APPENDIX VII. INFILTRATION RATE EVALUATION PROTOCOL AND FACTOR OF SAFETY RECOMMENDATIONS

VII.1. Introduction

Soil characterization and infiltration testing is required in order to properly size and locate stormwater management facilities. The purpose of this appendix is to provide guidance for investigating infiltration at both the project planning and design phases, as well as provide requirements for applying a factor of safety to testing results.

VII.1.1. Two phases of assessment

The role of soil characterization and infiltration testing differs with the phase of project development as described below.

Site Assessment / Project Planning Phase: Soil characterization or infiltration testing may be conducted to determine if infiltration is a potentially feasible BMP and/or where on the site infiltration is potentially infeasible. The intent of this investigation is to identify if the project site, or a portion of the site, has soils that are clearly unsuitable for infiltration. For those sites or portions of the site where soils are unsuitable, infiltration BMPs can be eliminated from consideration. The intent of this testing is not to prove definitively that infiltration is feasible. Simpler methods may be used to determine infiltration potential at this phase. The observed infiltration rate is adjusted to account for the type of test and the uncertainty of the testing method and reported as the *measured infiltration rate* for the purpose of evaluating feasibility. These methods are not appropriate to determine the *design infiltration rate*.

Site Planning / Design Phase: Where infiltration BMPs are selected, infiltration testing must be conducted to determine the *design infiltration rate* of proposed facilities, except in limited cases where infiltration rate is presumed to be sufficient as identified in Section **VII.1.2**. The required size of the proposed facilities strongly depends on the design infiltration rate; therefore, testing may be required at the preliminary site design phase to facilitate site planning. However, infiltration testing must be conducted as close to the proposed facility as possible, therefore, conducting testing after preliminary site design also has merits. Use of more sophisticated methods at this phase allows better confidence in testing and therefore a lower factor of safety on observed infiltration rates (and therefore smaller facility designs). Factors of safety are discussed in **VII.4**.

Soil characterization and infiltration testing can be considered to fulfill two functions:

1. Determine where infiltration is potentially feasible and must be considered (if other limitations, such as depth to groundwater or contamination, do not restrict infiltration). This role is satisfied through simple infiltration tests, or use of maps and available data.
2. Determine the design infiltration rate for proposed facilities. This function is satisfied through more sophisticated investigation methods, conducted by a qualified professional.

Table VII.1 provides required methods of assessing infiltration rate for each purpose.

Table VII.1: Recommended Infiltration Investigation Methods

Methods for Identifying Areas Potentially Feasible for Infiltration	• **Use of Regional Maps and "Available Data"**[1] **OR** • **Simple Open Pit Infiltration Test** **OR** • Any of the testing methods used to establish design infiltration rate (below)
Methods for Establishing Design Infiltration Rate	• **Open Pit Falling Head Procedure** • **Single Ring Infiltrometer Test** • **Double Ring Infiltrometer Test** • **Well Permeameter Method (USBR Procedure 7300-89)** • **Percolation Test Procedure** (Riverside County Department of Environmental Health) • Other analysis methods at the discretion of the project engineer and approval of the reviewing agency

[1]Available data is defined in Section **VII.2** below and does not require additional investigation.

VII.1.2. Waiver of Infiltration Testing Requirements

The infiltration testing requirements described in this appendix are not applicable for certain combinations of BMP type and general soil condition. In cases where available soils information indicates that the soils are clearly sufficient to support the level of infiltration required for proper function of the BMP and uncertainty in infiltration rate would not significantly influence the performance of the practice, it is not mandatory to conduct infiltration testing. Conditions under which infiltration testing requirements are waived include:

- **Impervious area dispersion** (See **HSC-2: Impervious Area Dispersion**): Testing requirements are waived for this BMP for all soil types. Soil amendments are required to use this practice where site soils are hydrologic soil group C or D.
- **Localized on-lot infiltration** (See **HSC-1: Localized On-Lot Infiltration**): Testing requirements are waived for this BMP for A, B, and C soil types if soil type and general drainage conditions are confirmed with site-specific information. This BMP is not suitable for D soils unless infiltration testing demonstrates that the ponded depth would drain within 24 hours.
- **Porous pavement designed to be self-retaining** (See **INF-6: Permeable Pavement (concrete, asphalt, and pavers)**): Testing requirements for this BMP are waived for A, B, and C soil types if soil type and general drainage conditions are confirmed with site-specific information. This waiver does not apply to porous pavement that accepts run-on from a tributary area larger than 50 percent of its area.
- **Bioinfiltration** (See **INF-4: Bioinfiltration Fact Sheet**). Based on the LID BMP hierarchy, this type of BMP may only be used if infiltration of the full DCV is not feasible; therefore exploratory infiltration rate assessment (Section **VII.2**) is required. However, testing to determine design infiltration rate (Section **VII.3**) is not required. See **Appendix XI** for instructions for sizing the infiltration component of a bioinfiltration BMP to achieve maximum feasible infiltration.

VII.1.3. A Note on "Infiltration Rate" vs. "Percolation Rate"

A common misunderstanding is 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 because they incorporate both downward and horizontal fluxes of water, whereas infiltration only refers to a downward flux of water. When using borehole-type methods, the percolation rate obtained shall be converted to a reasonable estimate of the infiltration rate using the Porchet Method (aka Inverse Borehole Method) (See Example VII.1).

VII.1.4. 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.

VII.1.5. 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) USBR 7300-89, "Procedure for Performing field Permeability Testing by the Well Permeameter Method" (Section **VII.3.7** below). Note that this result must be converted to an infiltration rate.
2) The percolation test (Section **VII.3.8** below). Note that this result must be converted to an infiltration rate.

VII.1.6. 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.

For shallow fill depths, fill material can be selectively graded to provide reliable infiltration properties. However, in some cases, due to considerable fill depth, the extension of the BMP down to natural soil and selective grading of fill material may prove infeasible. In that case, because of the uncertainty of fill parameters as described above, an infiltration BMP may not be feasible.

VII.2. Methods for Identifying Areas Potentially Feasible for Infiltration

This section describes methods that shall be used, as applicable, to determine whether soils are potentially feasible for infiltration, and where potentially feasible soils exist. Soils would be considered potentially feasible for infiltration if the *measured infiltration rate* obtained from field-testing or obtained by applying professional judgment to available data taken within the Project vicinity is greater than 0.3 inches per hour. *Measured* rates shall account for uncertainty and bias in measurement methods by applying a factor of safety of 2.0 to testing results.

The *measured infiltration rate* calculated for the purpose of infiltration infeasibility screening (**TGD Section 2.4.2.4**) shall be based on a factor of safety of 2.0 applied to the rates obtained from the infiltration test results. No adjustments from this value are permitted. The factor of safety used to compute the *design infiltration rate* shall not be less than 2.0, but may be higher at the discretion of the design engineer and acceptance of the plan reviewer, per the considerations described in Section **VII.4**.

VII.2.1. Use of Regional Maps and "Available Data"

This section describes a method that satisfies the requirements for infiltration screening of small projects as defined by the TGD Infeasibility Screening Criteria (**TGD Section 2.4.2.4**). This method uses regionally mapped data coupled with all applicable data available through other site investigations to identify locations not potentially feasible for infiltration as a result of low infiltration rate or high groundwater table.

Via this method, areas of a project identified as having D soils or identified as having depth to first groundwater less than 5 feet are considered infeasible for infiltration if available data confirm these determinations.

Infiltration constraint maps are available in **Appendix XVI** and will be refined as part of the development of Watershed Hydromodification and Infiltration Management Plans. These maps identify constraints, including hydrologic soil group (A,B,C,D), and depth to first groundwater, which should be confirmed through review of available data.

"Available data" is defined as data collected by the project or otherwise available that provides information about infiltration rates and/or groundwater depths. Applicable data is expected to be available as part of nearly all projects subject to New Development and Significant Redevelopment stormwater management requirements in Orange County. Data sources may include:

- Geotechnical investigations
- Due diligence site investigations
- Other CEQA investigations
- Investigations performed on adjacent sites with applicability to the project site

For projects permitted to utilize this method, additional infiltration testing data is not required to be obtained, however, infiltration testing data which is already available from previous studies must be used.

For the purpose of this method, large projects and small projects are defined in Table VII.2. The distinction between large and small projects based the lower spatial variability expected on smaller projects and the lower project value. In these cases, the expense associated with infiltration testing of HSG D soils to attempt to identify localized exceptions to this mapped and supported determination is considered to be an unreasonable economic burden.

Table VII.2: Definition of Project Size Categories

	Residential	Commercial, Institutional	Industrial
Small Projects	Less than 10 acres and less than 30 DU	Less than 5 acres and less than 50,000 SF	Less than 2 acre and less than 20,000 SF
Large Projects	Greater than 10 acres or greater than 30 DU	Greater than 5 acres or greater than 50,000 SF	Greater than 2 acre or greater than 20,000 SF

VII.2.2. Simple Open Pit Infiltration Test

The Simple Open Pit Infiltration Test is a site-specific method which can be used to provide a preliminary screening value. This approach cannot be used to find a design infiltration rate. The intent of the Simple Open Pit Infiltration Test is to determine whether or not the local infiltration rate is potentially adequate for LID infiltration BMPs. This approach does not need to be conducted by a licensed professional.

1. The test should be at the proposed facility location or within the immediate vicinity.
2. Excavate a test hole to an elevation 2 feet deeper than the bottom of the infiltration system to account for soil amendment. If the depth of the proposed facility is not known at the time of testing, the excavation should be 6 feet deep. The test hole can be excavated with small excavation equipment or by hand using a shovel, auger, or post hole digger. The hole should be a minimum of 2 feet in diameter and should be sufficient to allow for observation of the water surface level in the bottom of the hole. Remove loose material, as much as possible from the bottom of the hole but avoid compaction of the bottom surface. If a layer hard enough to prevent further excavation is encountered during excavation, or if noticeable moisture/water is encountered in the soil, stop and measure this depth. Proceed with the test at this depth.
3. Fill the hole with water to a height of about 6 inches from the bottom of the hole, and record the exact time. Check the water level at regular intervals (every minute for fast-draining soils to every 10 minutes for slower-draining soils) for a minimum of 1 hour or until all of the water has infiltrated. Record the distance the water has dropped from a fixed reference point such as the top edge of the hole.
4. The infiltration rate is calculated by dividing the change in water elevation time (inches) by the duration of the test (hours).
5. Repeat this process two more times, for a total of three rounds of testing. These tests should be performed as close together as possible to accurately portray the soil's ability to infiltrate at different levels of saturation. The third test provides the best measure of the saturated infiltration rate.

6. For each test pit required, record all three testing results with the date, duration, drop in water height, and conversion into inches per hour.

VII.3. Methods for Establishing Design Infiltration Rate

Allowable methods of establishing design infiltration rate include:

- Open Pit Falling Head Procedure (Section **VII.3.4**)
- Single Ring Infiltrometer Test (Section **VII.3.5**)
- Double Ring Infiltrometer Test (Section **VII.3.6**)
- Well Permeameter Method (USBR Procedure 7300-89) (Section **VII.3.7**)
- Percolation Test Procedure (Riverside County Department of Environmental Health) (Section **VII.3.8**)
- Other analysis methods at the discretion of the project engineer and approval of the reviewing agency

A qualified professional must exercise judgment in the selection of the infiltration test method. Where satisfactory data from adjacent areas is available that demonstrates infiltration testing is not necessary, the infiltration testing requirement may be waived. Waiver of site specific testing is subject to approval by the local approval authority. Recommendation for foregoing infiltration testing must be submitted in a report which includes supporting data and is stamped and signed by the project geotechnical engineer or project geologist.

VII.3.1. Testing Criteria

1. Testing must be conducted or overseen by a qualified professional, either a Professional Engineer (PE) or Registered Geologist (RG) licensed in the State of California.
2. The elevation of the test must correspond to the facility elevation, plus 2 feet to account for soil amendments under the infiltration system. If a confining layer, or soil with a greater percentage of fines, is observed during the subsurface investigation to be within 4 feet of the bottom of the planned infiltration system, the testing should be conducted within that confining layer. The boring log must be continued to a depth adequate to show separation between the bottom of the infiltration facility and the seasonal high groundwater level.
3. Tests must be performed in the immediate vicinity of the proposed facility. Exceptions can be made to the test location provided the qualified professional can support that the strata are consistent from the proposed facility to the test location.
4. Infiltration testing should not be conducted in engineered or undocumented fill.

VII.3.2. Minimum Number of Required Tests

- A total of two infiltration tests for every 10,000 square feet of lot area available for new or redevelopment (minimum 2 tests per priority project).

- An additional test for every 10,000 square feet of lot area available for new or redevelopment.
- At least one test for any potential street facility.
- One test for every 100 lineal feet of infiltration facility.
- In general no more than five valid tests are required per development, unless more tests would be valuable or necessary (at the discretion of the qualified professional assessing the site, as well as the reviewing agency).

Where multiple types of facilities are used, it is likely that multiple tests will be necessary, since different facility types may infiltrate at different depths and an infiltration test can test only a single soil stratum. It is highly recommended to conduct an infiltration test at each stratum used. Additional testing may be required at the discretion of the local approval authority.

VII.3.3. 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:

1. Over time, the surface of infiltration facilities can become plugged as sedimentary particles accumulate at the infiltration surface.
2. Post-grading compaction of the site can destroy soil structure and seriously impact the facility's performance.
3. Testing procedures in general are subject to errors which can skew the results.

The method for determination of the factor of safety described in Section **VII.4** includes, among other factors, a consideration of the testing methods used to measure infiltration rate. The open pit falling head test (see Section **VII.3.4**) is considered the most reliable infiltration testing method if constructed to the recommended dimensions.

VII.3.4. Open Pit Falling Head Procedure

The open pit falling head procedure is performed in an open excavation and therefore is a test of the combination of vertical and lateral infiltration. The tester and excavator should conduct all testing in accordance with OSHA regulations regarding open pit excavations.

1. Excavate a hole with bottom dimensions of at least 2 feet by 4 feet into the native soil to the elevation 2 feet below the proposed facility bottom to account for amendment of soils under infiltration areas. If a smooth excavation bucket is used, scratch the sides and bottom of the hole with a sharp pointed instrument, and remove the loose material from the bottom of the test hole. The bottom of the hole should not be compacted and should be as level as possible.
2. Fill the hole with clean water a minimum of 1 foot above the soil to be tested, and maintain this depth of water for at least 4 hours (or overnight if clay soils are present) to

presoak the native material. In sandy soils with little or no clay or silt, soaking is not necessary. If after filling the hole twice with 12 inches of water, the water seeps completely away in less than 10 minutes, the test can proceed immediately.

3. Determine how the water level will be accurately measured. The measurements should be made with reference to a fixed point. A lath placed in the test pit prior to filling or a sturdy beam across the top of the pit are convenient reference points.
4. After the pre-saturation period, refill the hole with water to 12 inches above the soil and record the time. For deep holes, it may be necessary to use remote sensing equipment to accurately measure changes in water level. Alternative water head heights may be used for testing provided the presaturation height is adjusted accordingly and the water head height used in infiltration testing is 50 percent or less than the water head height in the proposed stormwater system during the design storm event. Measure the water level to the nearest 0.01 foot (⅛ inch) at 10-minute intervals for a total period of 1 hour (or 20-minute intervals for 2 hours in slower soils) or until all of the water has drained. In faster draining soils (sands and gravels), it may be necessary to shorten the measurement interval in order to obtain a well-defined infiltration rate curve. Constant head tests may be substituted for falling head tests at the discretion of the professional overseeing the infiltration testing.
5. Repeat the test. Successive trials should be run until the percent change in measured infiltration rate between two successive trials is minimal (<10 percent). The trial should be discounted if the infiltration rate between successive trials increases. At least three trials must be conducted. After each trial, the water level is readjusted to the 12 inch level. Record results.
6. The average infiltration rate over the last trial should be used to calculate the unadjusted (pre-factor of safety) infiltration rate. The final rate must be reported in inches per hour.
7. Upon completion of the testing, the excavation must be backfilled.
8. For very rapidly draining soils, it may not be possible to maintain a water head above the bottom of the test pit. If the infiltration rate meets or exceeds the flow of water into the test pit, conduct the test in the following manner:
    a) Approximate the area over which the water is infiltrating.
    b) Using a water meter, bucket, or other device, measure the rate of water discharging into the test pit.
    c) Calculate the infiltration rate by dividing the rate of discharge (cubic inches per hour) by the area over which it is infiltrating (square inches) and correcting to units of inches per hour.

VII.3.5. Single Ring Infiltrometer Test

Single ring infiltrometer tests using a large ring in diameter (40 inches or larger is optimal) have been shown to closely match full-scale facility performance (**Figure VII.1** to **Figure VII.3**). 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 D5126).

To help maintain a constant head, a variety of devices may be used. A hook gage, 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:

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

where:

I_t = tested infiltration rate, in/hr
V = volume of liquid used during time interval to maintain constant head in the ring, in^3
A = internal area of ring, in^2
t = time interval, hr.

Figure VII.1. Photo of Single Ring Infiltrometer

Figure VII.2. Single Ring Infiltrometer Construction

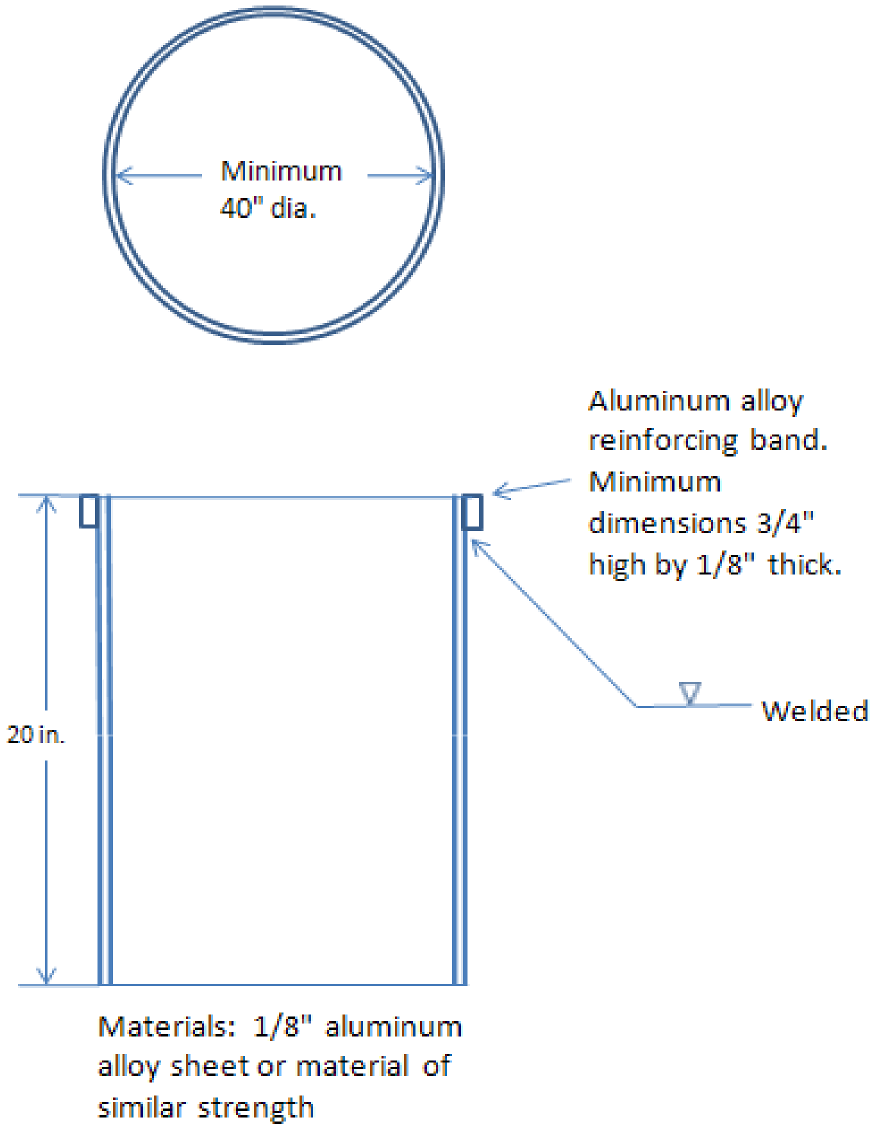


Figure VII.3. Single Ring Infiltrometer Setup with Mariotte Tube

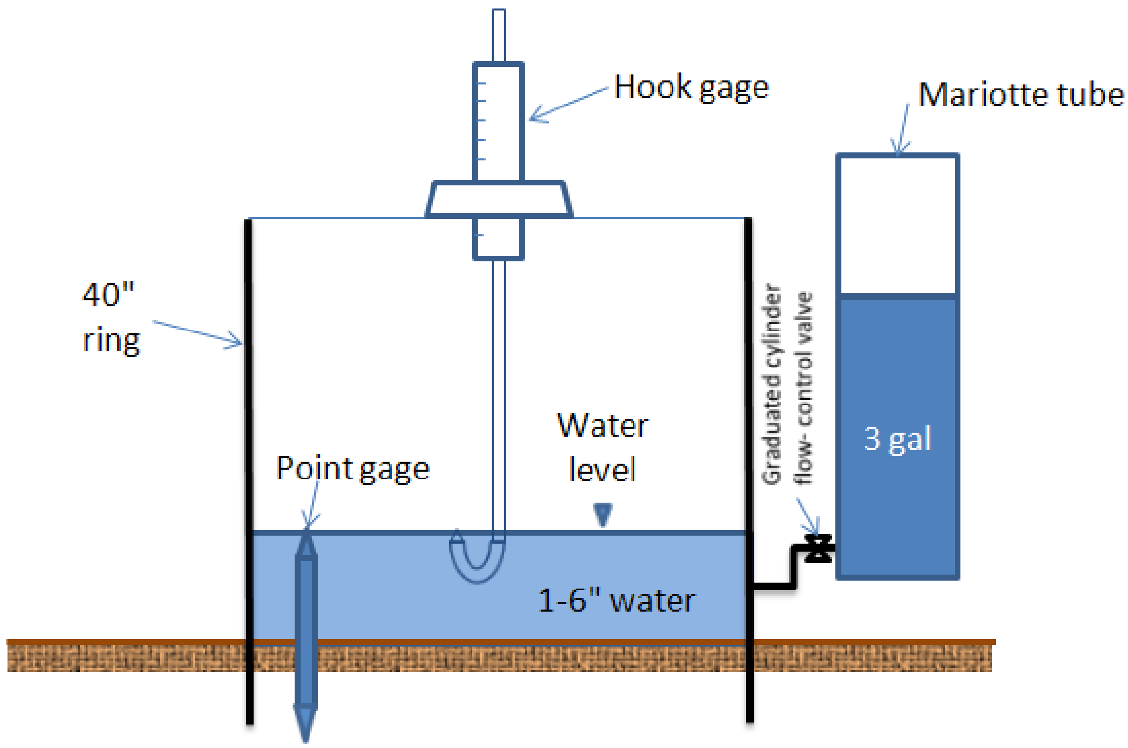


Figure VII.4. Sample Test Data Form for Single Ring Infiltrometer Test

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, $I = (Q_f/A_r)/$**

VII.3.6. Double Ring Infiltrometer Test

The double ring infiltrometer test (ASTM D3385) is a well-recognized and documented technique for directly measuring the soil infiltration rate of a site (see **Figure VII.5** to **Figure VII.12**). 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. The double-ring infiltrometer test should be performed at an elevation 2 feet below the proposed elevation of the infiltration surface to account for the use of soil amendments below the infiltration system.

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 gage, 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:

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

where:

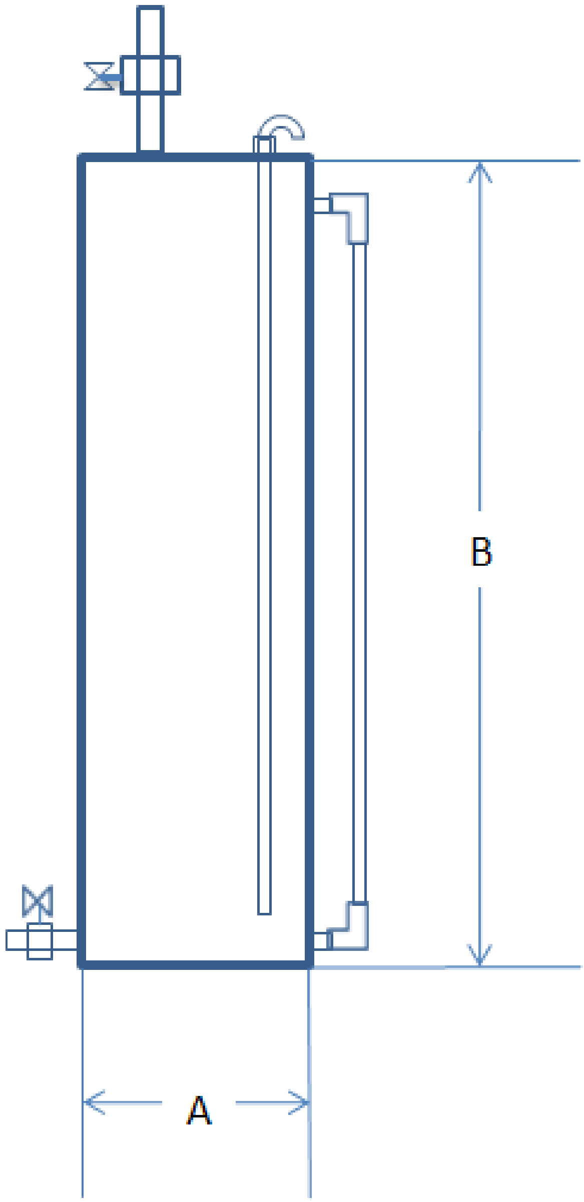
I_t = tested infiltration rate, in/hr
V = volume of liquid used during time interval to maintain constant head in the inner ring, in^3
A = area of inner ring, in^2
t = time interval, hr.

Figure VII.5. Photo of Simple Double Ring Infiltrometer

Figure VII.6. Photo of Pre-fabricated Double Ring Infiltrometer

(Photo courtesy of Turf-Tec International)

Figure VII.7. Mariotte Tube



Mariotte Tube
Useful Capacity

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

Figure VII.8. Double Ring Infiltrometer Construction

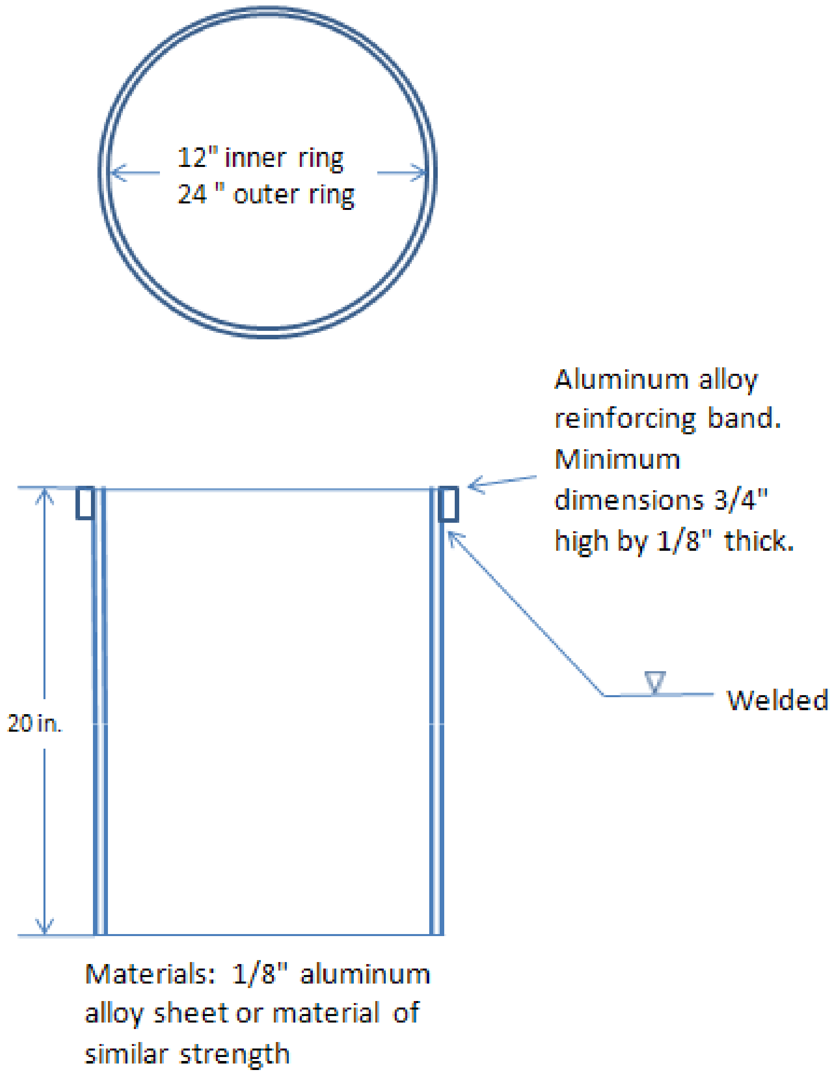


Figure VII.9. Double Ring Setup with Mariotte Tubes

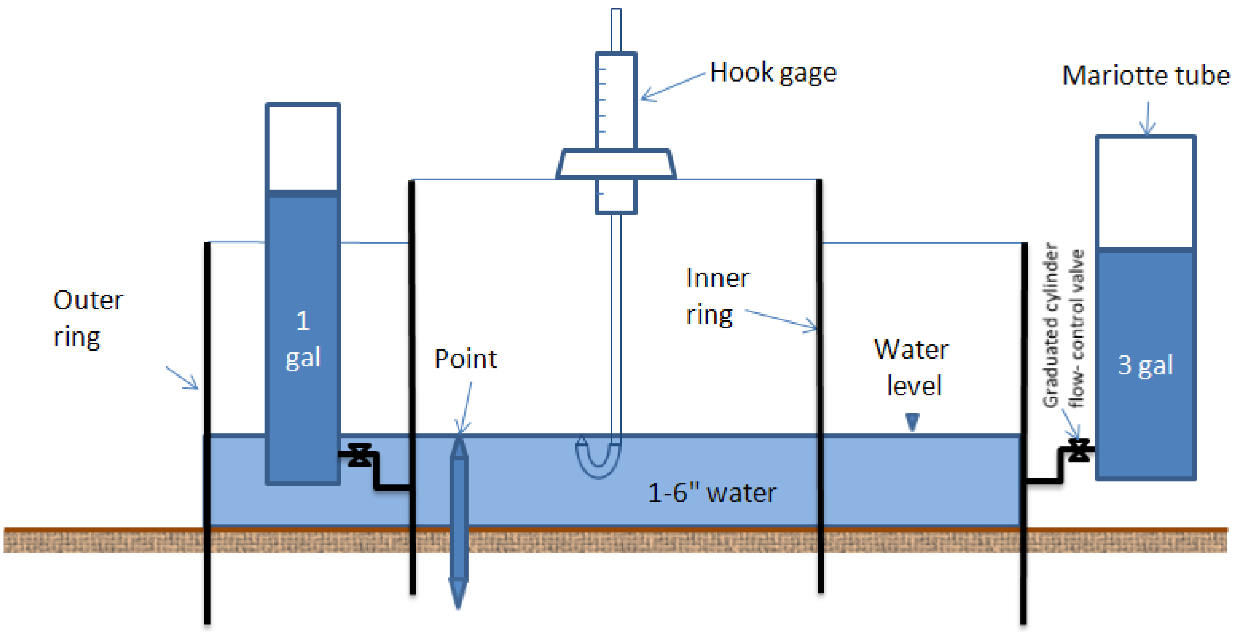


Figure VII.10. Double Ring Infiltrometer Set-up with Mariotte Tubes

(Photo courtesy of Turf-Tec International)

Figure VII.11. Double Ring Infiltrometer Set-up for Test at Basin Surface Elevation

(Photo courtesy of Turf-Tec International)

Figure VII.12. Sample Test Data Form for Double Ring Infiltrometer Test

DOUBLE RING INFILTROMETER TEST DATA

Project Name and Test Location:		Constants-	Ring Data		Liquid Containers	
			Area, A_r (in^2)	Depth of Liquid (in)	No.	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										
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8 - Start										
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9 - Start										
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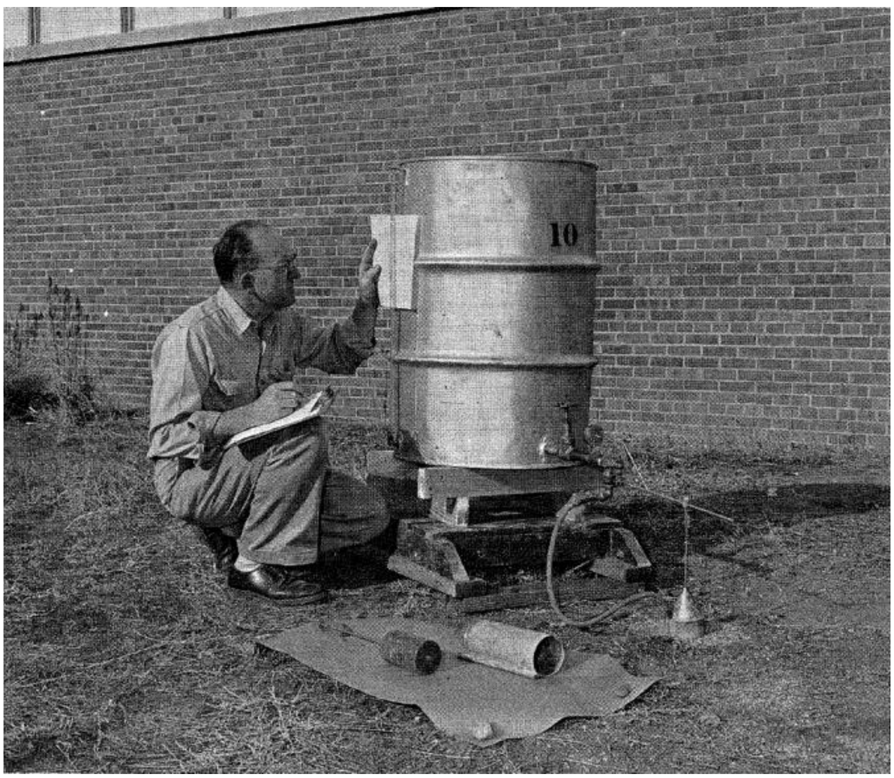
10 - Start										
End										
11 - Start										
End										
12 - Start										
End										
13 - Start										
End										
14 - Start										
End										
15 - Start										
End										

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

VII.3.7. Well Permeameter Method (USBR Procedure 7300-89)

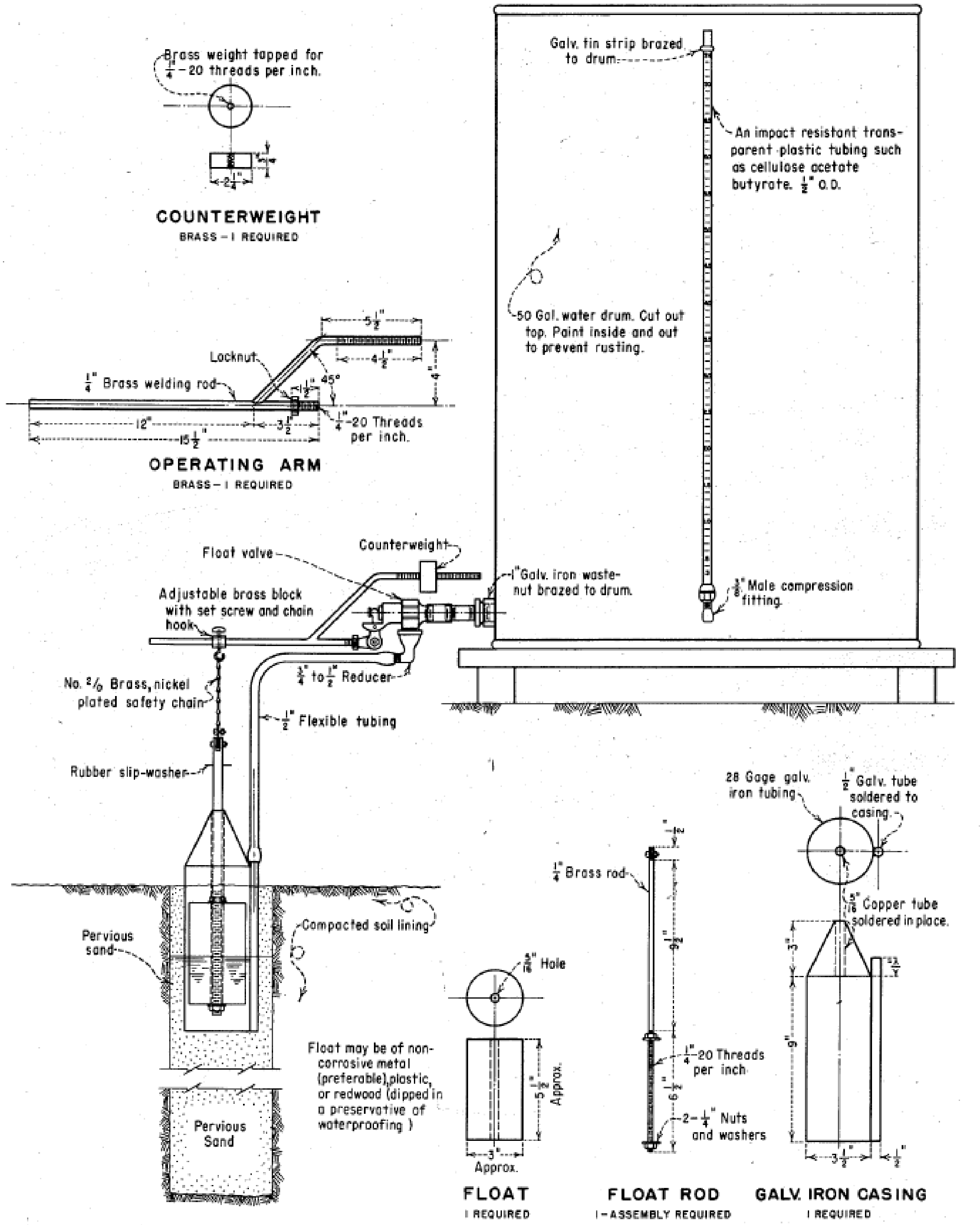
Similar to a constant-head version of the percolation test used for seepage pit design is the Well Permeameter Method of the United States Bureau of Reclamation (see **Figure VII.13** and **Figure VII.14**). [12]USBR 7300-89 is an in-hole hydraulic conductivity test performed by drilling test wells with 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 not an infiltration rate, but this procedure uses special equation(s) to establish an infiltration rate from the data produced. See USBR procedure 7300-89 for more details.

Figure VII.13. Typical Well Permeameter Test Installation



[12] 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.

Figure VII.14. Well Permeameter Test Equipment



VII.3.8. Percolation Test Procedure

The percolation test procedure below (per Riverside County Department of Environmental Health) should only be performed by those individuals trained and educated to perform, understand and evaluate the field conditions and 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 Hydrogeologist.

The procedure for this test varies, depending on the depth of the hole to be used. Procedures for both scenarios (less than 10 feet or 10 - 40 feet deep) and diagrams (**Figure VII.15** to **Figure VII.17**) are included below. 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.

VII.3.8.1. 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.

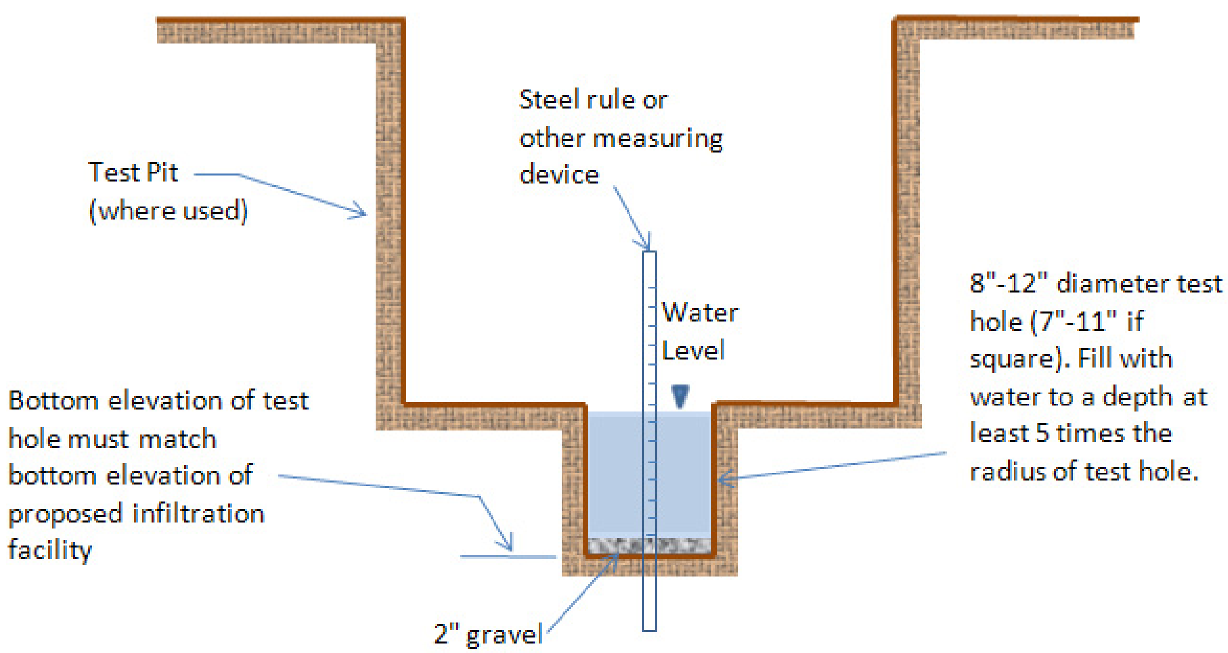
Test Procedure

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 VII.15. Test Pit for Shallow Percolation Test



VII.3.8.2. Deep Percolation Test (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.

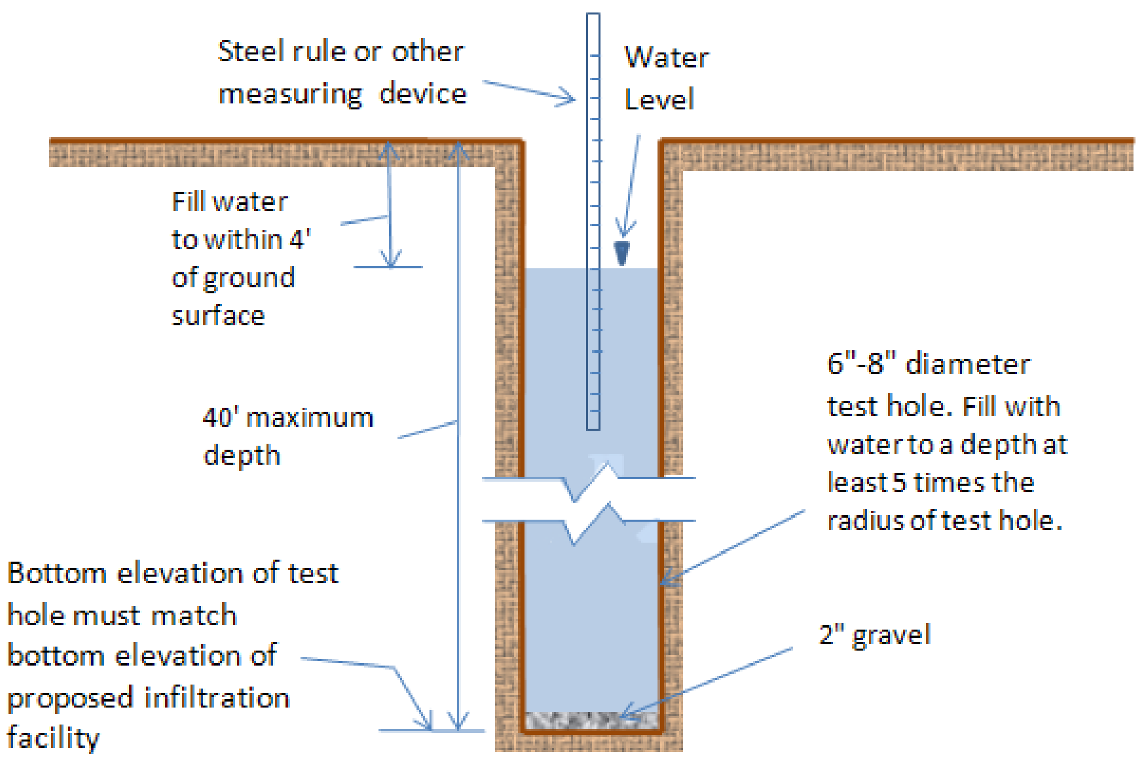
2) The bottom elevation of the test hole shall correspond to the bottom elevation of the proposed basin (infiltration surface). Keep in mind that this procedure will require the test hole to be filled with water to a depth of at least 5 times the hole's radius.

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 "continuous pre-soak procedure" is not accepted. When sandy soils (as described below) are present, the test shall be run immediately.

Figure VII.16. 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.

Figure VII.17. Photo of Percolation Test Pit.

(Use of perforated PVC pipe is a variation.)

Figure VII.18. Sample Test Data Form for Percolation Test

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:

Example VII.1: Percolation Rate Conversion Example

(Porchet Method, aka Inverse Borehole Method):

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. The data collected at the final interval is as follows:

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

The conversion equation is used:

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

"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.

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

[13] 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., $r = (A/\pi)^{0.5}$).

VII.4. Considerations for Infiltration Rate Factor of Safety

Given the known potential for infiltration BMPs to fail over time, an appropriate factor of safety applied to infiltration testing results must be mandatory. The infiltration rate will decline between maintenance cycles as the BMP surface becomes occluded and particulates accumulate in the infiltrative layer. Monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design infiltration rates. The design infiltration rate discussed here is the infiltration rate of the underlying soil, below the elevation to which soil amendments would not be provided.

The factor of safety that should be applied to measured infiltration rates is a function of:

- Suitability of underlying soils for infiltration
- The infiltration system design.

These factors are discussed in the following sections.

The *measured infiltration rate* calculated for the purpose of infiltration infeasibility screening (**TGD Section 2.4.2.4**) shall be based on a factor of safety of 2.0 applied to the rates obtained from the infiltration test results. No adjustments from this value are permitted. The factor of safety used to compute the *design infiltration rate* shall not be less than 2.0, but may be higher at the discretion of the design engineer and acceptance of the plan reviewer, per the considerations described in the following sections.

It is recognized that there are competing objectives in the selection of a factor of safety. There is an initial economic incentive to select a lower factor of safety to yield smaller BMP designs. A low factor of safety also allows a broader range of systems to be considered "feasible" in marginal conditions. However, there are both economic and environmental incentives for the use of an appropriate factor of safety to prevent premature failure and substandard performance. The use of an artificially low factor of safety to demonstrate feasibility in the design process is shortsighted in that it does not consider the long term feasibility of the system.

The best way to balance these competing factors is through a commitment to thorough site investigation, use of effective pretreatment controls, good construction practices, the commitment to restore the infiltration rates of soils that are damaged by prior uses or construction practices, and the commitment to effective maintenance practices. However, these commitments do not mitigate the need to apply a factor of safety to account for uncertainty and long term deterioration that cannot be technically mitigated. Therefore, a factor of safety of no less than 2.0 shall be used to compute the design infiltration rate.

VII.4.1. Site Suitability Considerations

Suitability assessment related considerations include (**Table VII.3**):

- Soil assessment methods – the site assessment extent (e.g., number of borings, test pits, etc.) and the measurement method used to estimate the short-term infiltration rate.
- Predominant soil texture/percent fines – soil texture and the percent of fines can greatly influence the potential for clogging.
- Site soil variability – site with spatially heterogeneous soils (vertically or horizontally) as determined from site investigations are more difficult to estimate average properties for resulting in a higher level of uncertainty associated with initial estimates.
- Depth to seasonal high groundwater/impervious layer – groundwater mounding may become an issue during excessively wet conditions where shallow aquifers or shallow clay lenses are present.

Table VII.3: Suitability Assessment Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Assessment methods (see explanation below)	Use of soil survey maps or simple texture analysis to estimate short-term infiltration rates	Direct measurement of ≥ 20 percent of infiltration area with localized infiltration measurement methods (e.g., infiltrometer)	Direct measurement of ≥ 50 percent of infiltration area with localized infiltration measurement methods or Use of extensive test pit infiltration measurement methods
Texture Class	Silty and clayey soils with significant fines	Loamy soils	Granular to slightly loamy soils
Site soil variability	Highly variable soils indicated from site assessment or limited soil borings collected during site assessment	Soil borings/test pits indicate moderately homogeneous soils	Multiple soil borings/test pits indicate relatively homogeneous soils
Depth to groundwater/ impervious layer	<5 ft below facility bottom	5-10 ft below facility bottom	>10 below facility bottom

Localized infiltration testing refers to methods such as the double ring infiltrometer test (ASTM D3385-88) which measure infiltration rates over an area less than 10 sq-ft, may include lateral flow, and do not attempt to account for heterogeneity of soil. The amount of area each test represents should be estimated depending on the observed heterogeneity of the soil.

Extensive infiltration testing refers to methods that include excavating a significant portion of the proposed infiltration area, filling the excavation with water, and monitoring drawdown. The excavation should be to the depth of the proposed infiltration surface and ideally be at least 50 to 100 square feet.

In all cases, testing should be conducted in the area of the proposed BMP where, based on review of available geotechnical data, soils appear least likely to support infiltration.

VII.4.2. Design Related Considerations

Design related considerations include (**Table VII.4**):

- Size of area tributary to facility – all things being equal, risk factors related to infiltration facilities increase with an increase in the tributary area served. Therefore facilities serving larger tributary areas should use more restrictive adjustment factors.
- Level of pretreatment/expected influent sediment loads – credit should be given for good pretreatment by allowing less restrictive factors to account for the reduced probability of clogging from high sediment loading. Also, facilities designed to capture runoff from relatively clean surfaces such as rooftops are likely to see low sediment loads and therefore should be allowed to apply less restrictive safety factors.
- Redundancy – facilities that consist of multiple subsystems operating in parallel such that parts of the system remains functional when other parts fail and/or bypass should be rewarded for the built-in redundancy with less restrictive correction and safety factors. For example, if bypass flows would be at least partially treated in another BMP, the risk of discharging untreated runoff in the event of clogging the primary facility is reduced. A bioretention facility that overflows to a landscaped area is another example.
- Compaction during construction – proper construction oversight is needed during construction to ensure that the bottoms of infiltration facility are not overly compacted. Facilities that do not commit to proper construction practices and oversight should have to use more restrictive correction and safety factors.

Table VII.4: Design Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Tributary area size	Greater than 10 acres.	Greater than 2 acres but less than 10 acres.	2 acres or less.
Level of pretreatment/ expected influent sediment loads	Pretreatment from gross solids removal devices only, such as hydrodynamic separators, racks and screens AND tributary area includes landscaped areas, steep slopes, high traffic areas, or any other areas expected to produce high sediment, trash, or debris loads.	Good pretreatment with BMPs that mitigate coarse sediments such as vegetated swales AND influent sediment loads from the tributary area are expected to be relatively low (e.g., low traffic, mild slopes, disconnected impervious areas, etc.).	Excellent pretreatment with BMPs that mitigate fine sediments such as bioretention or media filtration OR sedimentation or facility only treats runoff from relatively clean surfaces, such as rooftops.
Redundancy of treatment	No redundancy in BMP treatment train.	Medium redundancy, other BMPs available in treatment train to maintain at least 50% of function of facility in event of failure.	High redundancy, multiple components capable of operating independently and in parallel, maintaining at least 90% of facility functionality in event of failure.
Compaction during construction	Construction of facility on a compacted site or elevated probability of unintended/ indirect compaction.	Medium probability of unintended/ indirect compaction.	Heavy equipment actively prohibited from infiltration areas during construction and low probability of unintended/ indirect compaction.

VII.4.3. Determining Factor of Safety

A factor of safety shall be used. To assist in selecting the appropriate design infiltration rate, the measured short term infiltration rate should be adjusted using a weighted average of several safety factors using the worksheet shown in **Worksheet H** below. The design infiltration rate would be determined as follows:

1. For each consideration shown in **Table VII.3** and **Table VII.4** above, determine whether the consideration is a high, medium, or low concern.
2. For all high concerns, assign a factor value of 3, for medium concerns, assign a factor value of 2, and for low concerns assign a factor value of 1.
3. Multiply each of the factors by the corresponding weight to get a product.
4. Sum the products within each factor category to obtain a safety factor for each.
5. Multiply the two safety factors together to get the final combined safety factor. If the combined safety factor is less than 2, then 2 shall be used as the safety factor.
6. Divide the measured short term infiltration rate by the combined safety factor to obtain the adjusted design infiltration rate for use in sizing the infiltration facility.

The design infiltration rate shall be used to size BMPs and to evaluate their expected long term performance. This rate shall not be less than 2, but may be higher at the discretion of the design engineer.

Worksheet H: Factor of Safety and Design Infiltration Rate and Worksheet

Factor Category		Factor Description	Assigned Weight (w)	Factor Value (v)	Product (p) p = w x v
A	Suitability Assessment	Soil assessment methods	0.25		
		Predominant soil texture	0.25		
		Site soil variability	0.25		
		Depth to groundwater / impervious layer	0.25		
		Suitability Assessment Safety Factor, $S_A = \Sigma p$			
B	Design	Tributary area size	0.25		
		Level of pretreatment/ expected sediment loads	0.25		
		Redundancy	0.25		
		Compaction during construction	0.25		
		Design Safety Factor, $S_B = \Sigma p$			
Combined Safety Factor, $S_{TOT} = S_A \times S_B$					
Measured Infiltration Rate, inch/hr, K_M (corrected for test-specific bias)					
Design Infiltration Rate, in/hr, $K_{DESIGN} = S_{TOT} \times K_M$					
Supporting Data					
Briefly describe infiltration test and provide reference to test forms:					

Note: The minimum combined adjustment factor shall not be less than 2.0 and the maximum combined adjustment factor shall not exceed 9.0.

VII.5. References

ASTM D 3385-94, 2003. “Standard Test Method for Infiltration Rate of Soils Field Using Double-Ring Infiltrometer.” American Society for Testing Materials, Conshohocken, PA. 10 Jun, 2003.

Caltrans, 2003. “Infiltration Basin Site Selection”. Study Volume I. California Department of Transportation. Report No. CTSW-RT-03-025.

City of Portland, 2010. *Appendix F.2: Infiltration Testing.* Portland Stormwater Management Manual, Revised February 1, 2010.

United States Department of the Interior, Bureau of Reclamation (USBR), 1990a, "Procedure for Performing Field Permeability Testing by the Well Permeameter Method (USBR 7300-89)," in Earth Manual, Part 2, A Water Resources Technical Publication, 3rd ed., Bureau of Reclamation, Denver, Colo.