Stormwater Retention Pond Infiltration Analyses in Unconfined Aquifers

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Conclusions and Recommendations

There are many different field and laboratory test methods which can be used to explore and estimate hydrogeologic conditions and hydraulic parameters of an aquifer. In most instances, the limitations of the various methods are not clearly understood. To measure the horizontal hydraulic conductivity of the entire effective aquifer thickness, we recommend using short or long term pumping tests. This method, if used properly, provides the most reliable results. Slug tests are the next best means of measuring the hydraulic conductivity of the entire aquifer thickness, but the accuracy of this method is usually hindered by the need to install the piezometer in an undisturbed condition. For instance, if a clayey fine sand or clay is encountered in the profile in which the well is to be installed, unreliable results are usually obtained due to smearing of the soil surface during drilling and piezometer installation.

Laboratory permeability measurements on undisturbed samples generally yield accurate results, but the value of hydraulic conductivity is usually representative of a point of a soil stratum within the aquifer. Therefore, to characterize the entire aquifer system, permeability tubes would need to be collected in each soil strata comprising the aquifer system. This method is generally limited by the number of tests required and the fact that undisturbed samples must be collected.

Therefore, it is our opinion that the most effective method of hydraulic conductivity testing is a combination of laboratory and field tests that produce the most reliable results. These would include laboratory tests on undisturbed samples obtained from shallow depths, field auger/tube tests in sandy soils and above ground water table, piezometer slug tests with properly installed and developed wells in deeper sandy deposits and short term or long term pump tests for multi-layer aquifer systems. A summary of recommended methods for the various exploration and testing techniques is presented in **Table 3-4**.

It should be realized that the information contained in this chapter is intended for planning purposes. Good, sound engineering judgment is still needed to determine when and where a particular method is applicable, to assess the limitations of each method and the validity of its results.

Table 3-4.
Recommended Field and Laboratory Testing Methods for Stormwater Retention Pond Infiltration Analysis

CONDITIONS	TEST METHOD
Soil Exploration	
Type and condition of soil	
<10 feet	hand or power auger borings
>10 feet <60 feet	power auger borings
In-situ density needed (any depth)	Standard Penetration Test Boring
Accurate ground water level reading is critical	Hand or power auger boring and allow water level to stabilize for a minimum of 24 hours
Hydraulic Conductivity Measurement	
Shallow hydraulic conductivity measurement above ground water table (sandy soil)	
<4 feet	Excavate test pit with post-hole digger or shovel, hand drive shelby tube and perform laboratory permeameter tests
>4 feet <10 feet	Excavate test pit with backhoe or other equipment, collect shelby tubes by hand and perform laboratory permeameter tests.
>10 feet <50 feet	Drill power auger borings to depth of proposed test. Install casing to bottom of borehole and screen the desired test interval. Conduct field hydraulic test using well permeameter method (U.S.B.R. Designation E-19).
Hydraulic Conductivity Measurement below Ground Water Table (sandy soil) <30 feet	Install piezometer to desired depth, develop piezometers, stabilize for 24 hour minimum and conduct slug test or constant head test (Hvorslev, 1951, U.S. Navy, 1974 and Bouwer & Rice, 1971)
Accurate Determination of Hydraulic Conductivity is critical. Measurement below ground water table. Any depth.	Install two wells and conduct short-term pumping test (Lohman, 1972)

Table 3-4.
Recommended Field and Laboratory Testing Methods for Stormwater Retention Pond Infiltration Analysis

CONDITIONS	TEST METHOD
Hydraulic Conductivity Measurement	
Estimate K_v (unsaturated initial infiltration)	Conduct Double Ring Infiltrometer tests. Alternatives, obtain undisturbed tube sample in the vertical direction. Conduct laboratory permeameter test and then estimate K_v (unsaturated) by empirical methods
Deep hydraulic conductivity measurement below restrictive soils or confining unit (sandy soil). Ground water table below bottom of restrictive soil	Install piezometer(s) to desired depth and screen below confining unit. Grout from bottom of confining unit to land surface. Conduct slug test in piezometer(s) (Hvorslev, 1951; U.S. Navy, 1974)
Deep hydraulic conductivity measurement below restrictive soil or confining unit (sandy soil). Ground water table above confining unit. Leakance suspected to be high through confining unit.	Install two (2) piezometers to desired depth and screen below confining unit. Grout from bottom of confining unit to land surface. Conduct long-term pumping test (Lohman, 1972)
Shallow or deep hydraulic conductivity measurement of restrictive soils (clayey sand, clays and hardpan)	Collect shelby tube soil sample by hand or with drill rig and conduct laboratory permeameter test in triaxial machine.
Approximate estimate of hydraulic conductivity after drilling is completed	Remold sample collected during drilling program to the approximate *in-situ* unit weight and conduct laboratory test in triaxial machine.
Unsaturated Vertical Infiltration Estimate, Direct Method	Conduct double ring infiltrometer test at pond bottom level. Compact test surface to the approximate post-construction density. Use final (I_c) infiltration rate determined during test.

Review of Field and Laboratory Test Methods

General Considerations

One of the most important steps in the evaluation of a stormwater retention pond is determining which test methods and how many tests should be conducted per site or per system. Typically, a soil boring and some type of hydraulic conductivity measurement is conducted for each stormwater retention pond, as a minimum. The number of soil borings and hydraulic conductivity tests performed are usually based on site topography, subsurface hydrogeologic conditions, pond size and pond geometry. Judgement and experience are usually applied in the decision-making process. In this report, we have developed methods for estimating the required number of borings and hydraulic conductivity tests in order to characterize the shallow aquifer system for retention pond designs. These methods should only be used as a guide and more or less tests may become necessary based on local experience and knowledge of site hydrogeologic conditions.

Soil Borings

To explore the subsurface soil and ground water table conditions within an area proposed for a stormwater retention pond, Standard Penetration Test (SPT) borings (ASTM D-1586) or auger borings (ASTM D-1452) can be used. Standard Penetration Test borings provide a reasonable soil profile and an estimate of the relative density of the soils. However, measurement of the ground water table depth in SPT borings is usually less accurate than in auger borings due to the drilling fluid (bentonite-mud) used during the drilling process. Power auger borings generally provide more accurate soil profiles and a better estimate of depth to the ground water table. Therefore, a combination of SPT and auger borings in a retention pond would provide the best data to characterize the effective aquifer system.

In general, it is preferable to extend soil borings to the confining layers of the effective aquifer system. However, for small retention pond systems (<1,000 ft^2), such a requirement may not be practical or cost effective. A more appropriate method of estimating minimum soil boring depth would be to extend the boring to the confining layers or a minimum of 10 feet below proposed pond bottom. For modeling purposes, confining layers should be set at the encountered elevations of poorly permeable soil layers (confining layers) or at the bottom of the test borings, if confining layers are not encountered.

When selecting the minimum number of borings, a minimum of one soil boring should be drilled to at least 10 feet below the proposed pond bottom elevation within the pond area. When more than one boring is required, the following approximate equation (empirical equation developed by Jammal & Associates, Inc.) can be applied to estimate the recommended number of soil borings required. The approximate equation takes into consideration the average area and configuration of the proposed pond:

$$B = 1 + \sqrt{2A} + \frac{L}{(2\pi W)} \qquad (3\text{-}1)$$

Where:

B = number of recommended borings
A = average pond area in acres
L = length of pond, in feet
W = width of pond, in feet
Π = pi (3.14)

In addition, an approximate equation to estimate the recommended number of hydraulic conductivity tests to be conducted was also developed by Jammal & Associates, Inc., and is presented below:

$$P = 1 + \frac{B}{4} \qquad (3\text{-}2)$$

Where:

P = number of hydraulic conductivity tests required
B = number of borings drilled

These equations are useful in determining the minimum number of tests that should be conducted. Additional tests may be required for systems located within a site which has complex hydrogeology and/or appreciable topographic relief.

A Rational Procedure for Estimating Preliminary K_V and K_H

The applicant did **not** provide any on-site soil borings or permeability tests. The local USDA-NRCS soils maps of the area show that the upland areas of the site in question are comprised entirely of Ona series soils (HSG of "B/D") with a Seasonal High Ground Water Table (SHGWT) from 0" to 12" below the ground surface, and the following **vertical** permeability rates

Depth From Surface	Vertical Permeability (K_V)
0" - 9"	6.0 - 20.0 in./hr
9" - 16"	0.6 - 2.0 in./hr
16" - 80"	6.0 - 20.0 in./hr

1. Determine a composite vertical permeability (K_V) for the soil in question using the following equation:

$$K_V = \frac{Z_1 + Z_2 + \overset{......}{\quad} + Z_N}{\frac{Z_1}{K_{V1}} + \frac{Z_2}{K_{V2}} + ... + \frac{Z_N}{K_{VN}}}$$

Where: K_{V1} , K_{V2} ,..... K_{VN} - Vertical hydraulic conductivities of soil layers

Z_1 , Z_2 , ... Z_N - Thickness of soil layers

From the local USDA-NRCS soils information, assume the **average** vertical permeability as follows:

Depth	Range of K_{Vi}	Average K_{Vi}
0" - 9"	6.0 - 20.0 in./hr	13.0 in./hr
9" - 16"	0.6 - 2.0 in./hr	1.3 in./hr
16" - 80"	6.0 - 20.0 in./hr	13.0 in./hr

Therefore: Z_1 = 9" , Z_2 = 7" , Z_3 = 64"

K_{V1} = 13 in./hr, K_{V2} = 1.3 in./hr, K_{V3} = 13 in./hr

and **K_V = 7.27 in./hr. (14.54 ft./day)**

2. Determine a composite horizontal permeability (K_H) for the soil in question using the following equation:

$$K_H = \frac{K_{H1} \cdot Z_1 + K_{H2} \cdot Z_2 + ... + K_{HN} \cdot Z_N}{Z_1 + Z_2 + ... + Z_N}$$

Use a 1.5 multiplier as an <u>approximate</u> conversion factor between K_H and K_V.

Therefore: Z_1 = 9" , Z_2 = 7" , Z_3 = 64"
K_{H1} = 19.5 in./hr, K_{H2} = 1.95 in./hr, K_{H3} = 19.5 in./hr

and **K_H = 17.96 in./hr (35.92 ft./day)**