Development of Appropriate Stormwater Infiltration BMPs: Part II
Design of Infiltration BMPs

Scott Taylor, PE
Robert Bein, William Frost Associates
Irvine, CA 92619-7057

and

G. Fred Lee, PhD, PE, DEE
G. Fred Lee & Associates
El Macero, CA 95618-1005

Biographical Sketch

Scott Taylor is an Associate with Robert Bein, William Frost and Associates where he heads the firm's storm water quality group. Mr. Taylor has 15 years of experience in flood control design and storm water quality investigation and design. He has developed storm water quality programs for large public works infrastructure projects including most recently a 26 mile stretch of SR 241, 261 and 133 in Orange County. Mr. Taylor has been a part-time instructor at Cal State Long Beach and the University of California at Irvine instructing undergraduate courses in hydraulic design and hydrologic engineering.

Abstract

Infiltration BMPs treat a portion of Stormwater runoff or "capture" volume by infiltrating a portion of the runoff into the soil. Infiltration practices include basins, trenches and porous pavement. This paper presents design guidance for infiltration basins and trenches. Site conditions are important for an infiltration BMP to function effectively. Criteria include a sufficient infiltration rate at the site, sufficient distance from the proposed device invert to the seasonal high groundwater table and sufficient lateral extent from adjacent wells. Further, infiltration basins are not suitable where large volumes of particulate constituents are likely. Much guidance has been published relative to design and siting criteria for infiltration devices, but less information is available as to practical methods for siting, operating and maintaining them.

Siting of a stormwater runoff infiltration device should be done in consultation with a geotechnical engineer. Preliminary analysis of soil at the proposed site can reveal if the site is viable for more detailed investigation. Sites that meet pre-screening criteria should be further investigated using in-field permeability tests. A site that meets or exceeds acceptable permeability rates and corresponding drain times as demonstrated through in-field testing, and meets other geometric and hydraulic constraints can be considered for final design. Infiltration practices may be best designed as "off-line," bypassing less frequent larger discharge storms. The design capture volume for an infiltration practice is typically the statistical 6-month or 1-year rainfall event. Consideration must be taken during design to ensure that the facility does not become a jurisdictional wetland, that vector control (and possibly abatement) is accommodated,

and that maintenance is facilitated. Long-term viability of the installation hinges on maintaining the design infiltration rate. Maintenance of the facility is necessary to remove accumulated sediments, excess vegetation, and debris.

Introduction

There is much guidance available concerning the design and construction of infiltration facilities for storm water runoff, with many of the design guidelines varying considerably (Young et al., 1996, WEF/ASCE, 1998, Schueler et al., 1992). The objective of this paper is to present a step-wise procedure for the design of infiltration facilities and provide some guidance relative to the various design criteria proffered in design manuals. The design procedures and recommendations in this paper are most applicable to the southwest in relatively arid areas where the groundwater table is usually not near the surface and considerable silts and clays may be present in the soil/strata.

Three primary topic areas will be discussed; 1) Site selection, 2) design guidance and 3) maintenance and operation. Site selection for infiltration BMPs is of primary importance and will require the expenditure of significant resources. It is estimated that the cost for site selection of infiltration BMPs will range from a minimum of about $6,000 to a maximum of about $25,000. Resources needed for design are consistent with other types of BMPs; the preparation of plans, specifications and estimates for a single site can be expected to cost from $15,000 to $30,000. Construction costs vary widely depending on the application (trench or basin) and the size of the facility, which depends on the tributary area. For planning purposes, construction of an infiltration trench can be expected to cost between $50,000 and $100,000, an infiltration basin should fall in the range of between $100,000 and $300,000.

Site Selection

Site selection is the most difficult part of the infiltration system design process. In general, the device must be located at the low point in the watershed, sufficient space must be available for construction, and adjacent structures and land use must be compatible with the installation. Infiltration trenches are typically recommended for drainage areas up to 10 acres (Young et al, 1996), making them suitable for parking areas, corporation yards and commercial lots. Infiltration basins may be used for drainage areas from about 5 to 50 acres (Young et al., 1996) making them suitable for municipal installations, mixed use developments and transportation facilities.

Site selection proceeds in two distinct phases, 1) preliminary screening and 2) site investigation. An experienced engineer should be part of the preliminary and final site selection and design team. Further, a geotechnical engineer must also be employed to for the second site investigation phase. Urbonas and Stahre (1993) describe a formalized procedure for prescreening of potential infiltration sites.

Preliminary Screening. A suitable site must be located that allows sufficient space for the BMP to be located. Once the site is chosen that meets drainage criteria (i.e., at the low point of the catchment) the remaining preliminary screening criteria may be investigated. The screening criteria are:

- Soil Type: Only SCS soil types A or B may be considered potentially suitable
- Proximity to water wells
- Proximity to building foundations or other structure foundations or slopes
- Proximity to highway pavement
- Available space

Once a preliminary site is selected, the criteria indicated above may be evaluated. Soil maps available from the SCS should be consulted to determine the soil type, which can be verified through field observation. Sites with category C or D SCS (USDA, undated) type soils are not viable candidates for infiltration devices since the infiltration rates for these soils fall below the recommended minimum rate. The site should also be checked for proximity to water wells. Schueler (1987), recommends that infiltration devices be placed at least 100 ft from domestic water wells to avoid contamination. As discussed in Part I of this paper, such generic guidance is potentially unprotective, and additional investigation and monitoring must be undertaken to ensure that the existing or potential water supply is adequately protected. Given the wide variety of alternative storm water BMP practices available to the engineer, it is of questionable judgement to place infiltration devices in any relative proximity to domestic water supplies given the uncertainty of the types of constituents in storm water runoff and their potential mobility in groundwater.

Infiltration devices must also be located sufficiently away from building or structure foundations. Without detailed geotechnical investigation, a minimum of 100 feet of separation is recommended. This minimum separation may be reduced with concurrence from a geotechnical and structural engineer, depending on the type of structure. For example, the primary concern relative to building foundations is potential seepage, and the geotechnical engineer should be able to assess this potential. More detailed analysis is required for more complex situations such as highway bridge columns, where foundations are often designed for seismic and vertical loads. Highway pavements can also be impacted by infiltration. Many highway pavement systems incorporate permeable base materials and underdrains that discharge to the storm drain system. Infiltration devices constructed directly adjacent to highway pavements may simply discharge to the pavement subgrade drainage system with potential adverse impacts on the pavement and ineffective disposal of storm water. Infiltration devices should also not be located adjacent to slopes where seepage or slope stability problems could develop.

Finally, sufficient space must be available for installation of the BMP. For infiltration tenches and basins, the surface area required for the device may be estimated from the tributary area. Infiltration devices are typically designed to intercept the 'first flush' volume, generally defined as the first one-half inch of runoff (Young, 1996). Many constituents in storm water runoff do not exhibit 'first flush' characteristics (Irish, 1995) or the first flush phenomena is not well pronounced. The design volume of the infiltration facility must be developed with this in mind. It may be most effective to design the facility to intercept the one to three year average storm event, thereby capturing most of the storm water runoff while bypassing more rare events. Further, given the relative uncertainty of the potential conditions that may lead to groundwater contamination, and considering the wide range of recommended design criteria, design for larger runoff volumes may be desirable. Design of facilities to intercept runoff from a storm with a larger return period than about 1-year may not be economical however.

Surface area for the BMP may be estimated by multiplying the design rainfall runoff volume by the tributary drainage area. Knowing the depth of the BMP, the surface area may then be computed. Typically, trench depths should be kept at or below 10 feet to allow for ease of construction and maintenance, and basin depths should be kept at or below a depth o f three feet, for safety purposes. Given these maximums, an minimum required surface area may be computed, and the site suitability determined. It is also important to provide sufficient area adjacent to the device to allow for maintenance. A 10-foot maintenance road should be provided around infiltration basins. Infiltration trenches should be set back from the property line on a 1:1 slope from the bottom of the trench.

Site Investigation.

Once a preliminary site has been selected, a more detailed geotechnical investigation is required. SCS soil surveys are region rather than site specific, and local heterogeneity in the soils can easily render a site unsuitable for infiltration practices.

An in-drill hole permeability test is recommended for the site (U.S. Dept. Interior, 1985). The test is conducted by drilling a hole at the location of the BMP, and conducting a field permeability test of the site. Samples may also be collected for laboratory permeability testing, however, site values should be used in design.

The permeability test is conducted in a 'test zone' of a 4" well. Typically the test zone is about 5 feet. A 10" bore is drilled with a hollow stem auger to a depth of 30 feet or to groundwater, which ever is less. If the depth of groundwater is know precisely, the depth of the bore need not be deeper than several feet past the test zone. The top of the test zone should be coincident with the constructed invert of the infiltration device, e.g., the floor of the trench or the basin invert elevation. A 4" PVC threaded casing is inserted into the bore hole. The casing is slotted to ensure that the permeability of the casing exceeds the expected permeability of the surrounding soil. The bottom of the hole is backfilled with hydrated bentonite chips and medium aquarium sand or other suitable filter pack is used around the casing within the test zone. Finally, hydrated bentonite chips are used to seal the top of the well. The bore hole is pre-saturated to loosen sidewall cake and saturate the formation for a minimum of one day prior to testing. Permeability is computed by taking several water level measurements with respect to time and using equations found in the Bureau of Reclamation *Ground Water Manual* (U.S. Dept. Interior, 1985) or most groundwater texts.

Minimum recommended infiltration rates vary in the US. The practical published minimum would appear to be 0.27 in/hr (Young, et al., 1996). Other minimum recommended values include 0.5 in/hr (Yu and Kaighm, 1992, Schueler, 1992). Table 1 provides a summary of various recommended infiltration values.

Design Guidance

Once a site with a suitable infiltration rate is found, design of the facility is relatively straight forward. The principle variable is the facility drain time. An absolute maximum drain time of 72 hours is recommended to preclude vector control problems and the formation of algae that may clog the soil. The facility design volume must be determined through selection of a design storm. As discussed previously, a one to three year return interval is suggested to compute the design storm volume. This is a larger design capture volume than is generally recommended in literature, but is made in response to the uncertainties associated with groundwater infiltration from both a technical and regulatory perspective. Further, in the future it is possible that by-pass runoff (runoff from events more rare than the design storm) will be required to meet water quality standards. Once the total design rainfall is known, the runoff volume may be estimated by selecting an appropriate runoff coefficient based on the type of land use in the watershed. The SCS has a well documented rainfall-runoff depth relation (McCuen, 1989) or a small area unit hydrograph procedure may be used.

The facility surface area may be computed using an assumed depth and the computed design volume. The depth for an infiltration basin should not exceed 3 feet unless precautions are taken for public safety that include positive barriers to exclude pedestrians and vehicles. The maximum depth of a trench will be determined by such factors as available surface area, depth to bedrock and the location of the water table. The maximum drain time will also be a factor in determining the surface area. Drain time may be computed from the equation:

$$T = d/f$$

where: T is drain time in hours
d is design depth (in)
f is soil infiltration rate (in/hr)

Many references recommend a safety factor of two when using the above equation. This is generally a good practice given that the performance of the facility is likely to degrade over time. The volume of the infiltration tench is computed using the trench dimensions and assuming a void ratio of about 30% for the rock media used to fill the trench. The volume of the infiltration basin may be computed using standard earthwork methods and allowing 1 foot for freeboard, although freeboard may be optional.

Pre-treatment is also recommended where a moderate to high sediment load may be expected, or where such treatment may be beneficial in removing constituents of concern that could otherwise contaminate the groundwater. Pitt (1996) provides a good discussion of this aspect of infiltration BMP operation. Pre-treatment generally includes biofiltration, either through the use of swales or strips, but may also include detention ponds. Infiltration basins may also include a sediment forebay for pre-treatment. The sediment forebay should be designed to intercept the coarse sediment fraction. Young (1996) provides some guidance on forebay design.

Table 1 summarizes design criteria for infiltration BMPs. A column is also provided in the table indicating the recommended criteria as discussed in this paper.

Infiltration devices should completely dewater between storms. The drain times indicated above will achieve this criteria. Depth to the water table or confining layer (aquitard) is important relative to groundwater contamination as discussed in Part I of this paper (Lee and Taylor, 1998). The selection of this value is typically dictated by regional conditions (Dorman et al., 1988). Literature indicates values from 3 to 10 feet, with areas of high groundwater generally adopting standard values in the range of 2 to 4 feet. Other areas, with relatively deeper groundwater tables generally adopt a minimum standard of about 10 feet. It would not appear prudent to use a minimum separation that would allow for mounding of the groundwater from the water table to the BMP under any circumstances. As discussed previously, the selection of this depth must be made based on the characteristics of the aquifer and the constituents of concern in the runoff.

Infiltration basins may be constructed as either in-line or off-line. Off-line construction is the generally preferred method whereby once the design capture volume is within the basin, further runoff is bypassed from the facility. In-line facilities intercept all flow regardless of the magnitude, discharging surplus flows through a spillway or other outlet. On a practical level, in-line designs may not incur significant disadvantage as compared to off-line designs since the goal of the BMP is to intercept more frequent events as opposed to relatively rare events.

Maintenance

Maintenance of infiltration systems is absolutely essential for effective operation. Infiltration device will clog over time, as evidenced by increasingly longer drain times from a basin or trench-full condition. The State of Maryland, (1985,1986) provides some guidelines for maintenance of infiltration BMPs. Sediments should be removed from basins to restore infiltration capacity when the time to drain from a full facility exceeds 72 hours. Sediment removal should only be carried out when the facility is dry. Only rubber tired vehicles should be used and equipment should be as small and light as possible. Further, basins should be tilled annually to aerate the soil, and a good vegetation cover should be encouraged on the basin side slopes and the invert.

Table 1
Design Criteria

Design Element	**Criteria Description**	**Recommended Criteria**
Ponding Time	72 hrs (Minnesota, Maryland, Florida) 48 hrs (Washington, Caltrans) 12 hrs (WEF/ASCE)	72 hrs
Drainage Area	*Infiltration Basin* 50 acres (max) (Washington, Young, Minnesota, Schueler) 5 acres (Caltrans) *Infiltration Trench* 15 acres (Washington) 5 acres (Schueler, Caltrans) 10 acres (Young, Schueler,)	50 acres 10 acres

Infiltration Rate	0.25 in/hr (Caltrans) 0.27 in/hr (Minnesota) 0.3 in/hr (Young, Dorman, ASCE/WEF) 0.5 in/hr (Schueler) 4.0 in/hr (Washington)	0.3 in/hr
Design Storm	6-month 24 hour (Washington) 0.5 in of runoff (Florida) 1-year, 24 hour (Caltrans) 1 inch of runoff (Minnesota) 0.5 inches from imperv. area (Maryland)	1 to 3 year storm
Depth	*Infiltration Basin* 3-12 feet (Washington) 1 foot (WEF/ASCE) *Infiltration Trench* 2-10 feet (Schueler) 3-6 feet (WEF/ASCE)	3 feet (Basin) 10 feet (Trench)
Lining	*Infiltration Basin* Vegetation (Washington, Young, Minnesota)	Vegetation

(The references are listed in parenthesis in abbreviated form from the reference list)

Infiltration trenches may also begin to exhibit excessively long drain times, or, depending on trench design, may also begin to loose storage volume as sediment accumulates in the rock matrix. Most trench designs include a layer of filter fabric about 1 foot from the trench surface to extend maintenance periods. The entire rock matrix must be removed once it becomes filled with sediment, although only the top 1 foot and the filter fabric must be serviced in most instances.

Infiltration devices should be inspected after each significant storm event to observe how long runoff remains in the structure. Infiltration trenches are generally designed with an observation well for this purpose. Other inspection items include erosion, the growth of woody vegetation, sediment accumulation and the coverage of the vegetation (basins).

Vegetation in basins should be maintained at a height from about 6 to 8 inches to preclude vector control problems. An identified maintenance schedule is also important to ensure that the facility does not become a jurisdictional wetland. Jurisdictional agencies may require an initial agreement relative to the maintenance of the basin, consistent maintenance is usually a requirement of such agreements. All clippings and vegetation should be removed from the basin during maintenance operations.

The restoration of infiltration capacity may be achieved for more mature facilities by tilling the basin floor to a deeper depth (3 feet). During such an operation, sand or gravel may also be added to increase permeability. In some instances, the original permeability of the facility may not be restored, in these cases, it is likely that the pre-treatment system is inadequate and the facility should be reconstructed using over-excavation techniques.

Monitoring

Groundwater monitoring is an essential element of the maintenance program for an infiltration BMP to ensure that groundwater supplies are protected. A monitoring well should be installed both up gradient and down gradient from the infiltration device (outside of the maintenance area) for the purpose of sampling. The number and placement of groundwater monitoring wells may be adjusted relative to the type of strata in the area, the depth to the groundwater table, and the beneficial use of the groundwater in the area of the infiltration device(s). There is no substitute for a groundwater monitoring program however since formations that are conducive to infiltration tend to allow high mobility of constituents in the zone of aeration.

Conclusions

The use of infiltration BMPs is attractive in that groundwater recharge is achieved, potential pollutants are generally assumed to be prohibited from reaching receiving waters and they are relatively simple to construct. However, infiltration devices may be difficult to site in areas were soils contain relatively higher percentages of silts and clays, and sufficient distance must be maintained from the seasonal high groundwater table, wells, and structures.

Infiltration devices may also function more efficiently and with less maintenance if pre-treatment is used. Biofilters (swales or strips) are generally well suited for this purpose to remove settleable material prior to discharge to the infiltration device. Tributary areas with mostly impervious or highly stabilized pervious cover may not require pre-treatment, but it may also be considered as a mechanism to remove potential pollutants that could otherwise contaminate groundwater sources.

Infiltration devices remain as one of many BMPs that may be selected by the engineer to assist in achieving surface water quality goals. The quality of groundwater should not be compromised or jeopardized in the pursuit of these goals. Consequently, in instances where significant uncertainty exists relative to the potential for groundwater contamination by the infiltration device, another type of BMP may be the best solution.

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