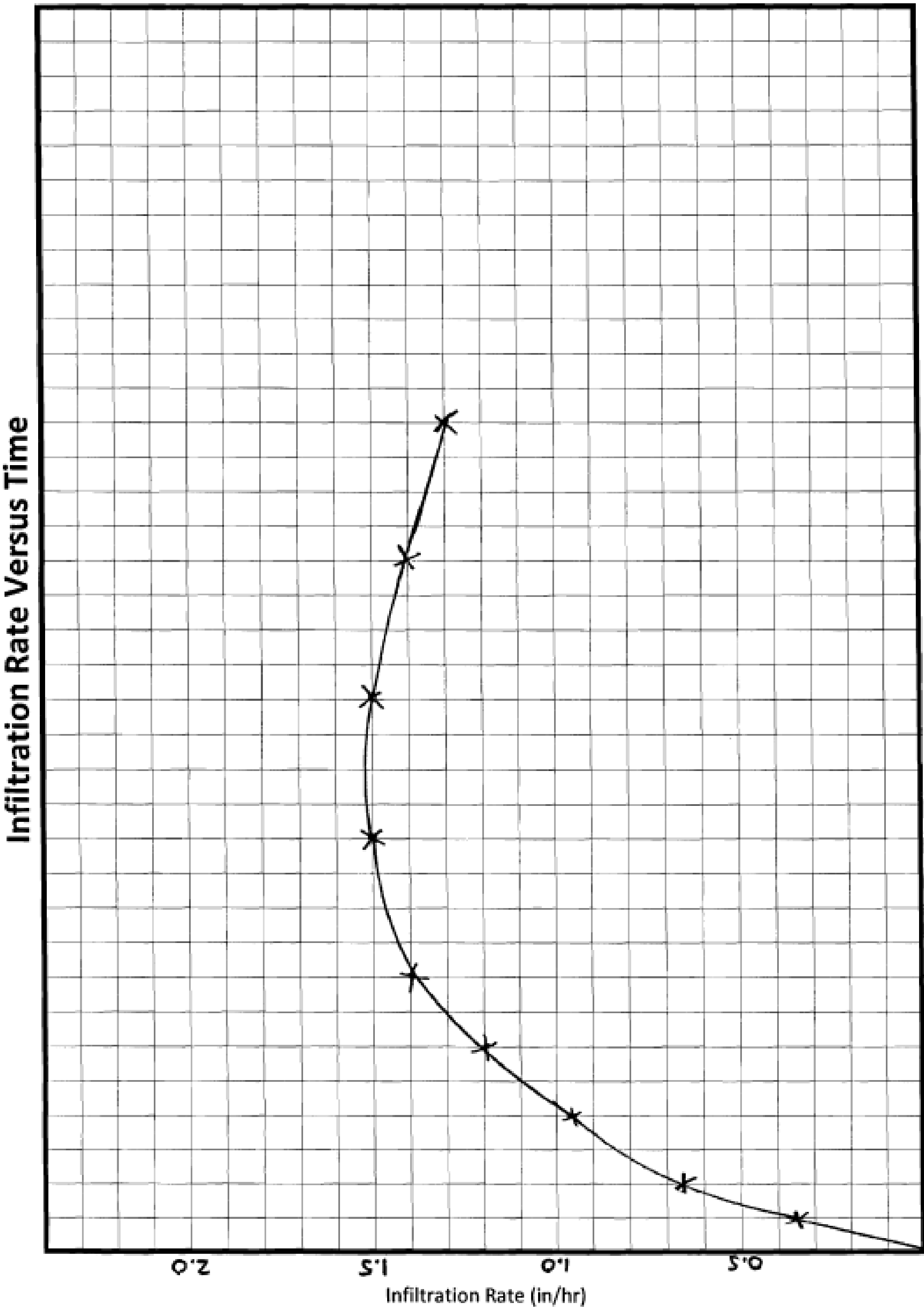


FIGURE 4 – Plot of Sample Test Data for Single Ring Infiltrometer Test

2.2.2 - Double Ring Infiltrometers

The ***double ring infiltrometer*** test (ASTM D 3385) is a well recognized and documented technique for directly measuring the soil infiltration rate of a site (see Figure 5, 6 and 7; Photos 2, 3, 4 and 5). Double ring infiltrometers were developed in response to the fact that smaller (less than 40 inch diameter) single ring infiltrometers tend to overestimate vertical infiltration rates. This has been attributed to the fact that the flow of water beneath the cylinder is not purely vertical and diverges laterally. Double ring infiltrometers minimize the error associated with the single-ring method because the water level in the outer ring forces vertical infiltration of water in the inner ring. Care should be taken when driving the rings into the ground as there can be a poor connection between the ring wall and the soil. This poor connection can cause a leakage of water along the ring wall and an overestimation of the infiltration rate. Another potential source of error is attributed to the size of the cylinders. As such, the use of cylinder sizes less than those prescribed in ASTM D 3385 is not recommended.

A typical double ring infiltrometer would consist of a 12 inch inner ring and a 24 inch outer ring. While there are two operational techniques used with the double-ring infiltrometer, the constant head method and the falling head method, ASTM D3385 mandates the use of the constant head method. With the constant head method, water is consistently added to both the outer and inner rings to maintain a constant level throughout the testing. The volume of water needed to maintain the fixed level of the inner ring is measured. To help maintain a constant head, a variety of devices may be used. A hook gauge, steel tape or rule, or length of steel or plastic rod pointed on one end, can be used for measuring and controlling the depth of liquid (head) in the infiltrometer ring. If available, a graduated Mariotte tube or automatic flow control system may also be used.

The volume of liquid used during each measured time interval may be converted into an incremental infiltration velocity (infiltration rate) using the following equation:

$$I_t = \Delta V/(A*\Delta t)$$

Where:

I_t = tested infiltration rate, in/hr

ΔV = volume of liquid used during time interval to maintain constant head in the inner ring, in^3

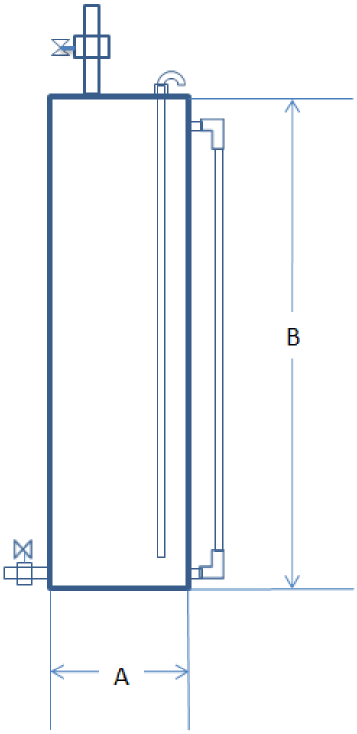
A = area of inner ring, in^2

Δt = time interval, hr.

Final Report - Ultimately, as discussed in Section 1.7, a final report shall be provided and, based on the test results, an infiltration rate shall be recommended.

Photo 2 – Simple Double Ring Infiltrometer

Photo 3 – Pre-fabricated Double Ring Infiltrometer
(Photo courtesy of Turf-Tec International)



Mariotte Tube
Useful Capacity

	1 gal	3 gal
A =	3 in.	6 in.
B =	18 in.	24 in.

Figure 5 - Mariotte Tube

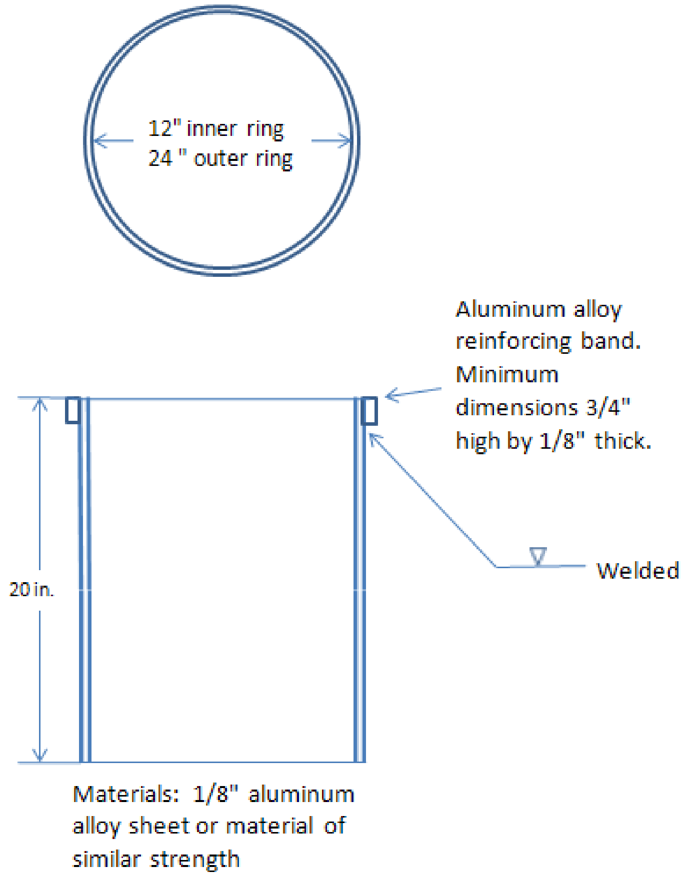


Figure 6- Double Ring Infiltrometer Construction

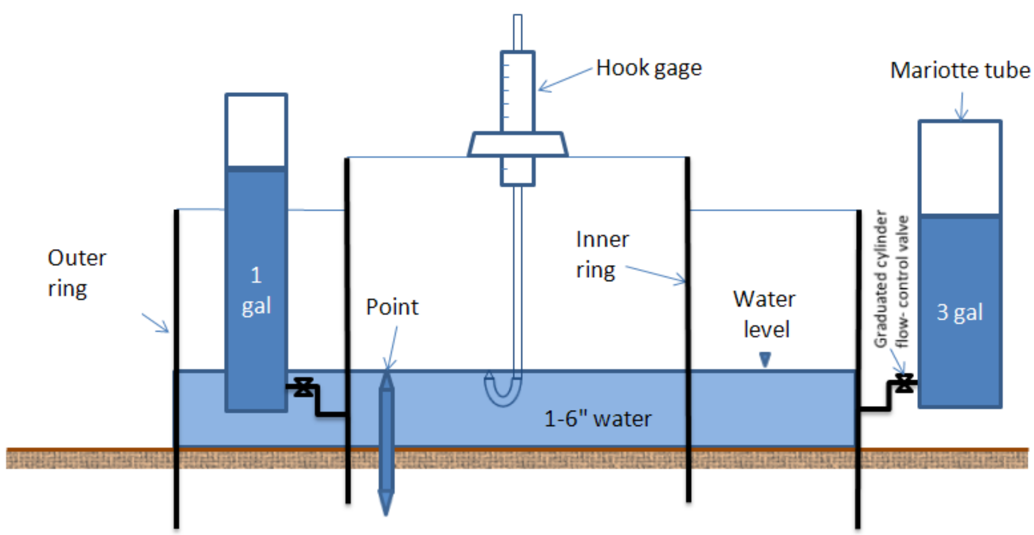


Figure 7- Double Ring Setup with Mariotte Tubes

Photo 4- Double Ring Infiltrometer Set-up with Mariotte Tubes
(Photo courtesy of Turf-Tec International)

Photo 5 – Double Ring Infiltrometer Set-up for Test at Basin Surface Elevation
(Photo courtesy of Turf-Tec International)

DOUBLE RING INFILTROMETER TEST DATA

Project Name and Test Location:				Constants-	Ring Data: Area, A_r (in^2)	Ring Data: Depth of Liquid (in)	Liquid Containers: No.	Liquid Containers: Vol., V_r (in3/in)
				Inner Ring:				
Test By:		USCS Class:		Annular Space:				
Water Table Depth:		Penetration of Rings into Soil (in.):		Inner:		Outer:		
Date of Test:		Liquid Used:		pH:		Ground Temp (·F):		at Depth:
Liquid Level Maintained by using:	( ) Flow Valve ( ) Float Valve ( ) Marriotte Tube ( ) Other:							
Additional Comments:								

Time interval	Time (hr:min)	Dt (min) & Total	Inner Ring Elev., H (In)	Inner Ring ΔH (in) &	Annular Ring Elev., H (In)	Annular Ring ΔH (in) &	Liquid Temp °F	Infiltration Rate, I** Inner in/hr	Infiltration Rate, I** Outer in/hr	Remarks
1 - Start										
End										
2 - Start										
End										
3 - Start										
End										
4 - Start										
End										
5 - Start										
End										
6 - Start										
End										
7 - Start										
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8 - Start										
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9 - Start										
End										
10 - Start										
End										
11 - Start										
End										
12 - Start										
End										
13 - Start										
End										
14 - Start										
End										
15 - Start										
End										

***Flow, $Qf = \Delta H \times Vr$ **Infiltration Rate, $I = (Qf/Ar)/\Delta t$**

Table 3 – Sample Test Data Form for Double Ring Infiltrometer Test

DOUBLE RING INFILTROMETER TEST DATA									
Project Name and Test Location:				Constants-		Ring Data		Liquid Containers	
ACME Industrial Site 24166 Elm, Riverdale (Western corner of site, near warehouse)						Area, A_r (in^2)	Depth of Liquid (in)	No.	Vol., V_r (in3/in)
					Inner Ring:	113	4	1	78.54
Test By:	CMD	USCS Class:	SM		Annular Space:	339	4.1	2	176.7
Water Table Depth:	40 ft.	Penetration of Rings into Soil (in.):				Inner:	3.0	Outer:	7.0
Date of Test:	3/22/09	Liquid Used:	tap water	pH:	8.0	Ground Temp (·F):	57.2	at Depth:	16 in.
Liquid Level Maintained by using:		( ) Flow Valve ( ) Float Valve (X) Marriotte Tube ( ) Other:							
Additional Comments:		Dry Gound							

Time interval	Time (hr:min)	Dt (min) & Total	Inner Ring Elev., H (In)	Inner Ring ΔH (in) &	Annular Ring Elev., H (In)	Annular Ring ΔH (in) &	Liquid Temp °F	Infiltration Rate, I** Inner in/hr	Infiltration Rate, I** Outer in/hr	Remarks
1 - Start	9:00	15	3	0.2	3	0.4	59	0.6	0.8	Cloudy, slight wind
End	9:15	15	3.2	15.71	3.4	70.68	59			
2 - Start	9:15	15	3.2	0.35	3.4	0.6	59	1.0	1.3	
End	9:30	30	3.55	27.49	4	106	59			
3 - Start	9:30	15	3.55	0.5	4	0.9	59	1.4	1.9	
End	9:45	45	4.05	39.27	4.9	159	59			
4 - Start	9:45	15	4.05	0.65	4.9	1.2	59	1.8	2.5	
End	10:00	60	4.7	51.05	6.1	212	60			
5 - Start	10:00	30	4.7	1.5	6.1	2.65	60	2.1	2.8	
End	10:30	90	6.2	117.8	8.75	468.3	61			
6 - Start	10:30	30	6.2	1.7	8.75	2.75	61	2.4	2.9	
End	11:00	120	7.9	133.5	11.5	485.9	62			
7 - Start	11:10	60	3.25	3.75	2.5	5.9	62	2.6	3.1	
End	12:10	180	7	294.5	8.4	1043	63			Refilled tubes
8 - Start	12:20	60	3.5	3.9	3	5.7	64	2.7	3.0	
End	13:20	240	7.4	306.3	8.7	1007	64			Refilled tubes
9 - Start	13:30	60	3	3.6	3.1	5.5	64	2.5	2.9	
End	14:30	300	6.6	282.7	8.6	971.9	64			Refilled tubes
10 - Start	14:40	60	3.25	3.45	3	5.4	64	2.4	2.8	
End	15:40	360	6.7	271	8.4	954.2	64			Refilled tubes
11 - Start	15:50	60	3.3	3.4	2.9	5	64	2.4	2.6	
End	16:50	420	6.7	267	7.9	883.5	64			Refilled tubes
12 - Start	18:00	60	3	3.5	3.1	4.9	64	2.4	2.6	Refilled tubes
End	19:00	480	6.5	274.9	8	865.8	64			Cloudy, no wind
13 - Start										
End										
14 - Start										
End										
15 - Start										
End										

***Flow, Qf = ΔH x Vr**   ****Infiltration Rate, I = (Qf/Ar)/Δt**

Table 4 – Sample Test Data Form for Double Ring Infiltrometer Test

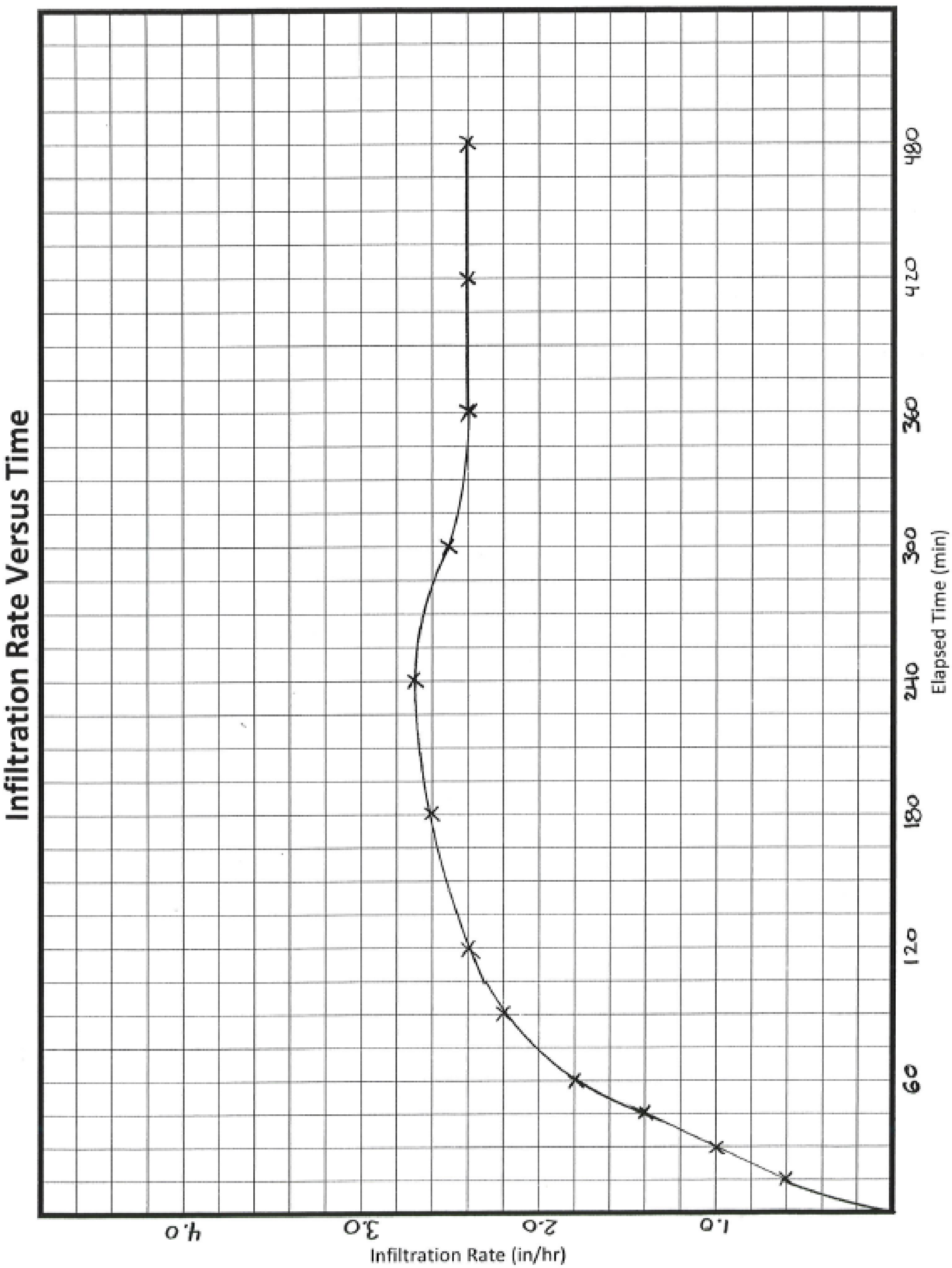

FIGURE 8 – Plot of Sample Test Data for Double Ring Infiltrometer Test

2.3 - Percolation Tests

The ***percolation test*** is widely used for assessing the suitability of a soil for onsite wastewater disposal. Depending on the required depth of testing, there are two versions of the percolation test. For shallow depth testing (less than 10 feet), the procedure would be as shown in Figure 8 (Photo 6). For deep testing (10 feet to 40 feet), the procedure is as shown in Figure 9. For deep testing, special care must be taken to ensure that caving of the sidewalls does not occur.

This test measures the length of time required for a quantity of water to infiltrate into the soil and is often called a "percolation rate". It should be noted that the percolation rate is related to, but not equal to, the infiltration rate. While an infiltration rate is a measure of the speed at which water progresses downward into the soil, the percolation rate measures not only the downward progression but the lateral progression through the soil as well. This reflects the fact that the surface area for infiltration testing would include only the horizontal surface while the percolation test includes both the bottom surface area and the sidewalls of the test hole. However, there is a relationship between the values obtained by a percolation test and infiltration rate. Based on the [1]"Porchet Method", the following equation may be used to convert percolation rates to the tested infiltration rate, I_t:

$$I_t = \frac{\Delta H\ \pi r^2\ 60}{\Delta t(\pi r^2 + 2\pi r H_{avg})} = \frac{\Delta H\ 60\ r}{\Delta t(r + 2H_{avg})}$$

Where:

I_t = tested infiltration rate, inches/hour
ΔH = change in head over the time interval, inches
Δt = time interval, minutes
*r = effective radius of test hole
H_{avg} = average head over the time interval, inches

An example of this procedure is provided on Page 26 based data form Table 5, *Sample Percolation Test Data*. Figure 11 provides a plot of the converted percolation test data.

*Where a rectangular test hole is used, an equivalent radius should be determined based on the actual area of the rectangular test hole. (i.e., $r = (A/\pi)^{0.5}$)

Note to the designer: The values obtained using this method may vary from those obtained from methods considered to be more accurate. The designer is encouraged to explore the derivation of these equations (Ritzema; Smedema)

Final Report - Ultimately, as discussed in Section 1.7, a final report shall be provided and, based on the test results, an infiltration rate shall be recommended.

[1]H.P. Ritzema, "Drainage Principles and Applications," International Institute for Land Reclamation and Improvement (ILRI), Publication 16, 2nd revised edition, 1994, Wageningen, The Netherlands.

Percolation Test Procedure

Only those individuals trained and educated to perform, understand and evaluate the field conditions and tests may perform these tests. This would include those who hold one of the following State of California credentials and registrations: Professional Civil and Geotechnical Engineers, Certified Engineering Geologist and Certified Hyrdrogeologist. The District will only approve the percolation test method described in this Chapter.

When the percolation testing has been completed, a 3 foot long surveyor's stake (lath) shall be flagged with highly visible banner tape and placed in the location of the test indicating date, test hole number as shown on the field data sheet, and firm performing the test. Field data shall be included in the Final Report as described in Section 1.7.

Shallow Percolation Test (less than 10 feet)

Test Preparation

1.) The test hole opening shall be between 8 and 12 inches in diameter or between 7 and 11 inches on each side if square.

2.) The bottom elevation of the test hole shall correspond to the bottom elevation of the proposed basin (infiltration surface). Keep in mind that this procedure will require the test hole to be filled with water to a depth of at least 5 times the hole's radius.

3.) The bottom of the test hole shall be covered with 2 inches of gravel.

4.) The sides of the hole shall remain undisturbed (not smeared) after drilling and any cobbles encountered left in place.

5.) **Pre-soaking** shall be used with this procedure. Invert a full 5 gallon bottle (more if necessary) of clear water supported over the hole so that the water flow into the hole holds constant at a level at least 5 times the hole's radius above the gravel at the bottom of the hole. Testing may commence after all of the water has percolated through the test hole or after 15 hours has elapsed since initiating the pre-soak. However, to assure saturated conditions, testing must commence no later than 26 hours after all pre-soak water has percolated through the test hole. The use of the "continuous pre-soak procedure" is no longer accepted. When sandy soils (as described below) are present, the test shall be run immediately.

Test Procedure

Test hole shall be carefully filled with water to a depth equal to at least 5 times the hole's radius (H/r>5) above the gravel at the bottom of the test hole prior to each test interval.

- In **sandy soils**, when 2 consecutive measurements show that 6 inches of water seeps away in less than 25 minutes, the test shall be run for an additional hour with measurements taken every 10 minutes. Measurements shall be taken with a precision of 0.25 inches or better. The drop that occurs during the final 10 minutes is used to calculate the percolation rate. Field data must show the two 25 minute readings and the six 10 minute readings.

- In **non-sandy soils**, obtain at least twelve measurements per hole over at least six hours with a precision of 0.25 inches or better. From a fixed reference point, measure the drop in water level over a 30 minute period for at least 6 hours, refilling after every 30 minute reading. The total depth of the hole must be measured at every reading to verify that collapse of the borehole has not occurred. The drop that occurs during the final reading is used to calculate the percolation rate.

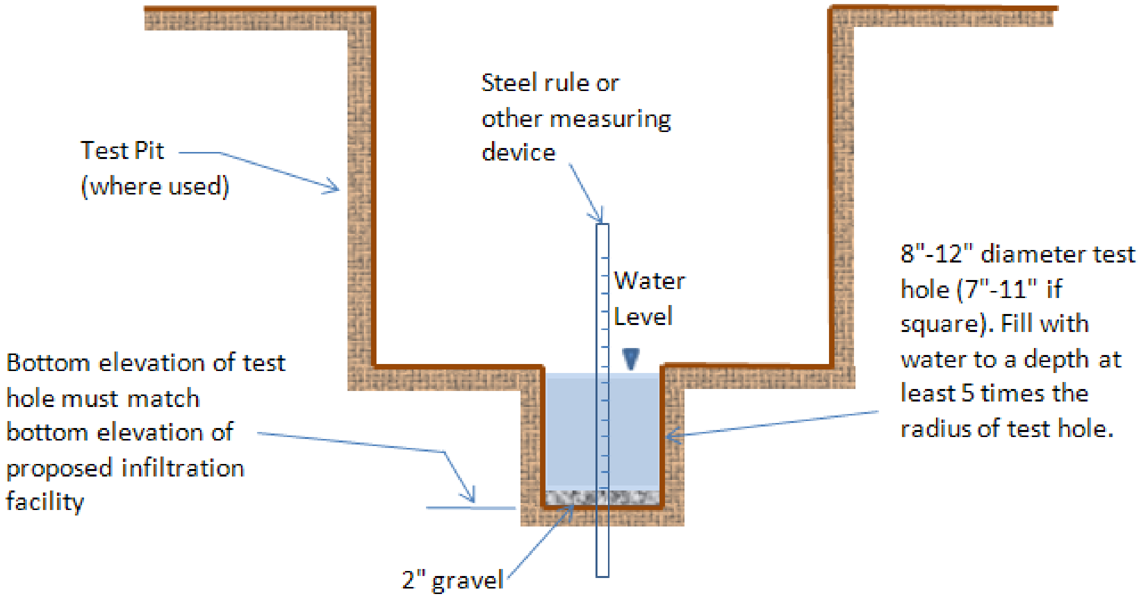

Figure 9- Test Pit for Shallow Percolation Test

Deep Percolation Test (Depths 10-40 feet)

Test Preparation

1.) Borehole diameter shall be either 6 inch or 8 inch only. No other diameter test holes will be accepted.

2.) The bottom elevation of the test hole shall correspond to the bottom elevation of the proposed basin (infiltration surface). Keep in mind that this procedure will require the test hole to be filled with water to a depth of at least 5 times the hole's radius.

3.) The bottom of the test hole shall be covered with 2 inches of gravel.

4.) The sides of the hole shall remain undisturbed (not smeared) after drilling and any cobbles encountered left in place. Special care should be taken to avoid cave-in.

5.) **Pre-soaking** shall be used with this procedure. Invert a full 5 gallon bottle of clear water supported over the hole so that the water flow into the hole holds constant at a maximum depth of 4 feet below the surface of the ground or if grading cuts are anticipated, to the approximate elevation of the **top** of the basin but at least 5 times the hole's radius (H/r>5). Pre-soaking shall be performed for 24 hours unless the site consists of sandy soils containing little or no clay. If sandy soils exist as described below, the tests may then be run after a 2 hour pre-soak. However, to assure saturated conditions, testing must commence no later than

26 hours after all pre-soak water has percolated through the test hole. The use of the "continuous pre-soak procedure" is no longer accepted. When sandy soils (as described below) are present, the test shall be run immediately.

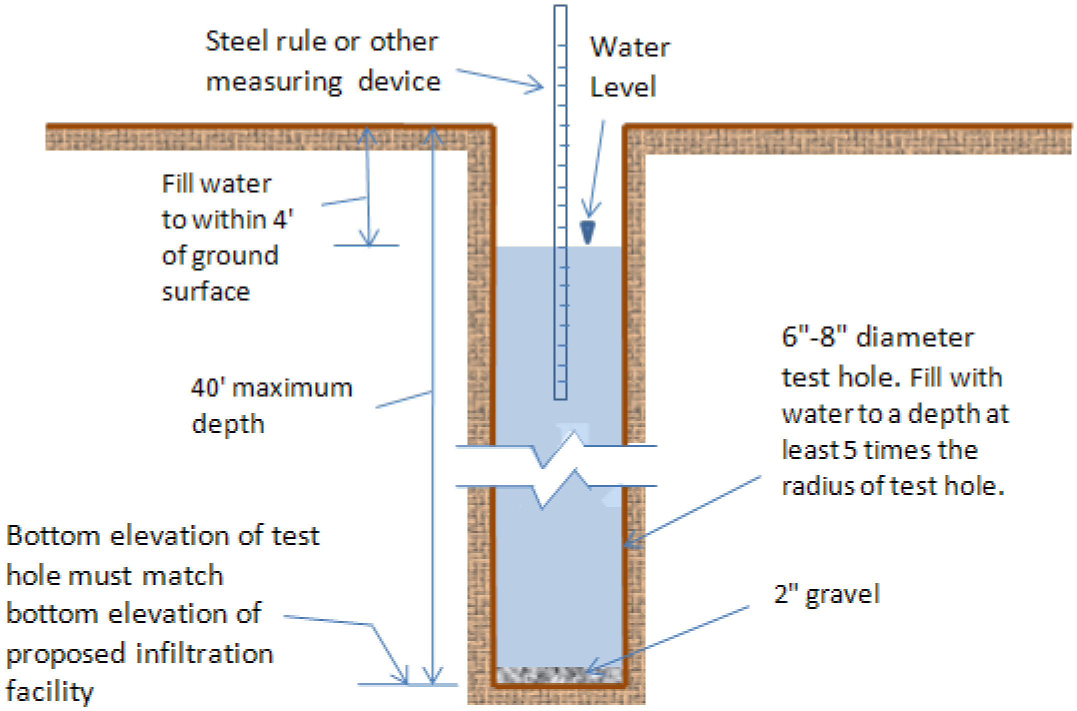

Figure 10- Test Pit for Deep Percolation Test

Test Procedure

Carefully fill the hole with clear water to a maximum depth of 4 feet below the surface of the ground or, if grading cuts are anticipated, to the approximate elevation of the **top** of the basin. However, at a minimum, the bore hole shall be filled with water to a depth equal to 5 times the hole's radius (H/r>5).

- In **sandy soils**, when 2 consecutive measurements show that 6 inches of water seeps away in less than 25 minutes, the test shall be run for an additional hour with measurements taken every 10 minutes. Measurements shall be taken with a precision of 0.25 inches or better. The drop that occurs during the final 10 minutes is used to calculate the percolation rate. Field data must show the two 25 minute readings and the six 10 minute readings.

- In **non-sandy soils**, the percolation rate measurement shall be made on the day following initiation of the pre-soak as described in Item #5 above. From a fixed reference point, measure the drop in water level over a 30 minute period for at least 6 hours, refilling after every 30 minute reading. Measurements shall be taken with a precision of 0.25 inches or better. The total depth of hole must be measured at every reading to verify that collapse of the borehole has not occurred. The drop that occurs during the final reading is used to calculate the percolation rate.

Photo 6 – Percolation Test Pit. Use of perforated PVC pipe is a variation.

Percolation Test Data Sheet							
Project:			Project No:			Date:	
Test Hole No:			Tested By:				
Depth of Test Hole, D_T:			USCS Soil Classification:				
Test Hole Dimensions (inches)					Length	Width	
Diameter (if round)=			Sides (if rectangular)=				
Sandy Soil Criteria Test*							
Trial No.	Start Time	Stop Time	Time Interval, (min.)	Initial Depth to Water (in.)	Final Depth to Water (in.)	Change in Water Level (in.)	Greater than or Equal to 6"? (y/n)
1							
2							
*If two consecutive measurements show that six inches of water seeps away in less than 25 minutes, the test shall be run for an additional hour with measurements taken every 10 minutes. Other wise, pre-soak (fill) overnight. Obtain at least twelve measurements per hole over at least six hours (approximately 30 minute intervals) with a precision of at least 0.25".							
Trial No.	Start Time	Stop Time	Δt Time Interval (min.)	D_o Initial Depth to Water (in.)	D_f Final Depth to Water (in.)	ΔD Change in Water Level (in.)	Percolation Rate (min./in.)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
COMMENTS:							

Table 5 – Sample Test Data Form for Percolation Test

Percolation Rate Conversion

Example:

The bottom of a proposed infiltration basin would be at 5.0 feet below natural grade. Percolation tests are performed within the boundaries of the proposed basin location with the depth of the test hole set at the infiltration surface level (bottom of the basin). The Percolation Test Data Sheet (Table 5) is prepared as the test is being performed. After the minimum required number of testing intervals, the test is complete. [1]**The data collected at the final interval is as follows:**

Time interval, Δt = 10 minutes
Final Depth to Water, D_f = 13.75 inches
[2]Test Hole Radius, r = 4 inches
Initial Depth to Water, D_0 = 12.25 inches
Total Depth of Test Hole, D_T = 60 inches

The conversion equation is used:

$$I_t = \frac{\Delta H\ 60\ r}{\Delta t(r+2H_{avg})}$$

"H_o" is the initial height of water at the selected time interval.

$H_o = D_T - D_0 = 60 – 12.25 =$ **47.75 inches**

"H_f" is the final height of water at the selected time interval.

$H_f = D_T - D_0 = 60 - 13.75 =$ **46.25 inches**

"ΔH" is the change in height over the time interval.

$\Delta H = \Delta D = H_o - H_f = 47.75 – 46.25 =$ **1.5 inches**

"H_{avg}" is the average head height over the time interval.

$H_{avg} = (H_o - H_f)/2 = (47.75 – 46.25)/2 =$ **47.0 inches**

"I_t" is the tested infiltration rate.

$$I_t = \frac{\Delta H\ 60\ r}{\Delta t(r+2H_{avg})} = \frac{(1.5\text{ in})(60\text{ min/hr})(4\text{ in})}{(10\text{ min})((4\text{ in}) + 2(47\text{ in}))} = \mathbf{0.37\ in/hr.}$$

Percolation Test Data Sheet

Project:	ACME SITE	Project No:	1106 B	Date:	2-18-09
Test Hole No:	3	Tested By:	CMD		
Depth of Test Hole, D_T:	60 IN.	USCS Soil Classification:	SM		
Test Hole Dimensions (inches)			Length	Width	
Diameter (if round)=	8	Sides (if rectangular)=			

Sandy Soil Criteria Test*

Trial No.	Start Time	Stop Time	Time Interval, (min.)	Initial Depth to Water (in.)	Final Depth to Water (in.)	Change in Water Level (in.)	Greater than or Equal to 6"? (y/n)
1	8:00	8:25	25	12.0	19.5	7.5	Y
2	8:30	8:55	25	12.0	18.75	6.75	Y

*If two consecutive measurements show that six inches of water seeps away in less than 25 minutes, the test shall be run for an additional hour with measurements taken every 10 minutes. Other wise, pre-soak (fill) overnight. Obtain at least twelve measurements per hole over at least six hours (approximately 30 minute intervals) with a precision of at least 0.25".

Trial No.	Start Time	Stop Time	Δt Time Interval (min.)	D_o Initial Depth to Water (in.)	D_f Final Depth to Water (in.)	ΔD Change in Water Level (in.)	Percolation Rate (min./in.)
1	9:00	9:10	10	12.0	14.25	2.25	4.4
2	9:10	9:20	10	11.5	13.5	2.0	5.0
3	9:20	9:30	10	12.0	14.0	2.0	5.0
4	9:30	9:40	10	11.75	13.5	1.75	5.7
5	9:40	9:50	10	12.0	13.5	1.5	6.7
6	9:50	10:00	10	12.25	13.75	1.5	6.7
7							
8							
9							
10							
11							
12							
13							
14							
15							

Data used for conversion to Infiltration rate.

COMMENTS: OVERCAST (62°F). GROUND DRY. FIRST (2) MEASUREMENTS MET SANDY SOIL CRITERIA.

Table 6 – Sample Percolation Test Data

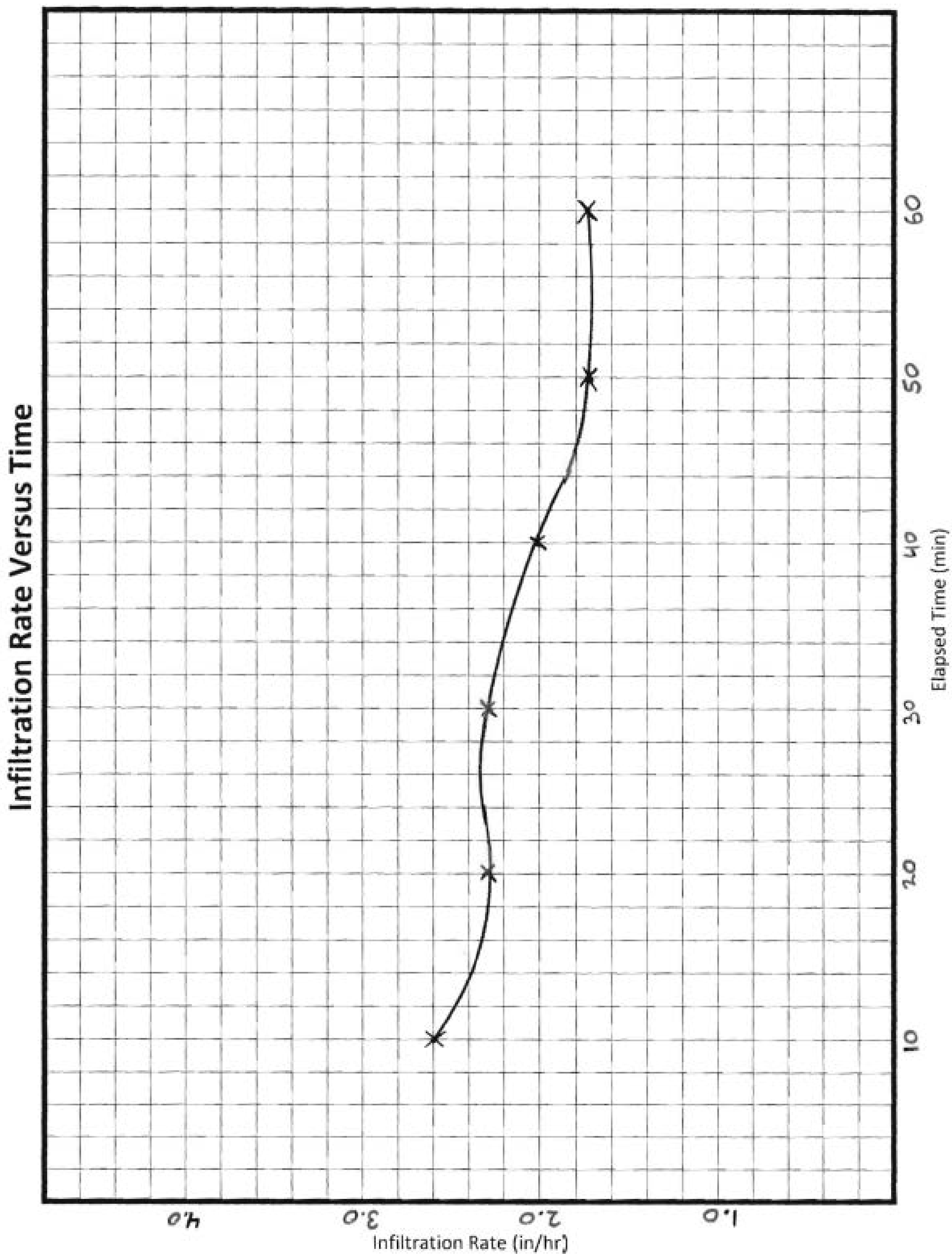

FIGURE 11 – PLOT OF CONVERTED PERCOLATION TEST DATA

2.4 - Field Permeability Test (Well Permeameter Method USBR 7300-89)

Similar to a constant-head version of the percolation test used for seepage pit design is the Well Permeameter Method of the United States Bureau of Reclamation. [1]USBR 7300-89 is an in-hole hydraulic conductivity test performed by drilling test wells with a 6-8 inch diameter auger to the desired depth. This test measures the rate at which water flows into the soil under constant-head flow conditions and is used to determine field-saturated hydraulic conductivity. As with the percolation test, the rate determined with this test is a "percolation rate" and is related, but not equal, to the infiltration rate. Infiltration rate is a measure of the speed at which water progresses downward into the soil. A percolation rate measures not only the downward progression but the lateral progression through the soil. However, this procedure uses the following equation(s) to establish an infiltration rate:

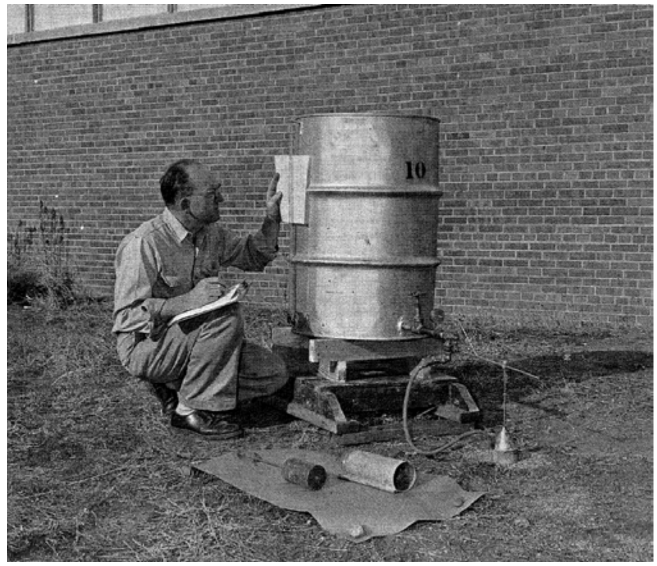

Photo 7 - Typical Well Permeamater Test Installation

Condition I: Typical condition (See Figure 12). The distance between the historical high water mark[2] and the water surface in the well is at least three (3) times the height of water in the well. In addition, there must be at least 10 feet from the bottom of the well to the historical high water table and at least 5 feet to impervious strata.

$$K_s = \frac{Q(\mu_T/\mu_{20})}{2\pi H^2}\left[\ln\left[\frac{H}{r}+\sqrt{\left(\frac{H}{r}\right)^2+1}\right]-\frac{\sqrt{1+\left(\frac{H}{r}\right)^2}}{\frac{H}{r}}+\frac{r}{H}\right]$$

Where:

K_s = saturated hydraulic conductivity (infiltration rate, inches/hour)
H = height of water in well (inches)
Q = percolation flow rate from selected time interval (cubic inches/hour)
r = effective radius of well (inches)
μ_T = viscosity of water at test temperature, T
μ_{20} = viscosity of water at 20˚C

[1]A detailed description of this procedure along with a complete example using the associated equations can be found in the United States Bureau of Mines and Reclamation (USBR) document 7300-89.

[2]The "historical high groundwater mark" is defined as the groundwater elevation expected due to a normal wet season and shall be obtained by boring logs or test pits.

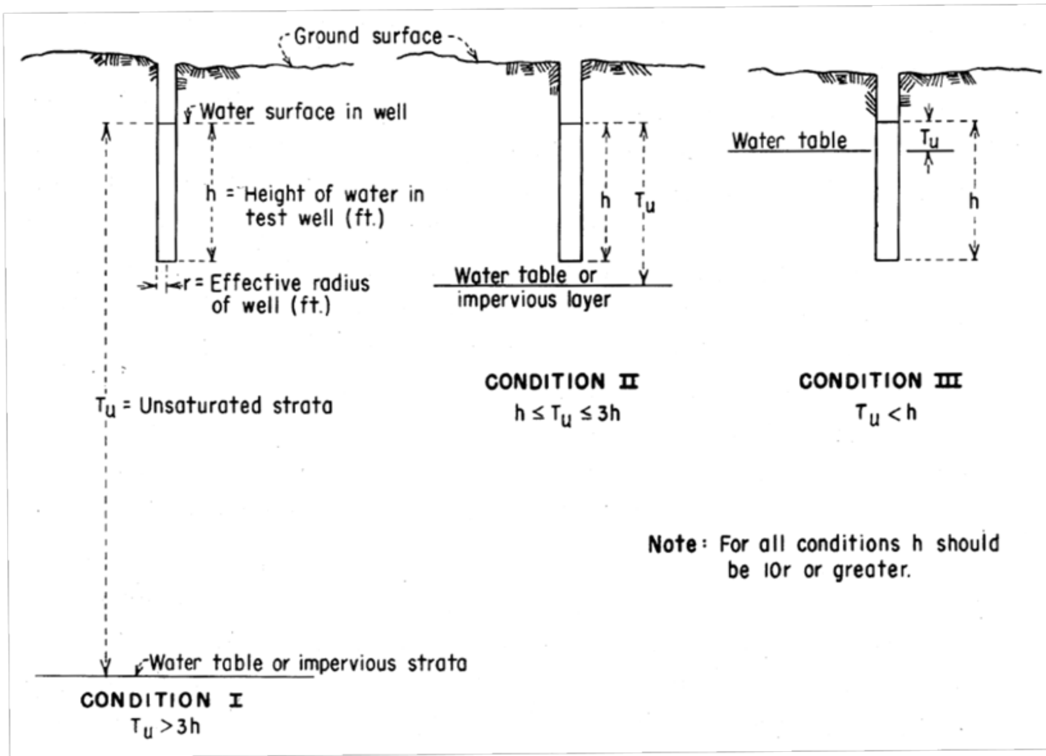

Figure 12 – Site Conditions Govern Procedure to be Used

Condition II: The distance between the historical high groundwater mark[1] and the water surface in the well is less than three (3) times, but at least equal to, the height of water in the well. In addition, there must be at least 10 feet from the bottom of the well to the historical high water mark[1] and at least 5 feet to impervious strata.

$$K_s = \frac{Q(\mu_{20}/\mu_T)}{2\pi H^2}\left[\frac{\ln\left(\frac{H}{r}\right)}{\frac{1}{6}+\frac{1}{3}\left(\frac{H}{T_u}\right)^{-1}}\right]$$

Where:

K_s = saturated hydraulic conductivity (infiltration rate, inches/hour)
H = height of water in well (inches)
Q = percolation flow rate from selected time interval (cubic inches/hour)
r = effective radius of well (inches)
μ_T = viscosity of water at water temperature, T
μ_{20} = viscosity of water at 20° C
T_u = unsaturated distance between the water surface and the water table or impervious strata

Condition III: Unacceptable location. The distance between the historical high groundwater mark and the water surface in the well is less than the height of water in well. As such, the base of the BMP would not be 10 feet above the historical high water mark or 5 feet from impervious strata.

Final Report - Ultimately, as discussed in Section 1.7, a final report shall be provided and, based on the test results, an infiltration rate shall be recommended.

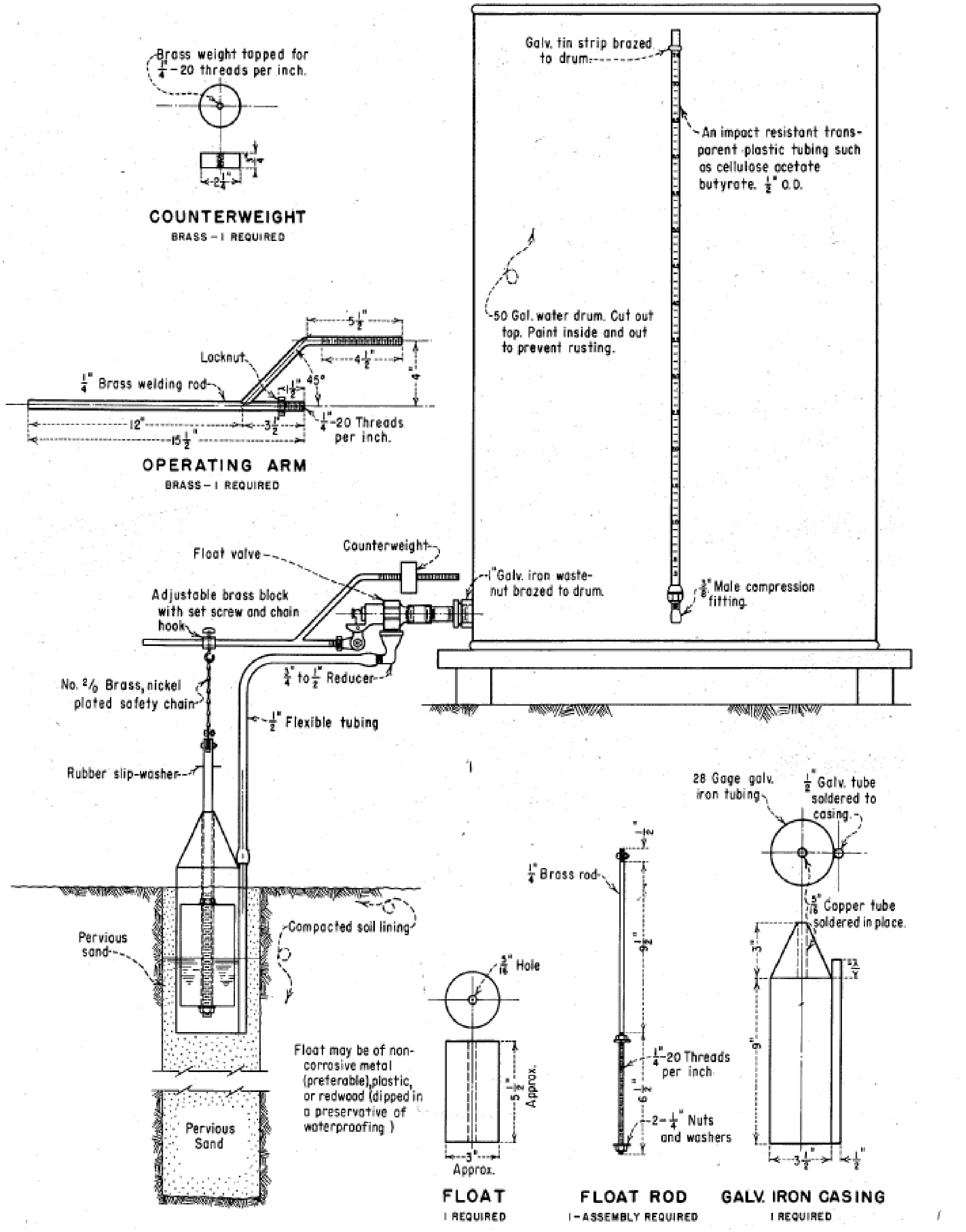

Figure 11 – Well Permeameter Test Equipment

2.5 - Borings and Test Pits

Borings and test pits are used to determine the thickness of soil and rock strata, estimate the depth to groundwater, obtain soil or rock specimens and perform field tests such as standard penetration tests (SPTs) or cone penetration tests (CPTs).

Test pits and trenches may be used to evaluate near-surface conditions up to about 15 feet deep but are often used for performing subsurface exploration at shallower depths. Test pits are often square in plan view and may be dug with shovels in less accessible areas. Trenches are long and narrow excavations usually made by a backhoe or bulldozer.

Borings (ASTM D 1452) are generally used to investigate deeper subsurface conditions. A cylindrical hole is drilled into the ground for the purpose of investigating subsurface conditions, performing field tests, and obtaining soil, rock, or underground specimens for testing. Borings can be excavated by hand (e.g., hand auger), although the usual procedure is to use mechanical equipment to excavate the borings.

Whatever method is used, testing shall be sufficient to establish USCS series and textural class (SM, CL, etc) of the soil beneath the infiltration surface of the BMP and of sufficient depth to establish that a minimum of 5 feet of permeable soil exists below the infiltration facility and that there is a minimum of 10 feet between the bottom of the infiltration facility and the historical high groundwater mark[1].

Photo 8- Auger Boring Rig

Photo 9 – Test Pit Excavation

[1]The "historical high groundwater mark" is defined as the groundwater elevation expected due to a normal wet season and shall be obtained by boring logs or test pits.

Infiltration Test Requirement Checklist

___ Where infiltration testing is to be performed, the measured infiltration rate of the underlying soil must be determined using either the single ring infiltrometer test (as described in ASTM D 5126, Section 4.1.2.1), the double ring infiltrometer test (ASTM D 3385), the well permeameter method (USBR 7300-89), or a percolation test per County of Riverside Department of Environmental Health (RCDEH) test procedures. A general explanation of these test methods can be found in Section 2 of this appendix. The minimum number of tests required can be found in Table 1 and is dependent upon the type of infiltration test performed.

___ Test pits and borings (ASTM D 1452) may be used to determine the USCS series and textural class (SM, CL, etc.) of the soil horizons throughout the depth of boring log or pit, the thickness of soil and rock strata, and estimate the historical groundwater depth. Test pits or boring logs must be of sufficient depth to establish that a minimum of 5 feet of permeable soil exists below the infiltration facility and that there is a minimum of 10 feet between the bottom of the infiltration facility and the historical high groundwater mark[1] (Section 1.7 and 2.5). The required number of test pits or borings is listed in Table 1.

___ A final report, prepared by a registered civil engineer, geotechnical engineer, certified engineering geologist or certified hydrogeologist shall be provided to the District or other EA which demonstrates through infiltration testing and/or soil logs that the proposed facility location is suitable for the proposed infiltration facility and an infiltration rate shall be recommended. In addition, any requirements associated with impacts to a landslide, erosion or steep slope hazard area should also be addressed in the final report. (Section 1.7)

___ Tests may be performed only by individuals trained and educated to perform, understand and evaluate the field conditions. The individual(s) supervising this field work must be named along with their education or training background in the final report as described in Item 3. (Section 1.7)

___ Preliminary site grading plans shall be provided to the District or other EA showing the proposed BMP locations along with section views through each BMP clearly identifying the extents of cut/fill.

___ All infiltration tests shall be performed within the boundaries of the proposed infiltration BMP and at the bottom elevation (infiltration surface) of the proposed infiltration facility. (See Photo 5)

[1]The "historical high groundwater mark" is defined as the groundwater elevation expected due to a normal wet season and shall be obtained by boring logs or test pits.