6.8 GROUNDWATER MODELING

The purpose of groundwater modeling is to generate a visual representation of an aquifer including the overall groundwater movement, and in the case of contaminated sites, the fate and transport of contaminants. Groundwater modeling is also used to predict contaminant plume movement into the future or to predict the aquifer and plume response to remedial activities.

Groundwater modeling may be done manually by using a calculator or spreadsheet and then creating a graphical depiction of the data using flow nets. Manual groundwater modeling methods may be useful for creating preliminary site conceptual models intended to depict aquifer characteristics and the initial contaminant plume extent.

However, if the purpose of groundwater modeling is to predict how a contaminant plume changes over time or how it will respond to water pumping or remedial activities, modeling becomes computationally intensive, and a computer model must be used. Thus computer modeling has become an important tool in the design of sampling strategies during site monitoring and in the design of groundwater remediation systems. Computer groundwater models are based on the geologic and hydrologic field data collected during drilling, geotechnical sample analysis and aquifer testing. Further, the computer models must be continually adjusted and calibrated based on additional information obtained throughout the project cycle.

6.8.1 Gradient and Flow Direction Determination

The simplest way to determine the groundwater gradient and flow direction is by graphically constructing a flow net for the site. A flow net is composed of two sets of lines: the equipotential lines and the flow lines. The equipotential lines connect points of equal head and the flow lines depict the interpreted groundwater flow path or flow direction.

To construct a flow net for a site, measure the hydraulic head in wells across the site following the groundwater gauging procedures detailed previously in this section. Enter the measurements onto a site map. Interpolate the hydraulic head between wells assuming that the change in head is linear between neighboring wells. Connect points of equal hydraulic head to depict the equipotential lines. Choose equipotential line intervals such that the drop in head between adjacent lines is constant. The equipotential lines represent the height of the water table or potentiometric surface above mean sea level or other datum plane.

Add flow lines to depict the movement of groundwater at the site. Groundwater follows the path of steepest groundwater gradient. At a site where the aquifer formation is isotropic and porous, the steepest groundwater gradient is the shortest path between equipotential lines. The shortest path is perpendicular to the equipotential lines. Draw flow lines such that the flow is equally divided between adjacent lines.

Calculate the groundwater gradient as follows: Measure the distance between two equipotential lines along a flow line, i.e. the shortest path. Determine the head loss between the equipotential lines. Divide the head loss by the distance.

The groundwater flow direction is along the flow lines. Depict flow lines as arrows pointing in the direction of groundwater flow, i.e., in the direction of declining hydraulic head.

6.8.2 Velocity, Transmissivity, Calculations,

Calculate the transmissivity, storativity and hydraulic conductivity using methods and references listed in Subsection 6.7, Aquifer Data Collection Methods.

Calculate the groundwater velocity (v) using the following equation:

$$v = q/n_e = (K\ dh/dl) / n_e$$

Where:

v = actual groundwater velocity

q = Darcy velocity

n_e = effective porosity (connected pore space through which groundwater can flow)

K = Hydraulic conductivity

dh/dl = groundwater gradient (change in groundwater elevation in two wells over distance between the wells)

Compare the calculated groundwater velocity to the velocity range expected based on aquifer lithology.

Note that the equation is for laminar flow through porous media. Flow through fractured rock may require a different approach. If the fractured rock is hydraulically equivalent to a porous medium, the above equation may be used. If this condition is not fulfilled, describe the flow in relation to individual fractures.

In most cases on the scale of a typical response site, the condition of hydraulic equivalence to a porous medium is not satisfied and the flow must be described in relation to individual fractures and fracture sets. This has many consequences. For example, in a hydraulically isotropic, porous formation, the groundwater flow direction is perpendicular to the equipotential lines of the water table/potentiometric map. This assumption cannot be made in a fractured formation, since the flow direction will follow the fracture orientation. The following parameters need to be known to describe flow in fractured rock: orientation, fracture density, degree of connectivity, aperture opening, and smoothness of fractures (Domenico et. al., 1990).

One approach to describing fracture flow was developed by Snow (Snow, 1968). He developed an equation to calculate equivalent hydraulic conductivity for a set of planar fractures. One square meter of fractured rock with an equivalent hydraulic conductivity of K will conduct as much water as one square meter of porous medium with a hydraulic conductivity of K, under identical hydraulic gradients (Domenico et. al., 1990).

6.8.3 Computer Models

Computer models may be used at a site for many different goals including: (1) estimating how the actual groundwater system functions; (2) selecting sampling approaches, objectives and locations; (3) predicting contaminant fate and transport at the site; (4) designing hydraulic containments; and (5) testing and designing remediation approaches and systems (USEPA, 1992a, 1995c).

Computer models may consist of analytical approaches or numerical approaches. Analytical approaches are relatively more simplistic, offer an inexpensive method to conduct preliminary groundwater analysis, and may be useful during the early phases of a project. Numerical approaches are generally more complex and require specialized knowledge and software. However, numerical approaches easily deal with variability in the groundwater flow and contaminant transport parameters, which provides flexibility in representing complex subsurface geologies. Numerical approaches are also useful for predictive evaluation of proposed remedial solutions and for the evaluation of environmental hazards.

A groundwater modeling report should, at a minimum, include (USEPA, 1992a):

- Previous studies
- Site conceptual model(s)
- Mathematical model describing the site conceptual model
- Selection of numerical model and codes
- Model calibration
- Model runs
- Model results
- Conclusions
- Tables, graphs, figures, maps, etc.
- List of symbols, abbreviations, references, codes, etc.