EVALUATING PLUME CAPTURE THROUGH MASS FLUX ESTIMATES

Samantha Sheer O'Toole, Peter Breen, Daniel T. Canavan
Geologic Services Corporation
20 Peachtree Court, Suite 201
Holbrook, New York

Monitoring dissolved plume recovery is a crucial component of evaluating groundwater pump and treatment remediation effectiveness. Classical techniques to evaluate plume capture include analytical and numerical capture zone analyses, monitoring groundwater quality trends downgradient of pumping well arrays, and pieziometric surface measurements/flow net generation. An additional line of evidence increasingly being required by regulatory bodies overseeing plume remediation incorporates contaminant mass flux measurements within the plume, at the plume recovery points and downgradient of plume recovery points to determine if remedial goals are being met and allow for remediation optimization. This technique can not be employed under all groundwater pump and treat scenarios, as high density vertical and horizontal plume and stratigraphical definition, as well as frequent groundwater monitoring, are required to ensure valid results. Most commonly, the technique is being incorporated into remediation effectiveness evaluations of large plumes of conservative contaminants (eg. MTBE) in unconsolidated porous media involving multiple recovery wells.

Mass flux field monitoring

To evaluate the mass flux of a dissolved contaminant, the mass flux is measured at three locations:

1. a transect of groundwater monitoring wells defining the vertical and horizontal extent of a plume oriented perpendicular to groundwater flow and located upgradient of plume recovery wells (upgradient transect);
2. the plume recovery well array; and
3. a transect of groundwater monitoring wells oriented perpendicular to groundwater flow and located downgradient of plume recovery wells (downgradient transect).

Mass flux calculations

To determine the mass flux at each of the monitoring locations listed above, the following techniques are used:

Transect method

The cross sectional area of each transect is divided into discrete cells. Each cell comprises a distinct area and is assigned a unique value of contaminant concentration and groundwater specific discharge. The area of the cells will be dependent on the degree of variation in contaminant concentration, hydraulic conductivity, and hydraulic head across the transect. Cell size will decrease with increasing variation in contaminant distribution and aquifer heterogeneity.

The total mass flux across the transect is determined by summing the mass flux of the individual cells according to the following equation (API, 2003):

$$w = \Sigma_{i=1}^{i=n} C_i q_i A_i$$

where
w = total mass flux across transect (M/T)
C_i = concentration of constituent in ith cell (M/L^3)
q_i = specific discharge in ith cell (L/T)
A_i = area of ith cell (L^3)

Detailed aquifer and plume characterization in the vicinity of the transect is necessary to ensure validity of the mass flux measurements. Aquifer characterization must be sufficiently detailed to identify localized vertical and horizontal variations in specific discharge (hydraulic conductivity and hydraulic head) within the transect, which can have a significant effect on total mass flux across the transect. Investigative techniques to evaluate specific discharge variations include down-hole geophysical gamma logs, grain size analyses, permeameter analysis, pumping tests, slug tests and monitoring of nested piezometers.

The plume monitoring well network within the transect must be sufficiently dense to define the entire current and projected vertical and horizontal extent of the plume, and identify localized variations in contaminant distribution associated with variations in stratigraphy and/or natural aquifer chemistry. Typical monitoring well networks consist of an array of multiple small diameter monitoring wells with discrete open screen zones installed at closely spaced vertical intervals within a single borehole.

Recovery well method
The total mass flux at a plume recovery well array can be determined by summing the mass flux of each individual pumping well according to the following equation (API, 2003):

$$w = \Sigma_{i=1}^{i=n} C_i Q_i$$

where
w = total mass flux from pumping well array (M/T)
C_i = concentration of constituent in ith recovery well (M/L^3)
Q_i = groundwater recovery rate at ith recovery well (L^3/T)

This method requires frequent monitoring of contaminant concentrations in groundwater recovered from each well and a relatively constant groundwater extraction rate.

Mass flux balance
Results of mass flux monitoring are used to generate a mass flux balance equation. Under ideal conditions of complete plume capture the mass balance is represented by:

$w_1 = w_2$

where
w_1 and w_2 = measured mass flux at upgradient transect and recovery well array,

respectively.

Situations where the recovery well array is ineffective at capturing the entire vertical and horizontal extent of the plume can be represented by:

$w_1 > w_2$

Calculating the mass flux of the downgradient transect will aid in monitoring the effectiveness of the recovery well array. The mass flux of the downgradient transect should attenuate to negligible levels under ideal conditions of plume capture. A persistently measurable mass flux in the downgradient transect during pump and treat remediation is evidence of incomplete plume capture.

Comparison of mass flux at different monitoring locations should not be applied to measurements collected from a constant time or sampling event. Monitoring intervals for comparison must account for the average liner groundwater velocity (under pumping conditions) and distance between each mass flux monitoring location.

Discrepancies in mass balance among the monitoring locations suggest incomplete plume capture. Under conditions involving multiple plume recovery wells, the mass flux measurements can be utilized to determine if incomplete capture is localized to a single recovery well or group of recovery wells, or is resulting from an entirely deficient pumping well array. The mass flux across unique segments of the upgradient and downgradient transects can be compared to that of a single or localized groups of recovery wells to pinpoint deficient recovery wells. Furthermore, this technique may aid in recognition of potential redundancies within the recovery well array, and identify where plume recovery may not be warranted due to limited mass recovery. Mass flux discrepancies can be corrected through addition of extra recovery wells, modification of pumping well design, and increasing pumping rates.

Reference

American Petroleum Institute, 2003, Groundwater Remediation Strategies Tool, pub. no. 4730, 80 p.