GUIDELINES FOR GEOTECHNICAL INVESTIGATION AND REPORTING
LOW IMPACT DEVELOPMENT STORMWATER INFILTRATION

Urbanization impacts the water resources of Los Angeles County by decreasing the amount of stormwater that infiltrates into the subsurface and increasing the potential for conveyance of pollutants into watersheds and the flood control system. Low Impact Development (LID) stormwater infiltration is a strategy that is used to mitigate some of these hydrological impacts. The goal of LID stormwater infiltration is to reduce runoff from the site using stormwater quality control measures that retain runoff. The objective of these guidelines is to facilitate stormwater infiltration in areas of Los Angeles County where ground conditions are suitable.

Compliance with the Los Angeles County LID Ordinance (Title 12, Section 12.84) is required before the issuance of a building or grading permit. The Department of Public Works prepared an updated *LID Standards Manual* in February, 2014 to compile previous documents, update standards, and assist applicants with the development process. The *LID Standards Manual* is available online at the following link: https://goo.gl/OaOQ0l. The procedure for calculating Stormwater Quality Design Volume (SWQDv) is provided in Section 6 of the document.

The geotechnical guidelines presented herein have been incorporated into the *LID Standards Manual* in "Section 4: Site Assessment and Design Considerations" and on the Fact Sheets in Appendix E. They provide technical guidance and specific requirements for geotechnical investigations to evaluate ground conditions for proposed stormwater infiltration sites. All proposed stormwater quality control measure Best Management Practices (BMPs) with an infiltration component require a geotechnical report. These LID stormwater quality control measures include but are not limited to:

- Bioretention
- Infiltration Trench
- Permeable Pavement
- Infiltration Basin
- Dry Well

Geotechnical reports prepared for stormwater infiltration BMPs must address the site requirements discussed in these guidelines. Data and analyses must be provided to substantiate the recommended infiltration rates and groundwater elevations. Geotechnical issues that must be addressed include pollutant and sewage mobilization, slope stability, static and seismic settlement, surcharge on adjacent structures, expansive soil and rock, potential impacts to offsite property, and any other geotechnical hazards. Geotechnical reports will be reviewed by the Geotechnical and Materials Engineering Division (GMED). Design infiltration rates and recommended areas of infiltration in compliance with these guidelines will be recommended for approval.

SITE REQUIREMENTS FOR STORMWATER INFILTRATION

1. Subsurface materials shall have a design infiltration rate equal to or greater than 0.3 inches per hour. Procedures for performing in-situ percolation tests and application of reduction factors are described later in these guidelines.

2. The invert of stormwater infiltration shall be at least 10 feet above the groundwater elevation. Procedures for determining the groundwater elevation are described later in these guidelines.

3. Stormwater infiltration is not allowed in areas that pose a risk of causing pollutant mobilization, such as on sites identified on environmental regulatory databases or similar files maintained by local agencies, or on properties with other documented environmental concerns.

4. Stormwater infiltration is not allowed in areas that pose a risk of causing sewage effluent mobilization from septic pits, seepage lines, or other sewage disposal.

5. Stormwater infiltration BMPs shall not be placed on steep slopes and shall not create the condition or potential for slope instability.

6. Stormwater infiltration shall not increase the potential for static settlement of structures on or adjacent to the site. Laboratory testing should be performed to evaluate the anticipated settlement and hydrocollapse potential of soils 10 feet below the proposed invert of infiltration.

7. Stormwater infiltration shall not increase the potential for seismic settlement of structures on or adjacent to the site. Liquefaction potential shall be evaluated considering the design volume of stormwater infiltration.

8. Stormwater infiltration shall not place an increased surcharge on structures or foundations on or adjacent to the site. The pore-water pressure shall not be increased on soil retaining structures on or adjacent to the site.

9. The invert of stormwater infiltration shall be set back at least 15 feet and outside a 1:1 plane drawn up from the bottom of adjacent foundations, unless otherwise recommended by the geotechnical consultant.

10. Stormwater infiltration shall not be located near utility lines where the introduction of stormwater could cause damage to utilities or settlement of trench backfill.

11. Stormwater infiltration is not allowed within 100 feet of any groundwater production wells used for drinking water.

GEOTECHNICAL INVESTIGATION

A site-specific geotechnical investigation performed for proposed stormwater infiltration quality control measures shall include subsurface exploration, laboratory testing, soil type classification, groundwater investigation, and in-situ percolation testing. The investigation must be conducted by or under direct supervision of a State of California certified professional geologist, geotechnical engineer, or civil engineer experienced in geotechnical engineering. Projects proposing to infiltrate a cumulative design volume of SWQDv greater than 10,000 gallons must also include a hydrogeologic assessment and be signed by a State of California certified professional geologist. It is highly desirable that large projects also utilize the services and input of a State of California certified hydrogeologist.

Subsurface Exploration

Subsurface exploration shall be performed to characterize the subsurface soil or bedrock through which water will infiltrate. Explorations shall be performed to a depth of at least 10 feet below the proposed invert of infiltration. Explorations must be performed at each proposed infiltration BMP location. Continuous methods of exploration (such as cone penetration testing or continuous sampling) are preferred. If continuous methods of exploration are not feasible, enough exploration shall be performed to sufficiently characterize the soil or bedrock.

Laboratory Testing

Tests shall be performed on samples collected at and below the proposed invert of stormwater infiltration. Sieve analysis, hydrometer, plasticity index, density, and moisture content tests provide indicators of infiltration potential. A discussion shall be provided on how these parameters will affect the proposed stormwater quality control measure BMP.

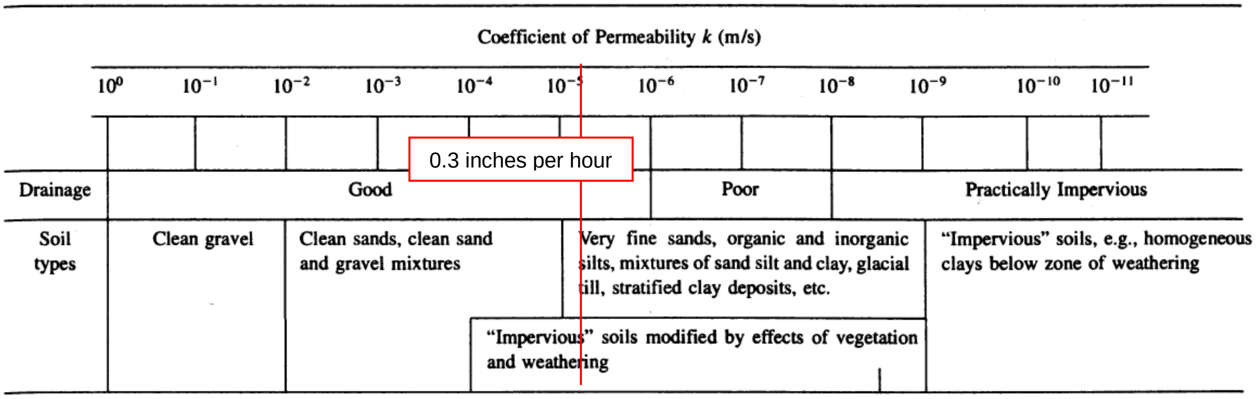
Laboratory testing should also be performed to evaluate the potential for settlement and ground subsidence to occur resulting from the operation of the proposed stormwater infiltration device. At a minimum, 10 feet of soil below the proposed invert of infiltration should be tested for consolidation and hydrocollapse.

Soil Type Classification

Soil type is one of the best indicators to determine if a proposed site is suitable for infiltration. Classification of soils at and below the proposed invert of infiltration shall be made in accordance with Unified Soil Classification System (USCS). The USCS is defined by the American Society for Testing and Materials (ASTM) International Standard D2487.

Coefficient of Permeability

The coefficient of permeability is a soil index property understood to be closely related to the infiltration potential of soils. The figure included herein presents typical coefficients of permeability for different soil type classifications. It is provided as a general reference. As shown, the required minimum design infiltration rate is 0.3 inches per hour.



Permeability and Drainage Characteristics of Soils from Terzaghi and Peck (1996)

Groundwater Investigation

Historic high groundwater maps may be used to verify the seasonal high groundwater elevation is greater than 10 feet below the proposed invert of infiltration. Historic high groundwater elevations may be available in the Seismic Hazard Evaluation Open-File Reports prepared by the California Geological Survey at the following link: https://goo.gl/VlESFZ.

Existing groundwater data may also be used to verify the seasonal high groundwater elevation is greater than 10 feet below the proposed invert of infiltration. Recent data from Geotracker, Envirostar, local water companies, and other resources may be used to establish a seasonal high groundwater elevation. Current groundwater data and historical publications are available online through the State's Department of Water Resources Website (https://goo.gl/qu8JsG), the Water Replenishment District of Southern California (https://goo.gl/enVgJG), and others. Groundwater data for a given project may be used from sites that are within 1,000 feet of the proposed project and have been collected within the last 5 years. Existing groundwater data must be clearly presented in the report and will be subject to review and approval by GMED.

If historic high groundwater maps and existing data are not available, site-specific exploration can be performed to establish the seasonal high groundwater elevation. At least two borings must be drilled a minimum of 10 feet below the proposed invert. The borings must be monitored for a period of at least 24 hours to verify the seasonal high groundwater elevation is greater than 10 feet below the proposed invert of infiltration.

Hydrogeology

Sites proposing to infiltrate a SWQDv of 10,000 gallons or more must have the geotechnical report signed and stamped by a State of California certified professional geologist. It is highly recommended that reports for large projects also be signed and stamped by a certified hydrogeologist. The consulting geologist of record should provide findings and conclusions regarding the local and regional geologic and hydrogeologic conditions and their effect on the proposed stormwater infiltration project. Features including but not limited to water tables, aquifers, past groundwater issues, confining units, stratigraphy, depth of bedrock, rock type, lithology, landslides, and faults should be discussed. Conclusions must be made regarding depth to seasonal high groundwater elevation.

IN-SITU PERCOLATION TESTING

Percolation testing must be performed to determine a reduced infiltration rate for design of the proposed stormwater infiltration quality control measures. At least two percolation tests shall be performed at each location and elevation where stormwater infiltration is proposed for mid-scale and large scale projects. Alternative test procedures must be submitted ahead of time and will be approved on a case-by-case basis. Specific procedures and durations may be required by Building and Safety Division (BSD), Land Development Division (LDD), or GMED at any time.

Percolation Test Requirements

	Small Scale	Mid-Scale	Large Scale
Stormwater Quality Design Volume (SWQDv)	<1,000 Gallons (<134 cubic feet)	1,000 - 10,000 Gallons (134 – 1,337 cubic feet)	>10,000 Gallons (>1,337 cubic feet)
Type of Test	Any	Any	Large Scale Testing Procedures
Minimum Test Duration	2 hours	4 hours	6 hours

Notes:

- Percolation tests must be performed for the minimum test duration or until the entire SWQDv for that location has been infiltrated during the test.

Double-Ring Infiltrometer Test (ASTM D3385)

A double-ring infiltrometer consists of two concentric metal rings. The rings are driven into the ground to preclude leakage, and then filled with water. Water in the outer ring keeps the flow in the inner ring vertical and the drop in water level in the inner ring is used to establish the vertical percolation rate. This testing procedure is useful for evaluating LID features that are proposed close to the ground surface, or can be performed at depth in a trench excavation. Procedures and example data forms for double-ring infiltrometer testing are provided in ASTM D3385. See photo below for example test setup. Field log template with example are attached on Plates 1-A, 1-B, and 1-C.

Double Ring Infiltrometer (ASTM D3385) Test Setup

Well Permeameter Test (USBR 7300-89)

The well permeameter procedure consists of introducing water into the subsurface through a slotted PVC pipe inserted into a borehole. This testing procedure is useful for LID features that are proposed at depth, since slotted sections of PVC pipe can be placed at any depth in the borehole. Careful attention must be paid to isolate the depth of the test section with an impermeable cap above and below it. The annulus between the slotted PVC and native materials in the test section depths must be backfilled with well-draining sand. The borehole below the desired test section depths, and the annulus between solid PVC and native materials above the desired test section, must be backfilled with bentonite or other low-permeability material. The borehole itself cannot create a path of less resistance for the water than the in-situ materials that are being tested.

Details for this test can be found in the Procedure for Performing Field Permeability Testing by the Well Permeameter Method (USBR 7300-89) attached in Appendix A. See photo below for example test setup. Field log template with example are attached on Plates 2-A, 2-B, and 2-C.

Well Permeameter (USBR 7300-89) Test Setup

Boring Percolation Test Procedure

This procedure is similar to the USBR 7300-89 Well Permeameter Testing Procedure and is useful for LID features that are proposed at depth, since the depth of testing can be isolated with slotted sections of PVC pipe, surrounded by a bentonite cap, and placed at any depth in the borehole. It requires the application of a reduction factor to account for non-vertical flow. A schematic of the test setup is attached on Plate 3-A. Field log template with example are attached on Plates 3-C and 3-D.

1. Using a hollow-stem auger, advance the boring at least 12 inches below the elevation of proposed invert of infiltration. Rotate the auger until all cuttings are removed. Care shall be taken to ensure smearing of clayey soils does not occur along augered surface as this will dramatically reduce the final calculated infiltration rate. Record the boring diameter and depth to be tested.

2. Install through the auger, a 2- to 4-inch-diameter perforated PVC casing with a solid end cap. Perforations shall be 0.02 inch slot or larger. Pour filter pack down inside of auger while withdrawing the auger such that the PVC casing is surrounded by the filter pack. The filter pack and perforated casing must have a larger hydraulic conductivity than the soil or rock that is to be tested.

3. For boreholes drilled below the proposed invert of infiltration that are being converted to boring percolation tests, careful attention must be paid to isolate the depth of the test section with an impermeable cap above and below it. The annulus between the slotted PVC and native materials in the test section must be backfilled with well-draining sand. The borehole below the desired test section, and the annulus between solid PVC and native materials above the desired test section, must be backfilled with bentonite or similar low-permeability material. The borehole itself shall not create a path of less resistance for the water than the in-situ materials being tested.

4. Presoak the hole immediately prior to the percolation testing for at least 1 hour to ensure the sand around the annulus of the perforated pipe is fully saturated.

5. Determine the time interval for recording the water drop between readings. Fill the excavation 12 inches above the bottom. Observe the drop in the water during the next 30 minutes and compare with the condition that applies below. This will determine the time interval for this test location.

   a. If water drains in less than 10 minutes, a constant head or high flowrate test procedures must be used to justify high recommended infiltration rates.

   b. If water remains in the hole after 10 minutes but drains before 30 minutes, the time interval between readings shall be 10 minutes.

   c. If water remains in the hole after 30 minutes, the time interval between readings shall be 30 minutes.

6. Once the time interval for the test has been determined, add water to the casing for the depth of soil to be tested. The water depth must be less than or equal to the water level used to presoak the hole and a minimum depth of 12 inches above the bentonite plug. For each successive percolation test reading, the starting water level must be at this initial water depth.

7. Conduct the percolation test by taking readings of the volume and water drop from the initial water depth. Record the time, volume, and drop in water level during the time interval determined in Step 5. Fill the boring back to the initial water depth and record the time of filling for each successive percolation test reading. A sounder or piezometer may be used to determine the water level for test sections at depth. Measurements of all water levels must be taken to the nearest ⅛-inch increment.

8. Repeat the percolation test readings a minimum of eight times A stabilized rate is when the highest and lowest readings are within 10 percent of each other from three consecutive readings.

9. The raw percolation rate shall be calculated by dividing the volume of water discharged, by the surface area of the test section (including sidewalls plus the bottom of the boring, if applicable), in a given amount of time. The average of the stabilized rate over the last three consecutive readings is the measured percolation rate at the test location, expressed in inches per hour.

Excavation Percolation Test Procedure

Similar to the double-ring infiltrometer, this testing procedure is useful for LID features that are proposed to be constructed close to the ground surface, or can be performed at depth in a trench excavation. It requires the application of a reduction factor to account for nonvertical flow. A figure is attached on Plate 3-B. Field log template with example are attached on Plates 3-C and 3-D.

1. Excavate a 1 cubic foot hole (1 foot deep x 1 foot wide x 1 foot long) at the elevation of the proposed invert of infiltration. Insert a wire-cage to support the walls. The actual excavation depth may be deeper than 12 inches; however, during the test the water shall be limited to 12 inches in depth.

2. Presoak the hole by filling it with water immediately prior to the percolation testing. If the water seeps completely away within 30 minutes after filling the excavation two consecutive times, and the subsurface exploration has yielded permeable soils beneath the proposed invert of infiltration, presoaking can be considered complete and the testing can proceed. If the water does not completely drain within 30 minutes, presoak the excavation maintaining 12 inches of water for at least 4 hours before conducting the percolation testing. Record all water levels to the nearest ⅛-inch increment.

3. Determine the time interval for recording the water drop between readings. Fill the excavation 12 inches above the bottom. Observe the drop in the water during the next 30 minutes and compare with the condition that applies below. This will determine the time interval for this test location.

    d. If water drains in less than 10 minutes, a constant head or high flowrate test procedures must be used to justify high recommended infiltration rates.

    e. If water remains in the hole after 10 minutes but drains before 30 minutes, the time interval between readings shall be 10 minutes.

    f. If water remains in the hole after 30 minutes, the time interval between readings shall be 30 minutes.

4. Once the time interval for the test has been determined, add water to 12 inches above the bottom of the excavation. For each successive percolation test reading, the starting water level must be at this initial water depth.

5. Conduct the percolation test by taking readings of the water drop from the initial water depth. Record the time and record the drop in water level during the time interval determined in Step 3. Fill the excavation back to the initial water depth and record the time of filling.

6. Repeat the percolation test readings a minimum of eight times or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate is when the highest and lowest readings are within 10 percent of each other for three consecutive tests.

7. The average drop of the stabilized rate over the last three consecutive readings is the percolation rate at the test location, expressed in inches per hour. The measured percolation rate must be reduced to account for the discharge of water from both the sides and bottom of the boring (i.e., non-vertical flow). Use the following formula to determine the infiltration rate:

   Reduction Factor (R_f) = $R_f = \left(\frac{2d_1 - \Delta d}{13.5}\right) + 1$

   d_1 = Initial Water Depth (in.)
   Δd = Water Level Drop of Final Period or Stabilized Rate (in.)
   DIA = 13.5 (Equivalent Diameter of the boring) (in.)

High Flowrate Percolation Test Procedures

If water drains completely in less than 10 minutes and the measured rate is greater than 14 inches per hour during a boring percolation test, excavation percolation test, or any other test procedure, a modified test must be performed to determine the infiltration rate. This test may be conducted in the following manner:

1. Determine the surface area through which the water is infiltrating including sidewalls and bottom horizontal surface area.

2. Flood test excavation area so the volume discharging into the test pit can be measured using a flow meter.

3. Maintain a constant head of water in the hole for at least two hours. Take readings of cumulative volume of water infiltrated every ten minutes.

4. Calculate the percolation rate by dividing the total volume of water infiltrated by the total duration of the test and dividing by the percolation surface area.

5. Apply reduction factors and recommend an infiltration rate in inches per hour.

LARGE SCALE PERCOLATION TESTING PROCEDURES

These test procedures are being provided due to an increased interest in large-scale, regional, stormwater infiltration facilities. These types of facilities include infiltration basins, galleries, dry wells, and other large-scale stormwater infiltration projects. Water quality innovation and technology is encouraged; alternative designs will be reviewed on a case-by-case basis.

Infiltration Basin Percolation Test – Constant Head

Large scale in-situ percolation tests must be performed using the constant head test procedure described below to determine a long-term design infiltration rate for design of stormwater infiltration basins and galleries. This test requires excavation of a large area to represent the proposed size of an infiltration basin or gallery and reduces some of the scaling errors associated with small and mid-sized tests. In summary, this test requires a large excavation, uses constant head of water, takes readings in gallons every 15-30 minutes using a flowmeter, and has a 6 hour minimum duration.

Procedure

1. Determine the required horizontal surface area of testing and determine the number and sizes of tests needed to satisfy the required testing area in the table below. Test pits are typically excavated using a backhoe for shallow facilities. Testing can also be performed at deeper depths in large diameter borings; however, the combined surface area of the bottom of the borings needs to meet the total required horizontal surface area in the table below for each proposed basin.

	Large Regional Projects	Extra-Large Regional Projects
Stormwater Quality Design Volume (SWQDv)	10,000 - 500,000 Gallons (1,337 – 66,840 cubic feet)	>500,000 Gallons (>66,840 cubic feet)
Required Horizontal Surface Area of Testing	32 square feet	100 square feet

2. Excavate the test pits to the same elevation as the proposed invert of the infiltration. Slopes should be laid back in accordance with CAL-OSHA safety requirements. If performing tests in a large diameter boring, a minimum 5 foot layer of gravel backfill should be placed at the bottom of borings to prevent caving and erosion of soils.

3. Document the size and geometry of test pits. Install a vertical measuring rod in the test pit marked in half-inch increments. If performing the tests in large diameter borings, insert one PVC pipe to introduce water and one slotted PVC pipe to measure and maintain the water surface elevation. The pipe being used to deliver water should be at least 4-inch-diameter, placed in the center of the boring, and have at least 5 feet of slotted section at the bottom of the hole. The water delivery PVC pipe should be embedded into at least 5 feet of gravel at the bottom of the hole to allow for unrestricted movement of water. The pipe being used to measure and maintain the water elevation may be a smaller diameter and must be slotted the entire length of the boring. A schematic of the test setup is attached on Plate 4a.

4. Use a hose with a splash plate on the bottom to convey water into the pit and reduce sidewall erosion and disturbance of the pond bottom. If performing the tests in large diameter borings, water can be introduced via a hose inserted at least 5 feet into the borehole or through the water delivery pipe described in Step 3.

5. Add water to the excavation at a rate that will maintain a constant head with the water surface elevation approximately 1 foot above the bottom of the test pit or boring and proposed invert of infiltration. A flowmeter can be used to measure the volume and instantaneous flow rate. The water elevation during testing may not exceed the maximum depth of water anticipated in the proposed facility. For facilities serving large drainage areas and designs with multiple feet of standing water, percolation tests may be performed with more than 1 foot of standing water.

6. Record the cumulative volume in gallons, instantaneous flow rate in gallons per minute, and water surface elevation every 15-30 minutes. If performing the tests in large diameter borings, a water sounder may be used to measure the water surface elevation in the slotted PVC pipe during the test.

7. Keep adding water to the test pit until at least one hour after the flow rate in the pit has stabilized. The stabilized flow rate can be defined when the highest and lowest readings are within 10 percent of each other, for three consecutive increments. The combined pre-soak time, testing duration, and at least one hour after the flow rate has stabilized shall be no less than 6 hours. For sites where percolation occurs very quickly, the test may be stopped after the entire SWQDv has been infiltrated during the test.

8. After the test is complete, turn the water off and record the drop on the measuring rod in inches per minute until the pit is empty. Consider running this falling head phase of the test several times to estimate the dependency of infiltration rate with water head.

9. At the conclusion of testing, over-excavate the pit to see 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 will vary depending on soil type and depth to hydraulic restricting layer, and shall be determined by the soils engineer. Mounding is an indication that a mounding analysis may be necessary. Over-excavation is not necessary if testing is performed in a large diameter boring at depth.

Data Analysis

10. Plot results of the percolation test as cumulative volume in gallons versus time in hours. The slope of the line during steady state conditions represents the stabilized flow rate for the percolation test.

11. Convert the stabilized flow rate in gallons per hour to cubic feet per hour. Divide the stabilized flow rate by the surface area of percolation to determine the raw measured rate. The surface area of percolation is the sum of the wetted surface including the bottom horizontal surface area and the average wetted sidewall surface area.

12. When multiple percolation tests are performed, consider whether an average or lower bound of the infiltration rates is more appropriate for design. Provide justification.

13. Apply reduction factors in accordance with guidance on Page 17 to determine a site-specific long term infiltration rate that can be used for design.

DRY WELL PERCOLATION TEST

There has been specific interest from Los Angeles County and the State Regional Water Quality Control Board regarding development of large scale dry well stormwater infiltration facilities. To address this interest, the following test procedure has been adapted from Los Angeles County Department of Public Health Guidelines: *Percolation Testing for Seepage Pit and Gravel Packed Pit Dispersal Systems*.

The test requires excavation of large diameter borings to model the proposed size of infiltration dry wells and reduces some of the scale errors associated with small scale and mid-size tests. In summary, the test requires a fire hose, flowmeter, and water sounder, takes readings every 15-30 minutes, and has a 6-hour minimum test duration.

Procedure

1. Excavate boring with minimum 18-inch-diameter for percolation testing. When safety concerns exist, the boring shall be filled with gravel or other well-draining materials. If the boring is backfilled, two separate pipes must to be inserted to conduct the test. A slotted pipe should be inserted the entire length of the borehole to measure the water level during the test. A separate pipe at least 4-inch-diameter should be placed in the center of the borehole to deliver water. The lower 5 feet of the water delivery pipe should be slotted for introduction of water into the borehole without interfering with pipe setup for water level measuring equipment. Mark the pipes at the surface to avoid confusion regarding which pipe is used for water delivery and which is for measurement. A schematic of the dry well test setup is attached on Plate 4b.

2. Boreholes may only remain open if there are no safety concerns. The covering and securing of open test excavations and borings shall be performed in accordance with CAL-OSHA safety requirements.

3. Introduce clear water under constant pressure into the solid pipe in the boring through a hose with minimum 1 1/2-inch diameter size, corresponding with the water meter. If the borehole is open, insert at least 5 feet of hose into the boring before filling with water to prevent caving and erosion of side walls.

4. Monitor the water level in the slotted pipe as the boring fills with water. Record the volume of water needed to fill the borehole.

5. Record the volume of water required to maintain a constant head in the borehole for equal time increments of 15 to 30 minutes. Maintain a head that is representative of the design head of the proposed drywell system.

6. Alternatively, if a constant head cannot be maintained, a modified falling head test can be performed. For a modified falling head test, allow the water to drop for equal time increments of 15 to 30 minutes. Record the drop in the water level and volume required to fill the hole back to the cap level (top of well) for each increment.

7. Continue adding water to the boring for a minimum 6 hours and until at least 1 hour after the flow rate into the boring has stabilized. The constant flow rate is defined as when the highest and lowest readings are within 10 percent of each other for three consecutive increments.

8. In situations where percolation occurs very quickly, the test may be stopped after 2 hours and the entire SWQDv or 2,000 gallons have been infiltrated.

9. At the conclusion of the constant head percolation test, it is beneficial to observe the drop in water level as a falling head test. The depth of water 24 hours after the conclusion of the at the test can be subtracted from the initial depth to determine a recommended height for proposed dry wells.

Data Analysis

10. Plot results of the percolation test as cumulative volume in gallons versus time in hours. The slope of the line during steady state conditions represents the stabilized flow rate for the percolation test.

11. Convert the stabilized flow rate in gallons per hour to cubic feet per hour. Divide the stabilized flow rate by the surface area of percolation during the test to determine a raw measured rate. The surface area of percolation during the test is the sum of wetted surfaces including the bottom surface area of the boring and the wetted sidewalls.

12. When multiple percolation tests are performed, consider whether an average or lower bound of the infiltration rates is more appropriate for design. Provide justification.

13. Apply reduction factors in accordance with guidance on the following page to determine a site-specific long term infiltration rate that can be used for design.

14. Present the recommended long term design infiltration rate for proposed dry wells in inches per hour and gallons per square foot per day. The total volume of water infiltrated during the test shall also be included.

15. Provide recommendation for the allowable depth of dry wells as the top of well at the anticipated inlet and the bottom of well at the elevation of water 24 hours after the conclusion of the constant head test. An alternative depth of infiltration may be recommended by the geotechnical consultant based on the site-specific stratigraphy. It is preferred that the bottom of each dry well be embedded at least 5-10 feet into a well-draining sandy layer. Recommendations for the allowable dry well depth will be subject to review and approval by GMED.

REDUCTION FACTORS

Measured percolation rates must be reduced to determine design values that will represent long-term performance of the proposed infiltration BMPs. It is the responsibility of the geotechnical engineer to recommend appropriate site-specific reduction factors that account for the test method, site variability, and long-term siltation. The recommended reduction factor should consider the SWQDv to be treated and the overall practicality of the project.

- Test-specific reduction factors must be applied to account for the direction of flow during the test and reliability of different test methods.
- Reduction factors for site variability, number of tests performed, and thoroughness of the subsurface investigation shall be selected by comparing the size and scope of subsurface exploration to similar projects.
- The reduction factor for siltation, plugging, and maintenance shall be selected based on the specified levels of pre-treatment and maintenance requirements.

The following table provides guidance for the range of values that may be used for each factor. All reduction factors will be subject to review and approval by the County.

Reduction Factors	
Double-ring infiltrometer Well permeameter Boring percolation Excavation percolation High flow-rate percolation Infiltration Basin Percolation Test Dry Well Percolation Test	$RF_t = 2$ $RF_t = 2$ $RF_t = 2$ $RF_t = R_f$ from test procedure $RF_t = 3$ $RF_t = 2$ $RF_t = 2$
Site variability, number of tests, and thoroughness of subsurface investigation	$RF_v = 1$ to 3
Long-term siltation, plugging and maintenance	$RF_s = 1$ to 3

Total Reduction Factor, $RF = RF_t \times RF_v \times RF_s$

Design Infiltration Rate = Measured Percolation Rate / RF

REPORTING

The geotechnical report shall provide an evaluation of the proposed specific stormwater quality control measures and their suitability for use in the project. The report must include the SWQDv proposed for infiltration. The report shall address any potential geotechnical hazards and contain a description of the subsurface conditions with logs of subsurface exploration, results of laboratory testing, soil classifications, depth to groundwater, and in-situ percolation test results. There shall be a discussion on the percolation test procedure including field data sheets, test results, and reduction factors. A recommended long term infiltration rate shall be provided for design, along with the depth at which the recommended infiltration rate can be applied. Guidance shall be provided to the developer that no grading or construction can disturb soils at or below the proposed invert depth of infiltration. The geotechnical consultant shall provide recommendations for underdrains and overflows, as necessary, and discuss best practices for operation and maintenance to maintain the effectiveness of the proposed facility for its design life. All recommendations from the geotechnical consultant must be incorporated in the design or shown as notes on the plans.

The report must be signed and stamped by a State of California licensed engineering geologist, geotechnical engineer, or civil engineer experienced in soil mechanics.

DISCUSSION

Infiltration rates are understood to have a very large range by orders of magnitude for different soil types. There is also substantial uncertainty associated with even the most rigorous testing procedures. For these reasons, it is important that the recommended design infiltration rate fall in the general order of magnitude for the soil type classifications at the site. If there is discrepancy between the presented data and the recommended infiltration rates, the consultant shall revisit soil descriptions, soil data, percolation testing procedure and analyses to provide a substantiated explanation for any variance. Additional testing and discussion may be necessary to verify the infiltration rates prior to acceptance by the County

Approved by:

Mitch Miller
Principal Engineer

Greg Kelley
Assistant Deputy Director

RESOURCES

1. American Standard Test Method (ASTM) Standard, Designation D 3385, *Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer* (latest edition). http://www.astm.org/Standards/D3385.htm

2. California Department of Conservation, *Seismic Hazard Zone Reports*, Division of Mines and Geology, Los Angeles County, 1998. http://www.consrv.ca.gov/cgs/shzp/pages/index.aspx

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DOUBLE-RING INFILTROMETER TEST
(use ASTM D 3385)

	Constants	Area (in^2)	Depth of water (in)	Water Containers No.	Volume/ΔH (in^2/in)
Project: ____________________					
Test Location: ____________________	Inner Ring				
____________________	Annular Space				

Water Source: ____________________ pH: ________

Tested By: ____________________ Water level maintained using: ☐ Flow valve ☐ Float valve ☐ Mariotte tube

Depth to water table: ________ Penetration of rings: Inner: ________ Outer: ________

Trial No.		Date	Time (24hr format)	Elapsed Time Δ/(total),	Flow Readings				Water Temp.	Incremental Infiltration		Remarks: weather conditions, etc.
					Inner Ring		Annular Space			Inner	Annular	
		____	hh:mm	min	Reading in	Flow in^3	Reading in	Flow in^3	°F	in/hr	in/hr	
1												

DOUBLE-RING INFILTROMETER TEST
(use ASTM D 3385)

Project: Practice Infiltration Testing

Test Location: 123 Drive Road, Alhambra, CA

Water Source: Potable Water pH: 7.5

Tested By: BDS, YH, & WM

Depth to water table: 17 ft

Constants	Area (in^2)	Depth of water (in)
Inner Ring	109.59	1.57
Annular Space	326.43	1.61

Water Containers No.	Volume/ΔH (in^3/in)
1	12.17
2	27.39

Water level maintained using: [ ] Flow valve [ ] Float valve [X] Mariotte tube

Penetration of rings: Inner: 3.0 in Outer: 6.9 in

Trial No.		Date 1982	Time (24hr format) hh:mm	Elapsed Time Δ/(total), min	Flow Readings: Inner Ring Reading in	Inner Ring Flow in^3	Annular Space Reading in	Annular Space Flow in^3	Water Temp. °F	Incremental Infiltration: Inner in/hr	Annular in/hr	Remarks: weather conditions, etc.
1	S	10/14	10:00	15	1.18	6.96	0.87	23.74	59	0.25	0.29	Cloudy, slight wind
	E	“ ”	10:15	(15)	1.75		1.73		59			
2	S	“ ”	10:15	15	1.75	12.94	1.73	48.51	59	0.47	0.59	
	E	“ ”	10:30	(30)	2.81		3.5		59			
3	S	“ ”	10:30	15	2.81	16.05	3.5	51.75	59	0.59	0.63	
	E	“ ”	10:45	(45)	4.13		5.39		59			
4	S	“ ”	10:45	15	4.13	18.67	5.39	57.67	59	0.68	0.71	
	E	“ ”	11:00	(60)	5.67		7.5		60			
5	S	“ ”	11:00	30	5.67	46.26	7.5	141.82	60	0.84	0.87	
	E	“ ”	11:30	(90)	9.47		12.68		61			
6	S	“ ”	11:30	30	9.47	51.75	12.68	157.44	61	0.95	0.96	Refilled tubes
	E	“ ”	12:00	(120)	13.72		18.43		62			
7	S	“ ”	12:10	60	1.38	118.63	0.87	360.16	62	1.08	1.1	“ ”
	E	“ ”	13:10	(180)	11.12		14.02		63			
8	S	“ ”	13:20	60	0.94	114.54	1.26	347.22	64	1.04	1.06	“ ”
	E	“ ”	14:20	(240)	10.35		13.94		64			
9	S	“ ”	14:30	60	1.69	103.5	1.85	308.41	64	0.95	0.94	“ ”
	E	“ ”	15:30	(300)	10.2		13.11		64			
10	S	“ ”	15:40	60	0.87	96.78	1.77	295.48	64	0.88	0.9	“ ”
	E	“ ”	16:40	(360)	8.82		12.56		64			Cloudy, slight wind

Graphical Representation of Data from Example

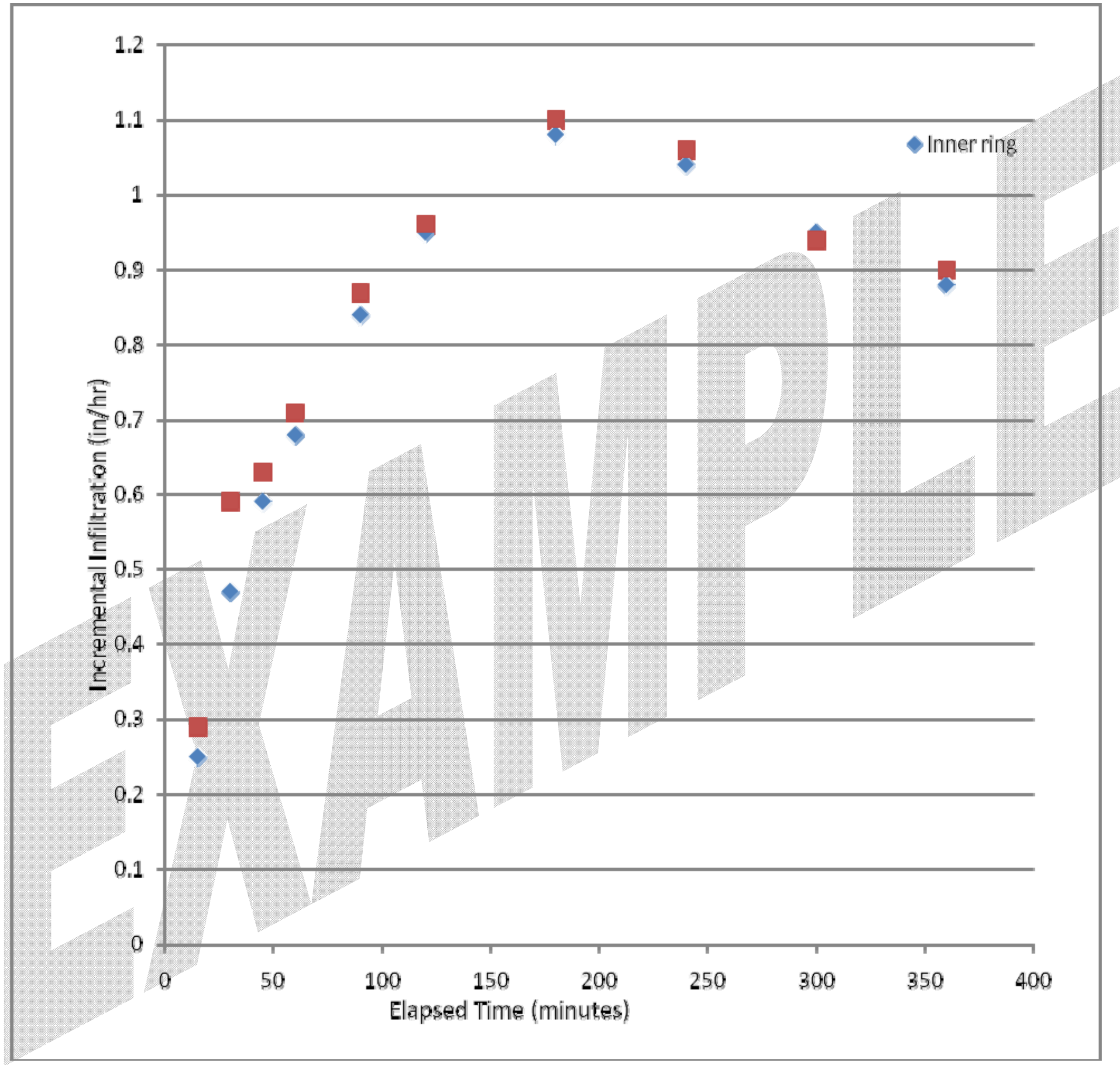


Plate 1-C

WELL PERMEAMETER TEST
(reference USBR 7300-89)

Project: ______________________

Test Location: ______________________

____

____

BMP Invert: ______________________

Water Source: ______________________

Turbidity: ______________________

Tested By: ______________________

Boring/Test Number: [ ]

r, radius of boring: ____ ft

D, boring depth below ground surface: ____ ft

h, depth of water maintained from bottom of hole: ____ ft

W, water table, or impervious layer, depth below ground surface: ____ ft

T_u, depth to water table or impervious layer from surface of water maintained: ____ ft Note: $T_u = W - D + h$

Date:

Condition I: $T_u \geq 3h$ [ ]

Condition II: $h \leq T_u \leq 3h$ [ ]

Water level determined by: [ ] Flow meter [ ] Float valve [ ] Calibrated tank

S, Anticipated Specific Yield: S ≈ 0.1 for fine grained & 0.35 for course grained.

$$V_{min} = 2.09S\left\{ h \frac{2}{\sqrt{\ln\left(\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 + 1}\right) - 1}} \right\}^3$$

Example: h = 3.5 ft, r = 0.5 ft, and S = 0.15, then the minimum water volume (V_{min}) needed for testing is 51 ft^3 or 381 gal.

$V_{max} = 2.05V_{min}$

Example: maximum water volume needed for testing, 381 gal(2.05) = 781 gal.

Trial No.	Date	Time (24hr format) hh:mm	Time Interval min	Accumulated Time min	Flow Meter / Tank Readings gallons	Flow Meter / Tank Readings Δ (gallons)	Accumulated Flow gallons	Water Temp. °F	Flow Rate, Q gpm	Flow Rate, Q ft^3/min	Remarks: weather conditions, etc.
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											

WELL PERMEAMETER TEST
(reference USBR 7300-89)

Project: Practice Infiltration Testing
Test Location: 123 Drive Road, Alhambra, CA
N33° 53' 12.1" W118° 21' 27.6"

BMP Invert: 5' below existing ground surface
Water Source: Potable Water
Turbidity:
Tested By: YH & CM

Boring/Test Number:
r, radius of boring: 0.5 ft Date: 5/4/1990
D, boring depth below ground surface: 6.0 ft
h, depth of water maintained from bottom of hole: 3.5 ft
W, water table, or impervious layer, depth below ground surface: 7.0 ft
T_u, depth to water table or impervious layer from surface of water maintained: 4.5 ft Note: $T_u = W - D + h$

Condition I: $T_u \geq 3h$ [ ]
Condition II: $h \leq T_u \leq 3h$ [X]

Water level determined by: [X] Flow meter [ ] Float valve [ ] Calibrated tank
S, Anticipated Specific Yield: 0.15 $S \approx 0.1$ for fine grained & 0.35 for course grained.

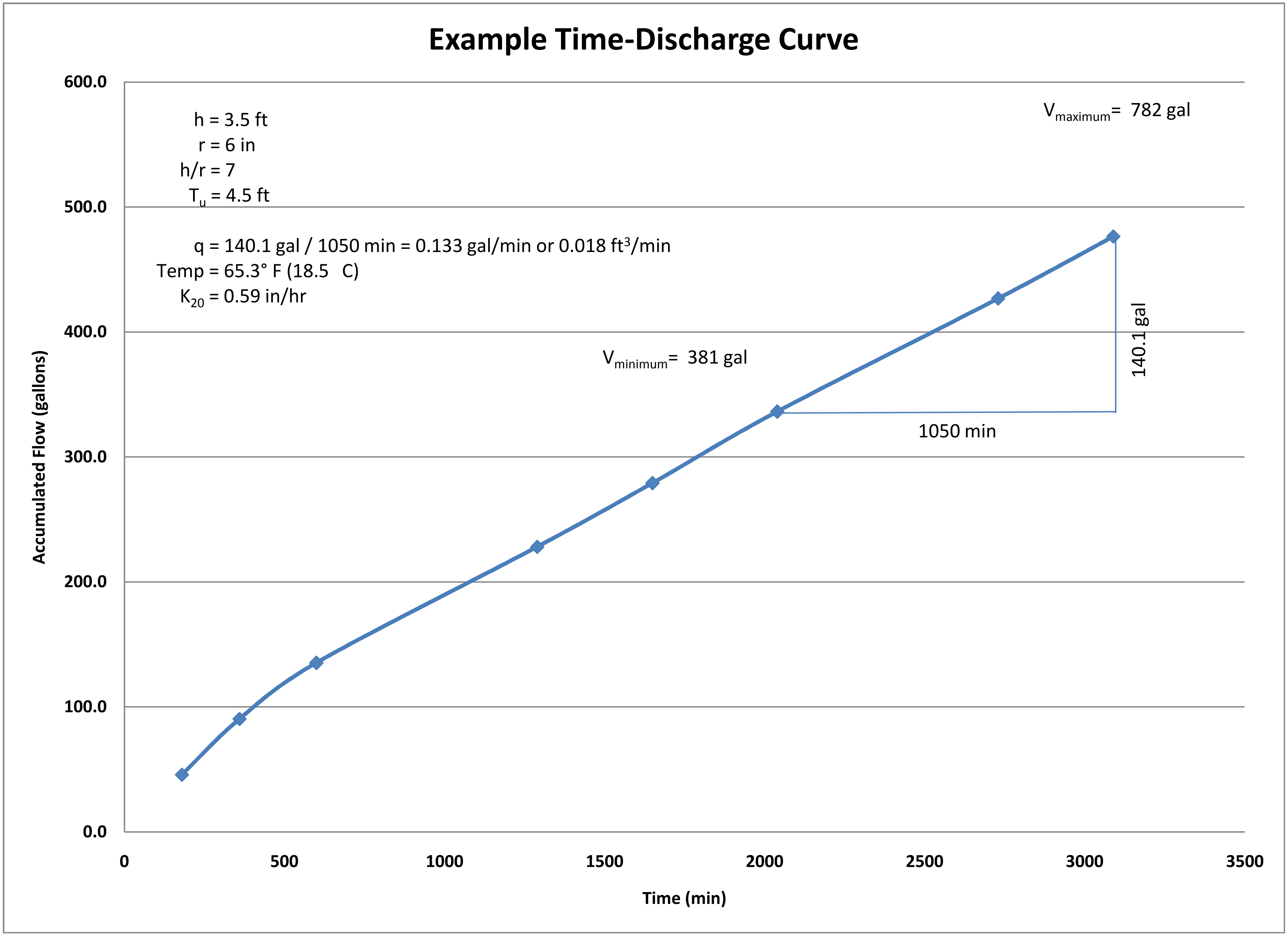
$$V_{min} = 2.09S\left\{ h \frac{2}{\sqrt{\ln\left(\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 + 1}\right) - 1}} \right\}^3$$

Example: h = 3.5 ft, r = 0.5 ft, and S = 0.15, then the minimum water volume (V_{min}) needed for testing is 51 ft^3 or 381 gal.

$V_{max} = 2.05V_{min}$

Example: maximum water volume needed for testing, 381 gal(2.05) = 781 gal.

Trial No.	Date	Time (24hr format) hh:mm	Time Interval min	Accumulated Time min	Flow Meter / Tank Readings gallons	Flow Meter / Tank Readings Δ (gallons)	Accumulated Flow gallons	Water Temp. °F	Flow Rate, Q gpm	Flow Rate, Q ft^3/min	Remarks: weather conditions, etc.
1	10/8	08:00	180	180	0	45.8	45.8	61	0.254	0.034	70's slightly cloudy, used one 55-gal drum. Refilled before next test.
	" "	11:00			45.8						
2	" "	11:15	180	360	0	44.6	90.4	64	0.248	0.0331	
	" "	14:15			44.66						
3	" "	14:30	240	600	0	44.9	135.3	65	0.187	0.025	Connected 2 55-gal drums together for trial no. 4.
	" "	18:30			44.9						
4	" "	19:00	690	1290	0	92.8	228.1	63	0.134	0.018	
	10/9	06:30			92.8						
5	" "	06:40	360	1650	0	51.0	279.1	61	0.142	0.019	
	" "	12:40			51						
6	" "	12:55	390	2040	51	57.2	336.3	66	0.147	0.0196	disturbed some soil into hole when observing for turbidity
	" "	19:25			108.2						
7	" "	19:30	690	2730	0	90.5	426.8	55	0.131	0.0175	
	10/10	07:00			90.5						
8	" "	07:20	360	3090	0	49.6	476.4	60	0.138	0.0184	
	" "	13:20			49.6						

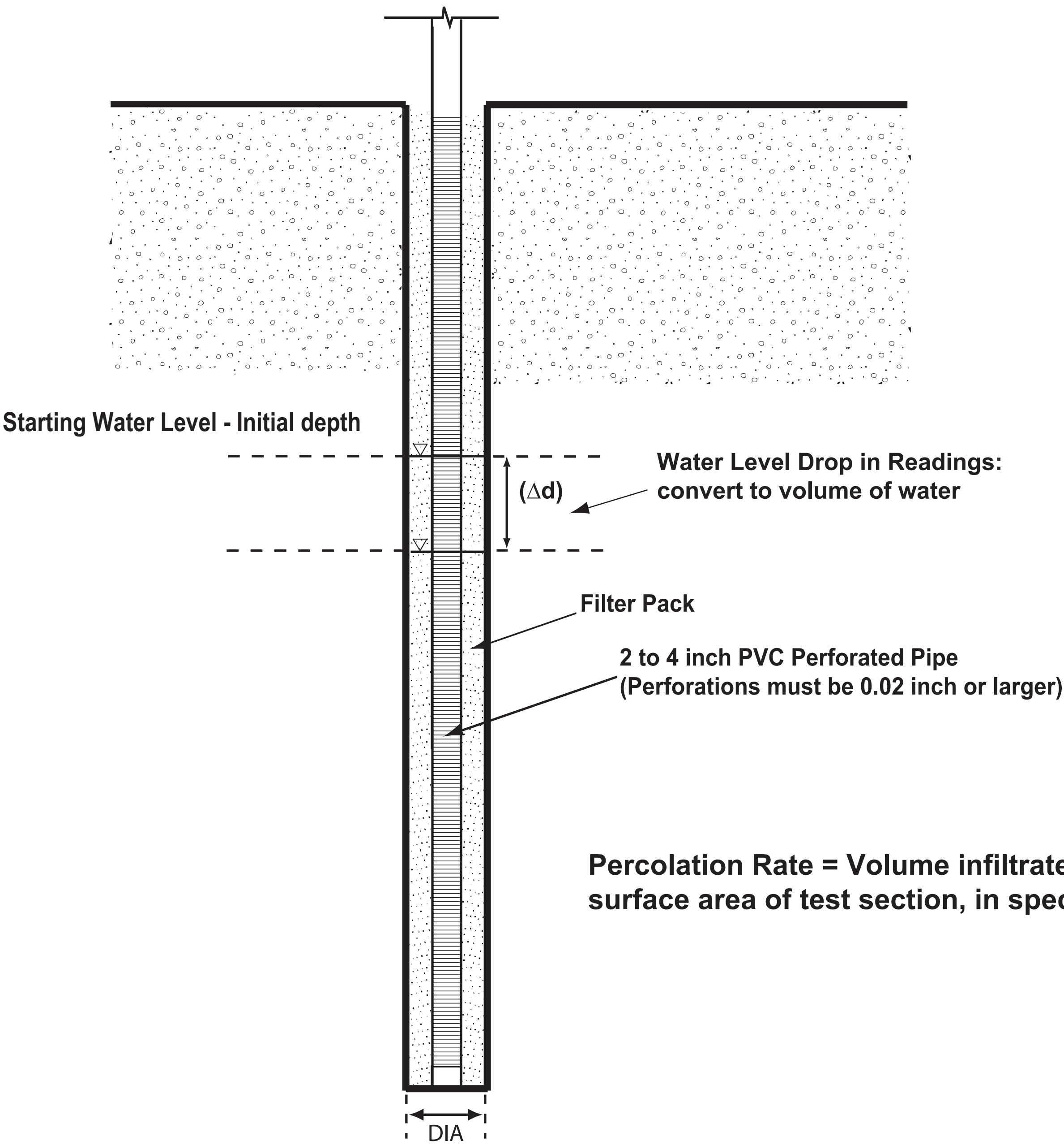


Example Time-Discharge Curve
h = 3.5 ft
r = 6 in
h/r = 7
T_u = 4.5 ft
q = 140.1 gal / 1050 min = 0.133 gal/min or 0.018 ft^3/min
Temp = 65.3° F (18.5 C)
K_{20} = 0.59 in/hr
$V_{maximum}$ = 782 gal
$V_{minimum}$ = 381 gal
140.1 gal
1050 min
Accumulated Flow (gallons)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0
500
1000
1500
2000
2500
3000
3500
Time (min)

Plate 2-C

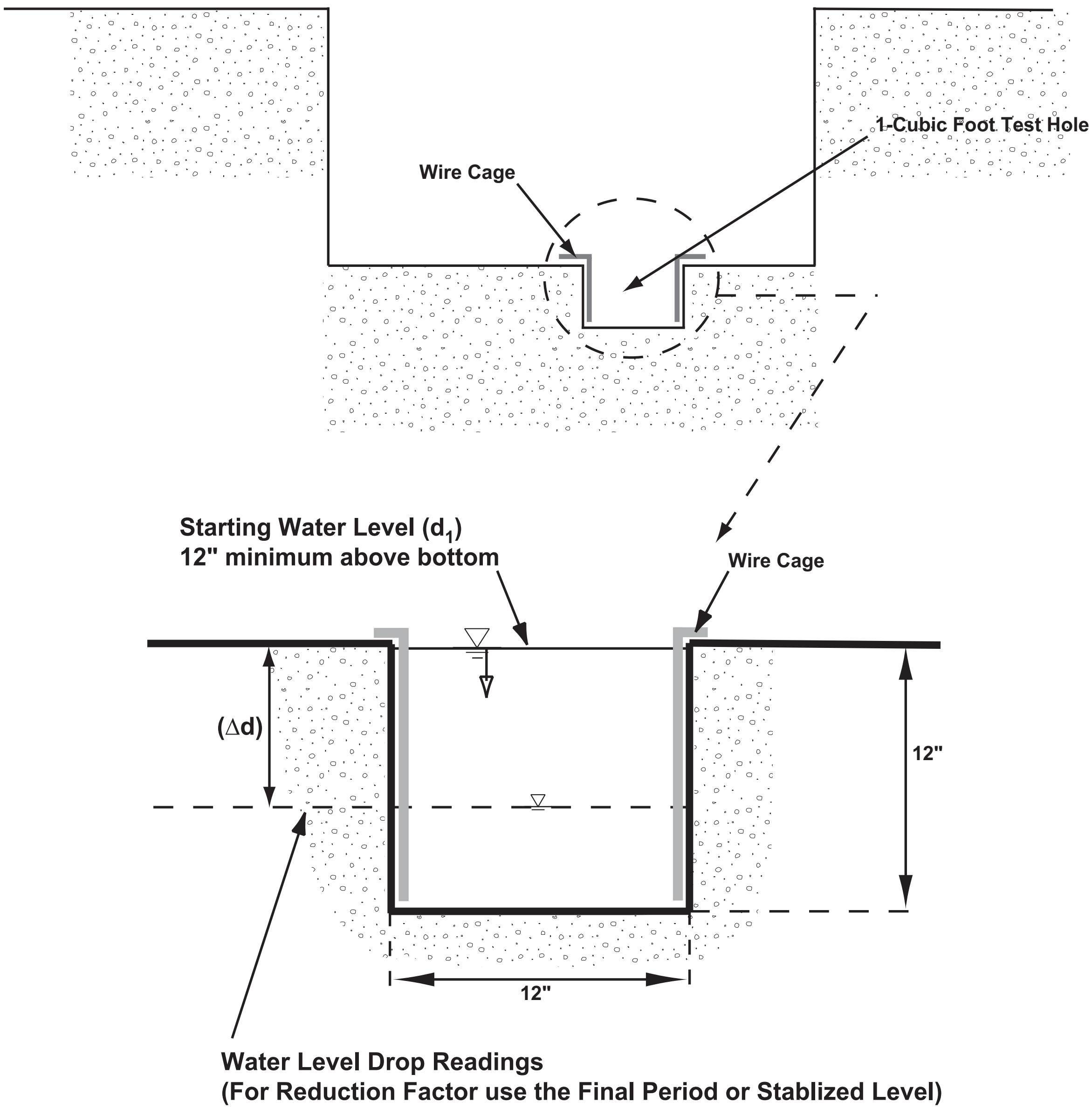
County of Los Angeles Administrative Manual
Low Impact Development - Best Management Practice GS200

Infiltration Testing Procedures
Boring Percolation Testing Method



Percolation Rate = Volume infiltrated divided by surface area of test section, in specified time

County of Los Angeles Administrative Manual
Low Impact Development - Best Management Practice GS200
Infiltration Testing Procedures
Excavation Percolation Testing Method



Infiltration Rate = Pre-adjusted Percolation Rate divided by Reduction Factor

Where reduction factor (Rf) is given by:

$$R_f = \left(\frac{2d_1 - \Delta d}{DIA} \right) + 1$$

With:
d1 = Initial Water Depth (in.)
Δd = Water Level Drop of Final Period or Stablized Level (in.)
DIA = 13.5 (Equivalent Diameter of the Boring)(in.)

Excavation Percolation Testing Field Log

Date ________

Project Location ________________________

Earth Description ________________________

Tested by ________________________

Liquid Description ________________________

Measurement Method ________________________

Time Interval Standard

Start Time for Pre-Soak ________________________

Start Time for Standard ________________________

Boring/Test Number ________________________

Diameter of Boring ________ **Diameter of Casing** ________

Depth of Boring ________________________

Depth to Invert of BMP ________________________

Depth to Water Table ________________________

Depth to Initial Water Depth (d_1) ________________________

Water Remaining In Boring (Y/N) ________________________

Standard Time Interval Between Readings ________________________

Reading Number	Time Start/End (hh:mm)	Elapsed Time Δtime (mins)	Water Drop During Standard Time Interval Δd (inches)	Percolation Rate for Reading (in/hr)	Soil Description/Notes/Comments

Excavation Percolation Testing Field Log

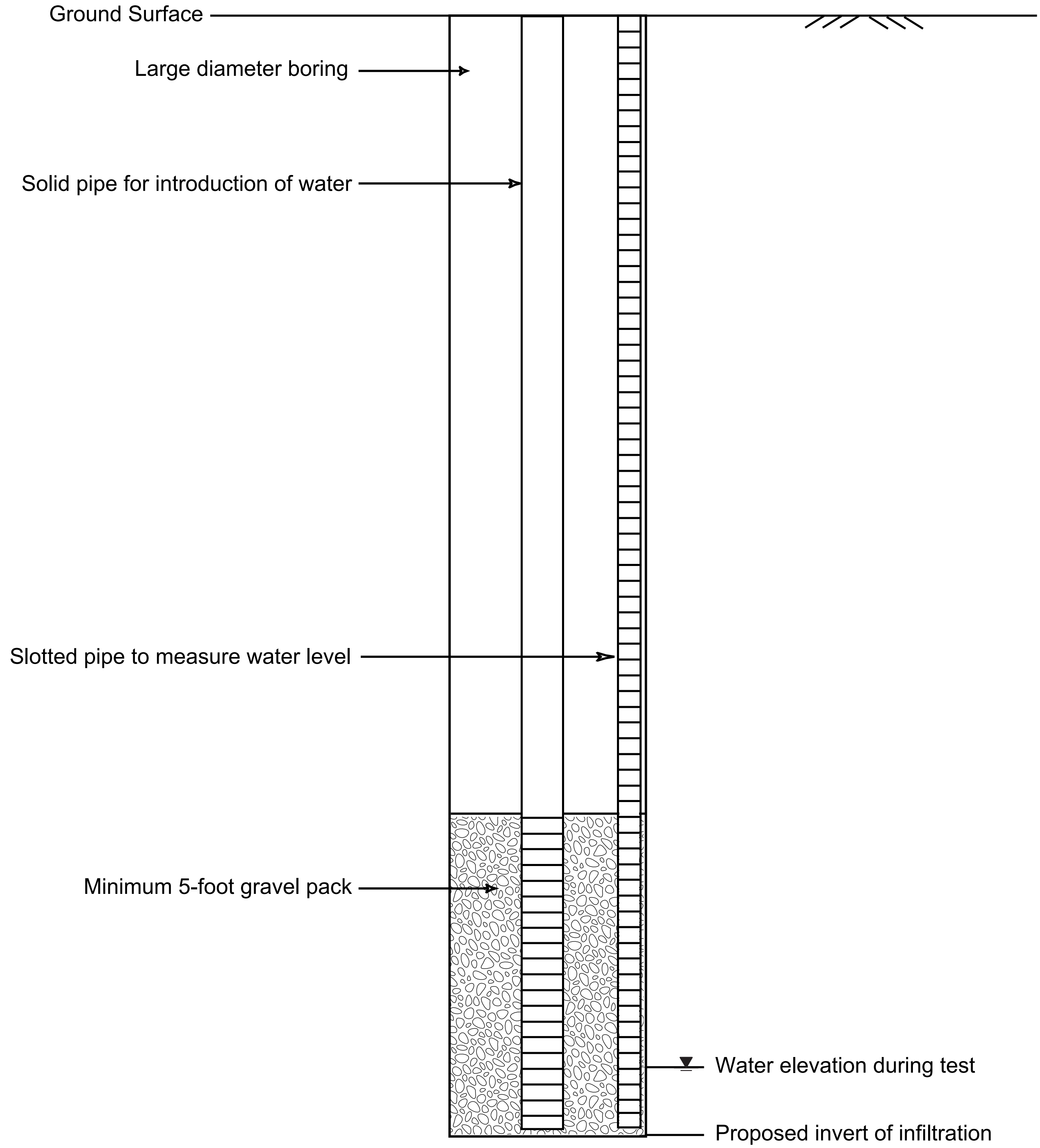
Date 2/20/2011

Project Location 900 S. Fremont Ave. Project
Earth Description Alluvial Fan
Tested by YM
Liquid Description Clear Clean Tap Water
Measurement Method Sounder

Time Interval Standard
Start Time for Pre-Soak 9:30am
Start Time for Standard 10:00am

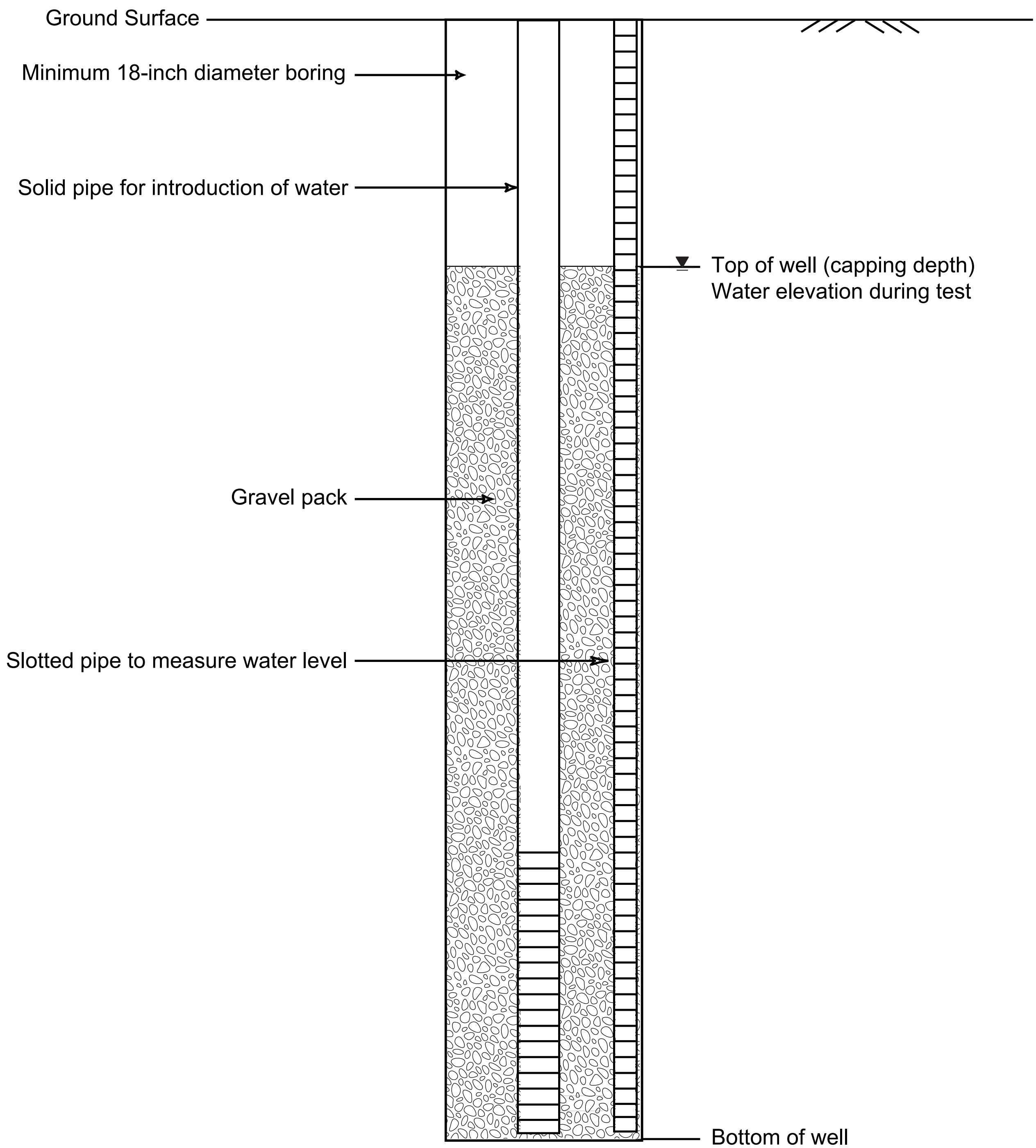
Boring/Test Number Boring 2 / Test 1
Diameter of Boring 6” **Diameter of Casing** 2”-4”
Depth of Boring 6’
Depth to Invert of BMP 5’
Depth to Water Table 30’
Depth to Initial Water Depth (d_1) 12”
Water Remaining In Boring (Y/N) Yes Water in Boring
Standard Time Interval Between Readings 30min/10min

Reading Number	Time Start/End (hh:mm)	Elapsed Time Δtime (mins)	Water Drop During Standard Time Interval Δd (inches)	Percolation Rate for Reading (in/hr)	Soil Description/Notes/Comments
1	10:30am 11:00am	30	3.00	6.00	SM, ML Moist, light brown
2	11:00am 11:30am	30	2.00	4.00	Water refilled every 30 mins to maintain initial water depth
3	11:30am 12:00pm	30	1.75	3.00	
4	12:00pm 12:30pm	30	1.50	3.50	
5	12:30pm 1:00pm	30	1.25	2.50	
6	1:00pm 1:30pm	30	1.10	2.20	
7	2:00pm 2:30pm	30	1.00	2.00	Stabilized Rate Achieved with Δd Readings 6, 7, and 8
8	3:00pm 3:30pm	30	1.00	2.00	



SAMPLE INFILTRATION BASIN
PERCOLATION TEST SETUP

COUNTY OF LOS ANGELES
DEPARTMENT OF PUBLIC WORKS
Geotechnical and Materials Engineering Division



SAMPLE DRY WELL
PERCOLATION TEST SETUP

COUNTY OF LOS ANGELES
DEPARTMENT OF PUBLIC WORKS
Geotechnical and Materials Engineering Division

Appendix A

United States Bureau of Reclamation

Test Method 7300-89

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 7300-89

PROCEDURE FOR

PERFORMING FIELD PERMEABILITY TESTING BY THE WELL PERMEAMETER METHOD

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 7300. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation is used to determine the coefficient of permeability of semipervious and pervious soils. The types of soil for which the test is applicable range from mixtures of sand, silt, and clay with coefficients of permeability greater than 1 X 10^{-5} cm/s to relatively clean sands or sandy gravels with coefficients of permeability less than 1 X 10^{-1} cm/s. There is lack of experience with the test in soils with coefficients of permeability outside these limits. The effects of capillarity on permeability test results were not taken into account during development of the theoretical background.

NOTE 1.-This test is similar to the "Shallow Well Pump-in Test for Hydraulic Conductivity" in the *Drainage Manual* [1].[1] However, some of the float valves allow greater waterflow from the water reservoir than the carburetor valve of the *Drainage Manual* test.

2. Auxiliary Tests

2.1 Soil sampling by USBR 7010 and classificationof soil from different strata by USBR 5005 are required to identify soil stratification and location of any water table.

3. Applicable Documents

3.1 USBR Procedures:
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5005 Determining Unified Soil Classification (Visual Method)
USBR 7010 Performing Disturbed Soil Sampling Using Auger Boring Method
3.2 ASTM Standard:
E 1 ASTM Thermometers

4. Summary of Method

4.1 The method consists of measuring the rate at which water flows out of an uncased well under a constant gravity head. The coefficient of permeability of the soil is calculated using (1) the relatively constant flow rate which is reached after a period of time, (2) the water temperature, (3) the constant height of water in the well, and (4) the radius of the well.

[1] Number in brackets refers to the reference.

5. Significance and Use

5.1 The method is used to determine the average coefficient of permeability for soil in its natural condition, primarily along proposed canal alignments or at reservoir sites. The permeability results are used in appropriate equations for calculating approximate seepage rates to aid in decisions on lining requirements. Although the test is usually performed in auger holes, it can also be used in test pits.

6. Terminology

6.1 Definitions are in accordance with USBR 3900.

7. Interferences

7.1 Proper use of the test requires soil characteristics which allow excavation of an uncased well of reasonably uniform dimensions with the soil sufficiently undisturbed to allow unrestricted outward flow of water from the hole.
7.2 Test results are adversely affected by using unclean water for the permeant.
7.3 When relatively impervious or highly pervious soil layers are present around the well, this should be considered when evaluating test results.
7.4 For tests during cold weather, a shelter with heat should be used to maintain ground and water temperatures above freezing.

8. Apparatus

8.1 General Apparatus:
8.1.1 Augers.-Hand augers suitable for excavating permeability test holes. Power-driven augers may be used if it is determined that disturbance of soil around the well is no more than for a hand auger.

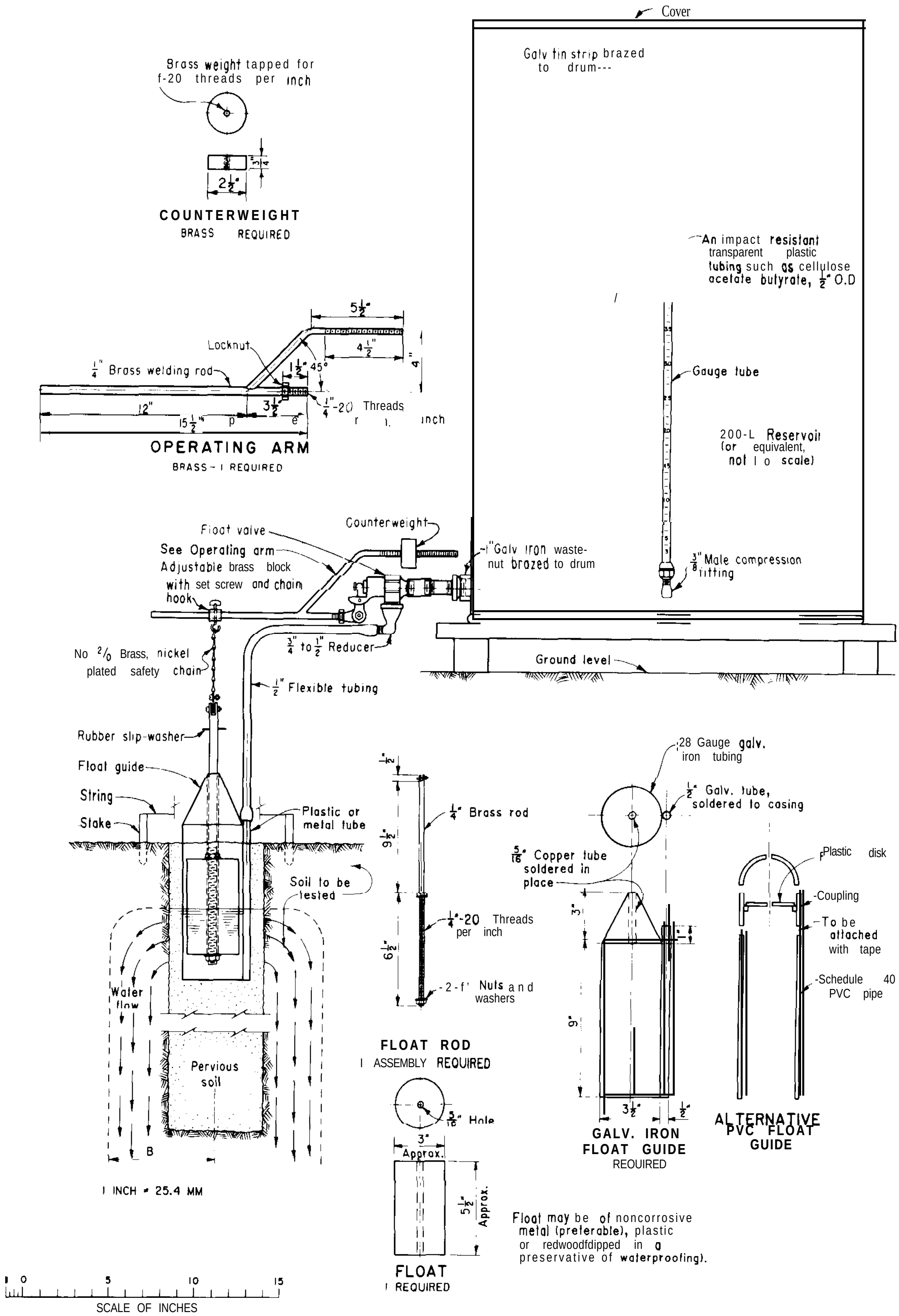


Figure 1. - Drawing of well permeameter test apparatus (101-D-38)

8.1.2 Thermometer.-0 to 50 °C, 0.5 °C divisions, conforming to the requirements of ASTM E 1.

8.1.3 Hammer, surveyors' stakes, and string for depth measurements in the well.

8.2 ***Equipment Unique to This Procedure (see*** figs. 1 and 2).

8.2.1 Water Reservoir.-A clean, covered, watertight reservoir of sufficient capacity which can be conveniently refilled at intervals to provide a continuous supply of water during the test. A 200-liter drum with a volume gauge tube of cellulose acetate butyrate has been found to be suitable for normal usage. Wooden blocking is required to raise the reservoir above the ground level.

8.2.2 K&e.-A float valve with operating arm (see fig. 3 for valve size).

8.2.3 Float.-A wooden, plastic, or metal float with brass stem.

8.2.4 Float Guide.-A guide of galvanized iron, PVC (polyvinyl chloride) or other materials to allow the float to move vertically.

8.2.5 Counterwe&hts.-Brass counterweights for arm of float valve.

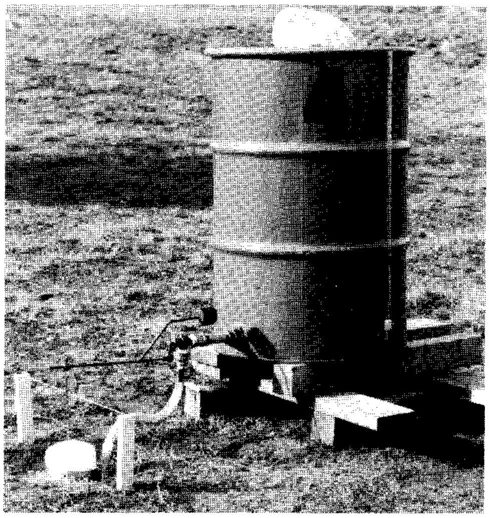


Figure 2. - Typical well permeameter test set-up.

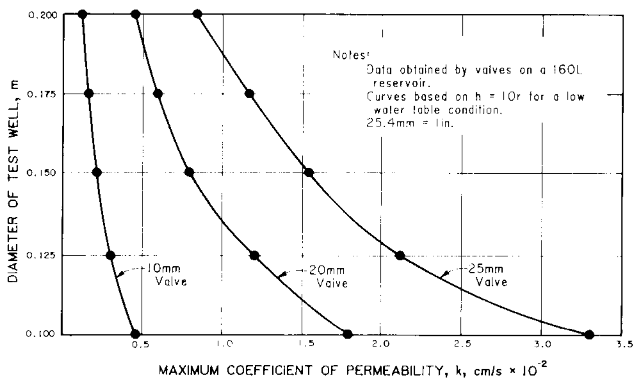


Figure 3. Maximum permeability coefficients measurable with typical float valves commonly used on stock-watering tanks.

NOTE 2.-There may be other appropriate valve-float equipment available for maintaining a constant water level in the test well.

8.2.6 Water Truck.-A water tank truck or tank trailer of sufficient capacity to provide a continuous supply of clean water for the number of test reservoirs in simultaneous use.

9. Reagents and Materials

9.1 ***Density*** San&Clean, dry, pervious, coarse sand (or fine gravel) calibrated for density and with a coefficient of permeability at least 1 X 10^2 cm/s greater than that of the soil to be tested is to be used for backfilling the test well. A washed sand graded between the U.S.A. Standard series No. 4 to No. 8 sizes (4.75 to 2.36 mm) or grave1 graded between the 3/8 to No. 4 (9.5 to 4.75 mm) sizes is recommended. The purpose of the pervious backfill is to (1) distribute water evenly in the well, (2) support the wall of the well and prevent sloughing during saturation of the soil, and (3) provide a means of indirectly determining the average radius of the well. The radius of the well is required for permeability calculations and, as explained later, a standard sand calibrated for mass per unit volume (density) can serve this purpose.

9.2 ***Water.-The*** water for this test is to be clean. Small amounts of suspended soil or other foreign material in the water may become deposited in the soil around the well and may greatly reduce the flow, causing erroneous results. When there is sediment in the water, arrangement should be made to remove the particles by settling or filtration. In some instances, a chemical reaction can take place between water of a particular quality and the soil being tested, which may cause an increase or decrease in soil permeability. Therefore, water similar in quality (exclusive of suspended sediment) to that expected to permeate the soil during project operation should be used for the permeability test.

10. Precautions

10.1 ***SafetyPrecautions.-*** Norma1 precautions taken for any fieldwork.

10.2 ***Technical*** *Precautions*:

10.2.1 In windy areas, protection from blowing soil may be needed to prevent interference to the operation of the valve-float mechanism and to prevent infiltration of soil into the top of the well.

10.2.2 Test equipment must be protected from disturbance by animals, moving equipment, children, or other sources.

11. Calibration

11.1 ***Water Reservoir*** (fig. 1).-Calibrate the volume of the water reservoir and mark the gauge tube in convenient increments for volume readings. For a 200-L reservoir, mark the volume gauge tube at 5-L intervals with the largest volume reading near the top of the tube so volume readings will decrease downward and permit volume determination by subtracting figures.

NOTE 3.-For a volume tube of cellulose acetate butyrate (which is recommended because it is durable for use under field conditions), ink with an acetate base makes a permanent mark on the tube. India ink can be used for marking if the surface of the plastic is first roughened with emery cloth or steel wool; the tube then should be coated with clear lacquer to preserve the ink marks.

11.2 ***Density*** San&Calibrate the sand by finding the density obtained by pouring the sand into a pipe or cylinder with dimensions approximately those of the test well. The pouring height above the top of the pipe should be approximately the same as that for the well. The calibrated density of sand is calculated from the mass of sand used to fill the pipe and the volume of pipe occupied by the sand; i.e., density equals mass per volume.

12. Conditioning

12.1 Special conditioning requirements are not needed for this procedure.

13. Procedure

13.1 ***Soil*** Logs.-Prior to performing field permeability tests for a seepage investigation, exploratory borings should be made at appropriate intervals and logs of the borings should be prepared to show a representative soil profile. Soil classifications of the different strata encountered should be recorded. The form shown in figure 4 can be used for this purpose.

The minimum depth of borings below a proposed canal invert or reservoir bottom should be to the ground-water table, to an impervious soil layer, or to a depth about twice the design water depth, whichever is reached first (see fig. 8). The location of soil layers that appear to be impervious and the depth to a water table, if reached, will affect permeability and seepage calculations. For depths below a canal invert or reservoir bottom greater than twice the water depth, the presence of a water table or soil layers of significantly different permeability than that of overlying soil will not influence permeability test results.

13.2 ***Size of Test*** We&For a low water table condition (see condition I, fig. 8), the depth of the well may be of any desired dimension provided the ratio of water height h in the well to well radius is greater than 1. To fulfill theoretical considerations in development of the equations for high water table conditions (conditions II and III, fig. 8), the ratio of water height h in the well to well radius should be greater than 10. A practical well diameter is usually 150 mm. Normally, in a canal seepage investigation, the water surface elevation in the well and the well bottom should correspond to the elevations of the proposed canal water surface and canal bottom, respectively. Test results would then provide an average permeability for the soils in the canal prism. For pervious soils, well size is limited by the capacity of the equipment to maintain a continuous supply of water at the desired constant head level. If necessary, more than one reservoir can be interconnected to increase water capacity. Figure 3 shows the maximum coefficients of permeability that can be measured in wells of various diameters using float valves of different sizes. This is of assistance in selecting the valve size to be used, although a valve of approximately 20-mm size is often used for general purposes.

13.3 ***Soil Permeability in Test Pits.-The*** well permeameter test method also can be adapted for use in test pits in a low water table condition if the ratio of water depth to pit radius is greater than 1, and sand or gravel backfill is used to prevent soil in the sides of the pit from sloughing. In this case, calibration of backfill is not necessary since dimensions of a test pit of regular shape can be found by averaging linear measurements. If a rectangular pit is used, the effective cylindrical radius for use in permeability calculations can be determined from the pit dimensions (see fig. 5).

13.4 ***Excavation of the Test Well.***-Wells for permeability tests should be prepared carefully to cause as little disturbance to surrounding soil as possible. Where moisture content of the soil is high, the wall of the hole can become smeared and outward flow of water restricted. In this case, the well should be excavated using two hand augers, one having a diameter at least 25 mm smaller than the other. First, auger a pilot hole with the smaller auger and follow this with the larger auger. This causes less disturbance to the wall of the well than if a single auger is used. If it is still apparent that the wall of the well is smeared, the walls should be scraped or scratched with improvised tools to remove the smeared surface. Remove any loose soil from the bottom of the well.

13.5 Depth of the Well (figs. 1 and 4).-Depth measurements in the well should be measured (and recorded) from a common base line. A convenient method is to measure from a horizontal string line stretched between two stakes driven firmly into the ground on opposite sides of the well (fig. 1). When the bottom of the well extends below ground-water level, insert a casing during excavation to prevent the wall from caving. Carefully pull the casing as the well is backfilled with sand through the casing.

NOTE 4.-For a very high ground-water condition, a "pump out" test for saturated soils is often more satisfactory than the well permeameter test or other "'pump in" types of tests.

13.6 Backfilling the Test Well.-Pour calibrated sand into the well in the same manner as during calibration of the sand for density. The top of the sand should be about 150 mm below the water level to be maintained. After completion of pouring, determine the remaining mass of sand and subtract from the original mass to find the mass of sand in the well. Measure and record the depth to the top of the sand and calculate the height of sand in the well. From the density of the calibrated sand and the mass and height of sand in the well, calculate the

7-1429 (5-89) Bureau of Reclamation	WELL PERMEAMETER METHOD (SOIL CLASSIFICATIONS AND WELL DIMENSIONS)	Designation USBR 7300 - 89

EST NO. 22	PROJECT Example	FEATURE Example

EST LOCATION Station 257+94	TEST LIMITS:	STATION 257+25	TO STATION 258+62

ROUND ELEVATION 122.6	CANAL DATA:	SIDE SLOPES 2:1	BOTTOM WIDTH 7.9 m	WATER DEPTH 1.890 m

ESTED BY	DATE	COMPUTED BY	DATE	CHECKED BY	DATE

[X] m [ ] ft

OBSERVATION HOLE

STRATA FROM	DEPTH TO	SOIL CLASSIFICATION
0	0.45	SILTY CLAY: approx. 85% fines with medium plasticity, slow dilatancy, medium dry strength, medium toughness; approx. 15% fine sand; maximum size, fine sand, moist, dark gray; easy to auger; some roots present; no reaction with HCl (CL-ML).
0.45	1.77	CLAYEY SILT: approx. 95% fines with low plasticity, slow dilalancy, low dry strength, low toughness; approx. 5% fine sand; maximum size, fine sand; wet, brown; easy to auger; no reaction with HCl (ML-CL).
1.77	3.87	SILTY SAND: approx. 60% fine to coarse, hard, angular sand; approx. 20% non-plastic fines; approx. 20% predominantly fine, hard, angular to subangular gravel; maximum size, 30mm; moist, brown; moderately hard to auger; slight reaction to HCl (SM).

(1) DEPTH TO WATER TABLE (FROM GROUND SURFACE) 3.75 [X] m [ ] ft

WELL DIMENSIONS (DEPTHS FROM STRING BASELINE)

(2) 0.213 [ ] m [ ] ft

(3) 1.222 [ ] m [ ] ft

(4) SAND 0.375 [X] m [ ] ft

(5) (3) - (4) 0.847 [X] m [ ] ft

(6) DEPTH TO WATER SURFACE IN WELL 0.280 [X] m [ ] ft

(7) HEIGHT OF WATER IN WELL h = (3) - (6) [illegible] [ ] m [ ] ft

DETERMINATION OF WELL RADIUS

(8) DENSITY OF STANDARD SAND 1400 [ ] kg/m³ [ ] lbm/ft³

(9) MASS OF SAND + CONTAINER BEFORE FILLING WELL 34.02 [ ] kg [ ] lbm

(10) MASS OF SAND + CONTAINER AFTER FILLING WELL 2.86 [ ] kg [ ] lbm

(11) (9) - (10) 31.16 [ ] kg [ ] lbm

(12) (11)/(8) 0.0223 [ ] m³ [ ] ft³

(13) $r = \sqrt{(12)/(5)\pi}$ 0.092 [X] m [ ] ft

Figure 4. - Well permeameter method (soil classifications and well dimensions) - example

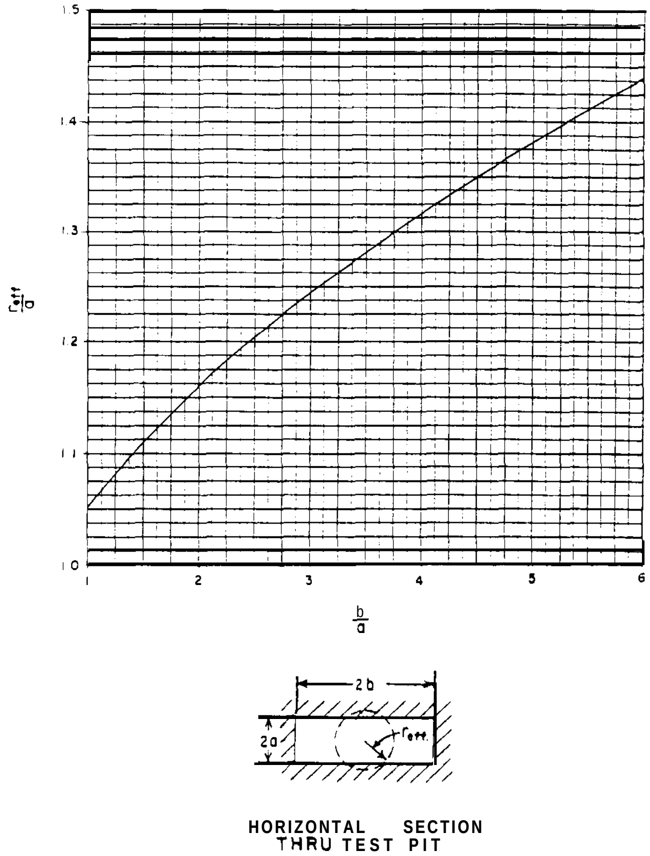


Figure 5. Effective cylindrical radius of rectangular test pits. (fig. 44 of ref. 2)

equivalent radius of the well (fig. 4). Development of the equation for determining the radius is:

$$V_s = \pi \, r_w^2 \, h_s = \frac{m_s}{\rho_s}$$

$$r_w^2 = \frac{V_s}{\pi h_s}$$

$$r_w = \sqrt{\frac{m_s}{\pi h_s \, \rho_s}} \qquad (1)$$

where:

V_s = volume of sand
ρ_s = density of sand
h_s = height of sand
m_s = mass of sand
r_w = equivalent radius of well

13.7 ***Test Equipment Set*** Up.-Place the float guide, with the float inside, on top of the sand in the well. Hold the float guide in place vertically and pour sand around it. When a test is to be conducted with the water level more than an arm's length below the ground surface, lower the float guide by the chain and drop sand around the guide to hold it in place during the test. The rubber slip washer on the float stem is to prevent particles of sand from becoming lodged between the float stem and the float guide. The mass of sand around the guide need not be known because it is not used in computations for well radius. Set up the water reservoir and valve-float arrangement with the flexible tube from the float valve to well and the chain attached to the float stem as shown on figures 1 and 2. The reservoir should be set on a firm platform or cribbing at a convenient height.

13.8 Performing the Test:

13.8.1 Open the valve on the reservoir and gradually fill the well with water.

13.8.2 After the water enters the float casing, readjust the counterbalance on the operating arm of the valve and the chain length as necessary to maintain the desired water level in the well.

13.8.3 After the water level in the well has stabilized, begin reading the volume gauge on the reservoir and record the gauge readings at convenient time intervals using the form as shown on figure 6. The well must be kept continuously full of water until the test is completed. In general, dry soil at the start of the test absorbs water at a comparatively high rate. However, as the moisture content of the soil increases around the well, the rate generally decreases and usually stabilizes. It is this constant rate after stabilization that is used to compute permeability.

13.8.4 As records of water discharge from the reservoir and time are made, plot a curve of accumulative flow versus time as shown on figure 7.

14. Test Duration

14.1 Minimum duration for the test is the theoretical time required to discharge the minimim volume of water into the soil to form a saturated envelope of hemispherical shape with a radius ***B*** ***(see*** fig. 1).

The minimum volume of water is determined by the equation:

$$V_{min} = 2.09 \, S \left\{ h \sqrt{\frac{2}{\ln\left[\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 + 1}\right] - 1}} \right\}^3 \qquad (2)$$

where:

V_{min} = minimum volume
S = specific yield of the soil
h = height of water in well
r = well radius

NOTE 5.-The quantity in brackets is the theoretical determination for radius B (fig. 1).

For soils in which this test would most likely be used, the specific yield varies from about 0.1 for fine-grained soils to 0.35 for coarse-grained soils. When the specific yield of the soil is unknown, the value of 0.35 should be used to give a conservative value for minimum volume and to ensure that the test duration is sufficient. Thus,

7-1428 (5-89) Bureau of Reclamation	**WELL PERMEAMETER METHOD (TIME AND VOLUME MEASUREMENTS)**	Designation USBR 7300 - 89

TEST NO. 22	PROJECT Example	FEATURE Example
TEST LOCATION 257+94	WATER SOURCE Youngfield River	GROUND TEMPERATURE 20° C
TESTED BY / DATE	COMPUTED BY / DATE	CHECKED BY / DATE

TIME		WATER VOLUME ☒ L ☐ ft³						WATER TEMPERATURE °C	
CLOCK (24hr.)	ACCUM. (min.)	DRUM NO. 3		DRUM NO. 4		TOTAL DIFFERENCE	ACCUM. FLOW (q)		
		READ	DIFFERENCE	READ	DIFFERENCE			WELL	RESERVOIR
8:00	0	201	--	204	--	---	---	--	--
8:50	50	127	74	124	80	154	154	19	25
9'40	100	80	47	74	50	97	251	19	--
10:30	150	42	36	34	40	76	329	19	--
11:20	200	8	34	1	33	67	396	20	26
11:30	210	202	--	201	--	--	---	--	--
12:10	250	179	23	179	22	45	441	20	--
13:00	300	153	26	153	26	52	493	21	--
13:50	350	124	29	125	28	57	550	21	27
14:40	400	97	27	98	27	54	604	22	--
15'30	450	71	26	70	28	54	658	22	--
16:20	500	46	25	44	26	51	709	21	--
17:10	550	19	27	19	25	52	761	20	--
17:20	560	204	--	202	__	--	---	--	--
18:00	600	181	23	181	21	44	805	20	27
18:50	650	154	27	154	27	54	859	20	--
19'40	700	127	27	127	27	54	913	19	--
20'30	750	100	27	99	28	55	960	19	--
21'20	800	74	26	73	26	52	1020	18	25
23:00	900	35	39	33	40	79	1099	17	--
24'40	1000	5	30	3	30	60	1159	15	--

Figure 6. Well permeameter method (time and volume measurements) — example.

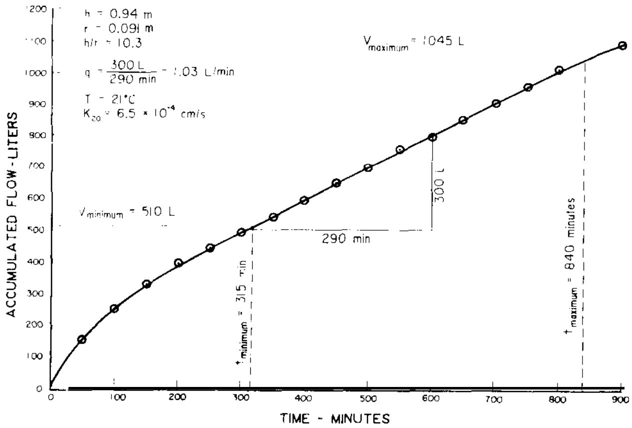


Figure 7. - Time-discharge curve for well permeameter test — low water table example.

with a known or assumed specific yield for the soil and with the dimensions of the well, the minimum volume can be computed and the test discontinued when the minimum volume has been discharged through the well. In pervious soils, it may appear that the volume-time curve has reached a uniform slope after several hours when points are plotted over short time intervals. However, in order to avoid discontinuing a test prematurely, it must be continued for at least 6 hours from the starting time so the slope can be determined over a period of 2 to 3 hours. The first straight portion of the curve should be used for determining the rate of discharge (fig. 7). The test must be conducted continuously without allowing the reservoir to run dry until the test has been completed.

14.2 Maximum Time.-If the test is continued for a long period, a water mound may build up around the well and render the test results inaccurate. The maximum time for test duration is the time necessary to discharge through the test well the maximum volume of water as determined using equation (2), substituting 15.0 for 2.09 and in this case, using an assumed minimum value (when the true value is unknown) of 0.1 for specific yield.

$$V_{max} = 2.05\ V_{min} \qquad (3)$$

15. Calculations

15.1 Computing Coefficient of *Permeability.*-Equations (4), (5), or (6) are provided for calculating coefficient of permeability, for the well permeameter test. The presence or absence of a water table or impervious soil layer within a distance of less than three times that of the water depth in the well (measured from the water surface) will enable the water table to be classified as condition I, II, or III, as illustrated on figure 8.

15.1.1 ***Low*** *Water* Table.-When the distance from the water surface in the test well to the ground-water table, or to an impervious soil layer which is considered for test purposes to be equivalent to a water table, is greater than three times the depth of water in the well, a low water table condition exists as illustrated by condition I (fig. 8). For determination of the coefficient of permeability under such a condition, equation (4) given in subparagraph 15.2 should be used.

15.1.2 High Water Table.-When the distance from the water surface in the test well to the ground-water table, or to an impervious layer, is less than three times the depth of water in the well, a high water table condition exists as illustrated by condition II or III. Condition II shows a high water table with the water table below the well bottom, and for this condition equation (5) should be used. Condition III shows a high water table with the water table above the well bottom. For this condition, equation (6) should be used.

15.2 Equations:

Condition I:

$$k_{20} = \frac{qV}{2\pi h^2}\left\{ \ln\left[\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 + 1}\right] - \frac{\sqrt{1 + \left(\frac{h}{r}\right)^2}}{\frac{h}{r}} + \frac{1}{\frac{h}{r}} \right\} \qquad (4)$$

Condition II:

$$k_{20} = \frac{qV}{2\pi h^2}\left[\frac{\ln\left(\frac{h}{r}\right)}{\frac{1}{6} + \frac{1}{3}\left(\frac{h}{T_u}\right)^{-1}}\right] \qquad (5)$$

Condition III:

$$k_{20} = \frac{qV}{2\pi h^2}\left[\frac{\ln\left(\frac{h}{r}\right)}{\left(\frac{h}{T_u}\right)^{-1} + \frac{1}{2}\left(\frac{h}{T_u}\right)^{-2}}\right] \qquad (6)$$

where:

k_{20} = coefficient of permeability at 20 °C
h = height of water in the well
r = radius of well
y = discharge rate of water from the well for steady-state condition (determined experimentally, see example, fig. 7)
$V = \frac{\mu_T, \text{ viscosity of water at temp. } T \text{ (see fig. 9)}}{\mu_{20}, \text{ viscosity of water at } 20\ °C}$
T_u = unsaturated distance between the water surface in the well and the water table

15.3 The preferred metric unit for coefficient of permeability is cm/s (centimeters per second). The value of 1 X 10^{-6} centimeters per second is approximately the same as the inch-pound unit of 1 foot per year.

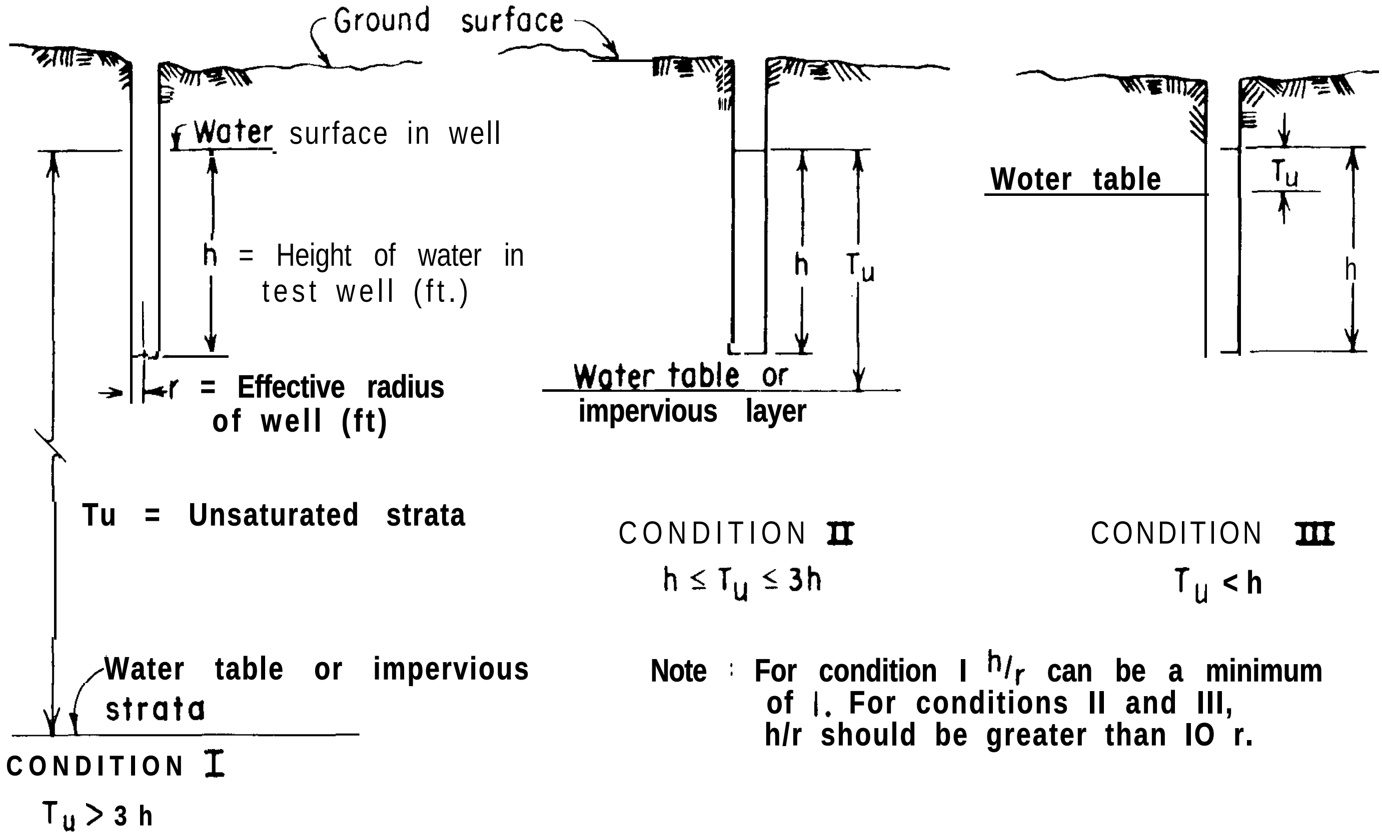


Figure 8. Relationship between depth of water in test well and distance to water table in well permeameter test.

16. Report

16.1 The report is to consist of the following completed and checked forms:

"Well Permeameter Method (Soil Classifications and Well Dimensions)" (fig. 4).

"Well Permeameter Method (Time and Volume Measurements)" (fig. 6).

Time-Discharge Curve (example on fig. 7).

Calculation of coefficient of permeability from equations (4), (5), or (6).

16.2 All calculations are to show a checkmark and all plotting must be checked.

17. References

[1] ***Drainage Manual,*** 1st ed., Bureau of Reclamation, U.S. Government Printing Office, Washington, D.C., 1984.

[2] Zanger, Carl ***Z., Theory and Problems of Water Percolation,*** Engineering Monograph No. 8, (app. B "Flow from a Test Hole Located Above Groundwater Level," development by R. E. Glover) Bureau of Reclamation, Denver, Colorado, April 1953.

[3] Ribbens, R. W. "Exact Solution for Flow From a Test Hole Located Above the Water Table," (unpublished technical memorandum), Bureau of Reclamation, Denver, Colorado, 1981.

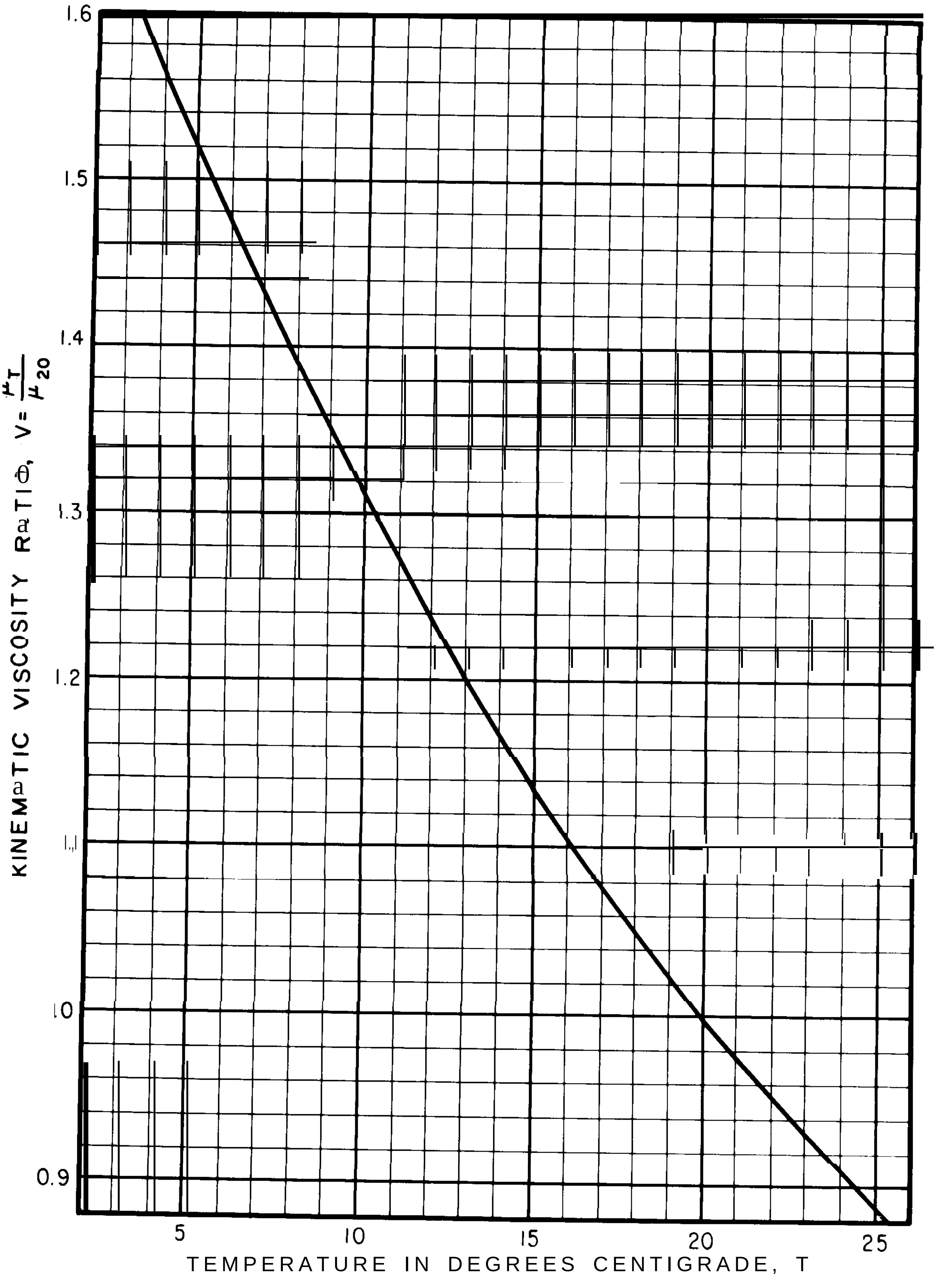


Figure 9. – Relationship between kinematic viscosity ratio of water and temperature