CHAPTER 7: EXFILTRATION SYSTEMS

7. EXFILTRATION SYSTEMS

7.1 GENERAL

7.1.1 Hydrology

Chapter 2 in this design guide and the *Drainage Manual* encompass the Department's general guidance regarding hydrology. Coordinate in advance with the District Drainage Engineer for approval of the design criteria and calculation methods.

7.1.1.1 Time of Concentration

Chapter 2 (Hydrology) defines and provides methods to calculate the time of concentration. A longer time of concentration usually reduces the calculated peak discharge. The Rational Method is very sensitive to changes in the time of concentration (i.e., if the time of concentration increases from 10 minutes to 60 minutes, the calculated peak discharge could be reduced by up to 60 percent). The Flow Hydrograph Methods are less sensitive to the time of concentration changes (i.e., up to 15 percent reduction in peak discharge if the time of concentration increases from 10 minutes to 60 minutes).

7.1.2 Hydro-Geology

7.1.2.1 Darcy's Law

Darcy's Law characterizes the flow through porous media, assuming that the viscosity, temperature, and density of the fluids are constants. The flow rate is a function of the flow area, the hydraulic gradient, and the proportionality constant (refer to Figure 7.1-1):

$$Q = k\ i\ A$$

where:

Q = Flow rate, in ft^3/sec

k = Permeability constant, in ft/sec

i = Hydraulic gradient ($i = \Delta H/L$)

A = Cross-sectional area of soil conveying flow, in ft^2

ΔH = Change in the hydraulic grade line, in ft

L = Distance between points of interest, in ft

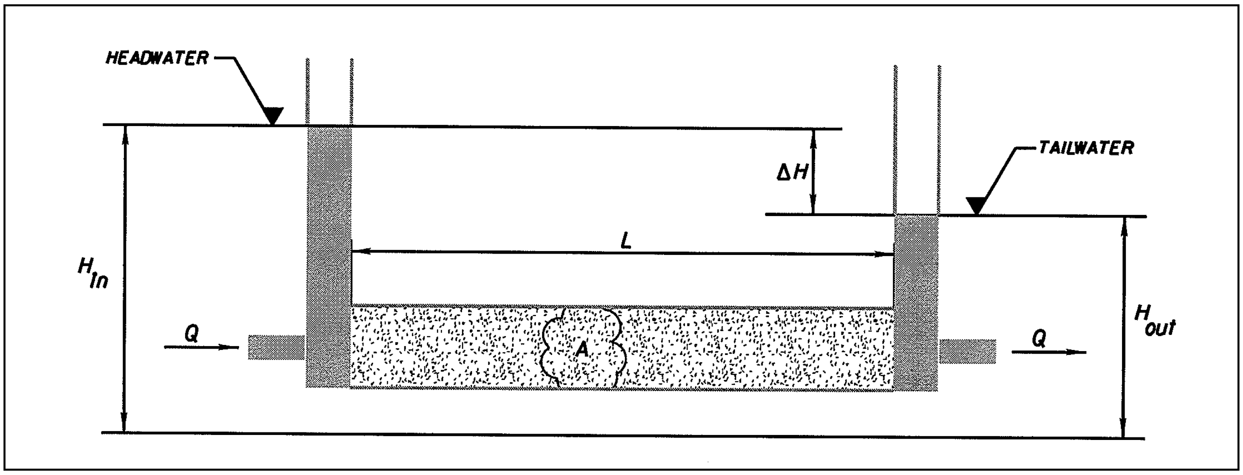

Figure 7.1-1: Saturated Flow through Porous Media

Darcy's Law was established for saturated flow. As such, it may be adjusted for unsaturated and multiphase flows.

7.1.2.2 Soil Permeability

The coefficient of permeability (k) in Darcy's Law is a measure of the rate of water flow through a saturated soil under a given hydraulic gradient in length unit over time unit (i.e., ft/day). The soil permeability is dependent on the grain-size distribution and void ratio. The coefficient of permeability (k) typically varies from 0.03 ft/sec (43 ft/day) for gravels to less than 10-8 ft/sec (1.44 x 10-5 ft/day) for clays (refer to Appendix J).

7.1.2.3 Hydraulic Conductivity of Soils

The hydraulic conductivity of a soil (K) measures the relative ease of water transmission through the soil:

$$K = \frac{Q}{A\,\Delta H}$$

where:
Q = Flow rate, in ft^3/sec
A = Flow area, in ft^2
ΔH = Hydraulic head, in ft

The hydraulic conductivity of a soil is the ratio between the discharge through the unit area of soil perpendicular to the flow per unit of head (i.e., cfs/ft^2 – ft of head). This is the primary factor used to determine the exfiltration rate of a system.

The flow transmission through a soil increases as the water content increases. As such, the maximum hydraulic conductivity occurs under saturated conditions. The hydraulic conductivity for horizontal-saturated flow (K_s) usually is several times greater than the hydraulic conductivity for vertical-unsaturated flow (K_u).

7.1.2.4 Hydro-Geologic Tests

The hydro-geotechnical properties of a soil can be measured in tests under falling or constant head, either in the laboratory or in the field. The most effective soil testing is a combination of laboratory and field methods. Laboratory tests on undisturbed soil samples usually provide accurate results representative of only a point among the soil stratum.

Evaluate the hydrologic and geologic characteristics of the site where the exfiltration system will be installed to define the test procedures to be used. The following tests are suggested:

- **Laboratory Permeameter Test** for saturated hydraulic conductivity on undisturbed soil samples (ASTM D 5084)
- **Double Ring Infiltrometer Test** to estimate the initial vertical unsaturated permeability data of the upper soil layer (ASTM D 3385)
- **Constant Head Test** in soils with permeabilities that allow keeping the test hole filled with water during the field test (AASHTO T 215)
- **Falling Head Test** in areas with excellent soil percolation where keeping the test hole filled with water is not feasible during the test (FM 5-513)
- **DOT Standard Test** (constant head) that can be used for the Department's projects (FM 1-T 215)
- **Well Test Holes** are performed to determine relative permeability and water quality characteristics of the aquifer (ASTM D4050); through continuous water quality testing, the test hole will indicate the depth at which a minimum of 10,000 milligrams per liter total dissolved solids (TDS) concentration is found; the test also will indicate the most favorable depth for stormwater discharge
- A **Pumping Test** is performed at the most favorable depth for stormwater discharge to determine the design discharge capacity normally in gallons per minute per foot of head; the test is normally performed in conjunction with well test holes

7.1.2.5 Seasonal High Water Table

Published information (such as data from the Natural Resources Conservation Service, formerly known as the Soil Conservation Service) provides preliminary guidance related to the water table at a specific location, but you will need site-specific water table information to design exfiltration systems.

The initial data to determine the seasonal high water table (SHWT) elevation is the measurement of the stabilized ground water level in a boring or well. Adjust the initial (encountered) water table elevation to estimate the SHWT based on antecedent rainfall, examination of the soil profile (color variations, depth to hardpan, etc.), consistency with water levels of the adjacent water bodies, vegetative indicators, etc.

7.1.2.6 Average Antecedent Moisture Conditions

The Antecedent Moisture Condition (AMC) indicates the wetness of a soil and its availability to infiltrate water. The soil moisture ranges from dry to saturated, depending on the rainfall amount prior to the moisture measurement. The average AMC means that the soil is neither dry nor saturated, but at an average moisture condition at the beginning of the design storm event.

7.1.3 Data Collection

The design of an exfiltration system requires a good understanding of the site conditions. Information required and potential sources include:

- **Topographic Data.** You usually can find preliminary topographic data in the United States Geological Survey (USGS) quadrangle maps, topographic LIDAR data, and previous project construction plans. Supplement this information with a detailed topographic survey of the project area.

- **Geotechnical Data.** The Soil Survey Reports by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) provide general geological and geotechnical properties information. Previous geotechnical reports for the project area and adjacent developments can provide more specific information regarding the geotechnical conditions at the project location. After preliminary evaluation of the available data, request a detailed geotechnical study. The site-specific geotechnical report should classify the types of soils within the project location and soil engineering characteristics, including hydraulic conductivity (refer to Section 7.1.2.3), ground water elevations, etc.

- **Receiving Water Bodies.** The Water Management Districts, FEMA, and some local agencies can provide information regarding water elevations under different storm frequencies for lakes, rivers, canals, and reservoirs. Some agencies also can provide potentiometric surface maps to assist in determining the ground water elevations. Tidal information is available on the National Oceanic and Atmospheric Administration (NOAA) website. You can determine the design tailwater elevation from the above sources.

- **Permit Data.** Previous permit information for the site and surrounding developments can provide information related to design criteria, existing wetlands, possible outfalls, discharge limitations, control elevations, off-site contributors, geotechnical data, prior soil testing results, etc.

- **Right-of-Way Data.** You can obtain the right-of-way information from the Department's right-of-way maps and county and city right-of-way documents.

- **Field Reviews.** Visiting and inspecting the site provides first-hand updated information to the designer regarding the existing drainage system, off-site contributors, water management facilities, outfalls, and other site conditions.

7.1.4 Permitting Considerations

Generally, you will develop the drainage design in compliance with all applicable federal, state, and local environmental regulatory programs. The respective permitting authorities have to be identified and contacted early in the design process. These agencies include local water control districts and county and state water management districts. Each permit agency has specific water quality requirements and may impose restrictions on the construction of exfiltration trenches and well systems.

7.1.5 Construction and Maintenance Considerations

Install stormwater exfiltration systems no less than two feet from parallel underground utilities and 20 feet from existing large trees that will remain in place. To avoid damaging adjacent properties, carefully evaluate the existing soils and the excavation method if the exfiltration system is located in close proximity to the right-of-way line. Implement erosion control measures to impede the access of sediments and debris into the exfiltration system during construction, which can clog the filter fabric and diminish the capacity of the exfiltration trench.

Typically, you would not use exfiltration systems within any type of manmade, compacted embankment since there is little to no percolation in compacted fill as compared to natural soils.

Do not install exfiltration systems in close proximity to or behind MSE walls. Install solid conveyance pipes behind the MSE wall in accordance with the *Drainage Manual*, Appendix D, and install exfiltration systems away from the walls. Do not use exfiltration trenches in locations where a 1H:1V mound could allow the filtrate to impact the MSE soil reinforcements. In this situation, the potential exists for accelerated corrosion of metallic reinforcements to occur without warning. Furthermore, seepage forces would need to be included in the design of the wall, and daylighting filtrate could result in soil washouts, unsightly mildew, vegetation, staining, and other maintenance problems.

Physical access devices must be provided with stormwater exfiltration systems to facilitate maintenance activities. Consider minimum pipe sizes and maximum spacing between drainage structures (refer to Sections 7.2.2.8 to 7.2.2.13) for the efficient operation of maintenance equipment. Also consider future expansion of the facilities and the possible increase of maintenance requirements.

In the case of drainage wells, provide the injection well chamber with physical access devices for maintenance activities. Maintenance of the injection well includes cleaning, removing debris, and, in some cases, redeveloping the well to re-establish discharge capacity. The well location needs to be accessible from the surface to allow these activities to take place.

7.2 EXFILTRATION TRENCHES

7.2.1 Description

An exfiltration trench is an underground drainage system consisting of a perforated pipe surrounded by natural or artificial aggregate, which stores and infiltrates runoff (refer to Figure 7.2-1). Catch basins located at the end of each exfiltration trench segment collect stormwater runoff; the perforated pipe delivers the stormwater into the surrounding aggregate through the pipe perforations. The stormwater ultimately exfiltrates into the ground water aquifer through the trench walls and bottom. As the treatment volume is not discharged into surface waters, exfiltration trench systems are considered a type of retention treatment.

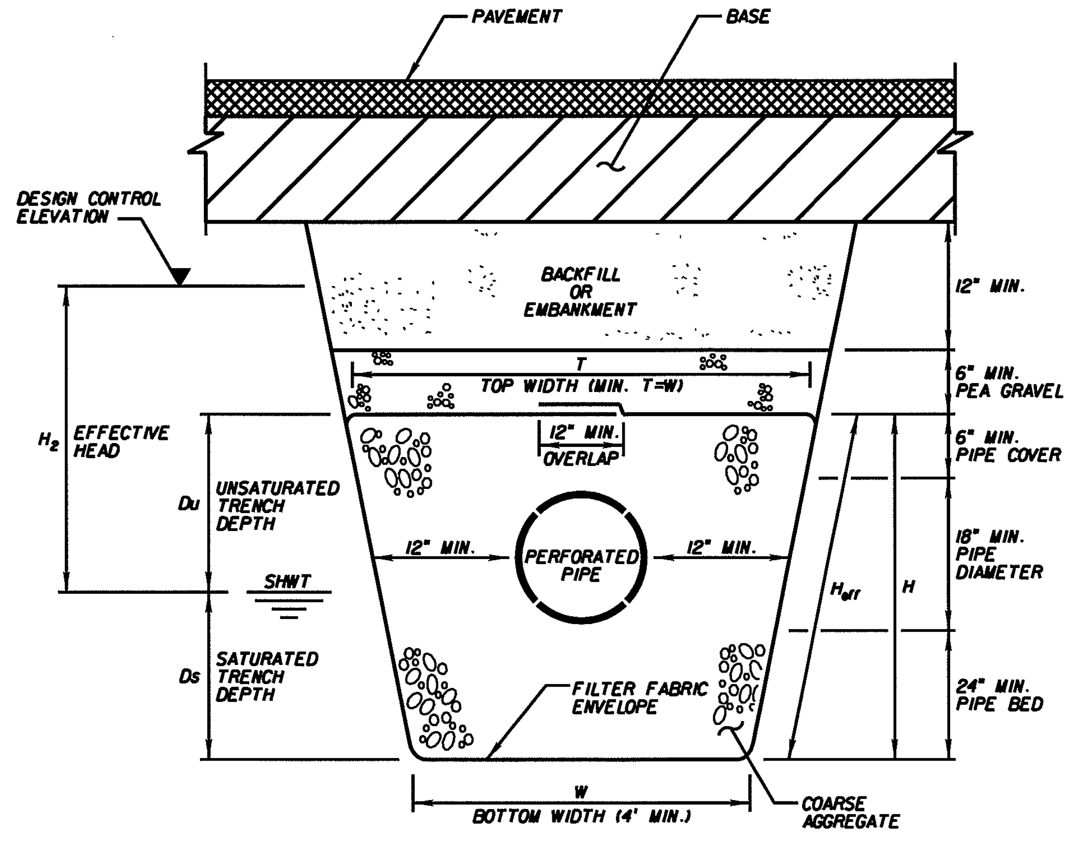

Figure 7.2-1: Typical Exfiltration Trench

The permeability of the soils at the exfiltration trench location and the anticipated water table elevation determine the applicability and performance of the exfiltration trench system. This system must exfiltrate the required stormwater treatment volume and draw down the treatment volume to return to its normal condition within a specific time after the design storm event. When the trench bottom is at or above the average wet season water table, the exfiltration trench is considered a dry system.

7.2.1.1 Use

For projects where the areas available for water management facilities are limited and high right-of-way acquisition costs are anticipated, exfiltration trench systems can provide the required stormwater treatment if the hydro-geological conditions are suitable for runoff infiltration (i.e., permeable soils with hydraulic conductivity exceeding 1 x 10^{-5} cfs/ft^2 per foot of head). Exfiltration trenches, like other types of retention systems, are able to efficiently remove stormwater pollutants. Additionally, exfiltration trenches contribute to recharge of the ground water aquifer, thus assisting in combatting saltwater intrusion in coastal areas.

Because of the direct infiltration of the surface runoff with its associated pollutant load into the ground water aquifer, do not install exfiltration trench systems in the proximity of potable water supply wells. Usually, you are not allowed to install exfiltration trenches within the 10-day well field protection contour, but you should verify specific requirements for each well field with the permitting authorities. Do not propose exfiltration trenches within or near contaminated ground water areas to avoid the potential migration of the polluted plume due to the direct injection of surface runoff into or adjacent to the contaminated groundwater plume. In areas with high ground water elevation, the available hydraulic head for exfiltration trench operation is minimal but the required hydraulic head can be obtained by pumping, if feasible.

The limited life span of exfiltration trenches is their main disadvantage. The accumulation of sediments and clogging of the filter fabric and the void spaces of the aggregates usually shorten the operational life of exfiltration trenches. Consider the need of future replacement costs in the evaluation of their effectiveness. Prior to replacing existing systems or using them as part of a new drainage system, test the remaining treatment capacity of existing exfiltration trenches.

7.2.2 Design Criteria

An exfiltration trench transmits the inflow runoff hydrograph into the groundwater during small storm events or in land-locked conditions; but in drainage areas with positive outfall, the fraction of the runoff hydrograph that is not transmitted into the groundwater and retained within the exfiltration trench is transmitted downstream, usually through an outfall control structure.

The *Standard Specifications for Road and Bridge Construction* (Section 443, French Drains) includes directions, provisions, and requirements for exfiltration trenches. Standard exfiltration trenches are detailed in Standard Plans, Index 443-001, French Drains. In the cases where Standard Plans, Index 443-001 is not suitable for a specific project need, develop a detailed design and include this information in the design documentation. The following are the Department’s general design criteria. It is recommended that additional specific criteria from the permitting agencies be evaluated in the design process.

7.2.2.1 Water Quality

You can install the exfiltration trenches off-line or on-line in the drainage system to provide water quality treatment to a watershed.

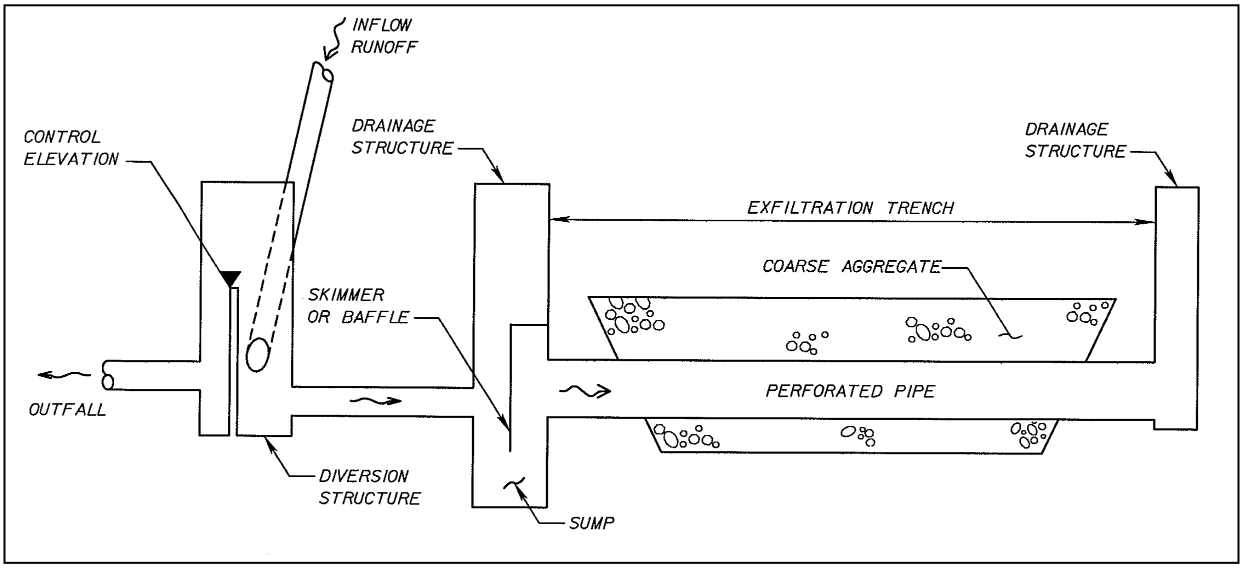

Figure 7.2-2: Off-Line Exfiltration System

The off-line treatment method (Figure 7.2-2) diverts runoff into the exfiltration trench designed to provide the required treatment volume; subsequent runoff in excess of the treatment capacity bypasses the off-line exfiltration trench toward the outfall. For off-line systems, a diversion drainage structure usually is required.

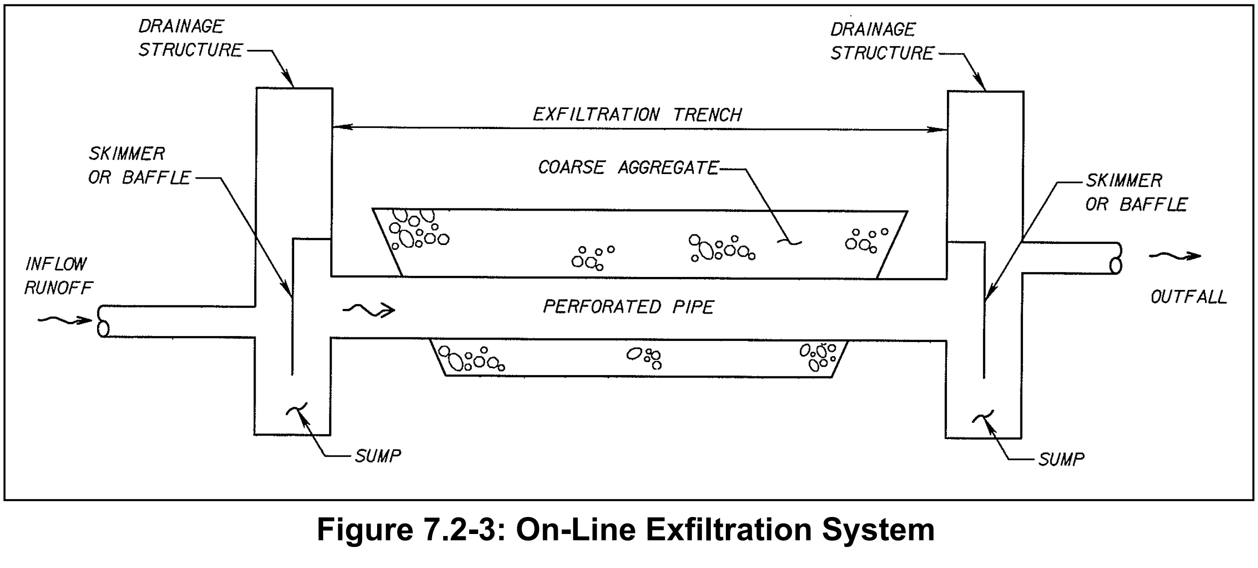

Figure 7.2-3: On-Line Exfiltration System

The on-line exfiltration trench (Figure 7.2-3) provides the required water treatment but the treatment volume is mixed with the total runoff volume. As such, runoff volume in excess of the treatment capacity carries a portion of the pollutant load to the receiving water body.

7.2.2.2 Water Quantity

For exfiltration trenches designed to satisfy water quality requirements rather than provide flood protection, only the fraction of the overall exfiltration trench storage volume, including pipe and aggregate voids, located above the design ground water elevation and below the outfall control elevation should be considered for discharge attenuation.

In some special locations (i.e., Miami-Dade County and Monroe County) with very limited area available for water treatment, the exfiltration trench systems could be credited for discharge attenuation if the ground water is considered variable, rising from the Seasonal High Water Table along with the design storm event.

7.2.2.3 Design Ground Water Elevation

Use the elevation to which the ground water can be expected to rise during a normal wet season to calculate the required exfiltration trench length.

7.2.2.4 Control Elevation

The minimum control elevation for an exfiltration trench system should be at the same elevation as the top of the perforated pipe. The maximum control elevation should not violate the base clearance criteria for the project or produce changes in the land use value of the properties located upstream and downstream of the drainage system. A site-specific survey, the permit files, and the field reviews are the main sources used to determine the design control elevation.

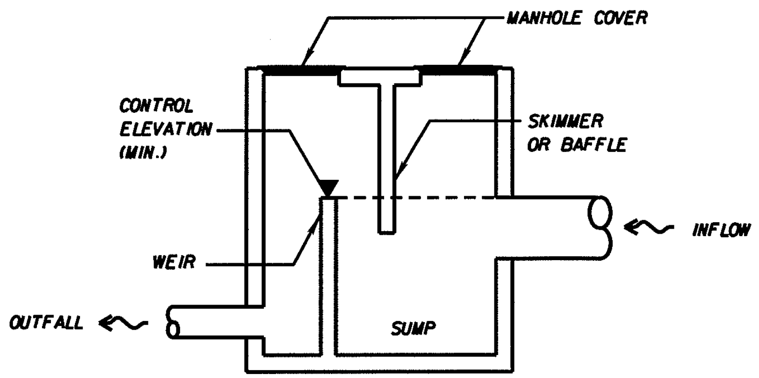

Figure 7.2-4: Outfall Control Structure

7.2.2.5 Effective Head

Positive Discharge. The effective head of the exfiltration trenches (H_{eff}) with discharge to an outfall should be the average vertical distance from the SHWT to the outfall control elevation:

$$H_{eff} = \frac{\text{Control Elevation} - \text{SHWT}}{2}$$

Closed Systems. The effective head for exfiltration trenches with no outfall (self-contained system) should be the vertical distance from the SHWT to the average distance between the SHWT and the design high water (DHW):

$$H_{eff} = \frac{\text{DHW} + \text{SHWT}}{2} - \text{SHWT} = \frac{\text{DHW} - \text{SHWT}}{2}$$

7.2.2.6 Recovery Time

If the permitting authorities with jurisdiction over the project location do not have specific recovery time requirements, the water treatment capacity of the exfiltration trench systems should be recovered within the 72 hours following the design storm event, assuming average AMC.

7.2.2.7 Safety Factor

Use a safety factor of two or more to calculate the required length of exfiltration trenches to consider possible geotechnical uncertainties.

7.2.2.8 Dimensions

The minimum pipe diameter is 18 inches, but 24 inches is preferable; and the minimum trench width is four feet. The maximum dimensions should depend on site-specific conditions and construction methods. In general, exfiltration trenches with bottoms wider than eight feet and/or deeper than 20 feet are not recommended. Perforated pipes with a diameter of more than 36 inches should be approved by the District Drainage Engineer.

Pipe perforations can be slotted or perforated. Standard locations and dimensions of the pipe perforations are included in the *Standard Specifications,* Section 443, French Drains.

7.2.2.9 Maximum Length

a. The maximum length of exfiltration trenches with access through both ends should be:

For 18-inch to 30-inch pipes	300 feet

For 36-inch and larger pipes	400 feet

b. The maximum length of the exfiltration trenches with access through only one end should be half of the maximum length of exfiltration trenches with access through both ends.

7.2.2.10 Pipe Invert

Make the invert elevation of the perforated pipe at least one foot above the trench bottom elevation. Locate the pipe invert above the SHWT to facilitate maintenance operations. This criterion may not be feasible in sites where the water table is close to the ground surface or where a deeply permeable stratum underlies low-permeability soils.

7.2.2.11 Aggregates

Use uniform-graded, natural or artificial coarse aggregate with no more than 3-percent weight of material passing the Number 200 Sieve at the point of use.

7.2.2.12 Filter Fabric

Enclose the coarse aggregate of an exfiltration trench in filter fabric. The perforated pipe also could be enclosed in filter fabric to increase the life span of the exfiltration trench if approved by the District Drainage Engineer.

The filter fabric will comply with the requirements established in the latest FDOT *Standard Specifications*, Section 985. Additionally, the permeability of the filter fabric must be equal to or greater than the permeability of the surrounding soil.

7.2.2.13 Drainage Structures

The minimum side dimension of the drainage structures for exfiltration trenches should be four feet. Inlets must include sediment sumps to collect sediments and skimmers/ baffles (refer to Standard Plans, Index 443-002) to prevent oil and floating debris from exiting the catch basin into the exfiltration trench. The minimum clear distance between baffles in the same drainage structure will be 2.5 feet. Fiberglass skimmers and baffles are not recommended due to possible damage from debris impact.

Drainage structures have to provide adequate access to the exfiltration trench for maintenance operations; the minimum grate size should be two feet and two-piece cast iron covers (Standard Plans, Index 425-001) are recommended. Provide manholes for inspection and clean out at the end of each exfiltration trench with no inlet. Inlets Type 1 to 4 (Standard Plans, Index 425-020) are recommended for exfiltration trenches installed along or from a gutter line.

Refer to Sections 3.10 and 3.12 of the *Drainage Manual* for standards related to drainage structures of exfiltration systems.

7.2.3 Boundary Conditions

The design and performance of an exfiltration trench system depends on the specific boundary conditions of the site, which are: the ground water elevation, the tailwater elevation (if positive outfall), and the allowable headwater.

7.2.3.1 Ground Water Elevation

The ground water elevation to design exfiltration trench systems will be the seasonal high ground water table as defined in Section 7.1.2.5, above.

7.2.3.2 Tailwater Elevation

The receiving water body defines the tailwater conditions for exfiltration trench systems with positive discharge. Define the design tailwater as per the latest *Drainage Manual*, Section 3.4.

7.2.3.3 Headwater Elevation

The maximum allowable stage upstream of the exfiltration trench system will limit the design high water elevation. The drainage design in general should limit the design high water during the design storm event to meet the base clearance requirements and cause no adverse impact to the land use value of the surrounding properties.

7.2.4 Methodologies to Design Exfiltration Trenches

There are several methodologies used to design exfiltration trench systems. All methods are similar in nature, with specific criteria and requirements set by the regulatory agencies and FDOT District Drainage Offices. As such, it is important to coordinate and get approval of the methodology used in each specific project from the District Drainage Engineer and the permitting authorities with jurisdiction over the area where the proposed drainage system will be installed.

The equations and formulas included in the following sections present the conceptual development of the procedures and calculations, which are applicable with any unit system. As such, the conversion factors are not included, but the designer has to convert the units of each parameter as required to be consistent.

To illustrate the calculation methods, use/calculate a sample roadway segment (Figure 7.2-5) with a contributing drainage area of 2.3 acres (including 0.8 acres of pavement) with on-line treatment.

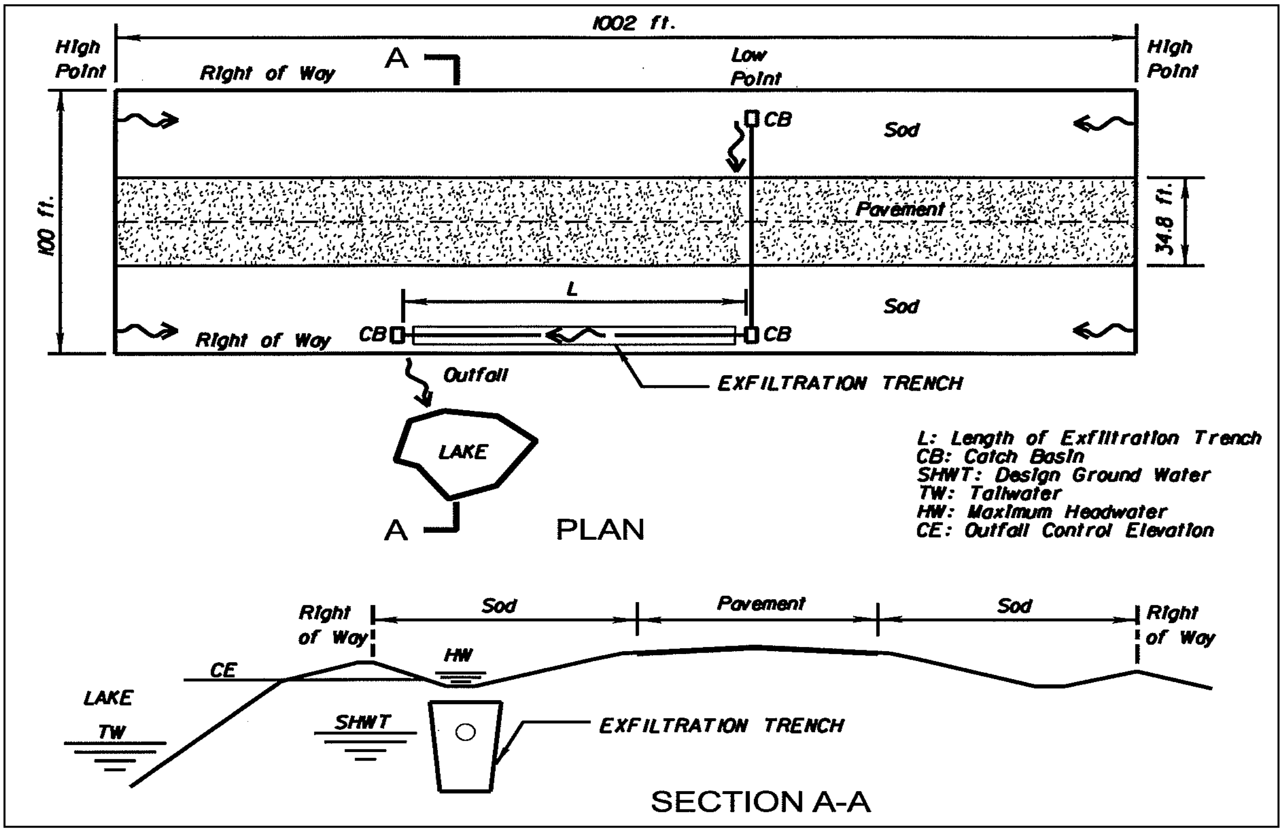

Figure 7.2-5: Sample Problem

7.2.4.1 Storage-Recovery Method

This method is acceptable for most of the permitting agencies and FDOT Districts because it provides the required water quality storage capacity within the exfiltration trench and assures that the treatment capacity will be available again within the required recovery time.

The storage-recovery method is recommended for exfiltration trenches with bottom elevation—or at least the perforated pipe invert—above the design ground water elevation. This method is not applicable if the top of the proposed exfiltration trench is below the design ground water elevation.

Storage-Recovery Design Procedure

Step 1: Data Collection

Total drainage area: A_T = 2.3 acres

Pavement area: $A_I = 0.8$ acre

Ground water elevation: SHWT = 6.00 ft

Tailwater elevation: TW = 10.00 ft

Headwater elevation: HW = 14.00 ft

Fillable porosity of soil: $f_s = 0.3$

Fillable porosity of aggregate: $f = 0.45$

Unsaturated hydraulic conductivity of soil: $K_u = 0.00007 \ \frac{\text{ft}^3\text{/sec}}{\text{ft}^2\text{-ft of head}}$

Saturated hydraulic conductivity of soil: $K_s = 0.00025 \ \frac{\text{ft}^3\text{/sec}}{\text{ft}^2\text{-ft of head}}$

Step 2: Calculate the required storage for water quality

Note: The water quality criterion from St. Johns River Water Management District (SJRWMD) is used for the sample problem.

If off-line treatment is proposed, use the greatest of the following volumes:

$V_T = 0.5$ inch/12 A_T $V_T = 0.096$ acre-ft

$V_I = 1.25$ inches/12 A_I $V_I = 0.083$ acre-ft $V_{off} = 0.096$ acre-ft

If you propose on-line treatment, increase 0.5-inch runoff on the total drainage area to the off-line treatment volume above:

$V_{on} = V_{off} + V_T = 0.096 + 0.096$; $V_{on} = 0.192$ acre-ft

If discharging into shellfish harvesting areas or other receiving water bodies with specific regulations, provide the water quality volume as required: $V_{spec} = 0$ acre-ft

Total required water quality volume: $V_{WQ} = V_{on}$; $V_{WQ} = 0.192$ acre-ft

Step 3: Define the preliminary characteristics of the exfiltration trench

Outfall control elevation: CE = 13.00 ft Perforated pipe diameter: D = 24 inches

Trench bottom width: $W_{tr} = 5.00$ ft Perforated pipe invert: $P_{inv} = 10.00$ ft
Trench bottom elevation: $B_{el} = 8.00$ ft

Trench top width: $T_{tr} = 5.00$ ft

Trench top elevation: $T_{el} = 13.00$ ft

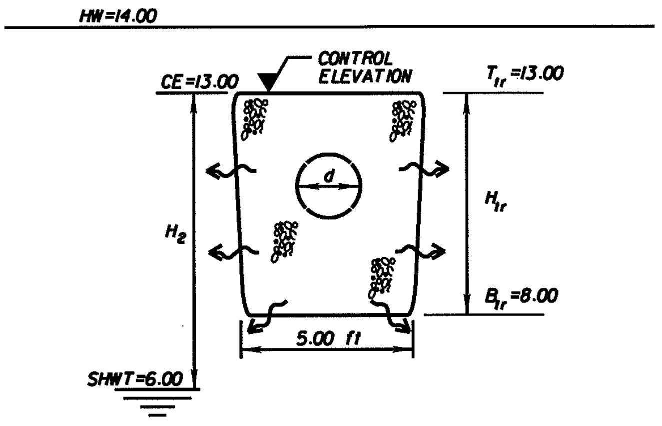

Figure 7.2-6: Sample Exfiltration Trench

Step 4: Calculate the required length of exfiltration trench

The storage capacity of an exfiltration trench is the available void space above the SHWT, including pipe and aggregate voids.

Storage within pipe:

If the pipe invert is higher than the SHWT, the storage area in the pipe is:

$$A_{full} = \frac{\pi D^2}{4} \qquad A_{full} = 3.142 \text{ ft}^2$$

Storage within aggregate:

Storage height in trench: (unsaturated depth) $D_u = T_{el} - SHWT$ $D_u = 7.00$ ft

Storage area in trench: $A_{trench} = f\,(W_{tr} \cdot D_u - A_{pipe})$ $A_{trench} = 14.34 \text{ ft}^2$

Note: Engineering judgment will be used regarding whether to consider the thickness of the pipe walls to calculate A_{trench}.

Net trench length: $L_{net} = \dfrac{V_{WQ}}{A_{pipe} + A_{trench}}$ $L_{net} = 477.7$ ft

Safety factor to account for hydro-geotechnical uncertainties ($SF \geq 2$) $SF = 2$

Required trench length: $L_{req} = SF\ L_{net}$ $L_{req} = 955$ ft

Note: If the required length does not fit within the available location, return to Step 2 and modify the preliminary characteristics of the exfiltration trench as necessary.

Step 5: Calculate the recovery time of the treatment volume

Effective head: $H_{eff} = \frac{DHW - SHWT}{2}$ $H_{eff} = 4.00$ ft

Trench height: $H_{tr} = T_{el} - B_{el}$ $H_{tr} = 5.00$ ft

Unsaturated exfiltration will occur only through the walls (2) and the bottom if the trench bottom is above the SHWT:

$A_{uwb} = L_{net}\ (2D_u + W_{tr})$ $A_{uwb} = 9{,}076\ ft^2$

Determine the unsaturated exfiltration capacity of the exfiltration trench:

$Q_u = K_u\ A_{uwb}\ H_{eff}$ $Q_u = 2.54\ ft^3/sec$

Recovery time ($T_{rec} \leq 72hr$): $T_{rec} = \underline{V_{WQ}}/Q$ $T_{rec} = 0.91hr$ OK

7.2.4.2 Empirical Equations Method

The following exfiltration trench design formulas have been developed by the South Florida Water Management District (SFWMD) and are included in the *SFWMD Environmental Resource Permit Information Manual*, Volume IV. This method calculates the required length of exfiltration trench based on a one-hour exfiltration time, which is representative of the majority of small-magnitude and short-duration rainfall events.

Empirical Equations Design Procedure

Step 1: Data Collection (refer to Figures 7.2-1 and 7.2-5)

Total drainage area: $A = 2.3$ acre

Pavement area: $A_i = 0.8$ acre

Ground water elevation: SHWT = 5.00 ft

Tailwater elevation: TW = 6.00 ft

Headwater elevation: HW = 8.00 ft

Saturated hydraulic conductivity: $K = 0.00025 \ \dfrac{\text{ft}^3\text{/sec}}{\text{ft}^2 \text{ - ft of head}}$

W.Q. reduction (0.5 for retention): %WQ = 0.5

Safety factor (2 Minimum): FS = 2

Step 2: Calculate the required storage for water quality

The empirical equations have incorporated the adjustment to consider that exfiltration trenches are retention systems (50 percent of the treatment volume required for wet detention systems) and have a safety factor of 2. As such, the treatment volume to be used in these formulas is the greatest of one-inch runoff on the contributing area or 2.5 inches on the pavement area:

$V_T = 1.0 \text{ inch}/12 \ A$ $V_T = 0.19 \text{ acre}\cdot\text{ft}$

$V_I = 2.5 \text{ inches}/12 \ A_i$ $V_I = 0.17 \text{ acre}\cdot\text{ft}$ $V_{WQ} = 0.19 \text{ acre-ft}$

Step 3: Define the preliminary characteristics of the exfiltration trench

Outfall control elevation: CE = 6.50

Perforated pipe diameter: D = 24 in

Trench bottom width: W = 5.00 ft

Perforated pipe invert: $P_{inv} = 10.00$ ft

Trench bottom elevation: $B_{el} = 1.00$

Trench top elevation: $T_{el} = 10.00$

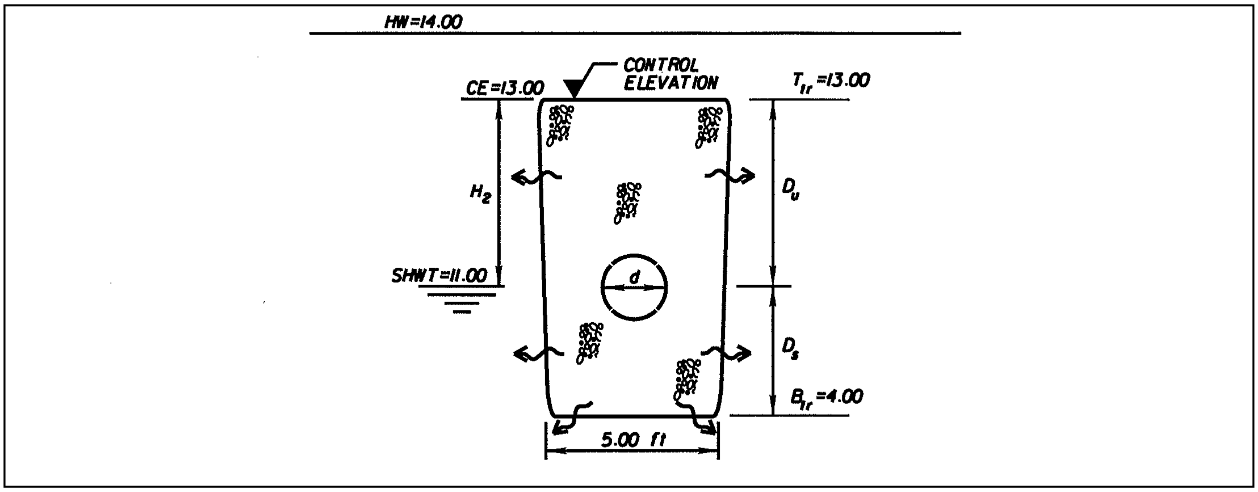

Figure 7.2-7: Sample Exfiltration Trench

Step 4: Calculate the required length of exfiltration trench

Treatment volume in acre-inches:	$V = 12V_{WQ}$	V = 2.30 acre-in
Effective head:	$H_{eff} = \frac{CE - SHWT}{2}$	H_{eff} = 1.50 ft
Trench height:	$H = T_{el} - B_{el}$	H = 9.00 ft
Unsaturated depth of trench:	$D_u = T_{el} - SHWT$	D_u = 5.00 ft
Saturated depth of trench:	$D_s = SHWT - B_{el}$	D_s = 4.00 ft

When the unsaturated depth of trench is greater than the saturated depth or the trench width is lesser than two times depth:

$$L_1 = \frac{FS\ \%WQ.V_{WQ}}{K\,(H_2W + 2H_{eff}\,D_u - D_u^2 + 2H_{eff}\,D_s) + 0.000139\ W\ D_u} \qquad L_1 = 33\text{ ft}$$

When the saturated depth of trench is greater than the unsaturated depth or the trench width is greater than two times depth:

$$L_2 = \frac{FS\ \%WQ.V_{WQ}}{K\,(2H_{eff}\,D_u - D_u^2 + 2H_{eff}\,D_s) + 0.000139 \cdot W \cdot D_u} \qquad L_2 = 579\text{ ft}$$

Required length of trench (use the greater of these two lengths):
$L_{req} = L_1$ if $D_u \geq D_s$ or L_2 if $D_u < D_s$ $\quad L_{req}$= 33 ft
$L_{req} = L_1$ if $W \leq 2H$ or L_2 if $W > 2H$ $\quad L_{req}$= 33 ft

For the sample problem, the saturated depth of trench is greater than the unsaturated depth, but the trench width is less than two times the trench depth. As such, the required length of trench is 33 feet.

7.2.4.3 FDOT District VI Method

The technical paper *Subsurface Drainage with French Drains*, prepared by the District VI Drainage Section on June 20, 1991 (available on the Department's ERC system as a District VI document) includes criteria and procedures to design exfiltration trenches. This method is acceptable for projects within the FDOT District VI jurisdiction, mainly within Miami-Dade County, and other areas if approved by the permitting authorities.

This method considers that there is no flow through the bottom of the exfiltration trench (assuming that the bottom is the first portion of the trench to get clogged), but only through the vertical areas (walls) of the exfiltration trench. The hydraulic conductivity of the existing soils at the depth where the exfiltration trench will be located is considered in calculating the dimensions and required length of the trench. A test procedure has been developed to determine the hydraulic conductivity (K) of the soils at different depths. The initial investigation includes soils from 0 to 10-foot depths; if the test hole exfiltration rate is less than 6 gpm, then soils from 10-foot to 15-foot depths are investigated. If the accumulated exfiltration rate is still less than 6 gpm, soils from 15-foot to 20-foot depths are investigated. Deeper exfiltration trenches are not considered economically practical. Construct the exfiltration trench with its bottom elevation coinciding with the depth of the selected test results.

FDOT District VI Design Procedure

Step 1: Data collection (refer to Figure 7.2-5)

Total drainage area:	$A = 2.3$ acres	Time of concentration:	$t_c = 11$ min
Pavement area:	$A_i = 0.8$ acre	Runoff coefficient	
Pervious area:	$A_p = A - A_i$	Impervious:	$C_i = 0.9$
Design frequency:	$F = 10$ years	Pervious:	$C_p = 0.3$
Ground water elevation:	SHWT = 11.00 ft	Tailwater elevation: TW=10.00	

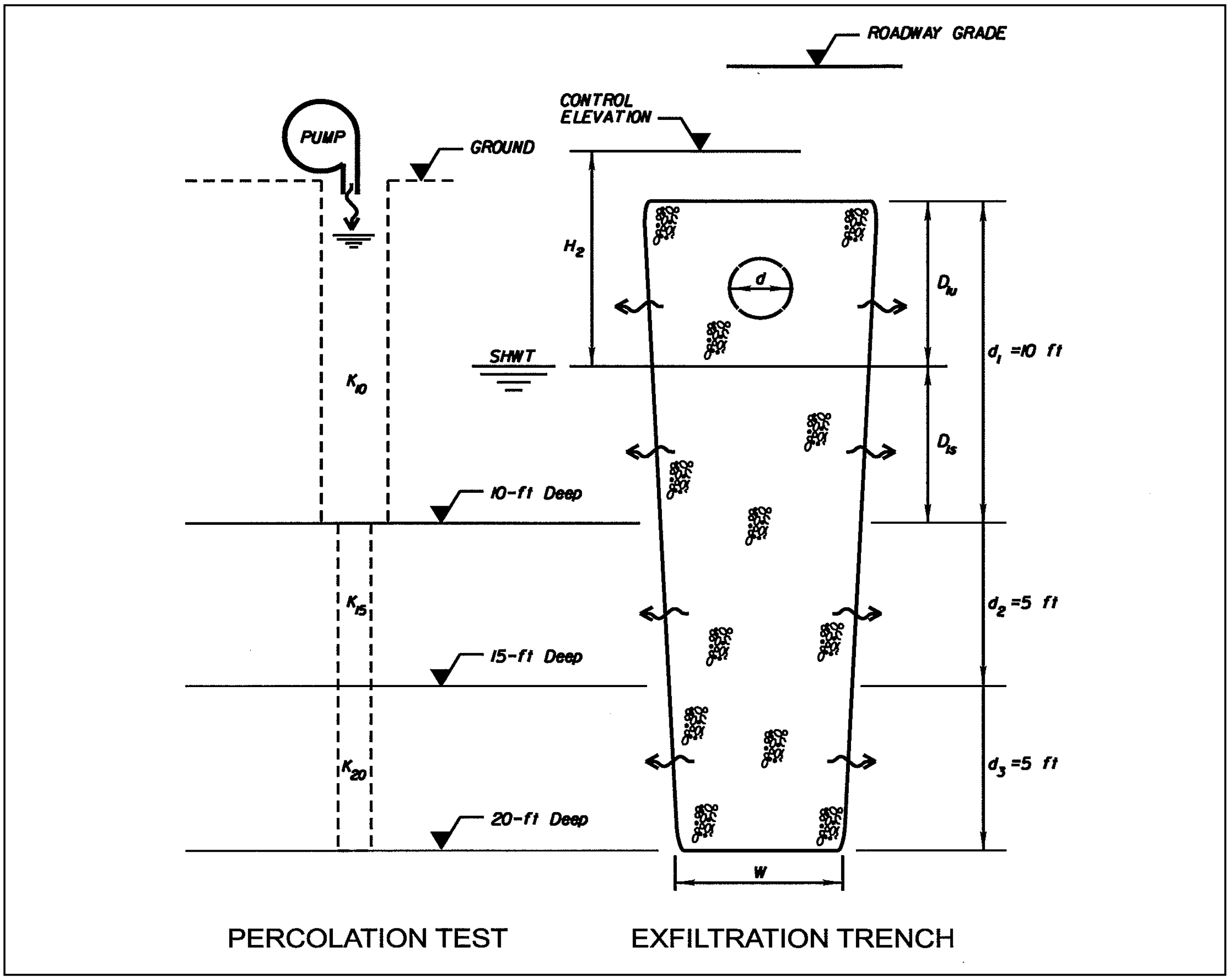

Figure 7.2-8: Sample Exfiltration Trench

Saturated hydraulic conductivity in cfs/square foot per foot of head:

Depth from 0 feet to 10 feet:	$d_1 = 10$ ft	$K_{10} = 0.000152$
Depth from 10 feet to 15 feet:	$d_2 = 5$ ft	$K_{15} = 0.000211$
Depth from 15 feet to 20 feet:	$d_3 = 5$ ft	$K_{20} = 0.000349$

<u>Step 2</u>: Determine the maximum polluted volume

Note: The following procedure is applicable only in Miami-Dade County, and it is required by the Miami-Dade Department of Environmental Resources Management (DERM).

Weighted runoff coefficient: $C = \frac{C_i \cdot A_i + C_p \cdot A_p}{A}$ $C = 0.51$

Time to generate 1” of runoff: $t_1 = \frac{2{,}940\ F^{-0.11}}{308.5\ C - 60.5(0.5895 + F^{-0.67})}$ $t_1 = 21.07$ min

Polluted runoff duration: $t_T = t_1 + t_c = 21.07 + 11$ $t_T = 32.07$ min

Rainfall intensity: $i = \dfrac{308.5}{48.6\,F^{-0.11} + T_T\,(0.5895 + F^{-0.67})}$ $i = 4.86$ in/hr
(For Miami-Dade-County)

Peak discharge $Q = C\,i\,A$ $Q = 5.70$ cfs

Maximum polluted volume: $V = 60\,Q\,T_T$ $V = 10{,}939$ ft^3

Note: All the runoff generated from a storm event lasting T_T or less is assumed to be polluted or contaminated. As such, the maximum polluted volume (V) usually is greater than the treatment volume required by the Water Management Districts.

Step 3: Define the preliminary characteristics of the exfiltration trench

Outfall control elevation: CE = 13.00 ft

Trench bottom width: W = 5.00 ft

Trench bottom elevation: $B_{el} = -7.00$ ft

Trench top elevation; $T_{el} = 13.00$ ft

Perforated pipe diameter: D = 24 in
Perforated pipe invert: $P_{inv} = 10.00$

Fillable porosity of aggregate: f = 0.5

Effective head: $H_{eff} = \dfrac{CE - SHWT}{2}$ $H_{eff}=2.00$ ft

Trench height: $H = T_{el} - B_{el}$ H=20.00 ft

Unsaturated depth of trench: $D_u = T_{el} - SHWT$ $D_u=2.00$ ft

Saturated depth of trench (0’ to 10’) $D_s = SHWT - B_e$ $D_s=8.00$ ft

Step 4: Determine the trench storage

The storage capacity of an exfiltration trench is the available void space above the design ground water elevation (SHWT), including pipe and aggregate voids.

Storage within pipe:

If the pipe invert is higher than the SHWT, the storage area in the pipe is:

$A_{full} = \frac{\pi\ (D/12)^2}{4}$ $A_{full}=3.14\ ft^2$

If the pipe invert is lower than the SHWT, the available storage depth in the pipe is:

$D_{pipe} = P_{inv} + \frac{D}{12} - SHWT$ $D_{pipe}=1.00ft$

Central angle of the circle segment: $\theta = 2acos\left[\frac{(D - 2D_{pipe})}{D}\right]$ $\theta = 0.82\ rad$

Storage area in pipe segment: $A_{seg} = \frac{(D/12)^2}{8}(\theta - sin\theta)$ $A_{seg}=0.04\ ft^2$

$A_{pipe} = A_{full}$ if $P_{inv\ I} \geq SHWT$
$A_{pipe} = A_{seg}$ if $P_{inv} < SHWT$

In this example: $A_{pipe} = A_{full}$ $A_{pipe}=3.14\ ft^2$

Storage within aggregate:

Storage height in trench:
(unsaturated depth) $D_u = T_{el} = SHWT$ $D_u = 2.00\ ft$

Storage area in trench: $A_{trench} = f\ (W\ D_u - A_{pipe})$ $A_{trench}=3.43\ ft^2$

Storage in trench: $S = A_{pipe} + A_{trench}$ $S = 6.57\ ft^3/ft$

<u>Step 5:</u> Determine the exfiltration rate per foot of trench

$$E_T = 2\ K_{10}\ (D_u/2 + D_s)\ H_{eff} + 2\ K_{15}\ d_2\ H_{eff} + 2\ K_{20}\ d_3\ H_2$$

$$E_T = 0.0167 \text{ cfs/foot of trench}$$

Note: The exfiltration rate values are limited by the District VI Drainage Section to 0.15 cfs/linear foot of trench.

<u>Step 6:</u> Determine the length of exfiltration trench for water quality

$L_{net} = \frac{V}{S + 60 \cdot E_T \cdot T_T}$ $L_{net} = 283\ ft$

Safety factor to account for hydro-geotechnical uncertainties (SF ≥ 2): SF = 2

$L_{req} = SF\ L_{net}$ $L_{req} = 566\ ft$

7.2.4.4 Other Design Methods

Design Curves for Exfiltration Systems. The exfiltration curves provide the ratio between the trench storage and the exfiltration rate from the trench to the soil. This method is based on the long-term mass balance of an exfiltration system under local rainfall conditions. As such, limit your use of exfiltration curves outside of areas where they have been developed.

Exfiltration Trenches for Discharge Attenuation. With the exception of Miami-Dade County and Monroe County, exfiltration trenches are not approved for discharge attenuation by most of the permitting agencies. As such, and only under very special conditions, the use of exfiltration trenches to attenuate the outfall discharge will be negotiated with the permitting authorities and with prior approval by the FDOT District Drainage Engineer.

The exfiltration trench design procedure for discharge attenuation should be similar to the procedures described above. The difference is the required treatment volume. For closed basins, the treatment volume should be the pre-development versus post-development discharge increase instead of the required water quality volume. You could apply the same criteria for basins with positive outfall if the Rational Method is used because this method considers the rainfall intensity constant throughout the storm duration. If you use hydrograph methods, the runoff hydrograph has to be combined with the exfiltration hydrograph to determine the outflow from the drainage system. Spreadsheets and modeling programs are available to perform hydrograph calculations.

7.3 DRAINAGE WELLS

7.3.1 Description

The term drainage wells includes all wells that are used to inject surface water directly into an aquifer, or transfer shallow ground water directly into a deeper aquifer. By definition, an injection well is any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system (refer to Standard Plans Index 444-T01).

Drainage wells in Florida are grouped into two broad types: surface-water injection wells and inter-aquifer connector wells. Surface-water injection wells are further categorized as either Floridan aquifer drainage wells or Biscayne aquifer drainage wells.

7.3.1.1 Use

The Floridan aquifer drainage wells generally are effective as a method of urban drainage and lake level control. They emplace more recharge into the Floridan aquifer than the recharge it would receive under natural conditions. The most common use of Floridan aquifer drainage wells is to supplement surface drainage for urban areas in the karst terrains of the topographically higher areas of central and north Florida. Be cautious, however, with regard to the water quality aspects of these wells because they often inject surface runoff into the same aquifer from which public water supplies are withdrawn.

In southeast Florida, drainage wells to the Biscayne aquifer dispose of stormwater runoff and other surplus water. The majority of these wells dispose of water from swimming pools or heated water from air-conditioning units. Some of the wells dispose of urban runoff or wastewaters from business and industry in the area. The use of Biscayne aquifer drainage wells should have minimal effect on aquifer water quality as long as the injection of runoff and industrial wastes is restricted to zones where chloride concentrations exceed 1,500 milligrams per liter and 10,000 milligrams per liter total dissolved solids (TDS).

7.3.2 Design Criteria

Designing a storm sewer system using drainage wells requires hydrologic analysis and determination of the design peak runoff rate of discharge from the project area. See Chapter 2 (Hydrology) for the procedures to determine the peak runoff rates.

The data collection for drainage well design should include researching similar installed wells within the project area. Local well contractors can provide an estimate of the discharge capacity of wells based on previous drainage well installations and pumping tests. In cases where there is no available data, perform test holes and pumping tests. The exfiltration capacity of a well will be determined in gallons per minute per foot of head.

7.3.3 Water Quality

Address water quality requirements before discharging into injection wells. The typical design of drainage wells provides for the use of a retention basin with baffles or skimmers prior to discharging into the drainage well. Determine the size of the retention basin based on a 90-second detention time. Other options include the use of exfiltration trenches and detention/retention treatment swales.

Stormwater pollutant load is very dependent on climatic and topographic features, such as storm intensity and duration, distribution over the basin, land use, and topographic features such as hills, swamps, and soil types. Design the type of stormwater treatment to meet the needs of the particular location (i.e., more stringent water quality measures should be required for wells discharging into the Floridan aquifer). Pretreatment methods include physical, chemical, and biological control measures. Physical treatment includes typical operations like settling and screening. An example of chemical treatment would be the injection of alum into the stormwater on a storm-by-storm basis. Biological treatment might be accomplished by using plants, fish, or other types of treatment in retention ponds. In many instances, a combination of the above methods are used prior to the discharge of stormwater into the freshwater injection well.

The discharge of the wells needs to occur below the 10,000 ppm Total Dissolved Solids (TDS) level.

7.3.3.1 Fresh Water-Salt Water Hydrostatic Balance

One major consideration in the design of drainage wells in coastal areas is the difference in density between fresh water and saline water. The hydrostatic balance between fresh water and saline water can be illustrated by the U-tube shown in Figure 7.3-2. Pressures on each side of the tube must be equal, therefore:

$$P_s\, g\, H_f = P_f\, g\, (Z + H_f)$$

where:
P_s = Density of the saline water, in lb/ft^3
P_f = Density of the fresh water, in lb/ft^3
g = Acceleration of gravity, in ft/sec^2
Z = Head difference, in ft
H_f = Fresh water height above Mean Sea Level, in ft

Solving for Z, the Ghyben-Herzberg relation is obtained:

$$Z = (P_f / P_s - P_f)\, H_f$$

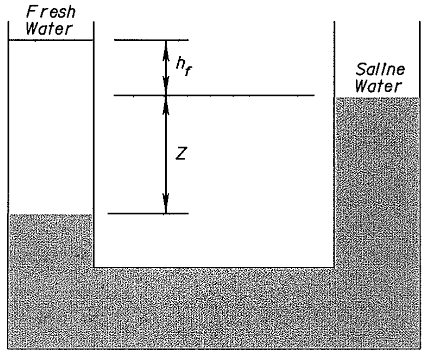

Figure 7.3-1: U-Tube Hydrostatic Balance between Fresh and Saline Water

Translating the U-tube to a coastal situation, as shown in Figure 7.3-3, H_f is the elevation of the water table above the sea level and Z is the depth to the fresh water-saline water interface below the sea level.

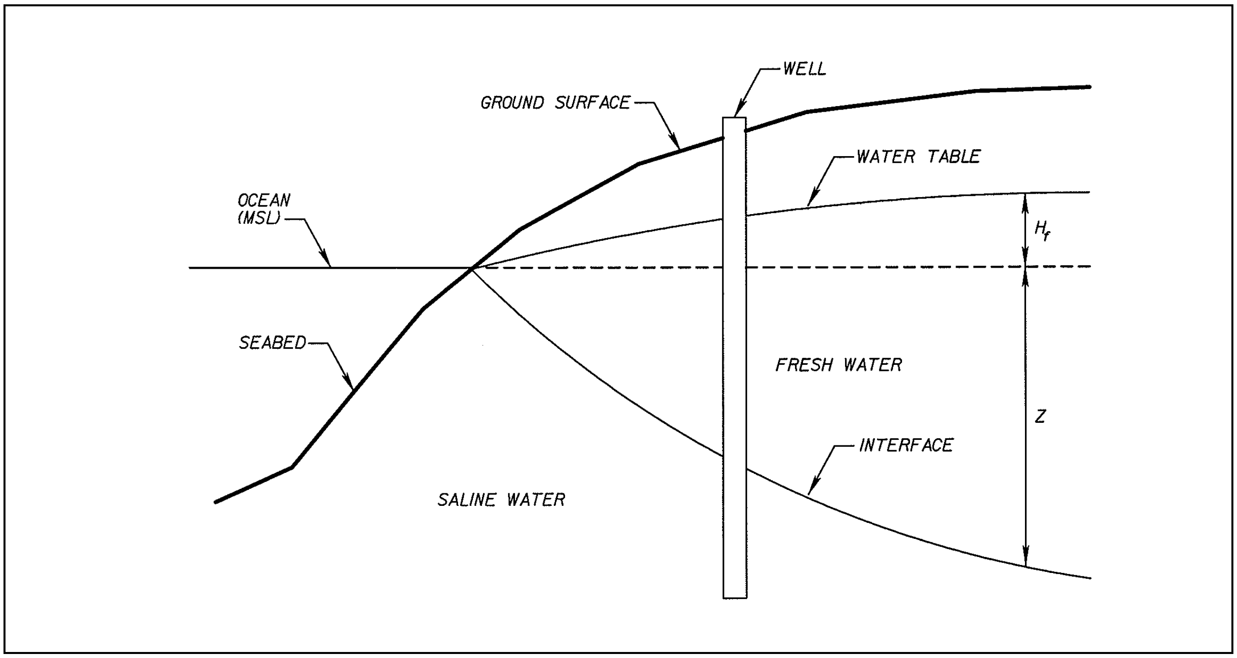

Figure 7.3-2: Fresh-Saline Water Interface

For typical seawater conditions (P_s = 63.9 lb/ft^3 and P_f = 62.4 lb/ft^3), the hydrostatic head balance is approximately: Z = 40 H_f.

The cased portion of drainage wells in coastal areas is placed at least up to the fresh-saline water interface. You can approximate the head loss due to the difference in the density of salt water and fresh water as one foot of head loss per 40 feet of casing based on the relationship Z = 40 H_f. As such, a typical design with 60-foot average casing up to the interface would require 1.5 feet of head to displace the salt water, which is the usual rule-of-thumb value used to design drainage wells discharging into the Biscayne aquifer. This additional head is not required for wells discharging into a freshwater aquifer.

7.3.3.2 Hydraulic Head

The maximum allowable stage upstream of the drainage wells limits the design hydraulic head for gravity drainage wells. The design high water for the design storm event should meet the base clearance requirements and cause no adverse impact to the land use value of the surrounding properties.

In areas where gravity head is not available, you can obtain the required hydraulic head artificially by pumping. Pressurized drainage wells basically have the same design requirements as the gravity wells but the hydraulic head is produced by a lift station. Runoff pretreatment is necessary prior to the lift station, which usually is provided by a retention basin with baffles and a bar screen for protection of the pumps. Typically, you can combine these features with a finer screen to block smaller debris from discharging into the well. The FDEP has waived the requirement of the Reasonable Assurance Report (refer to Appendix K) when a passive by-pass at or below 8.00-foot NGVD ’29 is provided from the pump’s common header. This requires a vertical stack pipe with a top elevation at 8.00-foot NGVD ’29. If the head on the pumps is larger, there will be overflow in this stack. Provide a cap/bird screen to avoid tampering.

7.3.3.3 Safety Factor

Due to some uncertainty related to geological and other factors of drainage wells, a safety factor of 1.5 is recommended for the design of drainage wells.

7.3.3.4 Dimensions

Drainage (deep) wells usually are 24 inches in diameter and 100 feet to 150 feet deep. When more than one well is necessary for the system, try to separate them by 75 feet to 100 feet.

7.3.3.5 Exfiltration Rate

A drainage well is drilled as an open hole until the desired level of exfiltration is found, based on the results of the well test holes and the pumping tests described in Section 7.1.2.4. Common values of well exfiltration rates (in Miami-Dade County) range from 500 gpm to 1,500 gpm per foot of head.

7.3.3.6 Casing

The casing point is usually determined by finding the required minimum total dissolved solid levels in the aquifer or by finding structurally stable rock formations. Typically, about 70 percent of the well depth is steel encased.

7.3.4 Methodologies of Calculation

The calculation methods to design gravity wells (Section 7.3.4.1) and pressurized wells (Section 7.3.4.2) are illustrated based on a sample roadway segment (Figure 7.3-4) with a contributing drainage area of 2.3 acres, including 0.8 acre of pavement to be drained into an injection well system.

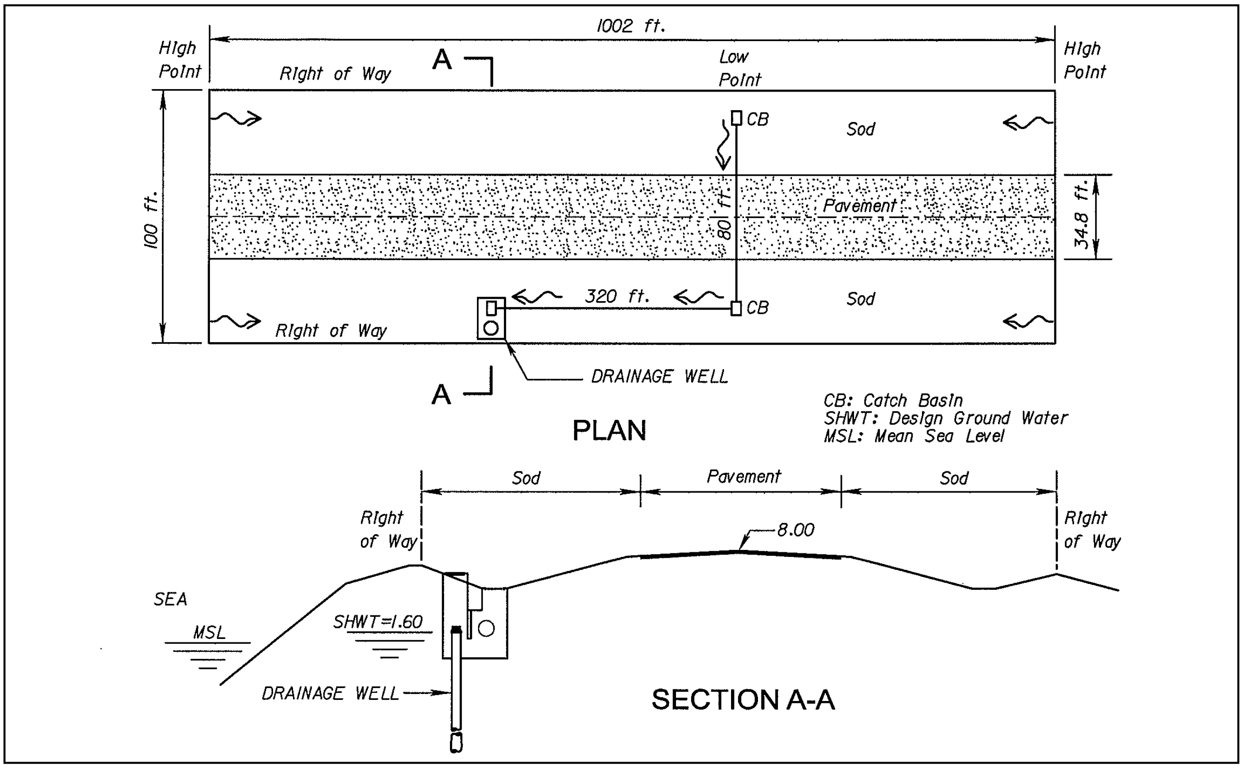

Figure 7.3-3: Sample Problem

7.3.4.1 Gravity Wells

<u>Step 1</u>: Data collection (refer to Figure 7.3-4)

Total drainage area: A = 2.3 acres

Pavement area: A_i = 0.8 acre

Pervious area: $A_p = A - A_i$

Ground water elevation: SHWT = 1.60

Minimum roadway grade: G = 8.00

Hydrologic location: Zone 10

Design frequency: F =3 years

Runoff coefficient

Impervious: $C_i = 0.95$

Pervious: $C_p = 0.30$

Control elevation: CE = 3.60 ft.

Well design data: (Based on information from other wells near the project site)

Well capacity: Q_W = 750 gpm/ft of head

Depth to interface: Z = 60 ft

Step 2: Determine the peak discharge rate into the gravity well system.

Weighted runoff coefficient: $C = \dfrac{C_i \cdot A_i + C_p \cdot A_p}{A}$ $C = 0.53$

Time of concentration (t_c):

Note: You will find methods to calculate the time of concentration in Chapter 2 (Hydrology). Use the Rational Method to solve the sample problem. For larger projects, you could use the Unit Hydrograph Method to design the system.

Inlet time: $t_i = 10$ min (based on the minimum t_c)

Travel time (pipe): $t_t = \underline{\text{Flow path length}} = \underline{80\text{ ft} + 320\text{ ft}} = 3.3\text{ min}$
Flow velocity: 2 ft/sec

$t_c = t_i + t_t$ $t_c = 13.3$ min

Rainfall intensity:
(For Miami-Dade County)

$$i = \frac{308.5}{48.6\,F^{-0.11} + T_T\,(0.5895 + F^{-0.67})} \qquad i = 5.39\text{ in/hr}$$

Note: You can determine the rainfall intensity for other project locations using the appropriate Intensity-Duration-Frequency (IDF) Curves. For IDF curves, go to NOAA Atlas 14 website for the Partial Duration Time Series.

Peak discharge $Q = C\,i\,A$ $Q = 6.52$ cfs

Note: Consider attenuating the peak discharge when substantial runoff storage capacity exists or is proposed within the contributing area. In these cases, use the NRCS (formerly SCS) Method.

Step 3: Calculate the exfiltration capacity of one gravity well.

Effective head: $H_{eff} = CE - SHWT - \Delta H$ $H_{eff} = 0.50$ ft

Note: The head loss ($\Delta H = 1.5$ ft.) used above is based on the rule of thumb described in Section 7.3.3.1. Although usually disregarded, you can consider additional head loss due to friction along the well casing (approximately 0.001 foot per foot of casing). You may need a more accurate head loss calculation when dealing with deep casings and very high flow rates coupled with low available hydraulic heads.

One-well capacity: $Q_w = 0.00223\,q_w\,H_{eff}$ $Q_w = 0.84$ cfs

Step 4: Determine the required number of gravity wells.

Safety factor: $SF = 1.5$

Number of gravity wells: $N_w = \frac{SF\ Q}{Q_w}$ $N_w = 11.69$ wells

Recommendation: Use 12 gravity wells at a minimum spacing of 75 feet. Distribute these wells within the project area or at one location. Consider head losses due to pipe lines to design the stormwater system.

Step 5: Determine the 90-second retention volume for **each** gravity well.

Required detention volume: $V_{90sec} = \frac{90\ Q}{N_w}$ $V_{90sec} = 48.9\ ft^3$
(for each gravity well)

Note: Provide the 90-second retention volume right before the drainage wells, below the top of the well (usually at the SHWT).

7.3.4.2 Pressurized Wells

Step 1: Data collection (refer to Figure 7.3-4)

(The same as Section 7.3.4.1 Step 1)

Step 2: Determine the peak discharge rate into the gravity well system.

(The same as Section 7.3.4.1 Step 2)

Step 3: Determine the net hydraulic head required for a pressurized well system.

Number of pressurized wells: $N_p = 1$ well

Safety factor: SF = 1.5

Pressurized net head: $H_p = \frac{SF\ Q}{0.00223\ q_w H_2} + \Delta H$ $H_p = 7.34$ ft

Note: The head loss ($\Delta H = 1.5$ ft.) used above is based on the rule of thumb described in Section 7.3.3.1. You can consider additional head loss due to friction along the well casing (approximately 0.001 foot per foot of casing), but usually you would disregard it. You may need a more accurate head loss calculation when dealing with deep casings and very high flow rates coupled with low available hydraulic heads.

Required head elevation: $Head = SHWT + H_p$ Head = 8.94 ft NGVD

Note: The sample problem would require approximately 12 wells to function by gravity (see Section 7.3.4.1, Step 4, above). By pressurizing the system with 7.34 ft head (at 8.94 ft NGVD), only one well would be needed. Notice that a Reasonable Assurance Report will be required by FDEP (see Section 7.3.3.2 and refer to Appendix K) because the head elevation at 8.94 ft NGVD is higher than 8.00 ft NGVD.

<u>Step 4</u>: Determine the 90-second retention volume for each pressurized well.

Required detention volume: $V_{90sec} = \frac{90\ Q}{N_p}$ $V_{90sec} = 586.8\ ft^3$
(for each gravity well)

Note: The 90-second retention volume has to be provided right before the pump station or stations for the pressurized drainage wells.

<u>Step 5</u>: Design the pump station.
Required pump discharge: $Q_p = SF\ Q$ $Q_p = 9.78$ cfs

Required head elevation (Step 3 above): HEAD = 8.94 ft NGVD

The pump station would have to deliver a flow of 9.78 cfs with a maximum head of 8.94 ft NGVD. The system design then will consist of pump selection, design of the pump pit, and the forced line, which is not in the contents of this document. The procedure for the lift station design could be done by manual methods, spreadsheets, and other computer software commercially available for lift station design.

7.4 MODELING EXFILTRATION SYSTEMS

7.4.1 Basic Modeling Concepts

Hydraulic modeling idealizes existing and proposed hydraulic systems for calculation purposes. The hydraulic models generated for a specific project may vary in complexity based on the accuracy needed by the designer. Several spreadsheets and modeling software programs are available to design or evaluate open and closed stormwater systems, but the designers have to use software accepted by the Department and the permitting agencies with jurisdiction over the area where the project is located.

The main elements in a hydraulic model setup are nodes and links. A node is a point with a defined location in the drainage system used to simulate inlets, manholes, grade breaks, bends, outlets, etc. Nodes usually are points that maintain the conservation of mass during the calculation process. Links are the connections between nodes used to simulate pipes, ditches, and channels. You can use links to transfer or convey water through the drainage system.

Other important modeling elements are the boundary conditions, which usually simulate the tailwater conditions as time-stage nodes, and the drainage areas, which are closed boundaries contributing into their respective nodes. Rainfall and peak runoff computations, usually related to the drainage areas, are calculated using the Rational Equation or the NRCS methods.

7.4.2 Exfiltration Trenches Modeling

To simulate the exfiltration trench performance, model the trench pipe as a normal pipe link between nodes. One of the nodes connected to the trench usually has the stage-area or the stage-volume characteristics of the exfiltration trench assigned to it. If the modeling program computes the emptiness of the links, only the voids in the aggregate will be considered in the stage-area or the stage-volume capacity of the exfiltration trench. Include a boundary node, usually as a time-stage node, to simulate the design groundwater elevation, which could be constant or variable with time as per the designer's criteria.

It is necessary to include a special link to model the transference of runoff from the node simulating the exfiltration trench to the node simulating the design ground water (See Figure 7.4-1). This special link usually is a head-discharge ratio or rating curve, which could be defined by giving different head values (ΔH) to calculate their respective discharges (Q) using the following equation (refer to Section 7.1.2.3):

$$Q = (K_u A_u + K_s A_s) \Delta H$$

where:
Q = Flow rate, in cfs
K_u = Unsaturated hydraulic conductivity (cfs/ft^2 – ft of head)
K_s = Saturated hydraulic conductivity (cfs/ft^2 – ft of head)
A_u = Unsaturated flow area (ft^2) = L_{net} ($2D_u$)
A_s = Saturated flow area (ft^2) = L_{net} ($2D_s + W$)
ΔH = Hydraulic head (ft)

If the unsaturated depth of the exfiltration trench (D_u) is less than one tenth of the total trench depth, disregard the unsaturated exfiltration because the unsaturated hydraulic conductivity usually is several times less than the saturated hydraulic conductivity of the soils. If the trench width is greater than two times the depth, disregard the exfiltration through the trench bottom ($A_s = 2L_{net} D_s$).

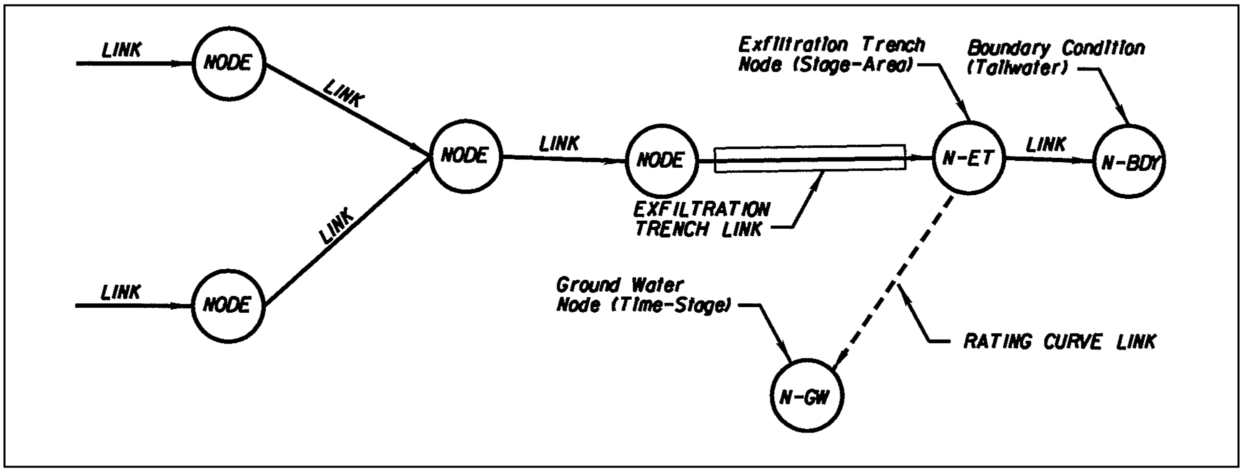

Figure 7.4-1: Sample Nodal Diagram for Exfiltration Trenches

The head-discharge ratio or rating curve may not be accurate if the design ground water is considered variable and the modeling program uses elevations instead of hydraulic head for calculations. You can consider the variable ground water to be rising from the average October ground water elevation to the anticipated ground water elevation at the end of the design storm event. In these cases, a family of tailwater-headwater-discharge rating curves is necessary to simulate the transference of runoff from the exfiltration trench to the ground water. You can calculate the rating curves by giving specific values to couples of tailwater and headwater elevations to calculate their corresponding head values (ΔH). Having the hydraulic head (ΔH), you can calculate the discharges (Q) using the above equation and the tailwater-headwater-discharge relationship would be complete.

7.4.3 Drainage Well Modeling

Calculate the inflow discharge using the approved hydrologic method and assign it to a node that could simulate the retention box. Analyze the drainage well, or a series of them, using rating curves with an elevation versus discharge relationship of the wells. The rating curve link will be connected to a time series node representing the water table at the discharge point. Following is a simple schematic nodal diagram of a well system model.

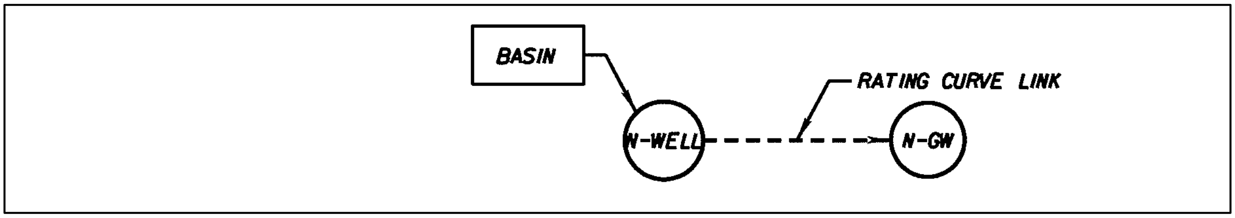

Figure 7.4-2: Rating Curve Link for Drainage Wells

Basin represents the drainage area contributing into the drainage well. Node N-WELL simulates the retention box prior to discharge into the well. The rating curve link simulates the well discharge into the water table. Node N-GW is the boundary node representing the ground water elevation.

Connect the rating curve link to a time series node representing the water table at the discharge point. If the system includes several drainage wells, you would develop a rating curve for each well. There are a number of acceptable computer software hydrologic and hydraulic models capable of analyzing the system.