THE CAPTURE-ZONE METHOD FOR RECOVERY SYSTEM DESIGN

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INTRODUCTION

Control of contaminant migration in ground-water is required by state and federal regulations generally at the property boundary, called the point of compliance (POC). One method to provide control at a POC is to install a line of wells that can be pumped to recover contaminated ground water. The pumped water is then treated and disposed.

Regulations require that the area affected by the recovery wells be well defined. The radius of influence of a well is commonly used in regulatory documentation to define the area affected by a given recovery well. Radius of influence is defined as the radial distance from a pumped well to the line of zero drawdown. This term significantly overstates the area affected by a pumping recovery well. Particle velocities in the outer regions of the area of influence may not be large enough to overcome other influences. These other influences may include uniform natural ground-water flow and seasonal recharge.

A more useful term to use to define the area of influence of a recovery well is the "capture zone". This term is defined as the area within which ground water will migrate to the pumping well. A pumped well derives water from a capture zone in the groundwater surrounding the well. The capture zone is defined as the area in which the velocity vectors (streamlines) intersect the pumped well. The capture zone is generally more limited than the "radius of influence" or "cone of depression" that are commonly defined by hydraulic gradient or water level drawdowns.

The purpose of this paper is to demonstrate the capture zone method. We will define the characteristics of the capture zone and demonstrate the design of recovery systems using capture zone techniques. The techniques are simple to define and easy to apply. It assumes horizontal, two dimensional ground-water flow. The method uses the natural regional, ground-water flow velocities and superimposes the velocity field established by the pumping well. The resulting relationships determine the parameters of the capture zone. The parameters include:

(1) Distance to the point of stagnation downgradient from the pumped well, (2) The side gradient width at the Point of Compliance, and (3) The upgradient width of the capture zone.

The capture zone concept has been simplified by assuming isotropic, homogeneous flow of uniform thickness. We also assume that the velocity field is affected only by the pumping well in a natural uniform ground-water flow. Recharge, heterogeneity, anisotropy, and boundary conditions are neglected.

METHODOLOGY

Figure 1 shows the general configuration of the capture zone of a recovery well in the vicinity of a contaminant plume. The natural groundwater flow is in the direction of the POC. The stagnation point and ground water divide created by the recovery well are shown, as well as the plume of contamination emanating from an upstream surface source.
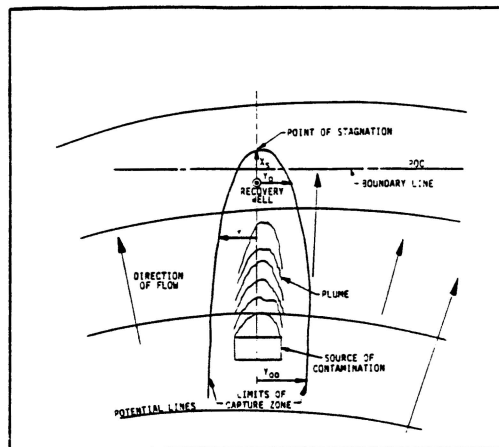

FIGURE 1. - SCHEMATIC OF CAPTURE ZONE AND GEOMETRIC ELEMENTS.

The mathematical expression for the groundwater divide in uniform groundwater flow is given by Bear (1979) and Todd (1980):

$$Y/X = \pm \tan (2\pi q_f BY/Q_w) \qquad (1)$$

where:

Y = distance to ground-water divide perpendicular to longitudinal axis

X = distance along the longitudinal axis of the capture zone

Q_w = recovery well discharge

B = aquifer thickness

q_f = regional ground-water flow = Ki

K = hydraulic conductivity = T/B

i = regional ground-water gradient

T = transmissivity

The stagnation point is the downgradient location where the particle velocity caused by pumpage in the recovery well equals the velocity imparted by regional flow. The net velocity is zero. Any ground water within the stagnation point will be captured by the recovery well. The distance to the stagnation from the pumped well is:

At limit Y/X -> 0

$$X = - \frac{Q_w}{2\pi B q_f} = - \frac{Q_w}{2\pi KiB} = - \frac{Q_w}{2\pi Ti} \qquad (2)$$

The width of the capture zone at the pumped well (at X = 0) is another important dimension for use in designing a recovery system.

At X = 0 $\qquad \pi/2 = \dfrac{2\pi q_f BY}{Q_w}$

$$Y_0 = \frac{Q_w}{4 q_f B} = \frac{Q_w}{4 KiB} = \frac{Q_w}{4Ti} \qquad (3)$$

Finally, the width of the capture zone upgradient from the pumped well (at X = infinity) is also important to define the capture zone of a recovery well.

At X = ∞ $\qquad \pi = \dfrac{2\pi q_f BY}{Q_w}$

$$Y_\infty = \frac{Q_w}{2 q_f B} = \frac{Q_w}{2 KiB} = \frac{Q_w}{2Ti} \qquad (4)$$

APPLICATION

The following example is used to illustrate the use of capture zone methodology. A surface contaminant source has created a plume in the underlying ground water. The natural ground-water flow has caused the plume to migrate toward the property boundary. The natural ground-water flow gradient is 0.05ft/ft and the hydraulic conductivity is 0.44 ft per day (3.3 gpd per ft^2). The aquifer thickness is 75 ft and relatively isotropic and homogeneous. The base of the unconsolidated aquifer is a relatively competent granitic rock. Figure 2 illustrates the example conditions. The width of the advancing plume is estimated to be about 600 ft. The objective is to find the minimum number of recovery wells to retard plume migration across the POC.
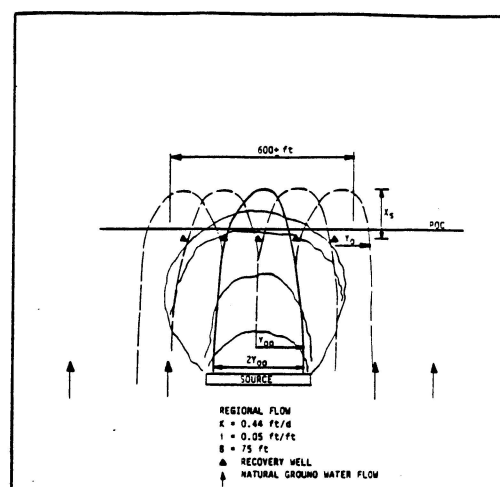

FIGURE 1. - EXAMPLE OF CAPTURE ZONE METHOD.

We can assume that complete capture in a series of recovery wells will occur if the wells are spaced between Y at X = 0 and Y at X = infinity. The width of the capture zone at infinity is twice the width of the capture zone at X = 0. Table 1 shows the results of computation for the stagnation point, and the width to the ground water divide at X = 0 and X = infinity.

Table 1. - Summary of Capture Zone Computation

Pumping Rate		X_s	Y_0	Y_∞	Drawdown at 10 ft
(gpd)	(gpm)		(ft)		
500	0.35	6.4	10	20	2.0
1000	0.70	12.9	20	40	3.9
1500	1.00	19.3	30	60	5.9
2500	1.70	32.1	50	100	9.7
5000	3.50	64.3	100	200	19.5
7500	5.20	96.5	150	300	29.2
15000	10.40	192.9	300	600	58.5

X_s = Distance to point of stagnation
Y_0 = Half the width of capture zone at X = 0
Y_∞ = Half the width of capture zone at X = ∞

Another important consideration in the design of a recovery system is the drawdown in the vicinity of the pumped well. Hydraulic parameters of the aquifer may be such that the aquifer may not yield water readily. Increased rates of pumpage can cause correspondingly large drawdowns near the pumped well. Therefore, choosing the optimum pumpage rate to minimize drawdown and maximize capture zone is essential. Table 1 also contains the estimated drawdown at 10 ft from the recovery well for our example, assuming steady state pumpage.

In our example, it appears that a pumping rate of about 5 gpm may be appropriate. This rate will cause about 30 ft of drawdown near the pumping well that has a static saturated thickness of 75 ft. The recovery well will capture contaminated water from about 95 ft downgradient. Well spacing can range from 150 to 300 ft. Therefore, we recommend that 5 wells be installed spaced at 150 ft across the leading edge of the plume. These wells equipped with pumps rated at about 5 gpm will control migration of the plume across the POC. Treatment facilities should be nominally designed to accommodate about 36,000 gpm.

LIMITATIONS

This capture zone methodology assumes steady state, isotropic, and homogeneous conditions. We assumed uniform (average) conditions throughout the flow region. Unsteady flow, and isotropic and heterogeneous conditions are more typical of actual field conditions. However, the assumptions and simplifications do not negate the value of the capture zone methodology in providing a tool to approximate field conditions. Preliminary engineering design and economic evaluations are valid extrapolations from this methodology.

CONCLUSIONS

A ground-water capture zone based on the velocity field set up by a pumping well is a better estimate of the effect of a recovery system than the radius of influence (cone of depression). The capture zone methodology considers the superposition of velocity fields of a pumped well on the regional ground-water flow field.

The capture zone method defines the geometry of the region that will supply water to a pumped well. There are three convenient points of interest: (1) The stagnation point, (2) The width of the ground water divide at X = 0, and (3) The width of the ground water divide at X = infinity. The simplifying assumptions do not negate the value of the method for preliminary design of recovery systems for contaminated ground water.

LITERATURE CITED

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