A Review of Infiltration Standards and Practices in Clark County

July 31, 2009

Prepared by

Infiltration Standards Review Committee
Southwest Washington Branch, Oregon Section
American Society of Civil Engineers

Table of Contents

Executive Summary

The Southwest Washington Branch of the American Society of Civil Engineers formed the Infiltration Standards Review Committee in 2005 to review current standards and practices in the design and construction of infiltration facilities in Clark County and the City of Vancouver. The Committee consists of representatives from Clark County, the City of Vancouver, and local engineers and geologists with experience in soil testing and/or the design of infiltration systems.

Particular concerns raised to the Committee included the failures of a handful of infiltration systems around the County. These were located within areas consisting primarily of mixed sands and silts. Because of this correlation, the Committee focused on the testing and evaluation of these soil complexes, though most of the recommendations are applicable in all areas of the County.

This paper contains background information and the Committee's recommendations on the following:

- Infiltration Testing & Reporting of Results
- Design of Infiltration Facilities
- Construction of Infiltration Facilities

Recommendations are based on the best science available and the members' experience with projects in Clark County.

1.0 Introduction

As the urban and suburban areas of Clark County advance north from the gravelly, well-drained soils of Vancouver, development has moved into areas where surface drainages are not immediately available and soils are not as well suited to infiltration as areas in the south and east portions of the City. Several infiltration facilities installed within these areas have failed to perform according to the original design or tested infiltration rate. Generally, these facilities are distributed through a broad area characterized by fine-grained soils (primarily silts and sands). As a result, both Clark County and the City of Vancouver have placed limitations on the design of stormwater infiltration systems in these areas.

The Southwest Washington Branch of the American Society of Civil Engineers (ASCE) was approached by one of its members in the spring of 2004 to review current standards from Clark County and other jurisdictions in the area, to research alternative standards, and to make recommendations for revisions to city and county codes relating to the design of stormwater infiltration facilities. In response, the Infiltration Standards Review Committee was formed. Several members of the engineering community were approached and a group was selected to provide a cross-section of individuals involved in testing and design. A short biography of each member is included as an appendix to this report. Regular meetings began in April of 2005 and continued through August 2007. An initial public review draft of this paper was finalized on August 31, 2007. After receiving and reviewing comments and suggestions, the Review Committee reconvened, updated and revised several text sections, and finalized the paper in July 2009.

This report is intended to summarize the Infiltration Standards Review Committee's findings and recommendations and is structured as follows:

- Section 2 - Background description of the infiltration process
- Section 3 - Factors that affect infiltration processes
- Section 4 - Process for evaluating site soils for infiltration suitability and design rates
- Section 5 - Design of infiltration systems
- Section 6 - Construction of stormwater infiltration systems and protection of those systems during infrastructure and building construction.

2.0 Background

Development processes convert areas covered with native vegetation to impervious areas such as roofs, roads, parking lots, and sidewalks and pervious areas such as landscaping and lawns. All of these areas contribute to increases in the quantity of runoff (both flow rate and the total volume) and limit the ability of stormwater to infiltrate into the soil surface. The effects of this additional runoff are compounded by changes to the hydrology, including reducing the travel time to the receiving waters and increasing the frequency and duration of streamflows (and greater flow velocities). The accompanying reduction in groundwater recharge impacts aquifers and near-surface flows which support dry weather streamflow.

In order to offset the effect that new development has on the natural hydrology, stormwater runoff is collected, detained, treated, and disposed in a controlled manner. One method of stormwater disposal is via infiltration of the water into the native soil subgrade. Common infiltration systems include: drywells, infiltration trenches or galleries, infiltration swales, pervious pavements, and infiltration ponds. There are two basic processes involved in the design of infiltration systems: the pre-design soils evaluation and subsequent sizing and layout of the system. The soils evaluation is typically completed by a geotechnical engineer or geologist and then summarized in a geotechnical or infiltration report. The soils evaluation generally includes site-specific characterization of subsurface soil conditions; estimation of the high groundwater level; and evaluation of the soil's infiltration rate (the speed at which water moves through the soil). The sizing and layout of the infiltration system is then completed by the project civil engineer based upon information provided by the geotechnical/infiltration report, runoff characteristics of the development, design storms, development patterns, etc.

Clark County has a history of failures of stormwater infiltration facilities and these failures are becoming more common, or at least more apparent, as larger and denser developments are constructed within the County limits. The "failure" of an infiltration system generally involves an inability of the facility to dispose of the quantity of water for which it was designed. Major failures may result in the system overflowing and flooding streets and private or public properties.

Failures of infiltration systems are usually the result of poor or improper design and/or construction. Design errors can occur either during the soils evaluation or sizing of the system. The most common errors associated with the soils evaluation include insufficient number of tests, improper or inadequate characterization of the soil's infiltration properties, tests not completed at the actual system location (horizontal or vertical), and underestimation of the high groundwater level, though other factors may also exist. A common error during the sizing of the system is a design that does not size the infiltration facility to store and dispose of runoff from short, intense storms (i.e. "microbursts") which results in temporary flooding that may be significant. Common construction-related problems include poor erosion control that causes excessive sedimentation or clogging, and smearing or compaction of the infiltrative soil subgrade that reduces infiltration rates. Regardless of the cause, these incidents often result in damage to public and private properties and a perception on the public's part that engineers and regulators are not fulfilling their professional obligations.

3.0 Factors That Affect Infiltration

3.1 Soils and Geology

Soil conditions are a frequent contributor to infiltration system underperformance. The majority of Clark County's problem facilities have been concentrated in a region around the northern limits of the City of Vancouver associated with particular soil types resulting from patterns of ancient flood deposition. Most of these "problem" soils consist of layered structures of fine sands and silts; examples of these are Hillsboro, McBee, Gee, and Dollar soils, as classified by the Natural Resource Conservation Service (formerly Soil Conservation Service), and generally shown as the orange area on the map included with this report. While these may be suitable for infiltration via properly designed systems, their fine structure is susceptible to clogging by sediments or migration of fine particles within the native soils and special care should be taken during the design of facilities located in these areas.

The characteristics of soils found in Clark County are shaped by Late Pleistocene age Missoula Flood depositional history. Permeability, among other soil engineering properties, is strongly influenced by the gradation of soils distributed by floods over the low-lying area of the County. As can be noted on the included map, soils are generally distributed in concentric bands or zones of coarse-grained to fine-grained soil from east to west, and south to north across the county. This distribution of soil is a result of the flow velocity and depositional energy associated with the Missoula Floods that inundated the County and surrounding areas several times during the last continental ice age advance about 15,000 to 13,500 years ago.

The glacial floods generally had the highest velocity and highest capacity to transport sediment in the southern and eastern part of the County adjacent to the Columbia River. As the floods inundated the Columbia and Willamette River systems, sediment-laden water spread beyond the river channels to form a broad temporary lake. In this temporary lake, deposition energy dropped, and the finer grained material (i.e. clay, silt, fine sand, and micaceous particles) that remained in suspension spread into the central, northern and western parts of the county beyond the zone of coarser sands and gravels. Here the fine-grained material dropped out of suspension to form broad, thin sedimentary beds that now represent the medium- to fine-textured near-surface soils of the area.

The fine-grained soils are locally interspersed with lenses or layers of medium-grained sand that were deposited under local pulses or surges of glacial flood waters that formed during draining of the temporary glacial lakes. Many of the sand lenses take the form of thin discontinuous sheets or shallow channels that are bedded within the fine-grained soils.

Within the fine-grained deposits, several soil units have been observed to yield occasional field permeability rates that indicate adequate capacity to dispose of concentrated storm water through subsurface infiltration methods. However, it is these medium- to fine-textured soils that have the highest incidence of storm water system failures in the County. In particular, storm water infiltration management systems in some areas of Hillsboro soils have a poor track record of long-term performance. Many of the failures appear to be due to poor construction practices and lack of erosion control methods during construction. Due to their fine texture, these soils are predisposed to caking and sealing of permeable soils as a result of particle migration. However, some storm water infiltration facility failures are probably due to improper understanding of the complexly layered soil and overestimation of bulk soil permeability.

It is generally accepted that the primary challenge of infiltration system evaluation and design in the Hillsboro and other silt and sand loam type soil is characterizing the complexly layered nature of the medium- to fine-textured soils. An inadequate understanding of the three-dimensional distribution of these soils has resulted in some system designs being based on the higher, short-term permeability rates obtained in medium-grained sand lenses, as opposed to the rates obtained in the fine-grained soil mass.

3.2 Sedimentation and Caking

Sediment consists of soil particles that are carried by the stormwater into the system. During heavy flows, sediment can include both coarse- and fine-grained materials. Treatment systems, such as grass-lined biofiltration swales or sedimentation basins are utilized to allow sediment to settle out of the stormwater. However, clay and micaceous fines are particularly problematic in that these small and light-weight soil particles remain suspended in water even after passing through many types of treatment systems. Also, wave action on small bodies of water or heavy flows can re-mobilize fines into suspension. Some of these particles literally float into suspension in initially clear water. Over time, the suspended particles can accumulate as a thin, nearly impervious cake on the prepared bottoms of infiltration systems. Such conditions lead to premature failure of infiltration systems. In extreme cases, system failure can occur over one rainy season. Attempts to rehabilitate the pond bottoms and infiltration systems by excavating the clay and mica-caked soils are rarely successful long-term solutions.

It is difficult to predict the degree of caking or clogging that clay, silt, and micaceous sediment can inflict on an otherwise well-designed storm water infiltration system. The presence of excessive sediment is often the result of poor erosion and sediment control during construction, though can also occur due to lack of maintenance or inadequately designed treatment systems.

3.3 Topography and Grading

Grading, filling, and in some cases excavating, can dramatically impact soil permeability, response to erosion, or susceptibility to caking. In general, installing infiltration systems in graded or filled soils is not acceptable, except in special circumstances. Common design cases where filling is acceptable include placement of washed drain rock in drywell backfill or placement of engineer-approved granular soil to protect pond or infiltration trench bottoms. Generally disturbing, grading, compacting, or tracking of construction equipment across soil intended for infiltration impairs the soil's ability to infiltrate water as intended.

Changes in soil stress from foundations, retaining walls, embankments such as berms or dams, and similar loads placed on soils can reduce soil permeability. If the designer does not consider changes in soil stress and its impact on soil permeability, failure of the system could occur.

The introduction of concentrated water near slopes can reduce stability by initiating subsurface seepage pressure and local reduction of effective stress through saturation of inter-granular space between soil particles. Excessive erosion, soil creep, or other soil slope problems can occur due to introduction of subsurface water. While these concerns may not affect the performance of the infiltration system, they should be considered when planning ponds or siting infiltration systems in proximity to slopes.

3.4 Groundwater

When groundwater levels are too close to the base of an infiltration system, the system can be flooded or groundwater "mounding" may occur. Groundwater mounding is a phenomenon where the groundwater table is locally elevated due to the introduction of water from an external source, such as an infiltration system. Mounding is essentially the opposite of the "drawdown" that occurs adjacent to a well pumping groundwater. Flooding or mounding can significantly reduce or essentially stop infiltration. Mischaracterization of the high groundwater table, the presence of an unidentified groundwater table, or a seasonally perched groundwater level can cause an infiltration system to fail as flooding or mounding occurs.

Seasonal perched groundwater, or evidence of such in the form of mottled, gleyed, or oxidized soil textures likely denotes a site or soil condition not generally appropriate for infiltration of storm water. Exceptions may apply in cases of wetland enhancement or other environmental restoration concepts. Evidence of seasonal perched groundwater can sometimes be nearly imperceptible and can lead to erroneous site characterization. Likewise, in certain pervious soils, seasonally fluctuating static groundwater levels can be misinterpreted during the dry season. Generally, geotechnical infiltration evaluations conducted during the wet season when groundwater should be at its higher elevations have a greater degree of confidence in establishing the actual perched and static groundwater levels that should be considered in the design. Depending on the annual rainfall totals, groundwater levels generally reach their highest elevations in late spring. The lowest groundwater levels are often recorded from September to November.

3.5 Testing and Reporting

Testing and reporting practices vary widely depending upon individual consultants and design professionals. Some test methods currently in use may not be appropriate for the type of facility proposed or the soils present in certain areas of concern. The lack of a standardized testing and reporting method creates difficulty for the reviewing agency and compromises the reproducibility, comparison, and evaluation processes. Recommendations for testing practice and reporting requirements are discussed later in this document.

3.6 Development Patterns and other Factors

Topographic, development and regulatory pressures contribute to the placement of infiltration facilities in this region. As the City of Vancouver's Urban Growth Boundary and the semi-urban development within Clark County continue to expand, increased development and density are required to meet Growth Management Act targets and limit urban sprawl. This results in more concentrated development with higher impervious surface coverage (roofs, roads, driveways, etc.) and leads to increased runoff from developed sites. Intensive development increases the detention volume required to offset the increased runoff rates while simultaneously reducing the area available for the placement of such detention facilities.

Many of the development sites within this region have traditionally been semi-rural; frequently, these sites are isolated from surface streams which might otherwise accept stormwater discharges from development. This isolation may be due to topography or intervening undeveloped properties. Storm sewers are also not available in these previously undeveloped areas. In order to avoid increasing the rate of runoff or concentrating runoff onto adjoining properties where no stream or drainage path exists, infiltration is sometimes the only alternative for the disposal of stormwater. However, many of these semi-rural areas are located in regions with fine-grained soils which, as previously discussed, have low infiltration rates and are susceptible to failure.

As its benefits (flow control, temperature reduction, groundwater recharge, etc.) in the natural environment become better understood, an increasing emphasis on infiltration is being incorporated into stormwater management guidance documents such as the 2005 Stormwater Management Manual for Western Washington. Infiltration is listed as the preferred method for the disposal of stormwater runoff where feasible. More stringent water quality standards implemented in response to the EPA Storm Water Phase II rules are also likely to encourage the use of infiltration or soil contact for temperature control and pollutant removal.

Increased development density to meet growth management goals can also result in potential conflicts with infiltration system location. As the most readily usable land is more densely developed, the area available for locating stormwater infiltration facilities is reduced. Those facilities must then be installed closer to areas which can be damaged by groundwater, such as foundations, potentially unstable slopes, or road subgrades. Increasing the number of infiltration facilities without proper protection also increases the risk of groundwater contamination due to pollutants entering runoff from human activities. These potential risks increase the complexity of the analysis and design required before these facilities are constructed.

In combination, these pressures result in the installation of infiltration systems in less-than-ideal conditions. Throughout the remainder of this report, specific recommendations relating to suitable soil identification, infiltration rate testing, design assumptions and procedures, and construction will be made to more uniformly ensure that installed systems continue to function over the life of the facilities.

4.0 Soils Evaluation

Proper evaluation of soils is critical to placement of infiltration facilities in marginal conditions. The soils evaluation process can be separated into the following two primary components: (1) field testing by an accurate and verifiable test method, and (2) presentation of results in a standardized reporting format. These components are discussed in the following text.

4.1 Field Test Method

Adequate understanding of the infiltration test method process requires discussion of the following items:

- definition of applicable standard terms,
- description of current infiltration testing methods,
- explanation of differences between infiltration and percolation,
- definition of a recommended infiltration test method,
- discussion of alternative test methods, and
- identification of specialized testing for unique sites.

These items are presented below.

4.1.1 Definition of Terms

Several of the most relevant terms used in the soil infiltration mechanistic and testing processes are defined below (Oram, 2005, Ferguson, 1994):

Infiltration – The one-dimensional (usually downward) entry of water into the immediate soil surface.

Infiltration Rate – The rate at which water penetrates the soil surface, expressed as velocity. It is a one-dimensional volume flux of water flowing into a two-dimensional soil surface area. The infiltration rate is constrained by the capacity of the soil and the rate at which water is applied to the surface. The infiltration rate of a given soil varies under saturated and unsaturated conditions. Because storm water management design must consider long-term conditions, the saturated infiltration rate is of primary interest to engineering professionals. Under saturated soil conditions, the infiltration rate is essentially equivalent to the soil coefficient of permeability, defined below. In this document, the term "infiltration rate", as defined by the measured and calculated coefficient of permeability, refers specifically to the assumed rate at which water will infiltrate vertically into a saturated soil.

Allowable Design Infiltration Rate – The final infiltration rate used by design engineers to size infiltration systems. It is calculated by applying correction factors to the infiltration rate defined above to compensate for soil variation, long-term system degradation, and other factors.

Percolation – The simultaneous three-dimensional vertical and lateral movement of water through soil by gravity.

Drawdown Rate – The direct raw field measurement of the rate of water drop during a given in situ infiltration test, expressed as velocity.

Coefficient of Permeability (also called Hydraulic Conductivity) – A quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient, expressed as velocity. As described later, the coefficient of permeability is calculated based upon the observed drawdown rate and configuration of the infiltration test apparatus. The coefficient of permeability commonly varies in the horizontal and vertical directions. Due to the effects of gravity, the vertical coefficient of permeability is the primary component of interest in the soil infiltration process. As described above, the saturated vertical soil coefficient of permeability may be assumed to equal the soil infiltration rate. Therefore, when discussing saturated vertical flow conditions in this document, the terms "coefficient of permeability" and "infiltration rate" are equal. The calculated coefficient of permeability is the infiltration rate. These terms should not be confused with the drawdown rate previously defined.

4.1.2 Description of Current Infiltration Testing Methods

Several different test methods are currently used to estimate local soil infiltration rates:

Surface Water Design Manual (King County, 1990)

The "King County Method" (or a modified version) uses a water-filled, 48-inch-long standpipe embedded six inches into the soil. King County abandoned this method shortly after adopting it in their 1990 Surface Water Design Manual, but it is still used by many jurisdictions and practitioners.

Falling Head Methods (EPA, 1980)

Modified falling head methods (based on 1980 EPA Falling Head Percolation Test method) are conducted through pipes of various lengths and diameters placed in pits excavated by a backhoe or through the casing of a hollow-stem auger boring rig. These tests are easy to conduct but can produce significantly varying test results depending on the standpipe length and test apparatus configuration.

Double-Ring Infiltrometer (EPA, 1997)

The double-ring infiltrometer method (EPA/600) uses an instrumented double-ring configuration to confine an inner plume of infiltrating water in a one-dimensional vertical direction. The double-ring infiltrometer test is typically used for soils with very low infiltration rates. The test is time-consuming, expensive, and can be subject to considerable error if installed incorrectly.

Stormwater Management Manual for Western Washington (DOE, 2005)

The Stormwater Management Manual for Western Washington (2005) [the Manual] has been adopted by many agencies for use in the design of stormwater treatment and disposal systems. Section 3.3.6 of the Manual discusses three methods for estimating infiltration rates for design of infiltration facilities:

- USDA Soil Textural Classification
- ASTM Gradation Testing at Full Scale Infiltration Facilities
- In-situ Infiltration Measurements

The first two methods consist of correlations between material gradations and long-term infiltration. However, the data used to develop these correlations were primarily based upon field data associated with infiltration ponds in the Puget Sound area. The use of infiltration ponds is unusual in Clark County, and the infiltration rate correlations are likely to be highly conservative for the more commonly used infiltration trenches and galleries.

For in-situ infiltration measurements, the Manual recommends use of a Pilot Infiltration Test (PIT Method). The PIT method uses a large open pit or trench flooded with a large volume of water over an extended period of time. This method may be assumed to provide fairly accurate infiltration rate estimates, but it is costly, time-consuming, and not practicable for many difficult-to-access sites. Safety concerns and the necessary disturbance of the PIT Method often also combine to prohibit its regular use.

The Manual also indicates that small-scale field tests, such as falling head or double-ring infiltrometer tests "are not recommended unless modified versions are determined to be acceptable by Ecology or the local jurisdiction" (DOE, 2005). The recommended procedure outlined in this section of this report is meant to provide an acceptable modified test method that is practical, cost-effective, and produces a reasonable estimate of soil infiltration rates.

4.1.3 Differences between Infiltration and Percolation

It is important that infiltration systems be designed based upon the soil *infiltration* rate and not the *percolation* rate. There are several important differences between infiltration and percolation. Percolation flow is multi-dimensional whereas infiltration is one-dimensional. Percolation is typically of interest to designers and practitioners under short-term, non-steady-state, unsaturated conditions. Infiltration is relevant for long-term, steady-state, saturated flow environments. Percolation rates are often used for unsaturated flow applications such as residential septic wastewater disposal trenches where flow volumes are limited and short-term. Infiltration is more representative of high volume, long-term subsurface injection of concentrated storm water. Percolation rates are not directly correlated to, or a component of, saturated flow equations (Oram, 2005). Percolation tests do not directly measure the coefficient of permeability or infiltration rate. Comparison tests have indicated that percolation tests may over-estimate the infiltration rate by 40 percent to more than 1,000 percent (Oram, 2005).

4.1.4 Alternative Infiltration Test Method

A successful estimation of the soil infiltration rate, indicated by the coefficient of permeability, depends upon a precise and accurate infiltration test method. An appropriate test method should:

- Be consistent, dependable, reviewable, and reproducible;
- Restrict flow to the vertical dimension;
- Prevent leaking or piping;
- Include an appropriate pre-soak phase to ensure saturated flow conditions;
- Be applicable and useful for Clark County soils;
- Have easily and accurately obtainable test measurements, parameters, and equation inputs; and
- Allow for precise and clear calculation of the coefficient of permeability.

For practical purposes, the test method would also have the following desirable characteristics:

- Not excessively difficult to install or operate; and
- Not excessively burdensome, time-consuming, or costly;

Infiltration testing can be conducted under steady-state (constant head) or non-steady-state (falling head) conditions. Constant head tests are often performed in a controlled laboratory environment, whereas falling head tests are usually conducted in the field. Either method is acceptable provided saturated conditions are maintained.

Finally, infiltration tests can also be performed with single-ring or double-ring devices. While there remains some dispute in the geotechnical community regarding the efficacy and accuracy of single-ring tests when compared to double-ring tests, if installed correctly, single-ring tests can provide reasonable soil coefficient of permeability estimates (Oram, 2005). Because single-ring test apparatus tend to be less complex and easier to install, many experienced professionals prefer some version of the single-ring test. Therefore, a modified single-ring falling-head infiltration method that meets the above requirements is defined in the following section.

Presentation of the mechanisms and processes of infiltration, discussion of the differences and significances of falling head/constant head and single-ring/double-ring tests, and mathematical derivation of the test method equations are provided in Appendix A.

Alternative Single-Ring Falling-Head Infiltration Test Procedure

1. Test Frequency and Location. Conduct one or more infiltration tests at each proposed infiltration location for ponds, subsurface galleries, reservoirs, or drainage trenches; or conduct one infiltration test for each proposed drywell location. Ideally, tests are conducted at the proposed depth and location of the final system, however, future system locations are often not known or accessible during the field testing. Therefore, as a minimum the tests should be conducted in the general vicinity of the future system and in soil conditions similar to those into which the infiltration system will discharge. The geotechnical engineer/geologist should determine the actual number of tests based upon the variability of subsurface soil and groundwater conditions, and degree of certainty related to the future location of the infiltration system(s).

2. Soil Classification and Testing. Qualified personnel should prepare a detailed soil log of the test pit or test exploration area in accordance with USCS specifications. Collect representative soil samples from the test location. Classify the soil according to ASTM D2487 and D2488 procedures. Perform appropriate laboratory testing (typically grain size distribution tests) as needed to verify soil classification.

3. Test Procedure. The test procedure is based in large part upon mathematical equations derived from Darcy's Law for saturated flow in homogeneous isotropic media. The mathematical derivations, presented in detail in Appendix A, conclude with the following equation for determining the soil coefficient of permeability [the equation is designated "equation (3)" in Appendix A; for simplicity of reporting, the same notation will be used here]:

$$k = \frac{L}{t} \ln \frac{h_1}{h_2} \tag{3}$$

where

k = coefficient of permeability (in/hr)

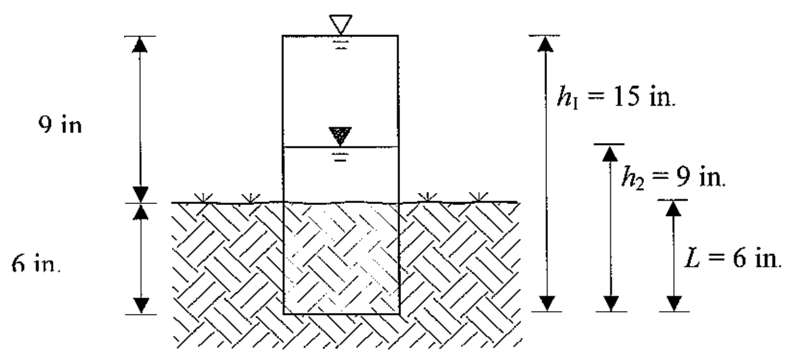
L = length of flow through the soil specimen in the pipe (in)

t = time (hr)

h_1 = initial head (in)

h_2 = final head (in)

The recommended test configuration and procedure described below has been developed using equation (3) so that the observed drawdown rate can be divided in half to achieve the approximate coefficient of permeability. However, different test configurations can be used to fit varying site conditions or test depths. In all cases, the coefficient of permeability should be calculated using equation (3) and the principles outlined in the following procedure. The test configuration and relevant parameters are shown below:



The infiltration test procedure should begin by embedding a 6-inch-diameter, 15-inch-long, rigid standpipe 6 inches (L, as noted in equation [3] and the above figure) into the ground at the depth and location of the proposed test. The standpipe should be as thin-walled as practicable, and the pipe should be carefully pressed or inserted vertically into the soil. Saturate or pre-soak the soil by maintaining measurable water in the standpipe for at least four hours. A four-hour pre-soak phase is assumed to allow adequate soil saturation to properly measure and calculate the coefficient of permeability. This should be verified by ensuring that the cumulative water drop in inches during the saturation period exceeds the standpipe embedment depth (L).

After the saturation period, fill the pipe to the top (i.e., the pipe will contain a 9-inch vertical column of free water). [Note that although the tube contains 9 inches of water, the initial system head (h_1) is 15 inches because head is measured from the top of the free water surface to the bottom of the soil specimen inside the pipe.] Perform as many repeated 6-inch drawdown trials as can be completed in a 1-hour time period (i.e., allow the water in the tube to drop from 15 to 9 inches [h_1 to h_2], and then repeat the process). Conclude the field test and record the following parameters: field observed drawdown rate, L, t, h_1, and h_2.

If the water level does not drop 6 inches in a 1-hour time period, the test can be concluded after one hour by recording the drawdown rate as the drop over the 1-hour time period. The applicable test parameters (L, t, h_1, and h_2) should also be recorded. In this case, h_2 would equal h_1 minus the amount of water drop observed over the 1-hr time period.

If desired, 6-inch drawdown trials may be performed during the saturation period. If 3 consecutive 6-inch drawdown trials indicate the rate has stabilized to within 5 percent variation between all 3 trials, the test may be concluded and the average rate of the three tests may be recorded as the drawdown rate. The applicable test parameters should also be recorded.

4. Explore below the Test Depth. Explore at least six feet below the test depth (typically the proposed facility base elevation) or deeper if site conditions or the proposed facility design warrant.. Record the presence or absence of heavy mottling, groundwater, confining clay/silt layers or bedrock that could impede vertical gradient and ability to infiltrate. If such conditions are present, the geotechnical engineer/geologist should consider greater depths of exploration. Additionally, if the proposed system has a depth of influence greater than six feet, such as the case for wide systems, then greater depths of exploration may be required (as discussed below). Representative soil samples should be collected from below the test depth. Classify the soils and conduct laboratory testing as described in Item 2 above.

5. Groundwater. Note the depth to and elevation of the groundwater table, seeps, or perched water. Also, identify signs of seasonal groundwater tables, such as mottled, gleyed, or oxidized soil textures.

   If the seasonal high groundwater elevation is not clearly identifiable through direct ofservation of water levels, interpretation of soil characteristics (e.g. mottling, etc.), review of local well logs or the *Southwest Clark County Generalized Water Table Altitude and Depth to Groundwater Mapping* (Clark County GIS, September 2005), or if the consequences of infiltration system failure are high, then piezometers should be installed to monitor groundwater elevations through at least one wet season prior to design of the permanent stormwater facilities. The placement and number of piezometers shall be recommended by the geotechnical professional in concert with the civil engineer. This determination shall be based on site characteristics and concerns, including:

   - Coefficient of permeability (measured or estimated);
   - Structure of proposed facility (pond/pipe gallery vs. drywell or single trench);
   - Anticipated depth to groundwater;
   - Potential risk due to facility failure;
   - Anticipated size of drainage catchment or runoff volume;
   - Proximity to wetlands or other topographic features; and
   - Surrounding topography (such as the lack of an overflow path).

   If the vertical distance to the groundwater table is less than fifteen feet from the stormwater facility base and piezometers are not installed, the geotechnical professional shall provide discussion in the Infiltration Investigation Report (as outlined in section 4.2 below) explaining the rationale for not installing piezometers.

6. Groundwater Mounding Analysis. Groundwater mounding analysis shall be completed if deemed appropriate by the geotechnical professional or civil engineer. Particular attention to mounding should be paid to systems where the base of the facility is wider than the system is deep (e.g. infiltration ponds or galleries, or a series of parallel, closely-spaced trenches). We recommend the following guidelines be utilized to help determine whether or not a mounding analysis is warranted:
    a. If groundwater depth is less than five feet below the base of the facility, a mounding analysis is required by the Underground Injection Control (UIC) Rules.
    b. If groundwater depth is between five and fifteen feet, evaluate the proposed system performance considering the factors listed in 5. Above. If a decision is made not to perform a mounding analysis, provide discussion in the Infiltration Investigation Report (as outlined in section 4.2 below) explaining the rationale for not conducting the analysis.
    c. If groundwater is greater than fifteen feet, a mounding analysis will generally only be required for wide systems, low permeability soils or other unusual site conditions or facility design parameters..

    If a mounding analysis is warranted, the appropriate mounding analysis method shall be selected using the same factors to determine the depth of study required. Potential modeling methods include Hantush, numerous commercially available programs (e.g. MODFLOW, MODRET SEEP/W), and a number of other analytical methods.

7. Calculate the Coefficient of Permeability. After the field test procedure has been performed and the relevant test parameters recorded, the coefficient of permeability should be calculated using equation (3). As described previously, the coefficient of permeability obtained from equation (3) is the approximate rate at which water can be expected to infiltrate vertically into a given soil surface under long-term saturated flow conditions. This value should be reported by the geotechnical engineer/geologist as the soil coefficient of permeability for the tested location.

8. Test Limitations. It should be noted that coefficient of permeability calculations identified above are based upon ideal homogenous isotropic media. Because Clark County soils are often fluvially deposited, stratified, and interbedded, they are frequently neither homogenous nor isotropic. This may result in permeability coefficients that vary with depth and direction. Groundwater mounding or an elevated seasonal groundwater table may also affect the infiltration rate. In rare cases, the soil's ability to infiltrate water may be determined by its horizontal rather than vertical coefficient of permeability. The design professional should verify whether these are reasonable assumptions to allow for an approximate estimate of the soil coefficient of permeability. If not, then specialized testing or analysis may be required.

    Because infiltration systems can be expected to undergo long-term degradation of infiltration capacity as a result of siltation, debris collection, and soil crusting, the unfactored calculated coefficient of permeability should not be used in the design of infiltration systems. Correction factors as discussed later in this document should be applied to the calculated coefficient of permeability to determine the allowable design infiltration rate.

9. Modification to the Suggested Test Method. The suggested test configuration described above has been strategically designed to produce an observed drawdown rate that is

approximately twice the coefficient of permeability. This is due to careful selection of the test configuration and geometry and may provide the benefit of simplicity and standardization. It is important to note that the coefficient of permeability will equal approximately half the observed drawdown rate only when full 6-inch drawdown trials are conducted and the relevant test parameters equal those indicated in the standpipe schematic shown under Item 3 of the test procedure section. However, the test configuration, standpipe length, embedment depth, etc. can be modified as desired by an experienced geotechnical professional, provided equation (3) is used to calculate the coefficient of permeability. This provides the professional consultant with flexibility to modify or tailor the test configuration based upon site-specific conditions. When modifying the test configuration or procedure, the consultant should consider the following implications of various modifications:

- Standpipe diameters smaller than six inches may be adversely affected by the presence of large gravels or cobbles.
- Standpipe embedments of less than six inches in some granular soils may result in an inadequate seal around the pipe, and subsequent seepage around the pipe tip, which may result in overestimate of the coefficient of permeability.
- Excessive head in the standpipe may result in overestimate of the coefficient of permeability. It is recommended that the head be limited to one-half the height of the anticipated water depth in the proposed infiltration system (e.g. a field test for a pond with a maximum retained water depth of 3 feet should have a maximum head of 1.5 feet).

4.1.5 Borehole Test Method

While the falling head method described above is a locally appropriate alternative method for infiltration testing, in some environments it is neither feasible nor practical. Examples of such environments may include cohesionless soils where open test pits pose a collapse hazard, systems at depths deeper than the reach of standard construction excavation equipment, or developed sites with existing asphalt or concrete pavements. In such situations infiltration testing is often conducted in exploratory hollow-stem auger boreholes by geotechnical engineers and geologists. Auger borehole infiltration testing is an acceptable alternative to the suggested method, provided the test method and calculation of the coefficient of permeability follow the procedure recommended below.

Alternative Auger Borehole Falling-Head Infiltration Test Procedure

1. Test Frequency and Location. Follow the recommendations identified above for the suggested standard method.

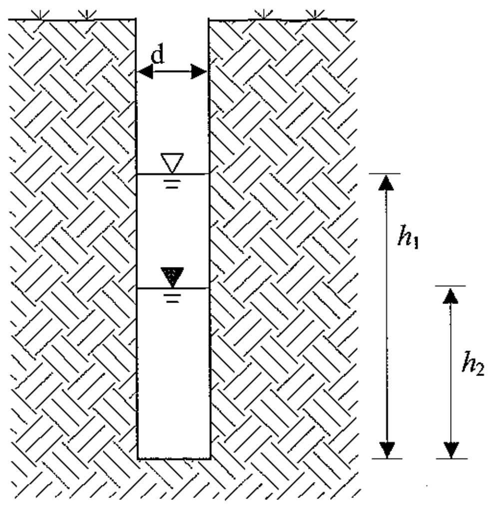
2. Soil Classification and Testing. Follow the recommendations identified above for the suggested standard method.

3. Test Procedure. Advance an auger borehole to the desired elevation of the infiltration test. The auger method must be hollow-stem or the boring must be cased to prevent lateral leakage. Sample subsurface soils at depth to confirm that appropriately granular soils are present at or below the auger tip. Log the boring in accordance with USCS specifications and collect a soil sample from the zone at which the infiltration test is performed. Classify soil as described in item (2) above.

As the tip of the auger reaches the test zone, apply down pressure to the drill pipe and advance the auger slightly into the soil to form a seal. Withdraw the inner plug and rod from the hollow stem auger to expose the test zone soil inside the auger. Measure and record the inner auger diameter (d). Pour water into the standpipe or auger and saturate the soils, as described previously.

After the pre-soak period, establish an initial head of water in the auger (h_1). Depending upon the soil gradation, range of expected infiltration rates, and proposed depth of retained water in the future infiltration system the head level may vary based upon the geotechnical professional's recommendations. However, an initial head in excess of four feet or greater than the future depth of retained water in the system is not recommended. Also, water levels should not rise above joints between auger sections, so that water does not leak out of the joints and skew drawdown readings.

Begin conducting the infiltration test by recording the time (t) required for the head in the auger to drop from the initial head (h_1) to the final head (h_2). Refill the standpipe or auger and conduct multiple test runs until relatively constant rates are achieved (less than 5 percent variation between 3 consecutive trials). An electric water level probe, indicator rod with pegs set at a six inch interval, or a float and tape may be used to aid in accurately measuring drop in head over elapsed time. The auger borehole test configuration and relevant parameters are indicated below:



After relatively constant drawdown rates are observed as described above, the final test parameters are recorded (d, h_1, h_2, and t).

4. Explore below the Test Depth. Follow the recommendations identified above for the suggested standard method.

5. Groundwater. Record groundwater observations in accordance with the recommendations identified above for the suggested standard method.

6. Groundwater Mounding Analysis. Conduct groundwater mounding analysis as described above for the suggested standard method.

7. Calculate the Coefficient of Permeability. After the field test procedure has been performed and the relevant test parameters recorded, the coefficient of permeability should be calculated using equation (4) (Lambe and Whitman, 1969). Equation (4) applies only for coefficient of permeability calculations using the auger borehole method. The value obtained from equation (4) should be reported by the geotechnical professional as the soil coefficient of permeability for the tested location.

$$k = \frac{\pi \cdot d}{11t} \ln \frac{h_1}{h_2} \tag{4}$$

where

k	=	coefficient of permeability (in/hr)
d	=	diameter of borehole (in)
t	=	time (hr)
h_1	=	initial head (in)
h_2	=	final head (in)

8. Test Limitations. The test limitations described above for the suggested standard method also apply to the auger borehole method. In addition, the borehole method assumes flush soil at the bottom of the auger and groundwater levels sufficiently below the depth of the test. Soil swelling, segregation, or consolidation are assumed to be negligible. Hydraulic loss in the auger is also assumed to be negligible. Furthermore, proper performance of this test method requires a tight seal at the base of the borehole, so that lateral flow or upwards "piping" of water does not occur. This method also assumes homogenous soils with directional isotropy (i.e., the horizontal and vertical coefficients of permeability are constant and equal). The design professional should verify whether these are reasonable assumptions to allow for an approximate estimate of the soil coefficient of permeability. If not, then specialized testing or analysis may be required.

   Due to the higher potential for inaccurate field test results (e.g. lateral seepage or upward piping, etc.) from the borehole method, we suggest a minimum Soil Correction Factor (as discussed in Sections 4.2 and 5.7) of 2 be applied to the resulting coefficient of permeability.

4.1.6 Specialized Testing for Unique Sites

Unique sites, such as those with very low or highly variable infiltration rates or shallow groundwater, may require specialized testing procedures and methods of analysis (such as pump tests or mounding analyses). In these cases, this specialized work should be based upon a plan and assessment agreed upon by the applicant and the local regulatory authority.

This paper was prepared to primarily address the design and evaluation of infiltration systems that discharge into relatively fine-grained materials which have demonstrated problems in the past. As previously mentioned, eastern Clark County has coarse-grained soil deposits (primarily sand with variable amounts of gravel and cobbles) which readily infiltrate. Failures of infiltration systems in these materials are rare. Unfortunately, characterization of infiltration properties into these coarse-grained soils is difficult to complete utilizing the single-ring falling-head infiltration test procedure described herein. Furthermore, the grain size distribution correlations in the Manual are often highly conservative for these granular materials.

A relatively common local test methodology for granular soils is to observe the percolation rate (e.g. multi-dimensional flow) via open test pit draw-down measurements. The results obtained from such readings should not be construed as a measurement of hydraulic conductivity, permeability, or infiltration rate, as defined in this paper. Section 4.1.3 of this paper discusses the differences between percolation and infiltration rates and the wide variations which can result between the two. When conducting open test pit draw-down measurements in coarse-grained soils with high draw-down rates, the geotechnical professional should to the extent possible follow the Manual guidelines for the PIT methodology. When access, safety, economic, or water supply considerations do not allow for a full-scale PIT test, the geotechnical professional should clearly outline the test methodology utilized and provide appropriate Soils Correction Factor to account for the variations in the measurements from the standard test methodologies outlined herein or in the Manual. We suggest a minimum Soils Correction Factor (as discussed in Sections 4.2 and 6.7) of 5 be applied when utilizing this method, though depending upon site conditions other values may be appropriate.

4.2 Infiltration Investigation Report

As described previously, an important component of developing an appropriate soils evaluation and infiltration testing process involves defining a standardized method of reporting the investigation and testing results. A comprehensive standard report format would assist the reviewing regulatory agency in understanding and confirming the test results, and likely lead to improved storm water management facility performance and reduced likelihood of system failure. The following text presents recommended content for a standard infiltration investigation report.

1. Introduction and Purpose – Provide a project introduction and describe the purpose and scope of the investigation.

2. Site Location, and Site Description – Provide a description of the site and location. Describe physical characteristics (e.g., existing improvements, topography, drainage patterns, signs of past grading, etc.) and visual observations.

3. Site Soil Conditions – Describe the soil conditions at the site. Reference Soil Survey of Clark County, Washington (United States Department of Agriculture, Soil Conservation Service [USDA SCS], November 1972) to determine USDA soil types present at the site. Briefly describe relevant characteristics, including permeability and available water capacity, of any soil type present at the site.

4. Regional Geology – Briefly discuss geology at the site and in the vicinity. Reference Geologic Map of the Vancouver Quadrangle, Washington and Oregon (Washington Division of Geology and Earth Resources, Open File Report 87-10, Revised November 1987) or other local geologic maps or references to determine the geologic units present at the site.

5. Groundwater – Describe local and regional groundwater conditions. Reference water well logs, other geotechnical reports, and published geologic or hydrogeologic maps that cover the

site vicinity. Described surface and subsurface water observed at the site. Provide an estimate of the seasonal high groundwater table elevation.

6. Field Exploration Activities – Discuss the field portion of the investigation, including the number of infiltration tests performed and any additional explorations performed during the investigation. Describe soil layers encountered and the characteristics of each layer. Describe spatial variability (both lateral and vertical) of soil conditions and any potential effects of such variability on the performance of infiltration systems. Indicate the maximum depth of exploration and depth to groundwater, if encountered, for each exploration.

7. Infiltration Analysis/Test Method Description – Describe the method of infiltration analysis. Include the test depth, test geometry, the duration of the saturation period, and the number of trials performed at each infiltration test location. Discuss any deviations from the methods described in this paper. Note any anomalies in the test procedure or results.

8. Results, Recommendations, and Conclusions – The results of the infiltration investigation should be clearly presented. The results section should include (preferably in tabular form) the test location, test depth (and elevation, if available), measured drawdown rate, calculated coefficient of permeability, test location, depth to groundwater (if encountered), total depth explored, and USCS soil classifications for each test location.

The report should include a discussion of site conditions that may influence installation or long-term performance of the proposed infiltration system(s) and provide necessary recommendations for design and construction. The report should clearly denote the recommended unfactored coefficient of permeability for use in the design of the proposed infiltration system. If different rates are to be used at different portions of the site, the areas should be clearly delineated on the site plan. The estimated seasonal high groundwater elevation at each proposed infiltration system location should be provided. The geotechnical professional should indicate if supplemental monitoring or exploration are required during the wet season to verify groundwater elevation estimates, or if groundwater mounding is a relevant design consideration.

As discussed later in Section 5.7 of this report, a base correction factor of 2 is initially applied to the recommended unfactored infiltration rate (coefficient of permeability) to account for basic soil variability, sedimentation potential, facility design features, etc. The geotechnical professional shall provide a recommendation for a Soils Correction Factor. If high quality field testing procedures were followed, uniform test results were obtained, and uniform site conditions are present, this value may be zero (0). However, if unusual circumstances, such as highly variable soil conditions, indeterminate groundwater elevation, layered soils, etc., are present, the geotechnical professional should provide an appropriate Soils Correction Factor based upon the geotechnical professional's expertise, local experience, and site knowledge to be applied to the unfactored infiltration rate. As previously mentioned, we suggest minimum Soils Correction Factors of 2 and 5 be used for the borehole and open test pit methods, respectively.

9. Figures – Provide a general area map indicating the location of the subject site in relation to surrounding area. Include a site plan indicating the subject site boundaries and the locations of all infiltration tests and other explorations. The site plan should include topographic contours in minimum 2-foot increments if available. If site-specific topographic surveys are not available, then the contour data available from the Clark County GIS department should be utilized. If available, include the development plan for reference.

10. Exploration Logs with USCS/ASTM Soil Classifications – Include a log for each exploration excavated at the site. Logs should include elevation of explorations, classifications,

and descriptions of all soil layers encountered at the site. The maximum depth of each exploration should be indicated along with depth(s) to groundwater or groundwater seeps, if encountered. Infiltration test results should be indicated on the corresponding exploration log at the depth the test was performed.

11. Laboratory Test Reports – Provide laboratory analytical reports for each sample submitted for analysis.

5.0 Design of Infiltration Systems

5.1 Selection of Design Storm

5.1.1 Background

Drainage facilities are designed to prevent excessive accumulations of water and to minimize property damage and other adverse impacts to traffic, utility service, and the health, safety and welfare of the public. However, it is not possible to eliminate all risk of flooding and it is seldom economically justifiable to do so. The selection of the design storm involves balancing the cost of the constructed facilities with the risk factors associated with flooding. The risk of flooding is usually expressed as a flood frequency, a statistical measure of likelihood of a flood of a given magnitude occurring within any given year. For example, the "100-year storm" is a potential storm event which has a 1% chance of occurring in any year. Currently, most jurisdictions in Clark County require that infiltration systems be designed to limit flooding during the 100-year, 24-hour storm.

In order to properly size drainage facilities, engineers and hydrologists have developed predictive models to estimate the amount of water that will run onto or off of a site for storms of varying storm frequencies. This is generally done by simulating the effect of an idealized "design storm" as it falls over a watershed characterized by its size and soil/cover condition. More rainfall will run off of highly urbanized areas, where a large percentage of the land is covered by pavement, roofs and other hard surfaces, than will run off of an area of equal size covered with trees, grasses, or permeable soils such as sands and gravels. The predictive hydrologic models used to estimate peak stormwater flows can be broadly classified into two categories: single event rainfall models and continuous flow models.

5.1.2 Single Event Rainfall Models

In single event rainfall models, such as the Rational Method, SCS TR-20, and the Santa Barbara Unit Hydrograph (SBUH), the peak flow rate used to design stormwater management facilities is estimated to be the maximum rainfall runoff produced by a single "design storm." These values are developed by the statistical analysis of recorded rainfall gathered by the National Weather Service and others, which are published and available to the design community. These values are typically presented in the form of an isopluvial map, on which varying amounts of rainfall are shown superimposed over a map for a given storm frequency. As required by County Code and City Ordinance, the majority of infiltration designs in Clark County and the City of Vancouver are based upon a 100-year, 24-hour design storm. Designers use rainfall depths found from isopluvial maps which are available from the County's Community Development Department. This design storm is used for the most common condition, where the facility is located in a drainage basin which has an overflow route to a stream, ditch, or pipe system. If the system has an overflow, the applicant's engineer reviews the overflow system being utilized to ensure that the additional drainage will not have an adverse impact to downstream property owners.

Some portions of the County are located in closed depressions, where there is not a route for high flows to leave the basin. This condition presents a higher risk of flooding and a more conservative design storm is used for the design of infiltration systems. The risk of flooding is more dependent on volume rather than flow, and the 100-year, 7-day design storm is typically used. In the closed depression analysis, the size and connectivity of the basin to other depressions and low spots in the local area must be considered.

5.1.3 Continuous Event Rainfall Models

In these types of hydrologic models, the response of a given watershed is modeled using long-term rainfall records directly. It is thought that this method will more accurately reflect the actual hydrologic conditions of the site and will more accurately predict flows and their impacts before and after development. This modeling philosophy forms the basis of the Western Washington Hydrologic Model, which is anticipated to form the basis of future revisions to Clark County design standards. In this method, there is no "design storm," but drainage facilities are sized by a statistical analysis of the modeled results.

5.2 Location of Stormwater Infiltration Facilities

Placement of stormwater infiltration systems is often critical to site success. First, locating the facility near the soils with the best coefficient of permeability results in the most economical system for the project. This is balanced against the desired site development pattern. Placement of infiltration systems near foundations, deep utilities, slopes, or in areas where pavement structures can be weakened can compromise the long-term viability of a development site. When infiltration facilities are proposed proximate to these features, the geotechnical professional should approve the proposal. Once the facility type and location have been determined, the facility size and configuration can be determined.

Current restrictions on the placement of stormwater facilities often make it difficult or impossible to site stormwater infiltration facilities on a development. Examples of these restrictions include prohibition of these systems within the public right-of-way, inflexible setbacks from property lines, foundations, and septic systems, and minimum infiltration rates. This is especially true in medium density single family residential development where reduced setbacks and smaller lots are permitted in order to encourage increased density. This group's recommendation is that more latitude be given to the design professionals to locate stormwater facilities within the project, subject to the review and approval of the geotechnical professional involved.

5.3 Infiltration Calculations for Selected Facilities.

Structures for the infiltration of stormwater generally fall into three categories: drywells, trench systems (with or without pipes), and ponds. Each has particular design requirements and concerns.

5.3.1 Drywells

Drywells typically consist of perforated manhole sections placed into soil horizons which support infiltration. Stormwater infiltrates through the drain rock surrounding the sides and base (if present) of the drywell. Infiltration through the drywell is calculated at the perimeter of the drain rock (at the rock-soil interface). We recommend that infiltration through drywells should be calculated by one of the following methods to compensate for potential loss of infiltration capacity through compacted base rock and the typical reduction in the lateral coefficient of permeability:

1. Apply an additional correction factor (after the application of the other factors mentioned later in this paper) to the coefficient of permeability used for infiltration through the sides of the drywell or

2. Reduce the area available for infiltration to one-half of the height of the drywell section.

It should be noted that the cone (if present) and solid wall manhole sections do not factor into the depth of the drywell for infiltration purposes, though the entire drywell can be used for storage if appropriate.

5.3.2 Trench Infiltration Systems

The trench infiltration system is identified by a long narrow system with a perforated pipe and rock layer that surrounds the pipe. This arrangement provides greater area along the system's walls and base. Application of the tested coefficient of permeability across the entire height of the wall may not accurately reflect what is happening due to the pressure gradient of the water in the system. There is also evidence that the horizontal coefficient of permeability is less than the vertical coefficient in many soils, further limiting the potential for infiltration through the sides of the trench. Currently, regulators allow the entire wall height to be used in the analysis, but with the pressure gradient the whole wall is not infiltrating at the same rate.

The recommendation is that the allowable infiltration be reduced by one of two methods:

1. Apply an additional correction factor (after the application of the other factors mentioned later in this paper) to the coefficient of permeability used for infiltration through the sides of the trench or

2. Reduce the area available for infiltration to one-half of the height of the trench (base to invert of pipe or the base to the top of the soil strata available for infiltration).

When applied in conjunction with the other correction factors listed later in this report, these measures are expected to be sufficient to predict the long-term horizontal infiltration capacity of the system.

Another issue that arises is the distance between parallel trenches. For multiple trenches in septic design EPA has required a minimum spacing of 10 feet. A clear spacing of twice the depth between the base of the perforated pipe and the base of the trench (or twice the depth available for infiltration in systems with constraints due to soil layering or other factors) should be sufficient to prevent interference in most soils. Where this cannot be provided, the effective area available for infiltration along the sides of the trenches should be reduced to one-half of the clear distance between the trench walls.

In storm events where the system is already saturated or difficult soil conditions exist, however, it may be difficult to obtain a hydraulic gradient sufficient to move the required water. Additional investigation may be required in special circumstances to determine the extent of the difficult soil conditions as previously described.

Calculation of storage volume within trench systems is relatively straightforward. Typically, a void ratio of 1/3 is assumed for locally produced drain rock. Volume within pipes and manholes or drywells is generally assumed to be available for storage; the exception to this is the sump of a sedimentation manhole.

In fine-grained soils, the design of infiltration trenches should include filter fabric geotextile over the top of the trench and, if the soils along the sides of the trench are stratified, along the sides of the trench through fine-grained layers.

5.3.3 Galleries and Ponds

In galleries and infiltration ponds, discharge through the bottom of the facility is most significant and usually dwarfs the sidewalls of the infiltration facility. In addition, the large areas excavated for these facilities tend to expose more variable and heterogeneous soils, with a greater chance of encountering localized areas of reduced infiltration capacity. As these facilities are inundated, the fine particles may be re-suspended and more evenly distributed. There is concern that this process of re-suspension of fine particles during periods of inundation leads to the eventual "caking" of the bottoms of these facilities. As the fine sediment settles and drops to the bottom of the system it causes a layer of fine particulate matter or sediment to drop onto, or be forced by pressure head into, the soil stratum. This material often settles in a uniform manner across the bottom of the facility and onto the gallery floor. This layer of caking can have a significant impact to the gallery depending on soil type that is encountered for infiltration. In coarse-grained soils it may reduce the rate of infiltration. In fine-grained soils it may significantly reduce the rate or stop infiltration from occurring. For this reason, a sacrificial layer of sand or filter fabric should be considered in the design of infiltration ponds.

5.4 Design for Long-Term Protection of Infiltration Facilities and Other Property

In areas of fine-grained soils, it is critical that the design of stormwater treatment systems which drain to infiltration facilities make provisions for removal of sediments prior to the infiltration facility. This will reduce the potential for clogging and extend the life of the system. Additional erosion control measures should also be identified for use during the construction of the infrastructure improvements and the homes or other structures to be built as discussed later in this document.

Appropriate BMPs for sediment removal include:

- Sediment Trap (typically used during construction)
- Sedimentation Manhole/Vortex Separator (CDS, Vortechnics, or equal)
- Stormwater Filter System (StormFilter or equal)
- Presettling Basin

The design of ponds for easy maintenance, such as the inclusion of a sacrificial sand layer, sedimentation manhole or filter system, and/or an access road, will extend the functional life of the facility without significantly increasing the construction cost in most instances. Where sufficient pretreatment cannot be incorporated into the design of the storm sewer system, an additional correction factor should be added. See Volume 3 of the *Stormwater Management Manual for Western Washington*, Chapter 3.3.6, for additional discussion and Chapters 3.5 and 6 of Volume 5 for information on pretreatment BMPs. This is of particular importance during the construction of infrastructure and other structures on the development site.

Education of builders, homeowners or other users within the drainage basin of the facility is also necessary to reduce the potential for inadvertent contamination of the infiltration system. This should include erosion control practices for use during small construction or maintenance projects, characteristics of the stormwater facilities, and other information depending on the location and type of facility.

For all projects relying on infiltration, a second "sacrificial" system should be provided to be used until the majority of the project is built out. The system should be sized for the 2-year design storm and be separated from the main system to the maximum extent feasible. Runoff should be prevented from entering the permanent system until all exposed soils are permanently stabilized.

Additional benefits can be achieved if the sacrificial system can be located "inline" between the potential sediment source and the permanent infiltration system or designed so that the sacrificial system fills prior to overflowing into the permanent system. Sacrificial systems can be located in areas subject to future development, subject to the removal of accumulated sediments and confirmation of unsuitable material removal by a geotechnical engineer. The design of infiltration systems should detail how the main system is to be protected during construction and provide recommendations on the following:

- When the system can be put into service.
- Maintenance that must be performed prior to putting into service, such as
    - Vactoring sediment traps & catch basins
    - Sweep Streets
    - Installation of filter cartridges

The sacrificial system should be left open to provide any infiltration capacity still available.

5.5 Emergency Overflow

An emergency overflow route should be identified in case of system failure or overload. The Technical Information Report should, at a minimum, clearly identify a flow route that storm water can take from the facility without negatively impacting housing or posing a risk to the public. A piped overflow is preferred, however if necessary, a cross-country or even pumped systems can be identified. The report shall qualitatively address the capability of the overflow route to convey the anticipated flow from the development area.

5.6 Stormwater Facility Size

In order to minimize the effects of failed systems on downstream properties, the use of smaller systems distributed through the project is generally preferred to a single large system; this is evident in the correction factor recommendations later in this document. Vancouver's emphasis on individual lot downspout system reflects this philosophy; areas with limited infiltration capacity may not be able to take advantage of these systems due to required setbacks and the size of the individual system which might be required. Testing during construction should not necessarily be required at each individual lot system location, but inspection should be performed by the geotechnical professional after excavation to ensure that the soil type is consistent with that described in the site investigations.

5.7 Correction Factors

The allowable design infiltration rate is determined by dividing the calculated coefficient of permeability by appropriate correction factors defined in the following table. These correction factors compensate for expected adjustments to infiltration system performance from the effects of long-term system degradation, soil variability, physical setting characteristic, and facility design features.

Additive Correction Factors Based on Design Conditions

Design Condition	Correction Factor
Base Correction Factor	
The base correction factor is meant to account for soil variability and long-term system degradation due to siltation, biofouling, crusting, or other factors.	2
Soils Correction Factor	
Additive correction factor recommended by geotechnical professional as a result of soil or groundwater conditions.	As recommended in Infiltration Report
Basin Size Correction Factor	
If the infiltration facility serves a basin having a runoff volume for the 100-year, 24-hour storm event which is greater than 50,000 cubic feet, but less than 150,000 cubic feet	Add 1/2
If the infiltration facility serves a basin having a runoff volume for the 100-year, 24-hour storm event which is greater than 150,000 cubic feet	Add 1
System Design Correction Factors	
If an overflow system is not available or provided	Add 1/2
If a sacrificial system is provided and left operational following permanent site stabilization	Subtract 1/2

As an example, consider a site in which:

- The geotechnical professional measures a coefficient of permeability of 8 inches per hour and recommends an additive correction factor of 1 due to variable site conditions (limited strata for infiltration, for example).
- Runoff entering the facility during the 100-year, 24-hour storm is 76,000 cubic feet.

- Overflows from the system run to the adjacent street, from which they flow into a storm sewer system discharging to a local stream.
- A sacrificial system is provided and left open after construction has been completed.

In this instance, the Correction Factor applied to the coefficient of permeability would be 2+1+1/2-1/2, or 3. The resulting design coefficient would be 8/3, or 2.67 inches per hour. The correction factors for medium and large infiltration facilities (Runoff Volume Correction Factors) are intended to reduce the risk of property damage due to failure of these systems and to encourage the use of smaller, distributed systems. The designer also has the option of increasing the correction factor beyond those listed where warranted by site conditions. The designer and the geotechnical professional should rely on each other to determine when additional correction factors are warranted.

5.8 Additional Issues to be Considered During Design

Pipe perforation design can also influence the ability of an infiltration facility to dispose of water adequately. The engineer should confirm that the perforation size and pattern specified is sufficient to pass the anticipated design flow.

Recommended notes and specifications for the construction of infiltration systems are included as Appendix B. These notes should be incorporated into engineering plans for these types of facilities. The notes may be modified by the design engineer to reflect specific site conditions.

6.0 Construction of Infiltration Systems and Sediment Control

Sediment control is necessary to protect permanent infiltration facilities from clogging during all phases of construction. This protection must continue until the entire tributary area is effectively stabilized and erosion is no longer a threat.

6.1 Construction of Infiltration Systems

On development sites that infiltrate all stormwater runoff, the primary concern in the preparation of the Construction SWPPP (storm water pollution prevention plan) is the protection of the infiltration facilities from fine sediments during the construction phase and protection of groundwater from other pollutants. The plan should emphasize minimizing ground disturbance and maintaining existing vegetation during construction. Generally, plans which are developed and fully implemented in accordance with Volume 2 of the *Stormwater Management Manual for Western Washington* are sufficient to protect these facilities.

Permanent infiltration trench systems should not receive untreated run-off until the entire contributing drainage area to the infiltration system has received final stabilization and permanent water quality treatment BMPs are in place and functioning. As previously discussed, alternative drainage such as a temporary infiltration pond, a sacrificial infiltration trench or a sacrificial drywell are recommended. Treatment technologies such as Chitosan-Enhanced Sand Filtration (CESF) have been used to treat construction runoff prior to infiltration in a permanent facility with approval from the Department of Ecology. Permanent infiltration facilities should not be made operational until all proposed project improvements which produce surface runoff are complete, especially re-vegetation and landscaping. In the cases of projects with individual lots remaining undeveloped, these lots must contain and infiltrate their runoff through individual sediment traps acting as infiltration ponds until permanent improvements and landscaping are established.

An alternative to this approach is to serve the undeveloped lots with a shared sediment trap or pond on an undeveloped tract or lot. At the completion of all construction, the sediment trap must be cleaned out (taking care that no sediment enters the drainage system) and filled in, and the flow routed to the permanent drainage system.

Use of permanent infiltration ponds for sedimentation basins during construction tends to clog the soils and reduce their capacity to infiltrate. If infiltration ponds are to be used, the sides and bottom of the facility must only be rough excavated to a minimum of 2 feet above final grade. Additional maintenance may be necessary during the construction period to remove accumulated sediment and maintain the intended infiltration rate. Final grading of the infiltration facility should occur only when all contributing drainage areas are fully stabilized. The infiltration pretreatment facility should be fully constructed and used with the sedimentation basin to help prevent clogging.

Runoff from fully stabilized areas may be discharged to the permanent treatment system and infiltration facility without a sediment removal BMP. Full stabilization means concrete or asphalt paving; quarry spalls used as ditch lining; or the use of rolled erosion products, a bonded fiber matrix product, or vegetative cover in a manner that will fully prevent soil erosion. The Local Permitting Authority should inspect and approve areas fully stabilized by means other than pavement or quarry spalls.

6.2 Construction Observation & Testing

During the construction of the infiltration facility, the geotechnical professional of record should be retained to observe the excavation and confirm that the soils are consistent with those tests on which the design was based. This observation must take place prior to the placement of any filter fabric or drain rock specified on the plans.

In addition to the observation, additional infiltration tests should be performed to confirm the original tests through the base of the facility. This is especially important in layered soils with mixed silt and sand. If the tested coefficient of permeability determined at the time of construction is at least two-thirds (2/3) of the uncorrected coefficient of permeability used to determine the design rate, construction should be allowed to proceed. If the tested rate does not meet this requirement, additional testing, excavation, and/or design revision may be necessary to ensure that the system will dispose of the necessary stormwater.

6.3 Dry Utility/Joint Trench Installation (CATV, Gas, Electricity, Phone)

Erosion control measures must be maintained during installation of behind the curb utilities such as power, gas, phone, and cable TV. Implementation of Erosion and sediment practices during site construction has improved significantly over the last several years, but trenching for these "dry" utilities has been a major source of erosion and sediment deposition after major construction has been completed. Trench lines are often dug along the entire length of a project and are left open for days with trench spoil piles left unprotected.

Utility construction in new and existing areas should require an erosion/sedimentation control plan to address this problem. The plan should identify a competent person (certified in erosion control) who is in charge of erosion control for the project. Erosion control measures must be in place and inspected by the Local Permitting Authority prior to starting construction. The following measures would be required:

- All downstream catch basins would be protected with a temporary BMP.
- Trench spoils should be placed on the uphill side of trench or on the lot side of the trench (not next to curb) if flat.
- The length of open trench should be limited so that trenches will be completed within 7 days during dry months and 3 days during wet months.
- Water from trenches may not be pumped into any storm system.
- Sediment tracked onto roadways should be shoveled and/or swept up immediately during wet weather or at the end of day during dry weather.
- Trenches should be stabilized after completion with hydro-seeding or a sufficient layer of straw (2-inch minimum covering all disturbed area) or other appropriate cover.

The project should be inspected after completion to insure all trenches have been properly stabilized. The developer will be ultimately responsible for ensuring erosion control measures are installed and maintained and may be fined for violations.

Currently, there is no mechanism for inspection and enforcement of erosion and sediment control during utility construction. Additional scrutiny and clear direction needs to be provided to the department in charge of this part of site development.

6.4 Homebuilding or Construction of Other Structures

Homebuilders must create a small site SWPPP for single-family home sites. The plan must be implemented and approved by the Local Permitting Authority inspector prior to any site construction. The builder will be ultimately responsible for insuring erosion control measures are installed and maintained and may be fined for any violations on site. This may include repair or replacement of infiltration facilities clogged by sediment-laden runoff.

6.5 Post-development Homeowner Improvements

Stockpiling of materials (top soils, bark dust, etc.) should not be allowed within the paved right-of-way. Stockpiles onsite should be protected from runoff, especially if placed in a driveway that drains to the street.

Homeowners should be notified of erosion control requirements when obtaining a building or plumbing permit for any ground-disturbing project. This should include stating the homeowner's responsibility for contractors that may work on their property and that they may be fined for erosion from the project. At this time, there is not a mechanism in place at any of the reviewing agencies to trigger this type of notification

7.0 Conclusion

The Infiltration Standards Review Committee acknowledges that certain soil types present in Clark County present challenges to the professionals responsible for testing and designing systems to successfully discharge concentrated stormwater via infiltration facilities. In order to provide guidance for regulators and designers, the members of this committee have brought their technical expertise together in a collaborative effort to attempt to standardize procedures to assess soil infiltration capacity, design systems to utilize that capacity, and protect those systems from damage during and following construction. Application of these procedures to new designs will reduce the risk of future property damage resulting from infiltration system failure and reduce the maintenance and replacement frequency for these systems while meeting the development and environmental protection goals of the public. It is the committee's hope that this information will be used to support decisions to change city and county codes to address current problems with the existing stormwater and erosion control codes.

In the body of this report, the Committee has made specific recommendations in the following areas:

- Soil testing and evaluation methods
- Reporting requirements
- Application of tested rates to the design of stormwater infiltration facilities
- Configuration of treatment and infiltration facilities to protect systems and extend their design life
- Construction methods and practices necessary to protect facilities from sedimentation throughout their design life.

Incorporation of these recommendations in the stormwater design standards will result in the design and installation of facilities with a significantly reduced risk of failure.

Appendix A: Mechanisms and Processes of Soil Infiltration

The infiltration process begins with addition of water to a given soil surface. A wetting front moves through the soil based upon the amount of water applied and the ability of the soil to accept flow. Initially the soil voids are unsaturated and the flow is multi-dimensional. Pore pressure may be negative. However, after sufficient time elapses to achieve steady-state conditions, the soil becomes saturated and the flow becomes primarily one-dimensional (vertical) under the influence of gravity. As indicated below, the infiltration rate is then defined by the soil coefficient of permeability and hydraulic gradient of the system in accordance with Darcy's Law for saturated flow in homogenous isotropic media. Although soils are variable in nature and characteristics, they are assumed to be homogenous and isotropic to allow for an approximate solution (Das, 2005). The volume of flow is represented by the following equation:

$$Q = -kAi \tag{1}$$

where

Q	=	flow (volume) (in^3/hr)
k	=	coefficient of permeability (in/hr)
A	=	cross-sectional area of flow (in^2)
i	=	$\Delta H/\Delta L$ (hydraulic gradient) (unitless)
ΔH	=	change in head (in)
ΔL	=	length of flow over which head is lost (in)

The average infiltration rate, defined as the one-dimensional volume flux of water flowing through a two-dimensional surface area, can be obtained by dividing the flow, Q, by the cross-sectional area of flow, A. This infiltration rate is often referred to as the Darcy flux, q_w. Therefore,

$$q_w = -ki \tag{2}$$

The vertical infiltration rate ultimately achieves a steady state condition approaching the coefficient of permeability as the lower bound. This is because the coefficient of permeability equals the infiltration rate when the hydraulic gradient is one. Although some lateral or horizontal flow will occur near the edges of the infiltration source during saturated steady-state conditions, infiltrating flow will generally tend to be vertical. This is particularly applicable for subsurface infiltration galleries, basins, or trenches with significant horizontal surface area. Therefore, according to the current state of the practice, the infiltration rate can be best represented by the soil vertical coefficient of permeability (Ferguson, 1994; Oram, 2005; Minton, 2006). Stated in different terms, under the assumptions outlined above, the coefficient of permeability measures the raw infiltration rate. Appropriate correction factors, discussed earlier in this document, should be applied to the infiltration rate prior to design use.

Several test methods have been used by geotechnical design professionals to estimate the soil coefficient of permeability. Standard ASTM methods are available for testing of samples in an analytical laboratory setting. However, the difficulty in obtaining, transporting, preparing, and testing undisturbed samples, particularly those with appreciable sand content, effectively limits the use and accuracy of laboratory testing. More commonly, design consultants devise and use field testing methods to allow for direct in situ analysis. While field testing can be performed with steady-state constant head assumptions, in situ testing more commonly uses falling head or non-steady state conditions. Falling head methods are acceptable provided saturated flow conditions are maintained. If Darcy's Law is integrated over time to accommodate falling head conditions and re-arranged to solve for the coefficient of permeability, the following equation emerges:

$$k = \frac{L}{t} \ln \frac{h_1}{h_2} \qquad (3)$$

where

k	=	coefficient of permeability (in/hr)
L	=	length of flow (in) through the soil specimen in the pipe
t	=	time (hr)
h_1	=	initial head (in)
h_2	=	final head (in)

Equation (3) can be used with a properly developed falling head test method to estimate the in situ coefficient of permeability in most external environments.

EXAMPLE

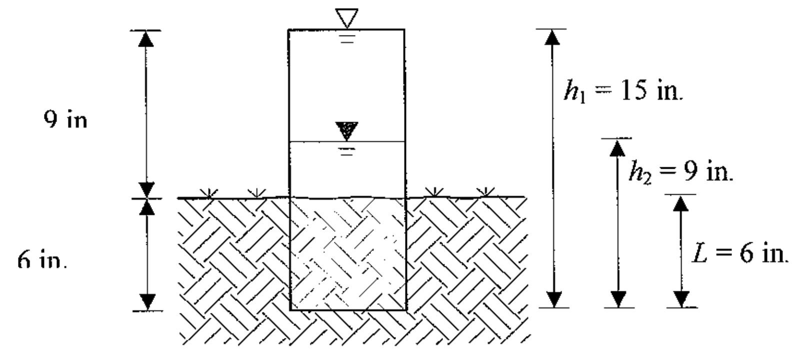
Given the infiltration test configuration shown below and the following observed field test data, determine the soil coefficient of permeability:

Average field observed rate of three 6-inch drawdown trials (change of head of six inches) after a 4-hour saturation period: 6 inches in 0.25 hr (i.e., approximate drawdown rate of 24 in/hr)

L = 6 inches

h_1 = 15 inches

h_2 = 9 inches



Inserting the relevant parameters into equation (3) results in a calculated coefficient of permeability, **k = 12.26 in/hr**.

Discussion of Results:

The coefficient of permeability obtained from equation (3) is the approximate rate at which water can be expected to infiltrate vertically into a given soil surface under long-term saturated flow conditions. Stated differently, under saturated conditions, the coefficient of permeability equals the infiltration rate. This value should be reported by the geotechnical professional as the soil coefficient of permeability for the tested location. To compensate for variable soil conditions and long-term system degradation, an appropriate correction factor should then be applied to the coefficient of permeability to arrive at the design infiltration rate.

The suggested test configuration described above has been strategically designed to produce an observed drawdown rate that is approximately twice the coefficient of permeability. This is readily apparent in the above example by observing that the calculated coefficient of permeability value of 12.26 in/hr is approximately half of the field observed drawdown rate of 24 in/hr. This is due to careful selection of the test configuration and geometry and may provide the benefit of simplicity and standardization. It is important to note that the coefficient of permeability will equal approximately half the observed drawdown rate only when full 6-inch drawdown trials are conducted and the relevant test parameters equal those indicated in the standpipe schematic shown above. However, the test configuration, standpipe length, embedment depth, etc. can be modified as desired by an experienced geotechnical professional, provided equation (3) is used to calculate the coefficient of permeability.

Appendix B: Infiltration Basins Notes and Specifications

The sequence of various phases of basin construction should be coordinated with the overall project construction schedule. A program should schedule rough excavation of the basin with the rough grading phase of the project to permit use of the material as fill in earthwork areas. The partially excavated basin, however, cannot serve as a sedimentation basin unless the base is left at least two feet above the permanent base elevation for reasons explained below.

Specifications for basin construction should state: (1) the earliest point in progress when storm drainage may be directed to the basin, and (2) the means by which this delay in use is to be accomplished. Due to the wide variety of conditions encountered among projects, each should be separately evaluated in order to postpone use as long as is reasonably possible.

1. Initial basin excavation should be carried to within 1 foot of the final elevation of the basin floor. Final excavation to the finished grade should be deferred until all disturbed areas on the watershed have been stabilized or protected. The final phase excavation should remove all accumulated sediment. Relatively light tracked equipment is recommended for this operation to avoid compaction of the basin floor. After the final grading is completed, the basin must provide a well-aerated, highly porous surface texture. Alternatively, the initial basin excavation could be carried to two feet above the final elevation for temporary (construction) use, then the remaining excavation completed once the remainder of the site has been permanently stabilized.

2. Infiltration basins in fine-grained soils may be lined with a 6- to 12-inch layer of filter material such as coarse sand (AASHTO Std. M-43, Sizes 9 or 10) to help prevent the buildup of impervious deposits on the soil surface. The filter layer can be replaced or cleaned when it becomes clogged. When a 6-inch layer of coarse organic material is specified for discing (such as hulls, leaves, stems, etc.) or spading into the basin floor to increase the permeability of the soils, the basin floor should be soaked or inundated for a brief period, then allowed to dry subsequent to this operation. This induces the organic material to decay rapidly, loosening the upper soil layer.

3. Establishing dense vegetation on the basin side slopes and floor is recommended, especially when the coefficient of permeability is less than 10 in/hr. A dense vegetative stand will not only prevent erosion and sloughing, but will also provide a natural means of maintaining relatively high infiltration rates. Erosion protection of inflow points to the basin shall also be provided.

4. Selection of suitable vegetative materials for the side slope and all other areas to be stabilized with vegetation and application of required lime, fertilizer, etc. shall be done in accordance with the NRCS Standards and Specifications or your local Standards and Specifications for Soil Erosion and Sediment Control.

5. Grasses of the fescue family are recommended for seeding primarily due to their adaptability to dry sandy soils, drought resistance, hardiness, and ability to withstand brief inundations. The use of fescues will also permit long intervals between mowings. This is important due to the relatively steep slopes which make mowing difficult. Mowing twice a year, once in June and again in September, is generally satisfactory. Clippings should be removed during or after mowing. Refertilization with 10-6-4 ratio fertilizer at a rate of 500 lb per acre (11 lb per 1000 sq ft) may be required the second year after seeding.

Group Resumes

Michael Barrette, P.E. - Clark County

Michael Barrette, P.E. has worked on all aspects of construction beginning as a Laborer Operator, Inspector, Design Engineer, Project Manager, and Review Engineer. He graduated from Oregon State University with a Bachelors of Science Civil Engineering Degree in 1995. Michael has been working in the civil engineering field as a public employee for approximately 11 years. His areas of expertise revolve around road and storm system design and construction.

Due to relocation to Texas, Michael Barrette was unable to complete his tenure with this committee, but his input and assistance are valued by the remaining committee members.

Bob Blakemore, P.E. - JBAK Consultants

No resume provided.

Richard Drinkwater, P.E. - Clark County

Richard Drinkwater, PE - Clark County, Department of Community Development, Engineering Services. Mr. Drinkwater has been employed with Clark County for the past 10 years, with responsibilities which included review of private development and capital improvement projects. Prior to his employment with Clark county, he spent years in private practice and at other public agencies. Mr. Drinkwater has been employed in engineering and land surveying for the past 43 years. He is licensed in Washington, Oregon, Alaska, Idaho and Nevada as a professional civil engineer and also holds licenses as a professional land surveyor in Oregon, Idaho and Nevada. He is currently a member of America Society of Civil Engineers, Professional Land Surveyors of Oregon and has held numerous officer positions in professional societies throughout his career.

Eric E. Golemo, P.E. - Sturtevant, Golemo, and Associates, Inc.

Eric Golemo has 12 years of experience in civil engineering and land planning. Mr. Golemo is the co-founder of Sturtevant, Golemo & Associates and is currently the director of Engineering. His responsibilities include project management, plan review, engineering design, contract administration, and client management. He has designed or supervised the design of stormwater facilities, single and multi-family developments, short plats, commercial projects, and public works projects in Southwest Washington.

He is a member of the American Society of Civil Engineers and has served as an officer in the Southwest Washington branch. He is active in the Development Engineering Advisory Board. He has served on numerous committees or work groups reviewing and providing feedback on code creation and revisions in Clark County, the City of Vancouver, Washougal, and La Center.

Paul Knox, P.E. - Hopper Dennis Jellison, PLLC

Paul brings over twelve years of diverse experience and talents to the transportation department. While working for Clark County, Paul reviewed land use approval applications for compliance with county development standards. This process has made him very aware of local standards and procedures. He was responsible for preparing staff reports and represented the county in public hearings and meetings, which gives him familiarity with the Public Involvement processes required with many complex projects.

As a water resources engineer, Paul prepared and stamped final design plans, conducted water resources studies, designed master plans and feasibility studies for water, sewer and drainage projects. He performed hydrologic and hydraulic evaluations for existing and proposed bridge projects. Additionally, Paul supervised design and survey departments, prepared and stamped final design plans, reports, specifications, and cost estimates for land development and commercial private projects.

R. Warren Krager, R.G., C.E.G. – Chinook Geoservices, Inc.

Mr. Krager is a registered professional Geologist and Registered Engineering Geologist in Oregon, Washington, and Idaho with over 20 years of local experience conducting engineering geologic and geotechnical studies. He has conducted and overseen numerous field investigations throughout Clark County to evaluate infiltration capacity of soils for a variety of planned storm water infiltration disposal methods. Professional society affiliations include membership in the Association of Environmental and Engineering Geologists (AEG) for more than 16 years with a recent five year term as Oregon Section Board member officer rotation, including Oregon Section Chair. He also attends most ASCE-Oregon Geotechnical Group professional society meetings. As a geotechnical consultant Mr. Krager actively markets and conducts geotechnical investigations throughout the Pacific Northwest for a broad spectrum of design professionals, developers, government agencies, contractors, and other interests.

Lance Lehto, P.E., M.S. - Columbia West Engineering, Inc.

Lance Lehto has 13 years of experience in geotechnical and environmental engineering. In 1999, Mr. Lehto founded Columbia West Engineering, Inc., a geotechnical and environmental engineering and construction materials testing firm based in Vancouver, Washington. The firm provides professional services for a variety of commercial, industrial, residential, and regulatory agency clients located throughout western Washington and Oregon. As president of the company, Mr. Lehto's responsibilities include project engineering, engineering design, field exploration and investigation, comprehensive company management and leadership, contract negotiation, report preparation and review, and employee supervision and management. Mr. Lehto is a licensed professional engineer in Washington and Oregon, and a member of the American Society of Civil Engineers and Chi Epsilon, a Civil Engineering honor society.

Charles E. McMurry, P.E. - Olson Engineering, Inc.

Charles (Chad) McMurry joined Olson Engineering, Inc. in 1996. Mr. McMurry's responsibilities include project management, plan review, engineering design, estimating, contract administration, specification preparation, and construction inspection. His experience includes single and multi-family residential development, commercial and industrial site development, and public transportation and water system improvements. His work at Olson Engineering has included the design of sanitary sewer, water and street improvements, the design of stormwater treatment and disposal systems, erosion control, stormwater permitting, preparation of Environmental Impact

Statements and public water system design and permitting. He is a member of the American Society of Civil Engineers and has served as President of the Southwest Washington Branch.

Michael J. Swanson, P.E. - City of Vancouver

Mr. Swanson has been with the City's Surface Water Management Department for more than seven years, where his responsibilities have included the review of development and capital improvement projects for compliance with City code. Prior to his work at the City, he spent eight years as a design engineer in the private sector with a firm in Clark County, specializing in stormwater facility design.

Daniel J. Trisler, P.E. – GeoDesign, Inc.

Dan Trisler has more than 14 years of experience involving soil mechanics, slope stability analysis, foundation and retaining system design, and hazards evaluations in support of various public and private developments. Dan leads GeoDesign's Vancouver office and his responsibilities include project management, engineering analysis, contract administration, report preparation and review, supervision of field and engineering personnel, specification preparation, and construction observations. Dan has conducted and overseen numerous infiltration studies for commercial, retail, residential, and transportation-related developments. He is a licensed civil engineer practicing geotechnical engineering in Washington, Oregon, Idaho, and California. He holds a master's degree in geotechnical engineering and bachelor's degree in civil engineering, both from Cornell University. He is a member of the American Society of Civil Engineers.

Peter A. Tuck, P.E. – Olson Engineering, Inc.

Peter Tuck has 17 years of experience in civil engineering. As Engineering Director for Olson Engineering, Inc., Peter has been responsible for planning, directing, and coordinating all project production and administration for the last 12 years. He has designed or supervised the design of hundreds of stormwater systems across the county, including infiltration systems for water quality treatment and disposal of stormwater runoff. His professional associations have included the following:

- Member of American Society of Civil Engineers
- Member of Clark County Drainage Ordinance Committee, 1997-1998
- Member of Burnt Bridge Water Shed Rates Sounding Committee
- Institute of Engineers Australia – Chartered Professional Engineer
- Member of ASCE Drainage Review Committee, 1995 –1998
- Member of Clark Co. Stormwater & Erosion Control Task Force, 1999-2001
- Clark County Clean Water Commission, 2000 – 2002

References

Stormwater Management Manual for Western Washington, Washington State Department of Ecology, February 2005.

Surface Water Design Manual, King County, Washington, 1990.

Storage/Sedimentation Facilities for Control of Storm and Combined Sewer Overflows - Design Manual (EPA/600), Metcalf & Eddy, Inc. for National Risk Management Research Laboratory, U.S. Environmental Protection Agency, 1997.

Soil Survey of Clark County, Washington, Natural Resources Conservation Service (formerly Soil Conservation Service), 1973.

ASTM Soil Classification System.

AASHTO Soil Classification System.

Stormwater Infiltration, Bruce K. Ferguson, 1994.

Stormwater Treatment, Gary Minton, 2002.

Soils, Groundwater Recharge, and On-site Testing, Brian Oram, Wilkes University; Geoenvironmental Sciences and Environmental Engineering Department, 2005.

A Better Way to Size Infiltration Basins, Gary R. Minton and Roger Sutherland, August 2006.

Fundamentals of Geotechnical Engineering, Braja M. Das, 2nd Edition, 2005.

Soil Mechanics, T. William Lambe and Robert V. Whitman, 1969.

Geologic Map of the Vancouver Quadrangle, Washington and Oregon, William M. Phillips, Washington State Department of Natural Resources, 1987.

Annual Book of ASTM Standards, Soil and Rock (I), v04.08, American Society for Testing and Materials, 2007.

Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1A: Specifications, 27th Ed., American Association of State Highway and Transportation Officials, 2007.

A Design Manual for Sizing Infiltration Ponds, Joel W. Massman, Washington State Department of Transportation, October 2003.

An Approach for Estimating Infiltration Rates for Stormwater Infiltration Dry Wells, Joel W. Massman, Washington State Department of Transportation, April 2004.

Definition of Terms

Several of the most relevant terms used in the soil infiltration mechanistic and testing processes are defined below (Oram, 2005, Ferguson, 1994):

Infiltration – The one-dimensional (usually downward) entry of water into the immediate soil surface.

Infiltration Rate – The rate at which water penetrates the soil surface, expressed as velocity. It is a one-dimensional volume flux of water flowing into a two-dimensional soil surface area. The infiltration rate is constrained by the capacity of the soil and the rate at which water is applied to the surface. The infiltration rate of a given soil varies under saturated and unsaturated conditions. Because storm water management design must consider the long-term condition, the saturated infiltration rate is of primarily interest to engineering professionals. Under saturated soil conditions, the infiltration rate is essentially equivalent to the soil coefficient of permeability, defined below. In this document, the term "infiltration rate", as defined by the measured and calculated coefficient of permeability, refers specifically to the assumed rate at which water will infiltrate vertically into a saturated soil.

Allowable Design Infiltration Rate – The final infiltration rate used by design engineers to size infiltration systems. It is calculated by adding necessary correction factors to the infiltration rate defined above to compensate for soil variation and long-term system degradation.

Flux - The amount of flow of a given substance through a unit area per unit of time (ft./sec.)

Flow - The volume of a given substance passing through a given surface area per unit of time. The integration of flux over a unit area yields the flow.

Percolation – The simultaneous three-dimensional vertical and lateral movement of water through soil by gravity.

Drawdown Rate – The direct raw field measurement of the rate of water drop during a given in situ infiltration test, expressed as velocity.

Coefficient of Permeability (also called Hydraulic Conductivity) – A quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient, expressed as velocity. As described later, the coefficient of permeability is calculated based upon the observed drawdown rate and configuration of the infiltration test apparatus. The coefficient of permeability commonly varies in the horizontal and vertical directions. Due to the effects of gravity, the vertical coefficient of permeability is the primary component of interest in the soil infiltration process. As described above, the saturated vertical soil coefficient of permeability may be assumed to equal the soil infiltration rate. Therefore, when discussing saturated vertical flow conditions, the terms "coefficient of permeability" and "infiltration rate" are equal. The calculated coefficient of permeability is the infiltration rate.

Geotechnical Professional - A Geologist or Professional Engineer licensed in the State of Washington with training and experience in the investigation and engineering evaluation of earth materials, including rock, soil, and groundwater and their interaction with civil engineering works.

ASCE Clark County Soil Conditions Map

As part of the preparation of this document, a map outlining general soil conditions pertaining to infiltration was prepared by Clark County GIS. A reduced copy of this map has been provided on the following page. The full-size version (a 12 MB download) is available by contacting Chad McMurry at Olson Engineering, (360) 695-1385 or chad@olsonengr.com.