Effects of Groundwater Extraction on Stream Flow in the Bear-Evans Creek Watershed

Prepared for

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by

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1. Introduction

This report summarizes evaluations regarding the effects of groundwater extraction on stream flow in the Bear-Evans Creek watershed. The objectives of these evaluations include the following:

1) Summarize the hydrogeology in the Bear-Evans Creek watershed.
2) Identify the locations of the primary municipal water supply wells in the Bear-Evans Creek watershed, with particular emphasis on the vertical and horizontal locations of these wells relative to the major streams in the watershed.
3) Develop preliminary and order-of-magnitude estimates for the time lag between extraction at a groundwater well and reduction in stream flow.
4) Suggest options for addressing the impact of groundwater wells on stream flow and stream temperatures.

2. Summary of Hydrogeology in the Bear-Evans Creek Watershed

Information on the geology and hydrogeology in the Bear-Evans Creek watershed is contained in a several reports and studies, including King County (1999), Washington Department of Ecology (1995), King County (1990), USGS (1968), and Leisch et al. (1963). The important characteristics of this watershed in terms of impacts of groundwater extraction on streamflow include the following:

1) Essentially all groundwater in the basin is derived from precipitation and subsequent infiltration into the groundwater system. This infiltration or recharge occurs primarily in the uplands along the eastern part of the basin. Wetlands in this eastern and upper part of the basin provide significant groundwater recharge.

2) There is no significant net flow of groundwater into the basin from adjacent areas. Groundwater flow in the area east of the Bear-Evans Creek watershed is described in Turney et al. (1995). There may be some limited groundwater inflow from this adjacent basin in shallow aquifers along the southern and south-eastern edges of the Bear-Creek watershed (in Township 25N, Range 6E). However, there is roughly an equal amount of groundwater outflow in these same aquifers along the north-eastern edge of the watershed (in Township 26N, R6E). Groundwater flow in the area north of the Bear-Evans Creek watershed is described in Thomas et al. (1997). Based on the information in this report, there is no significant groundwater flow to the Bear-Evans watershed from the north.

3) Groundwater in the shallow aquifers in the Bear-Evans Creek watershed discharges primarily to streams, and, to a lesser degree, to springs and Lake Sammamish. The groundwater flow direction is downward in the recharge area and upward in the

discharge area. The recharge area is roughly 80% to 90% of the basin, and the discharge area is approximately 10% to 20% of the surface area of the basin (AGI, 1995).

4) Groundwater in deeper aquifers may discharge out of the basin to the west toward Lake Washington (Liesch et al., 1963; King County, 1999) and to the east toward the Snoqualmie River (Turney et al., 1995). The amount of groundwater outflow in these deeper aquifers has not been reliably estimated.

5) The hydrogeology of the basin is comprised of a series of higher and lower permeability units that were deposited by glacial processes. These units do not form well-defined or spatially extensive aquifers and confining units in the traditional hydrogeologic sense. The aquifer system is more a series of higher permeability materials interspersed with lower permeability materials. There is not a spatially continuous set of aquitards that clearly separate these higher permeability materials.

6) The groundwater system in the Bear-Evans Creek Watershed is a leaky system. The higher permeability materials are clearly in hydraulic continuity with one another and with the most shallow water-bearing units. In a leaky aquifer system, a portion of the water extracted by wells may originate from storage in the pumped aquifer and a portion will come from leakage through confining layers. When pumping first begins, the water comes primarily from storage in the pumped aquifer. As time goes on, more of the water that is extracted originates as leakage through the confining layer. Leakage occurs more quickly in aquifers that are not spatially-extensive, as is the case in the Bear-Evans Creek

7) Because of the leaky nature of the aquifer system in the Bear-Evans Creek watershed, there is hydraulic continuity between the aquifers and the lakes, streams, and springs in the basin. Water extracted by the groundwater wells is water that would have fed streams and other surface water bodies.

8) The time lag between groundwater extraction and streamflow reduction is expected to be relatively short in the Bear-Evans Creek Watershed. The relatively permeable geologic materials and the close proximity of wells and streams cause these time lags to be on the order of days or weeks rather than months or years. The impact on streams from groundwater extraction will be approximately equal to the pumping rate, particularly during the summer months.

3. Summary of Groundwater Extraction in the Bear-Evans Creek Watershed

Table 1 provides a summary of the major municipal water supply wells that have been identified in the Bear-Evans Creek watershed. The table describes the horizontal and vertical locations of each well, the approximate static water level in each well, the capacity and depth of each well, and the distance to the nearest major stream or surface water body. Although information is currently missing for some of the wells, the information that is available suggests that most wells are located within several thousand feet of a major stream and most wells are screened at elevations above or near to the elevations of the streams and Lake Sammamish. (The Sammamish River is the eventual discharge point in the basin. The elevation of the river at the outlet of Lake Sammamish is approximately 50 feet and at the mouth at Lake Washington it is approximately 20 feet.).

The two deepest wells in the basin appear to be NE Sammamish Water and Sewer Well #4, which is screened from elevation -148 to -198, and Union Hill Well #1, which is screened from elevation -53 to -27 feet. Because of the leaky nature of the aquifer system in this watershed, it is likely that even these deeper wells derive most of their water from more shallow deposits in the immediate vicinity of the wells. The Redmond wells have shallow screens and extract water directly from the upper water table aquifer that is most likely in direct hydraulic connection with streams and Lake Sammamish. The Cross Valley wells have screens at elevations between 150 and 300 feet above sea level and are the furthest from surface water bodies.

4. Effects of Groundwater Extraction on Leakage from Upper Aquifers

The geologic and topographic characteristics of the Bear-Evans Creek Watershed result in a system that is, for the most part, hydrogeologically self-contained. Groundwater within the basin originates from infiltration and not from groundwater inflow from outside of the basin. Some component of groundwater outflow may occur to the west in deeper aquifers, but the amount has not been reliably estimated and is likely small relative to the amount of recharge from infiltration. Groundwater leaves the basin in one of two primary ways: through stream flow, ultimately in the Sammamish River, or through groundwater extraction wells. An increase in one of these end points necessarily results in a decrease in the other. As more water is removed through groundwater extraction wells, less water is available for stream flow.

Most of the municipal water supply wells in the Bear-Evans Creek Watershed are completed in a semi-confined or "leaky" aquifer. (Exceptions to this include the Redmond wells, which appear to be completed in a shallow unconfined aquifer that is in direct continuity with streams and Lake Sammamish.) In a leaky aquifer, a portion of the water extracted by the wells may originate from storage in the pumped aquifer and a portion may come from leakage through confining layers. When pumping first begins, the water comes primarily from storage in the pumped aquifer. As time goes on, more of the water that is extracted originates as leakage through the confining layer. This behavior can be described with equations which represent well hydraulics (e.g. Hantush, 1964, pp. 326-338). The following expression gives, as a function of time, the percentage of the extracted water that originates as leakage in a leaky-aquifer system:

$$Q_L/Q_W = 1 - \exp(-K't/Sb')$$

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In this expression Q_L is the volume of water that originates as leakage, Q_W is the volume of water that is extracted at the well, t is the time since pumping began, K' is the hydraulic conductivity of the confining layer, b' is the thickness of the confining layer, and S is the storage coefficient for the pumped aquifer. The storage coefficient is a measure of the compressibility of the aquifer.

At early times, when pumping has just begun, the right hand side of this expression equals zero, which means that all the water that is extracted from the wells is derived from the pumped aquifer. After the well has been pumped for longer times, the right hand side approaches one, which means that all the water that is extracted is derived from leakage through confining layers. Although this equation only approximates the actual aquifer system in the Bear-Evans Creek Watershed, it can be used to give at least a sense of the time scales that are important in this problem.

The thickness of the confining unit, b', was assumed to be 50 feet. This is chosen as a "typical" value based on information from well logs. The storage coefficient for the pumped aquifer, S, was assumed equal to 5×10^{-4}. This estimate is based on compressibility values published in the literature for sand aquifers (p. 59, Freeze and Cherry, 1979). The variable that is most important and uncertain in this expression is the hydraulic conductivity of the confining layer, K'. Figure 1 shows the contribution of leakage as a function of time for a range of values for K'. As the conductivity of the leakage layer increases, the contribution of leakage becomes more important more quickly. Although this variable has not been measured, a value of $K' = 10^{-7}$ ft/s (0.01 ft/day) may represent a lower bound for this parameter and a value of $K'=10^{-5}$ ft/s (1 ft/day) is a reasonable estimate.

Figure 1 indicates that the impact of the wells on shallow groundwater may occur quite rapidly. It is likely that after several days of pumping, the large majority of the water that is extracted from the groundwater wells in confined and semi-confined aquifers will have originated as leakage from more shallow aquifers.

5. Effects of the Groundwater Extraction on Discharge to Streams

The calculations described in the previous section consider the effect of the extraction wells on shallow groundwater systems. This section considers the effect of the wells on groundwater discharge to streams. The intent of these considerations is to develop order-of-magnitude estimates for how long it would take for groundwater extraction at a well to result in reduced flow in nearby streams. An approximation for the reduction in discharge for a fully confined aquifer can be developed from equations presented by de Marsily (1986, p. 199). The flow or discharge induced at a stream from a decline in the water level at a distance, X, from the stream is given by the following expression:

$$Q = \frac{2Th_o}{\sqrt{\pi}} \sqrt{\frac{S}{4Tt}} \exp(\frac{-X^2 S}{4Tt})$$

where Q is the flow per unit length of the stream, h_o is the decline in the water level at a distance X from the stream, S is the storativity for the aquifer, T is the transmissivity for the aquifer, and t is time. The time that is required for the effect of the well field to be realized depends upon the transmissivity for the aquifers. Higher values for transmissivity result in more rapid response. Figure 2 shows the response assuming three values of transmissivity. These values are based on estimates from reports on wells from Union Hill and NE Sammamish Water and Sewer Districts (AGI, 1995 and 1996). The value assumed for the storativity, S, was 0.005. This is representative of a sand aquifer (Freeze and Cherry, 1979). The distance between the well and the stream, X, was assumed to be 2,500 ft and the decline in the water level, h_o, was assigned a value of 1.0 ft. The results shown in Figure 2 suggest that the well field may affect discharge in the streams several days after the pumping is initiated. For example, after 1 day of pumping, the reduction in discharge to the stream equals 85% of the pumping rate if the transmissivity is equal to 8,000 ft^2/day.

The results shown in Figure 3 were developed assuming a storativity of 0.05. This larger value of storativity would be more representative of an unconfined aquifer similar to the Redmond wells. Although the larger storativity of the unconfined aquifer results in a slower response in Figure 3, the over-all impact from wells in unconfined aquifers generally occurs more quickly than impacts from wells in confined aquifers. This is because there are no confining units that separate the pumped aquifers from the aquifers that discharge to the streams.

6. Implications of Effects of the Groundwater Extraction on Discharge to Streams

Because of the relatively permeable materials in the Bear-Evans Creek Watershed and the close proximity of wells and streams, the time lag between groundwater extraction and streamflow reduction is likely relatively small - perhaps on the order of days or weeks rather than months or years. The magnitude of the impact from pumping is likely approximately equal to the pumping rate. Because of the relatively rapid response, water balances based on average annual groundwater recharge and extraction are not particularly meaningful. Water balances on a time scale of a month would be more appropriate in terms of quantifying effects of wells on streams. In the summer months, when groundwater recharge is often very small (Dinicola, 1990), groundwater extraction is typically at its peak. A water balance developed over this time scale may show that groundwater extraction is a significant proportion of stream flow in the Bear-Evans Creek Watershed.

The relatively short time lag also has implications for groundwater management options. Reducing groundwater extraction should have a relatively rapid effect on streamflow for many of the wells in the Bear-Evans Creek Watershed. Reductions in groundwater extraction rates could be linked to observed streamflow. For example, if the streamflow falls below some critical cutoff point, groundwater extraction might be reduced or eliminated at selected wells that are particularly connected to the streams. This reduction or elimination could then help mitigate the low flows in the stream within a time period of days or weeks. This type of management approach, in which groundwater extraction is linked to observed streamflow or groundwater levels, has been used in some areas (e.g. Woodward Clyde, 1997).

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Table 1 - Summary of Municipal Water Supply Wells

	Pumped in 1990	Location	Depth	Elevations (ft)		Stream/Distance
	(gallons)	(Qrt/S-T-R)	(ft)	Static	Screen	
Cross Valley 1	255,000	SW/24-27-5	191	318	249-269	0.8 mi., Bear Cr*
Cross Valley 3	22,000,000	NE/25-27-5	238	312	242-272	1 mi., Bear Cr*
Cross Valley 8		NE/25-27-5	244	312	236-306	1 mi., Bear Cr*
Cross Valley 7	13,400,000	SE/34-27-6				Out of basin
Cross Valley 7A	19,430,000	SE/34-27-6				Out of basin
Cross Valley 5	94,000,000	NW/24-27-5		314		1 mi., Bear Cr*
Cross Valley 6		NW/24-27-5	254	314	166-186	1 mi., Bear Cr*
Cross Valley 9		SW/24-27-5	300	314	145-184	0.8 mi., Bear Cr*
Cross Valley 10		NW/24-27-5	278	314	149-200	1 mi., Bear Cr*

*Bear Creek in Snohomish County

	Capacity	Location	Depth	Elevations (ft)		Stream/Distance
	(gpm)	(Qrt/S-T-R)	(ft)	Static	Screen	
Redmond #1	1000	NW/12-25-5	56	33		Bear Cr., 1500 ft; Samm. R, 2000 ft
Redmond #2	500	NW/12-25-5	72	30		Bear Cr., 1500 ft; Samm. R, 2000 ft
Redmond #3	500	NW/6-25-6	44	47		Bear Cr., 1500 ft.
Redmond #4	750	SE/2-25-5				Samm. R., 2000 ft
Redmond #5	1000	NE/12-25-5	41	38	+10 to +25	Bear Cr., 1500 ft.

	Capacity	Location	Depth	Elevations (ft)		Stream/Distance
	(gpm)	(Qrt/S-T-R)	(ft)	Static	Screen	
NE Sammam. #2R	385	NW/21-25-6	150	94	+15 to +45	Evans, 2000 ft.
NE Sammam. #3	585	SE/21-25-6	690	115	-198 to -148	Evans, 4000 ft.
NE Sammam. #4	600	SE/21-25-6	388	127	+4 to +34	Evans, 3,000 ft.
NE Sammam. #6	385	NW/21-25-6	156	91	-5 to +54	Evans, 1500 ft.

	Capacity	Location	Depth	Elevations (ft)		Stream/Distance
	(gpm)	(Qrt/S-T-R)	(ft)	Static	Screen	
Union Hill #1	825	SE/16-25-6	236	150	-27 to -53	Evans, 1000 ft.
Union Hill #2	220	SE/16-25-6	220	149	+9 to +39	Evans, 1500 ft.
Union Hill #3	360	NW/10-25-6	496	187	+73 to +130	Evans, 1500 ft.

Figure 1 - Contribution of Leakage to Well Effluent
($S = 5 \times 10^{-4}$, $S' = 5 \times 10^{-3}$, $b' = 100$ ft)

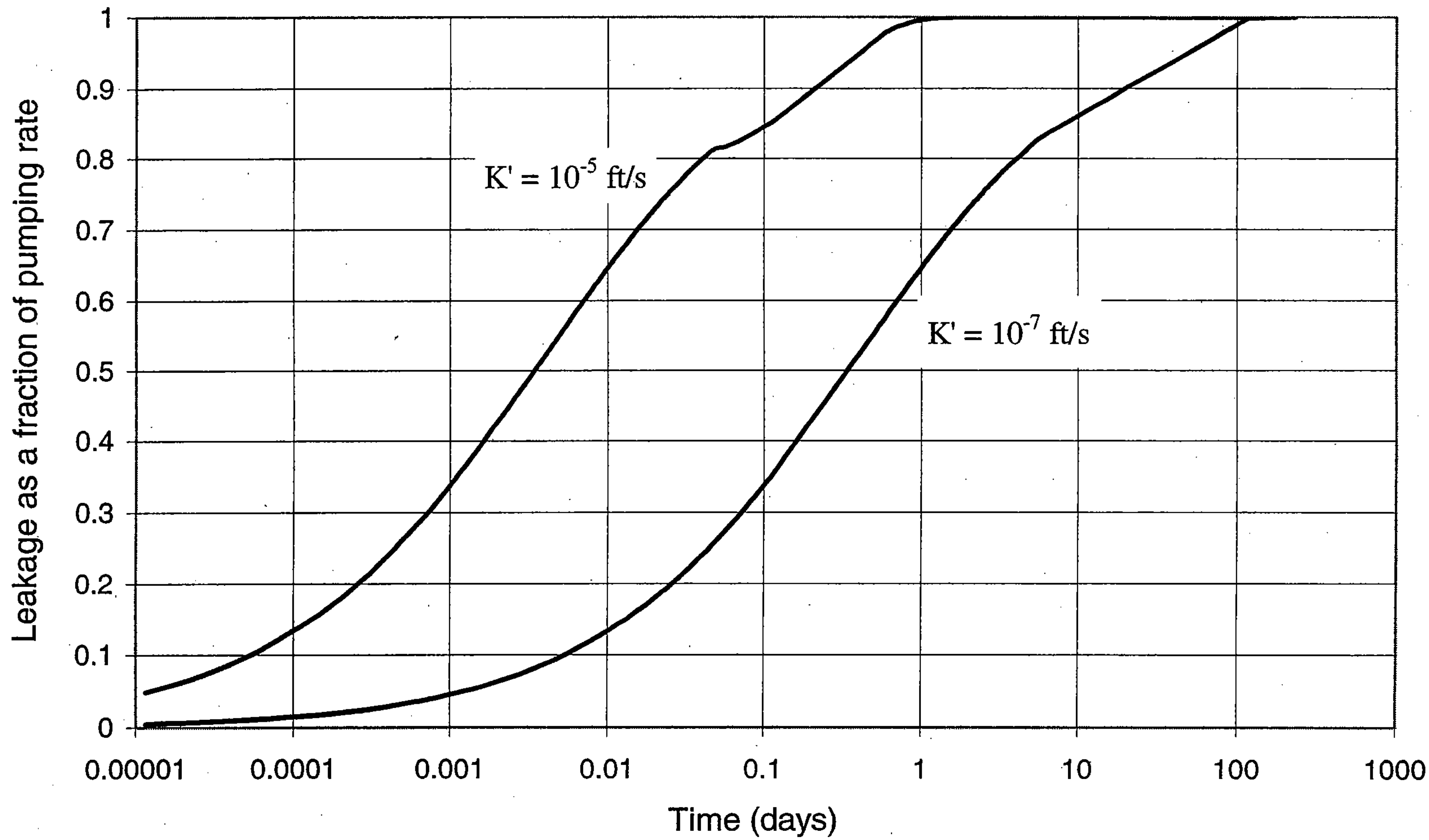

Figure 2 - Relative Discharge at Stream for Confined Aquifers

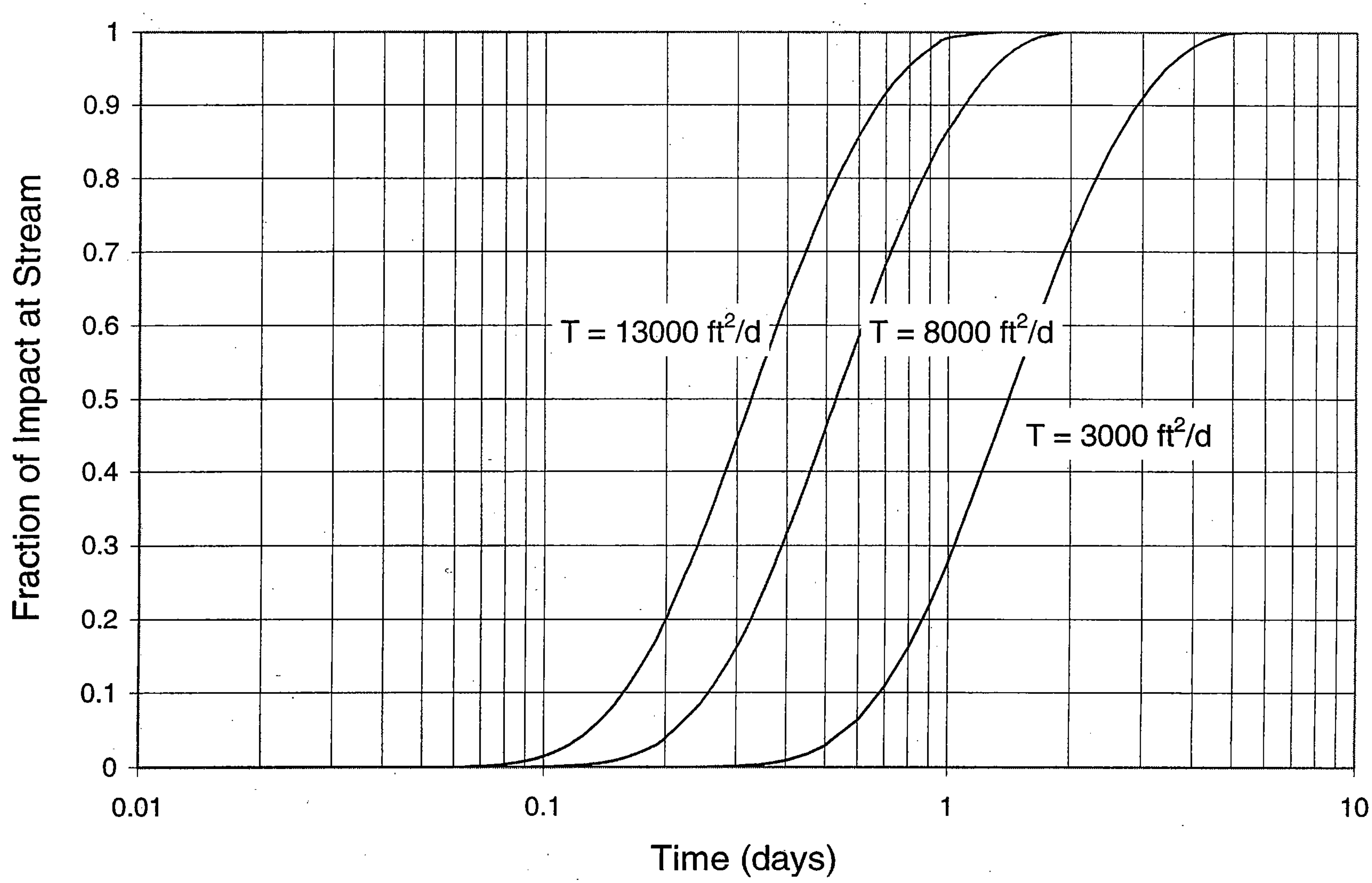

Figure 3 - Relative Discharge at Stream for Unconfined Aquifers