San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

# Determination of Design Infiltration Rates for the Sizing of Infiltration-based Green Infrastructure Facilities

## 1 Introduction

This document, developed by the San Francisco Public Utilities Commission (SFPUC) and reviewed by San Francisco Public Works (SFPW), provides procedures for determining subgrade Design Infiltration Rates used for the sizing of infiltration-based Green Infrastructure facilities. The approved methods for estimating a "measured" infiltration rate include simple field infiltration tests, in-situ infiltration rate measurements, and correlation to grain size distribution from soil samples. Correction factors are applied to these measured infiltration rates to establish a Design Infiltration Rate (long-term rate) used for the sizing of stormwater management facilities (also known as stormwater "Best Management Practices" or "BMPs"). Infiltration testing is required for all projects proposing infiltration-based BMPs to meet performance requirements contained in the SFPUC's *San Francisco Stormwater Management Requirements and Design Guidelines* (SMR).

Approved infiltration rate testing methods:

- Simple Infiltration Test (for small-scale projects only)
- Double Ring Infiltrometer Test
- Small Pilot Infiltration Test (PIT)
- Large PIT
- Soil Grain Size Analysis (for specific soil types only)

Alternate infiltration rate testing methods (require approval by SFPUC or SFPW):

- Boring Test Method

Methods that are NOT accepted for infiltration rate testing:

- Single Ring Infiltrometer
- USDA Soil Textural Classification

The infiltration testing described here is not considered a replacement for other subsurface or geotechnical investigations required to support the siting and design of infiltration facilities. Additional important considerations that are outside the scope of this document include, but are not limited to, separation from seasonally high groundwater or hydraulic restriction layer (e.g., a clay, bay mud, or rock layer), location within liquefaction zones, soil treatment capacity, and the potential for groundwater mounding or seepage.

## *1.1 Roles and Responsibilities of Licensed Professionals*

The procedures provided in this document do not preclude the use of professional judgment to evaluate and manage risk associated with design, construction, and operation of infiltration BMPs. Recommendations that deviate from the requirements specified in this document shall be included in a stamped and signed letter from a State of California licensed professional engineer, engineering geologist, geologist, or hydrogeologist, herein referred to as Licensed Professional, who has experience in infiltration testing and infiltration facility design. The letter must provide rationale and specific data supporting their professional judgment and must accompany the infiltration testing results report.

## *1.2 Infiltration Rate Testing Methods*

Infiltration rate testing methods vary based on project size and site soil characteristics, as shown in Table 1.

### Table 1. Applicability of Approved Infiltration Testing Methods

| Impervious Area Infiltrated on the Site [a] | Infiltration Testing Method Requirements | |
|---|---|---|
| | **Parcel Projects** | **Right-of-Way Projects** |
| < 4,000 ft$^2$ | • Simple Infiltration Test [b]; or<br>• Double Ring Infiltrometer; or<br>• Grain Size Analysis [c] | • Double Ring Infiltrometer; or<br>• Small PIT; or<br>• Grain Size Analysis [c] |
| ≥ 4,000 ft$^2$ to < 1 acre | • Double Ring Infiltrometer; or<br>• Small PIT; or<br>• Grain Size Analysis [c] | |
| ≥ 1 acre | • Large PIT [d, e]; or<br>• Grain Size Analysis [c] | • Small PIT [e]; or<br>• Grain Size Analysis [c] |

**Note: SFPUC or SFPW may approve deviations from the requirements in this table when justified by the Licensed Professional.**

[a] Projects proposing permeable pavement shall include proposed permeable pavement area plus any impervious contributing area.

[b] Projects proposing permeable pavement or projects with no off-site point of discharge to the municipal collection system may not use the Simple Infiltration Test.

[c] The Grain Size Analysis is only approved for Clean Sand and Dune Sand (SP) with $D_{10}$ between 0.1 and 2.5 millimeters; appropriate documentation required. Clean sand is defined as having less than 5% passing No. 200 sieve.

[d] Small PIT may substituted for Large PIT if the site has a high infiltration rate, making a Large PIT difficult, and the site geotechnical investigation suggests uniform subsurface characteristics; substitution upon approval of SFPUC or SFPW, dependent on agency oversight.

[e] In the event that a Large PIT or Small PIT is determined to be infeasible due to proven site constraints and inaccessibility, two (2) Double Ring Infiltrometer tests may be substituted for one (1) Large PIT or Small PIT; substitution upon approval of SFPUC or SFPW, dependent on agency oversight.

## ***1.3 Test Locations, Number, and Seasonal Timing***

Requirements for the locations, number, and timing of infiltration tests are provided below.

### *Test Location*

If possible, perform infiltration testing at the location of the proposed infiltration facility. Infiltration testing results from a location within 50 feet of the proposed infiltration facility may be submitted at the discretion of the Licensed Professional. If the infiltration testing is performed more than 50 feet from the final infiltration facility location due to existing site constraints (e.g., existing structure at location of proposed facility) and greater than 5,000 square feet is infiltrated on the site, then additional verification testing is required during construction. Infiltration testing depth requirements are specified per individual testing method.

### *Number of Tests*

Building Permit (or equivalent):

- A minimum of two (2) tests is required for projects with a cumulative infiltration facility footprint of 1,000 square feet or less.
- One (1) additional test is required for every additional 1,000 square feet of infiltration facility footprint, with a maximum of five (5) tests per project.
- A minimum of one (1) test per 300 linear feet of facility is required for infiltration-based BMPs in the Right of Way.
- In the event that a Large PIT or Small PIT is determined to be infeasible due to proven site constraints and inaccessibility, two (2) Double Ring Infiltrometer tests may be substituted for one (1) Large PIT or Small PIT.
- Changes to these requirements may be approved at the discretion of SFPUC or SFPW, dependent on agency oversight.

Street Improvement Permit (or equivalent):

- A minimum of one (1) test per 300 linear feet of facility is required for infiltration-based BMPs in the Right of Way.
- In the event that a Large PIT or Small PIT is determined to be infeasible due to proven site constrains and inaccessibility, two (2) Double Ring Infiltrometer tests may be substituted for one (1) Large PIT or Small PIT.
- Changes to these requirements may be approved at the discretion of SFPUC or SFPW, dependent on agency oversight.

If variable soil conditions or stratifications are observed at the site, multiple infiltration tests are recommended in the different soil types. Additional tests may also be required if BMPs with different bottom elevations are proposed.

*Seasonal Timing*

Whenever possible, field infiltration testing should be conducted in the wet season (between October and April) when soils are likely to have higher moisture content and groundwater levels are typically higher. Additional testing requirements apply for the Simple Infiltration Test (see Section 2) if tests are performed outside of the wet season.

# 2 Approved Infiltration Rate Testing Methods

This section provides procedures for approved infiltration rate testing methods. The test procedures may be modified due to limiting site conditions if recommended by the Licensed Professional. In these cases, adequate justification is required explaining why approved methods are not feasible and how the proposed modification(s) appropriately and accurately meet the intent of these standards. Any modifications to the testing methods must be justified by the Licensed Professional in the infiltration testing results report.

## *2.1 Simple Infiltration Test*

The Simple Infiltration Test is a small-scale infiltration test approved for small projects (< 2,000 sf contributing area) with an off-site point of discharge to the municipal collection system. (Note: Small projects with no off-site point of discharge may not use the Simple Infiltration Test.)

The testing procedure and data analysis requirements for the Simple Infiltration Test are provided below. Measurements and calculations shall be documented using the form in Appendix A and test location(s) shall be indicated on a site map.

The Simple Infiltration Test does not require that a Licensed Professional conduct or assess the results of the test.

*Procedure*

If testing is performed during the wet season (October through April), only one test per testing location is required. If the test is performed during the dry season (May through September), two tests must be performed in same location within 2 days, with the beginning of each test spaced 24 hours apart.

1. Dig a hole a 2 feet in diameter and a depth equal to the infiltrative subgrade (i.e. proposed facility bottom).
2. Record the type and texture of the soil. If the soil is primarily fine-grained such as silt or clay, or is bay mud, infiltration may not be feasible.
3. At the same time that you dig your test hole, check for groundwater by using a post hole digger to excavate a 3-foot deep hole approximately 5 feet from the test hole. If standing water or seeping water is observed in the hole, measure the depth to the standing water or seepage.
4. Pre-soak period**:**
    a. Add 12 inches of water to the hole. This can be measured using a ruler, scale, or tape measure. Be careful to avoid splashing which could erode the sides of the hole or disturb the soil at the base of the hole.
    b. Record the depth of water in the hole in inches.
    c. Record the time water was added to the hole.
    d. Check and record the time and depth of water in the hole on an hourly basis for up to two hours. Estimate the infiltration rate in inches per hour by calculating the drop in water level in inches for each hour. Based on the lowest of these measurements,

determine which time interval to use for the infiltration test by following these guidelines:

- >3 inch per hour fall, check at 15-minute intervals
- 3 inch to 1 inch per hour fall, check at 30-minute intervals
- <1 inch per hour fall, check at hourly intervals

5. Infiltration Test**:** Fill the hole with water to a depth of 12 inches. Check and record the time and depth of water in the hole at regular intervals based on the time interval determined during the presoak period for a total of six measurements. If the hole empties prior to the six measurements, refill and continue recording until you have recorded six measurements.

*Data Analysis*

Using the collected data, estimate the infiltration rate in inches per hour (in/hr) by calculating the change in water level, in inches, for each hour data was collected during the infiltration test. There should be a total of six values. The lowest calculated value is the measured infiltration rate in inches per hour (in/hr).

Adjust the measured infiltration rate using the correction factor described in Section 4 to establish the Design Infiltration Rate in inches per hour (in/hr).

## ***2.2 Double Ring Infiltrometer Test***

The double ring infiltrometer test can be used to estimate the Design Infiltration Rate based on small-scale in-situ field measurements. The testing and data analysis should be conducted per ASTM D3385-09 by a Licensed Professional. Refer to http://www.astm.org/Standards/D3385.htm to obtain testing standards.

Adjust the measured infiltration rate using the correction factor described in Section 4 to establish the Design Infiltration Rate in inches per hour (in/hr).

## ***2.3 Small Pilot Infiltration Test (Small PIT)***

The Small Pilot Infiltration Test (PIT) can be used to estimate a Design Infiltration Rate based on in-situ field measurements of infiltration rates.

The testing procedure and data analysis requirements for the Small PIT are provided below. The report for this test shall include documentation of the testing procedure, analysis, and results to establish the measured infiltration rate and an explanation of the correction factor used to determine the Design Infiltration Rate.

The Small PIT report shall be prepared by a Licensed Professional. The test method may be modified due to site conditions if recommended by the Licensed Professional and the justification is documented in the report.

*Procedure*

1. Excavate the test pit to the depth of the estimated bottom elevation of the proposed infiltration facility. In the case of bioretention, excavate to the lowest estimated elevation at which the imported soil mix or aggregate storage layer will contact the underlying soil. For permeable pavement, excavate to the elevation at which the aggregate storage layer will contact the underlying soil. If the underlying soils (subgrade) will be compacted, compact the underlying soils prior to testing. Refer to the SFPUC Permeable Pavement Specifications (available at http://sfpuc.org/smr) for subgrade compaction standards.
2. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
3. The size of the bottom of the test pit shall be a minimum of 12 square feet (sf). Accurately document the size and geometry of the test pit.
4. Install a device capable of measuring the water level in the pit during the test. This may be a pressure transducer (automatic measurements) or a vertical measuring rod (minimum 5 feet long) marked in half-inch increments in the center of the pit bottom (manual measurements).
5. Use a rigid pipe with a splash plate or some other device on the bottom to convey water to the bottom of the pit and reduce side-wall erosion and excessive disturbance of the pit bottom. Excessive erosion and bottom disturbance may result in clogging of the infiltration receptor and yield lower than actual infiltration rates.
6. Pre-soak period: Add water to the pit so that there is standing water for at least 6 hours. Maintain the pre-soak water level at least 12 inches above the bottom of the pit.
7. Steady state period:
    a. At the end of the pre-soak period, add water to the pit at a rate that will maintain a depth of 12 inches above the bottom of the pit over a full hour.
    b. Every 15 minutes during the steady state period, record the cumulative volume and instantaneous flow rate (in gallons per minute) necessary to maintain the water level at the same point (the design ponding depth) on the measuring rod or pressure transducer readout.
8. Falling head period: After 1 hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour every 15 minutes using the pressure transducer or measuring rod data, for a minimum of 1 hour or until the pit is empty.
9. At the conclusion of testing, over-excavate the pit to determine if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The depth of excavation is determined by the Licensed Professional and should be at least one foot deeper than the required vertical separation from bottom of facility to groundwater.

*Data Analysis*

Using the steady state flow rate established in Step 7, calculate and record the measured infiltration rate in inches per hour. Use the falling head data to confirm the measured infiltration rate calculated from the steady state data.

Adjust the measured infiltration rate using the correction factor described in Section 4 to establish the Design Infiltration Rate in inches per hour (in/hr).

## ***2.4 Large Pilot Infiltration Test (Large PIT)***

Like the Small PIT, the Large LIT can be used to estimate a Design Infiltration Rate based on in-situ field measurements of infiltration rates. A Large PIT will more closely simulate actual conditions for an infiltration facility and may be preferred at the discretion of the Licensed Professional if not already required per Table 1. The testing procedure and data analysis requirements for the Large PIT are provided below. The report for this test shall include documentation of the testing procedure, analysis, and results to establish the measured infiltration rate and an explanation of the correction factor used to determine the Design Infiltration Rate.

The Large PIT report shall be prepared by a Licensed Professional. The test method may be modified due to site conditions if recommended by the Licensed Professional and the reasoning is documented in the report.

*Procedure*

1. Excavate the test pit to the depth of the bottom of the proposed infiltration facility. In the case of bioretention, excavate to the lowest estimated elevation at which the imported soil mix or aggregate storage layer will contact the underlying soil. For permeable pavement, excavate to the elevation at which the aggregate storage layer will contact the underlying soil. If the underlying soils (subgrade) will be compacted, compact the underlying soils prior to testing. Refer to the SFPUC Permeable Pavement Specifications (available at http://sfpuc.org/smr) for subgrade compaction standards.
2. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
3. The size of the bottom of the test pit should be as close to the size of the planned infiltration facility as possible, but not less than 32 square feet in area. Where water availability is an issue, smaller areas may be considered, as determined by the Licensed Professional. Accurately document the size and geometry of the test pit.

Steps 4 through 9 are identical to the Small PIT procedure.

4. Install a device capable of measuring the water level in the pit during the test. This may be a pressure transducer (automatic measurements) or a vertical measuring rod (minimum 5 feet long) marked in half-inch increments in the center of the pit bottom (manual measurements).
5. Use a rigid pipe with a splash plate or some other device on the bottom to convey water to the bottom of the pit and reduce side-wall erosion and excessive disturbance of the pit bottom.

Excessive erosion and bottom disturbance may result in clogging of the infiltration receptor and yield lower than actual infiltration rates.

6. Pre-soak period: Add water to the pit so that there is standing water for at least 6 hours. Maintain the pre-soak water level at least 12 inches above the bottom of the pit.
7. Steady state period:
    a. At the end of the pre-soak period, add water to the pit at a rate that will maintain a depth of 12 inches above the bottom of the pit over a full hour.
    b. Every 15 minutes during the steady state period, record the cumulative volume and instantaneous flow rate (in gallons per minute) necessary to maintain the water level at the same point (the design ponding depth) on the measuring rod or pressure transducer readout.
8. Falling head period: After 1 hour, turn off the water and record the rate of infiltration (the drop rate of the standing water) in inches per hour every 15 minutes using the pressure transducer or measuring rod data, for a minimum of 1 hour or until the pit is empty.
9. At the conclusion of testing, over-excavate the pit to determine if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The depth of excavation is determined by the Licensed Professional and should be at least one foot deeper than the required vertical separation from bottom of facility to groundwater or bedrock.

*Data Analysis*

Using the steady state flow rate established in Step 7, calculate and record the measured infiltration rate in inches per hour. Use the falling head data to confirm the measured infiltration rate calculated from the steady state data.

Adjust the measured infiltration rate using the correction factor described in Section 4 to establish the Design Infiltration Rate in inches per hour (in/hr).

## ***2.5 Soil Grain Size Analysis***

The Soil Grain Analysis Method can be used to estimate a Design Infiltration Rate based on soil grain size distribution. **This method is only approved for native Clean Sand and Dune Sand (SP) with $D_{10}$ between 0.1 and 2.5 millimeters** (i.e. soils to which the Hazen formula is applicable)**.** This method is not allowed within areas of fill.

The testing procedure and data analysis requirements for the Soil Grain Size Analysis are provided below. The report for this test shall include documentation of the testing procedure, analysis, results to establish the measured infiltration rate, and an explanation of the correction factor used to determine the Design Infiltration Rate if different from the recommended correction factor in Table 2.

The Soil Grain Size Analysis report shall be prepared by a Licensed Professional. The test method may be modified due to site conditions if recommended by the Licensed Professional and the reasoning is documented in the report.

*Procedure*

1. Collect soil samples for each defined soil layer below the bottom of the proposed infiltration facility. Layers must be evaluated to the following depths, depending upon facility type:
    a. For bioretention facilities, analyze each defined layer below the infiltrative subgrade (i.e. proposed facility bottom) to a depth of at least 3 times the maximum ponding depth, but not less than 3 feet.
    b. For permeable pavement, analyze each defined layer below the infiltrative subgrade (i.e. proposed facility bottom) to a depth of at least 3 times the maximum depth of water within the base course, but not less than 3 feet.
    c. For other types of infiltration facilities serving drainage areas up to 10 acres, analyze each defined layer below the infiltrative subgrade (i.e. proposed facility bottom) to a depth of at least 2.5 times the maximum depth of water in the facility, but not less than 10 feet.
2. When assessing the hydraulic conductivity characteristics of the site, soil layers at greater depths must be considered if the Licensed Professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the facility, requiring soil gradation/classification testing for layers deeper than indicated above.
3. Submit the soil samples for laboratory testing of particle size analysis (ASTM D422, https://www.astm.org/Standards/D422.htm).

*Data Analysis*

1. As the Soil Grain Size Analysis method is only approved for soils with $D_{10}$ between 0.1 and 2.5 millimeters, the Hazen formula (below) may be used to calculate the soil permeability (K). Soil permeability shall be considered to be the measured infiltration rate.

    $$K = C (D_{10})^2$$

    Where K is in cm/s, C = 1, and $D_{10}$ is the soil particle diameter in mm for which 10% of all soil particles are finer (smaller) by weight.
2. Adjust the measured infiltration rate using the correction factor described in Section 4 to establish the Design Infiltration Rate in inches per hour (in/hr).

# 3 Alternate Methods

## *3.1 Boring Test Method*

Boring-based infiltration testing methods may be necessary within the City of San Francisco due to the limitations of existing developed site conditions. However infiltration testing within borings is not recommended unless no other approved infiltration rate testing method is feasible. Prior to use of the Boring Test Method, the Licensed Professional shall submit a request for approval to use this method, providing justification of why no other methods are feasible.

The testing procedure and data analysis requirements for the Boring Test Method are provided below. All projects approved to use the Boring Test Method must also conduct a soil particle size analysis to determine the soil $D_{10}$. The report for this test shall include documentation of the testing procedure, analysis, and results to establish the measured infiltration rate and an explanation of the correction factor used to determine the Design Infiltration Rate. For sites with $D_{10}$ less than 0.1 mm, the Licensed Professional shall also provide a justification of the proposed infiltration approach and confirm that the facility will drain within the allowable drawdown time (i.e. 24 hours for planted BMPs, 48 hours for non-planted BMPs).

The Boring Test Method report shall be prepared by a Licensed Professional. The test method may be modified due to site conditions if recommended by the Licensed Professional and the reasoning is documented in the report.

*Procedure*

Boring Test procedures shall be submitted with the infiltration results report. Minimum requirements include the following:

- Borehole diameter shall be at least 8 inches in diameter.
- Bottom elevation of test hole shall be set at the proposed bottom elevation of the infiltration facility.
- In sandy soils, borehole shall be cased.
- Pre-soaking must be performed to saturate surrounding soils. Refer to Small or Large PIT procedures (Sections 2.3 and 2.4) for pre-soak period methods.
- For infiltration measurement, maximum head over soil interface should be no more than anticipated ponding depth in facility or 12 inches, whichever is greater. Higher head will overestimate infiltration rate. Refer to Small or Large PIT procedures (Sections 2.3 and 2.4) for steady-state and falling head period methods.
- Submit soil samples for particle size analysis laboratory testing (refer to ASTM D422, https://www.astm.org/Standards/D422.htm).
- For guidance regarding alternate borehole testing procedure methods, refer to ASTM D6391-11 (http://www.astm.org/Standards/D6391.htm).

*Data Analysis*

Using the flow rate established from the steady-state period testing, calculate and record the measured infiltration rate in inches per hour. Use the falling head data to confirm the measured infiltration rate calculated from the steady state data.

Adjust the measured infiltration rate using the correction factor described in Section 4 to establish the Design Infiltration Rate in inches per hour (in/hr).

# 4 Infiltration Rate Correction Factor

The measured infiltration rate determined by the methods provided in Sections 2 and 3 shall be reduced using correction factors (CFs) to determine the Design Infiltration Rate as shown in the equation below.

***Design Infiltration Rate = Measured Infiltration Rate x CF***

The Design Infiltration Rate shall be used when sizing infiltration BMPs to meet applicable stormwater management standards. Regardless of test method and results, the Design Infiltration Rate used for sizing infiltration-based BMPs shall not exceed 5 inches per hour.

## *4.1 Correction Factor*

Correction factors (CFs) for all approved and alternate infiltration rate testing methods are provided in Table 2. These correction factors must be used for all projects unless modification is warranted by site conditions, as justified by a Licensed Professional. Modifications to correction factors must be approved by SFPUC or SFPW.

**Table 2. Correction Factors for Design Infiltration Rates**

| Infiltration Testing Method | Correction Factor (CF) |
|---|---|
| **Approved Methods** | |
| Simple Infiltration Test | 0.5 |
| Double Ring Infiltrometer Test | 0.33 |
| Small Pilot Infiltration Test (Small PIT) | 0.5 |
| Large Pilot Infiltration Test (Large PIT) | 0.5 |
| Soil Grain Size Analysis | 0.33 |
| **Alternate Methods** | |
| Boring Test Method | 0.15 (for $D_{10} \geq 0.1$ mm)<br>0.10 (for $D_{10} < 0.1$ mm) |

# 5 References

Hazen, A. 1892. *Some physical properties of sands and gravels*. Massachusetts State Board of Health, Annual Report, 539-556.

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# APPENDIX A. SIMPLE INFILTRATION TEST RESULTS TEMPLATE

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# SIMPLE INFILTRATION TEST RESULTS TEMPLATE

**Project Street Address: _____**

**Testing Date: _____**

**Table 1. Pre-Soak Results**

| | Water depth (in) | Time | Pre-soak infiltration rate (in/hr) |
|---|---|---|---|
| Initial | 12 | | -- |
| 1 hr | | | |
| 2 hr | | | |

**To determine Infiltration Test time interval: if the lowest pre-soak infiltration rate is:**

- >3 inch per hour fall, check at 15-minute intervals
- 3 inch to 1 inch per hour fall, check at 30-minute intervals
- <1 inch per hour fall, check at hourly intervals

**Table 2. Infiltration Test Results**

| | Water depth (in) | Time | Calculated infiltration rate (in/hr) |
|---|---|---|---|
| Initial | 12 | | -- |
| Measurement #1 | | | |
| Measurement #2 | | | |
| Measurement #3 | | | |
| Measurement #4 | | | |
| Measurement #5 | | | |
| Measurement #6 | | | |

Measured Infiltration Rate = _____ in/hr (lowest rate from Table 2 above)

Design Infiltration Rate = Measured Infiltration Rate x 0.5[a] = _____ in/hr

[a] CF for Simple Infiltration Test

Depth to groundwater in adjacent hole = _____ ft (N/A if groundwater not found)