6.7 AQUIFER DATA COLLECTION METHODS

This section provides general guidance for the determination of key characteristics used for evaluation of contaminant transport through groundwater. Hydraulic conductivity is a measure of the formation's ability to transmit water. It is therefore dependent on the permeability of the formation and the fluid properties. This section also describes methods to evaluate related characteristics of transmissivity, the average water transmission potential for a specific aquifer, and storativity or specific yield, the amount of water that a confined or unconfined aquifer will drain up for a certain change in hydraulic head. Hydraulic head is most commonly represented by groundwater elevation.

Permeability of soil/rock samples can be determined in the laboratory and then converted to hydraulic conductivity using the density and viscosity of the fluid being transmitted, in this case water or free phase product.

However, soil/rock samples collected from soil borings may not be large enough to be representative of the aquifer and may be disturbed during the drilling and collection process. Therefore, it is quite possible that hydraulic conductivities calculated from laboratory permeability data differ by several orders of magnitude from data collected using field methods.

Commonly used field test methods for the determination of hydraulic conductivity are slug tests and pumping tests. Both tests require access to one or more groundwater monitoring well(s) on site. Ensure that the wells are properly developed and in equilibrium with the surrounding aquifer before commencing aquifer tests.

On sites that are tidally influenced or show temporal groundwater fluctuations, monitor groundwater fluctuations in background wells throughout the duration of the aquifer test. The background wells must be placed outside the zone of the stressed aquifer, but close enough to be representative of the temporal fluctuations expected in the test wells. Use the background monitoring data to correct for changes in the water table and potentiometric surface that are not related to the aquifer test. Methods are available for correcting for most seasonal and temporal effects. These should be considered when designing aquifer tests and interpreting the results (USEPA, 1992d).

On sites with stratified aquifers, perform multiple aquifer tests at different depths. Select the depths based on the stratification observed in the formation during drilling. Determination of the vertical hydraulic conductivity may also be required at sites with stratified aquifers or those sites where vertical groundwater movement is significant.

The guidance presented below is adequate for porous formations. Determination of hydraulic conductivity in fractured rock requires a different approach, since the groundwater flow may be turbulent.

The slug test assumes that the aquifer is confined. For pumping tests, solutions are available for confined aquifers (Theis non-equilibrium method), for leaky aquifers (Hantush, 1956) and for unconfined aquifers (Neuman, 1975).

6.7.1 Slug Tests

A slug test is typically performed in a single well. Perform the slug test by either adding or removing an object of known volume (referred to as a “slug”) from a well and continuously monitoring the groundwater level while the well recovers to its original level (Freeze et. al., 1979). Addition or removal of the slug must be instantaneous and monitoring has to start immediately. Perform the slug test at least twice to confirm the results. There are commercially available software packages that can be used for evaluation of hydraulic conductivity.

If the well screen extends above the water table, use a slug withdrawal procedure (Domenico et. al., 1990). Do not add water to a monitoring well at a contaminated site. A slug can be a solid cylinder or closed stainless or PVC pipe filled with an inert material such as silica sand filter pack material. Ensure that the slug is heavy enough to instantaneously sink to the bottom of the well. If a slug is to be removed from the well, insert it into the water column, wait until the water level has recovered to its original level and then remove it as quickly as practicable.

In formations of high hydraulic conductivity, water level gauging must be continuous throughout the duration of the test. In this case, install a pressure transducer in the bottom of the well to log data continuously. Ensure that the water level has recovered to its original level after inserting the instrument prior to commencing the test. Design the test such that the slug does not interfere with the downhole equipment.

Accurately record the following: slug volume; water level within ±0.01 inch before, during and after the slug test; and the time of each water level measurement.

There are several graphic/calculation methods to evaluate hydraulic conductivity using slug test data. One example is the Bouwer method (Bouwer, H., 1989). Another is Hvorslev's method (Hvorslev, M.J., 1951).

Alternatively, determine the transmissivity and storativity of the aquifer by plotting the field data and comparing them with type curves. Cooper et. al. generated type curves for slug tests (Cooper et. al., 1967). Papadopulos et. al. later extended the range of curves (Papadopulos et. al., 1973). If different sections of the field data curve matches more than one type curve, Hvorslev's method should be used instead.

Specify in the project plan and report the methods used to interpret slug test data.

The slug test determines the transmissivity, storativity and hydraulic conductivity of the formation in the immediate surrounding of the well that was tested. The results are, therefore, limited. Conduct the slug test at different locations at each site to define the variability of the hydraulic conductivity and other parameters across the site (USEPA, 1992d).

Compare the results of the aquifer test with the data on the existing geologic units and confirm consistency between the hydrologic and geologic data.

6.7.1.1 Slug Tests in Stratified Aquifers

In stratified aquifers, determine the hydraulic conductivity for the various strata by performing slug tests either in wells that are screened within different stratigraphic units or by performing a multilevel slug test in one well. Only the stratigraphic units important for contaminant transport need to be tested.

The multilevel slug test data will only be reliable if the investigator succeeds in isolating portions of the aquifer, which is accomplished using two packers separated by a length of perforated pipe. The test is then performed by inducing water into the isolated section. The procedure provides reliable data when performed properly (USEPA, 1992d). Do not introduce water into a monitoring well that extends into a contaminant plume.

6.7.2 Pumping Tests

An accurate method of determining the hydraulic properties of water-bearing substrate is the pumping test. Pumping tests tend to involve a comparatively larger volume than slug tests and may be used as an alternative where large areas are of concern. Pumping tests also tend to involve greater effort and greater expense. Pumping tests involve the use of one or more pumping wells and may or may not include a varying number of observation wells. The change in hydraulic head is monitored, usually in terms of drawdown, or change in groundwater elevation in the aquifer in response to pumping and removal of water from the formation. The magnitude and rates of drawdown in the well, and rates of recovery after pumping has stopped can be used to evaluate the properties of transmissivity, storativity, and hydraulic conductivity of the aquifer surrounding the well.

6.7.2.1 Single Well Pumping Test

Single well pumping tests involve the measurement of water levels over time in a single monitoring well at different rates of pumping.

Measure the original water level in the well. Then pump down the well for a period of time. Record the time when pumping stops. At the time when pumping stops, start monitoring the recovery of the water level in the well as a function of time (Domenico et. al., 1990).

Storativity cannot be determined using a single well pumping test. The limitation of this single well test is that it determines only the transmissivity of the formation adjacent to the well. Perform the test in wells across the site to determine the variability in the aquifer transmissivity.

6.7.2.2 Multi-Well Pumping Tests

Multi-well pumping tests involve one pumping well and one or more observation wells. The tests are based on the relationship between the observation well and the pumping well, which stipulates that the water level change in the observation well, at a specified distance from the pumping well, is a function of the pumping rate, the properties of the aquifer and time. The advantage of using a multi well pumping test is that the aquifer parameters determined in this fashion represent average values for the formation between the wells.

The pump test methods described are, strictly speaking, only applicable to cases where the wells fully penetrate the aquifer. However, Hantush and Walton have conducted research for partially penetrating wells (Hantush, 1961 and 1964) (Walton, 1970). Hantush supplies some general guidelines for pump tests in partially penetrating wells. As long as the observation well is at a minimum distance from the pumping well, the partial penetration will not affect the test results. The distance must be:

$r > 1.5m\,(K/K')$

r = distance between pumping and observation well

m = aquifer thickness

K = horizontal hydraulic conductivity

K' = vertical hydraulic conductivity

If the horizontal and vertical conductivity are of the same magnitude, the condition is $r > 1.5m$.

<u>Confined Aquifers:</u>

For confined aquifers, plot the pump test drawdown data versus time site curve on logarithmic paper of the same scale as the Theis non-equilibrium type curve. Match the graphed investigation curve to the type curve by superimposing it. Choose a matching point anywhere on the overlapping sheets. Characteristics read off the Theis curve for the match point are used to estimate transmissivity and storativity of the aquifer based on the response observed in the pumping test (Domenico et. al., 1990).

<u>Leaky Aquifers:</u>

Leaky aquifers are confined by a low permeability unit that will still allow some leakage into the aquifer. Leakage may also arise through other sources such as connected bodies of surface water etc. In general, the first part of the drawdown will resemble that of a confined aquifer until the hydraulic gradient is large enough to induce leakage. So that the first part of the drawdown versus time curve can be analyzed with the Theis non-equilibrium type curve as discussed above.

At the time that leakage starts, the drawdown versus time curve will deviate from the Theis non-equilibrium type curve.

For leaky aquifers, plot the pump drawdown data versus time on logarithmic paper of the same scale as the type curve for leaky aquifers in the same fashion as for confined aquifers, but the data is compared to different type curves based on values for a given leakage (Hantush et. al., 1955; Hantush, 1956). The vertical hydraulic conductivity for these solutions is a measure of the leakage into the aquifer. The thickness of the boundary low permeability formation must be taken from well boring logs (Domenico et. al., 1990).

<u>Unconfined Aquifers:</u>

When water is withdrawn from confined aquifers, the aquifer does not undergo dewatering, unless the groundwater elevation/head is lowered below the confining layer. The water is released from storage through elastic compression of the matrix and expansion of the water. In unconfined aquifers lowering of water levels actually causes some dewatering of the aquifer and the value of storativity increases by several orders of magnitude. In an unconfined aquifer the storativity is referred to as specific yield (Domenico et. al., 1990).

In an unconfined aquifer the transmissivity can decrease during pumping due to the decrease in saturated aquifer thickness. This is inherent in the definition of transmissivity:

$$T = Km,$$

Where:

T = transmissivity

K = hydraulic conductivity

m = aquifer thickness

Therefore, T is not a constant as assumed by the Theis equation. Another assumption of the Theis equation is that water is instantaneously released from storage with decline in head. If this does not hold true, then the response will deviate from the response of a confined aquifer and the Theis type curve does not apply. For unconfined aquifers, the time-drawdown curve has three sections. The early section follows the Theis non equilibrium type curve, followed by an intermediate section where the slope of the curve decreases similar to that in a leaky aquifer, and the curve at later time will reveal a slope increase that will again follow a Theis non equilibrium type curve. The early part of the curve represents the storativity of the formation while the late part represents the specific yield.

Use the equation K = T/m to derive the horizontal hydraulic conductivity K.