A. Introduction

The emerging goal of urban stormwater management is to achieve effective control of pollutants in stormwater runoff and reduce the volume and rate of runoff to control downstream impacts from flooding and stream-channel erosion. Best management practices (BMPs) that mirror the natural process of infiltration found in undeveloped watersheds can effectively increase the volume of water returned to the soil and reduce the volume of direct runoff to streams and sewers. Increased infiltration will maintain pre-development baseflow in local streams, and also help reduce the frequency of bank-full flow in urban stream channels. Infiltration practices are the one group of BMPs that can effectively reduce the volume of net annual direct runoff to streams. When site conditions permit, a portion of urban stormwater runoff can be managed through infiltration. The water volume from infiltration is transferred to the soil-water system and released slowly over time through the local water table and into local and regional stream baseflow. Additional water is transferred back into the atmosphere through evapotranspiration.

B. Infiltration fundamentals

Infiltration is the downward movement of water from the land surface into the soil profile. Infiltration can occur naturally following precipitation, or can be induced artificially through structural modifications in the ground surface. Some water that infiltrates will remain in the shallow soil layer, where it will gradually move vertically and horizontally through the soil and subsurface material. Eventually, it might enter a stream by seepage into the stream bank. Some of the water may continue to move deeper (percolate), recharging the local groundwater aquifer. A dry soil has a defined capacity for infiltrating water. The capacity can be expressed as a depth of water that can be infiltrated per unit time, such as inches per hour. If rainfall supplies water at a rate that is greater than the infiltration capacity, water will infiltrate at the capacity rate, with the excess either being ponded, moved as surface runoff, or evaporated. If rainfall supplies water at a rate less than the infiltration capacity, all of the incoming water volume will infiltrate. In both cases, as water infiltrates into the soil, the capacity to infiltrate more water decreases and approaches a minimum capacity. When the supply rate is equal to or greater than the capacity to infiltrate, the minimum capacity will be approached more quickly than when the supply rate is much less than the infiltration capacity.

1. **Infiltration.** The downward entry of water into the immediate surface of soil or other materials.
2. **Infiltration capacity.** The maximum rate at which water can infiltrate into a soil under a given set of conditions.
3. **Infiltration rate.** The rate at which water penetrates the surface of the soil, expressed in cm/hr, mm/hr, or inches/hr. The rate of infiltration is limited by the capacity of the soil and the rate at which water is applied to the surface. This is a volume flux of water flowing into the profile per unit of soil surface area (expressed as velocity).
4. **Percolation.** Vertical and lateral movement of water through the soil by gravity.

As precipitation infiltrates into the subsurface soil, it generally forms an unsaturated (vadose) zone and a saturated (phreatic) zone. In the unsaturated zone, the voids (spaces between grains of gravel, sand, silt, clay, and cracks within rocks) contain both air and water. Although a lot of water can be present in the unsaturated zone, this water cannot be pumped by wells because it is held too tightly by capillary forces. The upper part of the unsaturated zone is the soil-water zone. The soil zone is crisscrossed by roots, openings left by decayed roots, and animal and worm burrows, which allow the precipitation to infiltrate into the soil zone. Water in the soil is used by plants in life functions and leaf transpiration, but it also can evaporate directly to the atmosphere. Below the unsaturated zone is a saturated zone where water completely fills the voids between rock and soil particles.

Water movement in the vadose zone is generally conceptualized as occurring in the three stages of infiltration, redistribution, and drainage or deep percolation, as illustrated in Figure C5-S1- 1. As described above, infiltration is defined as the initial process of water entering the soil resulting from application at the soil surface. Capillary forces or matric (negative pressure) potentials are dominant during this phase. Redistribution occurs in the next stage where the infiltrated water is redistributed within the soil profile after water application to the soil surface stops. During redistribution, both capillary and gravitational effects are important. Simultaneous drainage and wetting takes place during this stage. Evapotranspiration takes place concurrently during the redistribution stage, and will impact the amount of water available for deeper penetration within the soil profile. The final stage of water movement is termed deep percolation or recharge, which occurs when the wetting front reaches the water table. The term “infiltration” is typically used as a single terminology to describe all three stages of water movement through the vadose zone. The terms, “water flux", "infiltration rate", and "rate of water movement" are also used interchangeably.

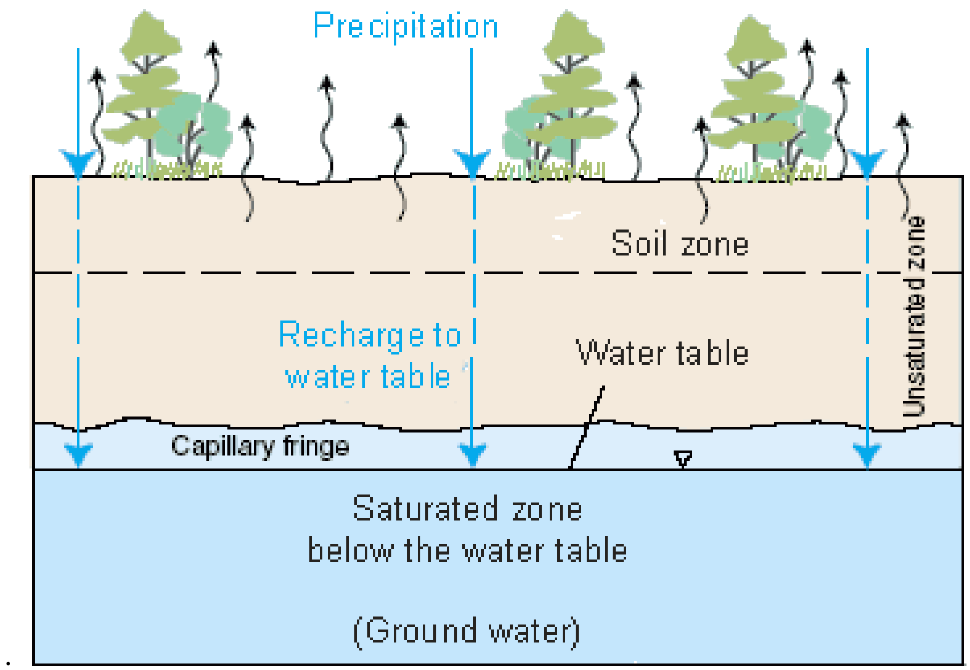

Figure C5-S1- 1: Water infiltration through the soil-water unsaturated zone and into the water table

The distribution of water during the infiltration process under ponded conditions is illustrated in Figure C5-S1- 2. In this idealized profile for soil-water distribution for a homogeneous soil, five zones are illustrated for the infiltration process.

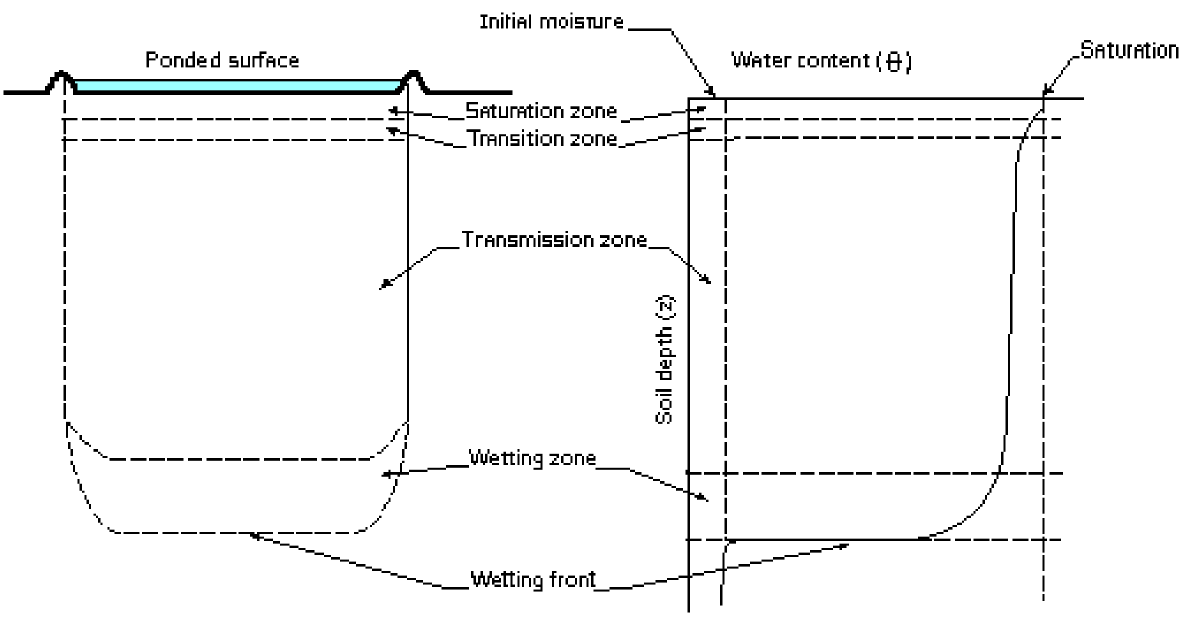

Figure C5-S1- 2: Zones of the infiltration process for the water content profile under ponded conditions

1. **Saturated zone.** The pore space in this zone is filled with water (saturated). Depending on the length of time elapsed from the initial application of water, this zone will generally extend only to a depth of a few millimeters.
2. **Transition zone.** This zone is characterized by a rapid decrease in water content with depth, and will extend a few centimeters.
3. **Transmission zone.** This zone is characterized by a small change in water content with depth. In general, the

transmission zone is a lengthening unsaturated zone with uniform water content. Gravity forces primarily drive hydraulic gradient in this zone.

4. **Wetting zone.** In this zone, the water content sharply decreases with depth from the water content of the transmission zone to near the initial water content of the soil.
5. **Wetting front.** This zone is characterized by a steep hydraulic gradient, and forms a sharp boundary between the wet and dry soil. The hydraulic gradient is characterized primarily by matric potentials.

Beyond the wetting front, there is no visible penetration of water. A comprehensive review of the principles governing the infiltration process has been published by Hillel (1982). Soil-water infiltration is controlled by the rate and duration of water application, soil physical properties, slope, vegetation, and surface roughness. Generally, whenever water is ponded over the soil surface, the rate of infiltration exceeds the soil infiltration capacity. On the other hand, if water is applied slowly, the infiltration rate may be slower than the soil infiltration capacity, and the supply rate becomes a determining factor for the infiltration rate. This type of infiltration process is termed “supply controlled” (Hillel, 1982). However, once the infiltration rate exceeds the soil infiltration capacity, it is the latter which determines the actual infiltration rate, and thus the process becomes profile-controlled. Generally, soil-water infiltration has a high rate in the beginning, decreases rapidly, and then slowly decreases until it approaches a constant rate. As shown in Figure C5-S1- 3, the infiltration rate will eventually become steady and approach the value of the saturated hydraulic conductivity.

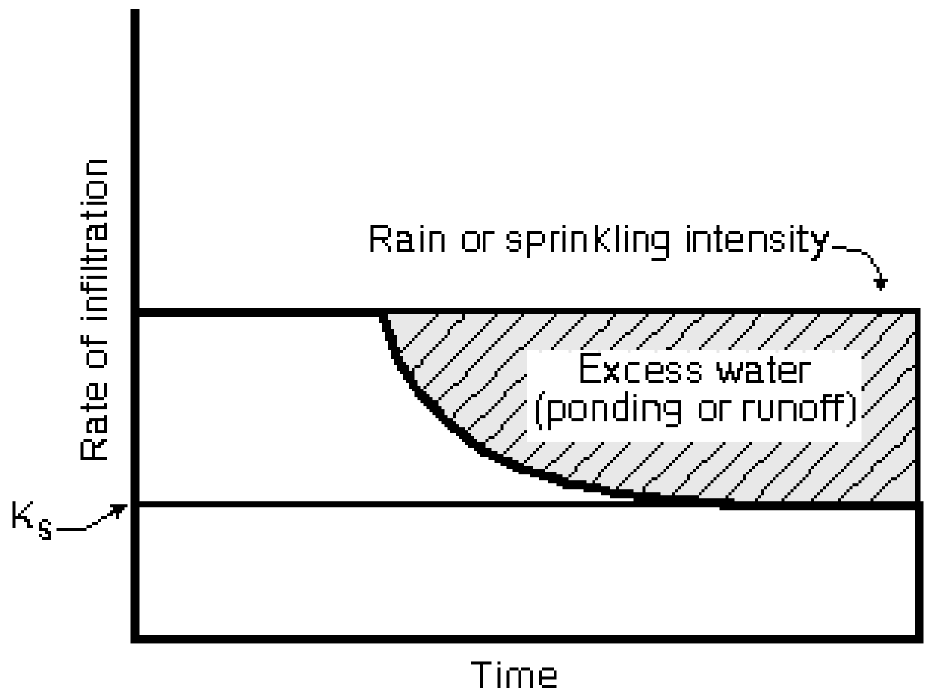

Figure C5-S1- 3: Decrease of infiltration rate
Source: Hillel, 1982

The slope of the land can also indirectly impact the infiltration rate. A steep slope will result in runoff, which will impact the amount of time the water will be available for infiltration. In contrast, gentle slopes will have less of an impact on the infiltration process due to decreased runoff. When compared to the bare soil surface, vegetation cover tends to increase infiltration by retarding surface flow, allowing time for water infiltration. Plant roots may also increase infiltration by increasing the hydraulic conductivity of the soil surface through the creation of additional pore space. Due to these impacts, infiltration may vary widely under different types of vegetation. The movement of water is described below.

1. **Groundwater.** Groundwater occupies the zone of saturation.
2. **Percolation.** Groundwater moves downward through the soil by percolation.
3. **Seepage.** Groundwater then moves toward a stream channel or large body of water as seepage.
4. **Water table.** The water table separates the zone of aeration (vadose zone) from the zone of saturation (phreatic zone). The water table fluctuates with moisture conditions; during wet times the water table will rise as more pore spaces are occupied with water.

5. **Aquifers.** Groundwater is found in these bodies of earth material that have the ability to hold and transmit water. Aquifers can be either unconfined or confined.
   a. **Unconfined.** Open aquifers connected to the surface above.
   b. **Confined.** Closed aquifers sandwiched between dense impermeable layers of earth material.

6. **Aquiclude.** Dense impermeable layers of earth material between which confined aquifers exist.
7. **Recharge zone.** Groundwater is replenished in the recharge zone of a confined aquifer, where the aquifer is exposed at the surface and water can enter it.

C. Infiltration systems

Surface infiltration can be achieved through the use of grass buffer strips, vegetated swales, and porous pavement systems. Infiltration systems such as infiltration trenches, infiltration basins, and bioretention areas (including rain gardens) are designed specifically to capture a defined volume of storm runoff and transfer it directly to the soil profile. Several integrated practices, such as soil quality restoration and native landscaping, can be used in conjunction with these practices to improve the infiltration capacity of compacted urban soils. An infiltration BMP is designed to capture a volume of stormwater runoff, retain it, and infiltrate all or part of that volume into the ground.

Infiltration of stormwater has a number of advantages and disadvantages. The advantages of infiltration include both water quantity control and water quality control.

1. Water quantity control can occur by capturing and retaining surface runoff and infiltrating the water into the underlying soil, reducing the volume of water discharged directly to receiving streams. Infiltration systems can be designed to capture the volume of stormwater from the smaller, more frequent storm events (water quality volume) and infiltrate this water into the ground over a period of several hours or days. Infiltration can provide a secondary benefit by increasing recharge of underlying aquifers and increasing baseflow levels of nearby streams.

2. Water quality treatment can be attained when pollutant removal occurs as water percolates through the various soil layers. As the water moves through the soil, particles can be filtered out. In addition, microorganisms in the soil can degrade organic pollutants that are contained in the infiltrated stormwater.

There are two general types of situations where infiltration practices may be used:

1. For determining the dimensions of an infiltration device that is required to provide storage of the WQv, Cpv, and/or Q_p.

2. Site conditions may dictate the layout and capacity of infiltration measures, and one might be interested in determining the level of control provided by such a layout. In the latter case, control may not be sufficient. Additional control, possibly from other BMPs, may be needed.

The same principles of design apply to both situations.

Although infiltration of stormwater has many benefits, it also has some drawbacks:

1. Infiltration may not be appropriate in areas where groundwater is a primary source of drinking water, due to the potential for contaminant migration. This is especially true if the runoff is from a commercial or industrial area where there may be contamination from organics or metals.

2. The performance of infiltration BMPs will also be limited in areas with low-permeability soils.

3. In addition, infiltration BMPs can experience reduced infiltrative capacity, and even clogging, due to excessive sediment accumulation. Frequent maintenance may be required to restore the infiltrative capacity of the system. Care must also be taken during construction to limit sediment generation and compaction of the soil layers underlying the BMP, to avoid reducing the infiltrative capacity.

D. Infiltration hydraulics and process

A fundamental principle for describing the flow of water in a homogeneous, porous media is given by Darcy's Law (Chow, Maidment, and Mays, 1988; McCuen, 1989):

Equation C5-S1- 1

$$Q = KA\Delta h/L$$

Where:
Q = flow (cfsec)
K = saturated hydraulic conductivity; characteristic of a specific porous medium when effectively saturated with water (fps)
A = cross-sectional area through the porous medium perpendicular to the flow (ft^2)
$\Delta h/L$ = hydraulic gradient, the difference in hydraulic head, Δh, per unit distance in the direction of flow, L ft/ft

The velocity of flow through the porous medium can be determined from Equation C5-S1- 1 by substituting the continuity equation Q = qA to obtain:

$$q = K\left(\frac{\Delta h}{L}\right)$$

q = velocity of water through a unit cross-section of the porous medium (fps)

The velocity of water through the pores of the medium is described by:

$$V = \frac{q}{\theta_s}$$

Where:
V = fluid velocity (in/hr)
θ_s = water content of the medium (in^3/in^3) equal to the medium's porosity less the volume of trapped air in the pore spaces

The infiltration rate is the flux of water into the soil in units of in/hr (Hillel, 1980). As shown in Figure C5-S1- 2 and Figure C5-S1- 3, infiltration downward into an initially dry soil occurs under the combined influence of ponding head and suction gradient (Hillel, 1980). As the water penetrates deeper and the transmission zone lengthens, the suction gradient decreases because the difference in matric suction between the saturated soil surface and the unwetted soil below the wetting front divides itself along an increasing distance (L). The suction gradient eventually becomes negligible and the gravity gradient becomes the remaining force pushing water downward. In vertical flow, each unit of decline in ponding depth (L) leads to an equal loss of gravity head (Δh), so the gravity gradient has a value of unity. Early in a ponding event, the total hydraulic gradient is higher than unity since the suction gradient and gravity gradient are both significant and acting together. Over time, the total hydraulic gradient declines approaching a lower limiting value of 1. As long as the vertical profile is homogeneous, the vertical movement of water settles down to a steady, gravity-induced rate approaching the hydraulic conductivity as a lower limiting value. Work done by Bouwer (1966) suggests a safety factor of 0.5 be applied to the measured soil hydraulic conductivity to account for any decrease in conductivity due to plugging of the soil interface and air trapped in the pore spaces.

E. Soils and infiltration

Factors that control infiltration rate and capacity:

- Vegetative cover, root development, and organic content
- Moisture content
- Soil structure and texture
- Porosity and permeability
- Soil bulk density and compaction
- Slope, landscape position, and topography

1. **Hydrologic soil group (HSG).** The HSG refers to the soil characteristics that tend to decrease or increase the amount of runoff produced from a precipitation event. The HSG is used in the determination of the runoff curve number (CN) developed by the Natural Resource Conservation Service (NRCS).

   a. Group A.
      1) Sand, loamy sand, or sandy loam soil types.
      2) Low runoff potential and high infiltration rates, even when thoroughly wetted.
      3) Includes deep and well- to excessively-drained sands and gravels.
      4) High rate of water transmission (hydraulic conductivity).

   b. Group B.
      1) Silt loam or loam.
      2) Moderate infiltration rate when thoroughly wetted.
      3) Includes moderately deep to deep, moderately well- to well-drained soils.
      4) Moderately fine to moderately coarse textures.

   c. Group C.
      1) Sandy clay loam.
      2) Low infiltration rates when thoroughly wetted.
      3) Consists primarily of soils with a layer that impedes downward movement of water.
      4) Moderately fine to fine structure.
      5) Perched water table at 40-60 inches; root-limiting at 20-40 inches.

   d. Group D.
      1) Clay loam, silty clay loam, sandy clay, silty clay, and clay.
      2) Very low infiltration rates when thoroughly wetted.
      3) Consists chiefly of clay soils with high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material.

2. **Soil texture.** The hydrologic design methods presented are based on the use of two hydrologic soil properties; the effective water capacity (C_w) and the minimum infiltration rate (f) of the specific soil textural groups, as shown in Table C5-S1- 1.

   a. **Effective water capacity.** The fraction of the void spaces available for water storage (in/in).
   b. **Minimum infiltration rate.** The final rate that water passes through the soil profile during saturated conditions (in/hr).

   The hydrologic soil properties are obtained by identifying the soil textures with a gradation test for each change in soil profile. The soil textures presented in Table C5-S1- 1 correspond to the soil textures of the US Department of Agriculture (USDA) Textural Triangle presented in Figure C5-S1- 4. The data presented in Table C5-S1- 1 are based on the analysis of over 5,000 soil samples by the USDA under carefully controlled procedures. The use of the soil properties established in the table for design and review procedures will offer two advantages. First, it provides for consistency of results in the design procedures. Second, it eliminates the need for the laborious and costly process of conducting field and laboratory infiltration and permeability tests.

   Based on the soil textural classes and the corresponding minimum infiltration rates, a restriction is established to eliminate unsuitable soil conditions. Soil textures that are recommended for infiltration systems include those soils with infiltration rates of 0.52 in/hr or greater, which include loam, sandy loam, loamy sand, and sand (soil clay content of less than 20% and a silt/clay content of less than 40%). Soil textures with minimum infiltration rates of less than 0.52 in/hr are not suitable for usage of infiltration practices. These include soils with more than 30% clay content, which are susceptible to frost heaving and therefore structurally unstable; in addition to having a poor capacity to percolate runoff.

3. **Suitability of soils.** As seen above, the HSG and soil texture at the site will have a direct impact on the suitability of the site soils for application of an infiltration practice. Other considerations such as the soil bulk density and

degree of compaction of the site soils should also be considered. The NRCS Soil Survey publications provide tables of physical and engineering soil properties for each of the soil series at a particular site. These tables can be useful for completing an initial screening of the site soils to determine if an infiltration system should be selected as a viable alternative.

Table C5-S1- 1: Hydrologic soil properties classified by soil texture

Soil texture class	**Hydrologic soil group**	**Effective water capacity (C_w) (in/in)**	**Minimum infiltration rate (*f*) (in/hr)**	**Effective porosity, θe (in^3/in^3)**
Sand	A	0.35	8.27	0.025 (0.022-0.029)
Loamy sand	A	0.31	2.41	0.024 (0.020-0.029)
Sandy loam	B	0.25	1.02	0.025 (0.017-0.033)
Loam	B	0.19	0.52**	0.026 (0.020-0.033)
Silt loam	C	0.17	0.27	0.300 (0.024-0.035)
Sandy clay loam	C	0.14	0.17	0.020 (0.014-0.026)
Clay loam	D	0.14	0.09	0.019 (0.017-0.031)
Silty clay loam	D	0.11	0.06	0.026 (0.021-0.032)
Sandy clay	D	0.09	0.05	0.200 (0.013-0.027)
Silty clay	D	0.09	0.04	0.026 (0.020-0.031)
Clay	D	0.08	0.02	0.023 (0.016-0.031)

**Minimum rate: soils with lower rates should not be considered for infiltration BMPs

Source: Rawls et al., 1982

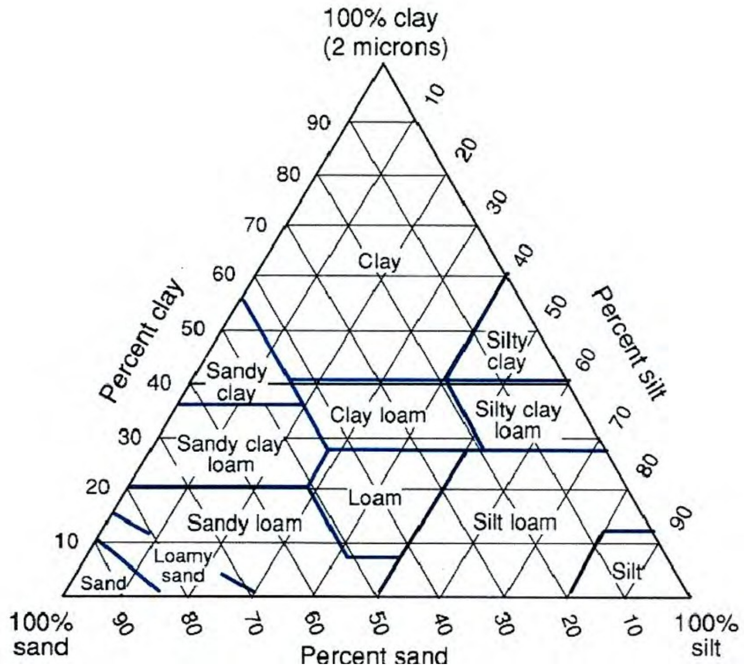

Figure C5-S1- 4: USDA Soil Textural Classification

F. Screening criteria for infiltration practices

1. Evaluation of the viability of a particular site includes:

    a. Determine soil type (consider NRCS Group A, B or C only) from mapping and consult USDA/NRCS soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30% clay or more than 40% clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration. If the surface and underlying soils are NRCS Group D or the saturated infiltration rate is less than 0.52 in/hr, the site should not be used for infiltration.

    b. Groundwater separation should be at least 4 feet from the basin invert to the measured groundwater elevation. Seasonal high groundwater should be a minimum of 4 feet below the infiltration surface.

    c. Bedrock or impervious soils should be a minimum of 4 feet from the infiltrating surface (i.e. bottom of trench).

    d. Location should be the following distances away from structures:
        1) Buildings, slopes, and highway pavement: greater than 25 feet
        2) Wells and bridge structures: greater than 100 feet

    e. Sites that are constructed of fill and/or have a baseflow or slope greater than 15% should not be considered.

    f. Infiltration practices should not be placed in locations that cause water problems to downgrade properties. Infiltration facilities should be set back 25 feet (10 feet for dry wells) down-gradient from structures.

    g. Ensure that adequate head is available to operate flow splitter structures when the trench is operated as an offline structure. Hydraulic design should prevent ponding in the splitter structure or creation of backwater upstream of the splitter.

    h. For infiltration basins, at least three in-hole conductivity tests should be performed using USBR 7300-89 or Bouwer-Rice procedures (ASTM D5084-03 Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials), the latter if groundwater is encountered within the boring; two tests at different locations within the proposed basin; and the third down-gradient by no more than 25 feet. The tests should measure permeability in the side slopes and the bed within a depth of 12 feet of the invert.

i. The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 0.5 in/hr. If any test hole shows less than the minimum value, the site should be disqualified from further consideration.

2. Should the initial site assessment described above not rule out infiltration as a BMP alternative, the point evaluation system described below can be used as the next level of site evaluation. The point system was developed by the Swedish Association of Water and Wastewater Works (1983) and was first recommended for use in the US by Urbonas and Stahre (1993). The protocol is based on evaluating various site conditions by assigning points for each category listed in Table C5-S1- 2. A site with fewer than 20 points is considered unsuitable. A site with more than 30 points is considered good. A site with 20-30 points is considered a suitable condition, with some occasional standing water on the infiltration surfaces possible.

3. These preliminary evaluation procedures should be coupled with a detailed site-specific engineering evaluation. This may include a standard series of soil borings at the proposed BMP locations to establish more definitive information on vertical soil textural/grain size classifications, as well as any restrictive layers in the soil profile. Direct in-situ measurement of soil infiltration rates can also be competed using a double-ring infiltrometer as described in the standard test method ASTM D3385-03, Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer.

4. The recommended procedure for final site evaluation of soils for infiltration practices is provided in Chapter 5, section 7.

Table C5-S1- 2: Point system for the evaluation of potential infiltration sites

1 Ratio between tributary-connected impervious area (AIMP) and the infiltration area (AINF):	
• AINF > 2 AIMP	20 points
• AIMP ≤ AINF ≤ 2 AIMP	10 points
• 0.5 AIMP ≤ AINF ≤ AIMP	5 points
Urban catchments with pervious surfaces smaller than 0.5 AIMP should not be used for infiltration.	
2 Nature of surface soil layer:	
• Coarse soils with low ratio of organic material	7 points
• Normal humus soil	5 points
• Fine grained soils with high ratio of organic material	0 points
3 Underlying soils:	
• If the underlying soils are coarser than surface soils, assign the same number of points as for the surface layer under criterion #2.	
• If the underlying soils are finer-grained than the surface soils, use the following points:	
➢ Gravel, sand, or glacial till with gravel or sand	7 points
➢ Silty sand or loam	5 points
➢ Fine silt or clay	0 points
4 Slope (S) of the infiltration surface:	
• S < 7%	5 points
• 7% ≤ S ≤ 20%	3 points
• S > 20%	0 points
5 Vegetation cover:	
• Healthy, natural vegetation cover	5 points
• Lawn – well established	3 points
• Lawn – new	0 points
• No vegetation – bare ground	5 points
6 Degree of traffic on infiltration surface:	
• Little foot traffic	5 points
• Average foot traffic	3 points
• High foot traffic (i.e. playing/sports fields)	0 points

Source: Adapted from Urbonas and Stahre, 1993

G. Types of infiltration practices

Design methodologies are presented for three infiltration practices and two integrated (complementary) practices below:

- Infiltration trenches
- Infiltration basins
- Bioretention area (and rain gardens)
- Soil quality restoration
- Native landscaping

The design procedures are based on either intercepting the WQv from the area contributing runoff or using the truncated hydrograph method for control of the runoff from an area for either Cpv or Q_p. The design equations may be defined for either case of stormwater quality or quantity control because the volume of water (V_w) stored in the individual infiltration practice may be determined from the methods described in Chapter 2 and Chapter 3.

Infiltration trench and infiltration basin systems rely directly on the site soil conditions to infiltrate the design capture volume of stormwater. Infiltration trenches and basins can be used on single/multi-family residential sites of up to 10 acres and up to 5 acres for commercial sites. Bioretention BMPs use an additional prepared soil and vegetation layer on top of the infiltrating soil surface to provide an additional filtration process prior to infiltrating all or part of the filtered stormwater. Rain gardens are a smaller design variant of the class of BMPs called bioretention areas. Rain gardens are typically constructed on residential sites and use a shallow depression in the native soil profile supplemented with permeable upper soil, mixed with vegetation, to capture and treat the runoff. A rain garden is typically constructed without an aggregate subbase or subdrain system, and the captured runoff volume will be limited to that which can infiltrate into the local subsoil within 12-24 hours. The last two practices, soil quality restoration and native landscaping, are intended as complementary integrated practices that can be implemented to improve the infiltration capacity of compacted urban soils, and provide a vegetation system to maintain a healthy soil profile for infiltration.

An important consideration in the design and construction of infiltration systems is to understand that the primary cause of failure is clogging of the infiltrating soil interface. On development sites where construction will continue over an extended period of time, the final implementation of the infiltration BMP should be completed after the site is fully developed and the entire catchment area is stabilized for control of sediment from construction activity. All of the structural infiltration practices should be provided with an upstream pre-treatment BMP for removal of sediment (i.e. grass buffer strip, vegetated swale, sediment forebay, etc). While an infiltration trench or basin will provide removal of suspended solids, the primary functions will be removal of very small particulates and soluble pollutants in the soil profile, reduction of the volume of direct annual runoff to the storm sewer system and local streams, and increasing the volume of recharge to the local water table.

H. Design criteria for infiltration practices

1. **Infiltration conveyance criteria.** The design of all infiltration practices includes an analysis of the site runoff conveyance configuration to ensure that excess flow is discharged at non-erosive velocities.
   a. The overland flow path of surface runoff exceeding the capacity of the infiltration system is configured to preclude erosive concentrated flow. If computed flow velocities do not exceed the non-erosive threshold, overflow may be accommodated by natural topography. Critical erosive velocities for grass and soil are summarized in Chapter 9, section 2.
   b. Infiltration systems are designed to fully de-water the entire WQv within 48 hours after the storm event.
   c. If the infiltration practice is used to control the Cpv or Q_p, the truncated hydrograph method can be used to determine the required detention volume (see Chapter 3, section 7).
   d. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice should be designed as an offline practice (see Chapter 4 for an example of an offline infiltration practice).
   e. Stormwater outfalls with capacity for the overflow associated with the 10-year design storm event are included and configured to prevent non-erosive velocities on the downslope.

2. **Infiltration pre-treatment criteria.**
   a. **Pre-treatment techniques to prevent clogging.** The purpose of pre-treatment is to protect the long-term integrity of the infiltration rate. The following techniques, at least three for infiltration trenches and two for infiltration basins, are installed in every infiltration practice:
      - Grass channel (see Chapter 9, section 2 for design requirements and example computation)
      - Grass filter strip (minimum 20 feet and only if sheet flow is established and maintained); see Chapter 9, section 4 for design requirements and example computation
      - Bottom sand layer
      - Upper sand layer (6-inch minimum) with filter fabric at the sand/gravel interface
      - Use of washed bank run gravel as aggregate

   b. **Pre-treatment volume.** A minimum of 25% of the WQv is pre-treated prior to entry to the infiltration practice. If the infiltration rate for the underlying soils is greater than 2 inches per hour, 50% of the WQv is pre-treated prior to entry into an infiltration facility. This can be provided by a sedimentation basin, stilling basin, sump pit, or other acceptable measures. Exit velocities from pre-treatment should be non-erosive during the two-year design storm.

3. **Infiltration treatment criteria.**
   a. The infiltration practice is designed to exfiltrate the entire WQv less the pre-treatment volume through the floor of each practice, using the design methods outlined in the subsequent design procedures for each practice.
   b. Infiltration practices are best used in conjunction with other BMPs, and downstream detention is often still needed to meet the Cpv and Q_p sizing criteria.
   c. The construction sequence and specifications for each infiltration practice is outlined in the SUDAS Specifications manual. Experience has shown that the longevity of infiltration practices is strongly influenced by the care taken during construction.
   d. A porosity value, n ($n=V_v/V_t$), of 0.40 is used in the design of stone reservoirs for infiltration practices.

4. **Infiltration landscaping criteria.**
   a. A dense and vigorous vegetative cover is established over the contributing pervious drainage areas before runoff can be accepted into the facility.
   b. Infiltration trenches are not constructed until all of the contributing drainage area has been completely stabilized.

5. **Infiltration maintenance criteria.**
   a. Infiltration practices may not serve as a sediment control device during the site construction phase. In addition, the erosion and sediment control plan for the site must clearly indicate how sediment will be prevented from entering the infiltration site.
   b. An observation well for monitoring the water level is installed in the infiltration practice, consisting of an anchored six-inch diameter perforated PVC pipe with a lockable cap.
   c. Consideration should be given in the infiltration design to include a dewatering method in the event of failure. This can be done with subdrain pipe systems to provide drawdown capability.
   d. Direct access is provided to all infiltration practices for maintenance and rehabilitation.