Effects of Groundwater Extraction on Stream Flow in the Issaquah Creek Valley 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 Issaquah Creek Valley watershed. The objectives of these evaluations include the following:

1) Summarize the hydrogeology in the Issaquah Creek Valley watershed.
2) Identify the locations of the primary municipal water supply wells in the Issaquah Creek Valley 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 Issaquah Creek Valley Watershed

The geology and hydrogeology in the Issaquah Creek Valley watershed have been described in a numerous reports and studies, including Liszak (1994), Golder Associates (1993; 1996), Washington Department of Ecology (1995), and Issaquah Creek Valley Groundwater Advisory Committee (1999). The important characteristics of this watershed in terms of impacts of groundwater extraction on streamflow include the following:

1) The Issaquah Creek Valley basin is hydrologically "closed" in terms of groundwater resources in that there are no significant amounts of groundwater that flow into the basin from adjacent areas. Essentially all groundwater in the basin is derived from precipitation and subsequent infiltration into the groundwater system. All groundwater flows through the lower Issaquah Valley aquifer system discharges to Lake Sammamish, the wetlands south of Lake Sammamish, or Issaquah Creek (Issaquah Creek Valley Groundwater Advisory Committee, 1999).

2) Groundwater recharge in the Issaquah Valley is estimated to be on the order of 20 to 25 cubic feet per second (cfs). This recharge occurs in the lower valley from infiltration that flows laterally along the bedrock surface until it reaches coarse-grained sediments along the valley floor. Recharge also occurs in the upper part of the valley along the Grand Ridge and Tradition Lake Plateaus. Discharge through the Hobart Gap from the upper valley to the lower valley is estimated to be less than 2 cfs (Golder Associates, 1993).

3) Groundwater discharge to Lake Sammamish and nearby wetlands is estimated to be between 15 and 20 cfs. Groundwater withdrawals equal approximately 5 cfs on an

annual basis. (Golder, 1993; Liszak, 1994). As of 1994, there were over 50 wells in the Issaquah Valley with water rights for approximately 10 cfs (Q_a of approximately 7000 acre-ft/yr). The annual seven day low flow on the main stem of Issaquah Creek is between 14 and 42 cfs. The greatest impact of groundwater extraction is presumed to be the North Fork of Issaquah Creek (Liszak, 1994).

4) 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.

5) The groundwater system in the Issaquah Creek Valley Watershed is a leaky system. The higher permeability materials that comprise the aquifer zones 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 Issaquah Creek Valley.

6) Because of the leaky nature of the aquifer system in the Issaquah Creek Valley 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.

3. Summary of Groundwater Extraction in the Issaquah Creek Valley Watershed

Groundwater provides a large majority of the potable water supply in the Issaquah Creek Valley. There are two municipal water supply systems in the Issaquah Creek Valley. The City of Issaquah has water rights at six wells and the Sammamish Plateau Water and Sewer District has rights at three wells in the Issaquah Creek Valley. Wastewater from the area is pumped to the Renton sewage treatment plant. This results in a net loss of water out of the Isssaquah Ground Water Management Area due to the municipal water supply systems. Groundwater levels in the Lower Issaquah Creek Valley Aquifer have shown a downward trend in recent years. Future water demands are expected to exceed current water rights (Issaquah Creek Valley Groundwater Advisory Committee, 1999).

Table 1 provides a summary of the major municipal water supply wells that have been identified in the Issaquah Creek Valley 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 a thousand feet of a major stream and most wells are screened at elevations below the elevations of the streams and Lake Sammamish. Issaquah Creek and the Sammamish River are the eventual discharge points in the basin. The elevation of Lake Sammamish is approximately 50 feet.

4. Effects of Groundwater Extraction on Leakage from Upper Aquifers

The geologic and topographic characteristics of the Issaquah Creek Valley 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. Groundwater leaves the basin in one of two 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 wells in the Issaquah Creek Valley Watershed appear to be completed in a semi-confined or "leaky" aquifer. 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:

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

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 Issaquah Creek Valley 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 and geophysical cross sections (Golder Associates, 1993). The storage coefficient for the pumped aquifer, S, was assumed equal to $5x10^{-3}$. 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^{-6} ft/s (0.1 ft/day) may represent a lower bound for this parameter and a value of K'=10^{-4} ft/s (10 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 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 Golder Associates (1993) and Carr Associates (1990). The value assumed for the storativity, S, was 0.05. This is representative of a semi-confined sand aquifer (Freeze and Cherry, 1979). The distance between the well and the stream, X, was assumed to be 1,000 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 well fields 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 is more than 95% of the pumping rate if the transmissivity is equal to 20,000 ft^2/day.

The results shown in Figure 3 were developed assuming a storativity of 0.1. This larger value of storativity would be more representative of an unconfined aquifer.

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

Because of the relatively permeable materials in the Issaquah Creek Valley 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 Issaquah Creek Valley 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 Issaquah Creek Valley 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

	Capacity (gpm)	Location (Qrt/S-T-R)	Depth (ft)	Screen Elevation (ft) Screen	Stream/Distance
Issaquah #1	600	M/27-24N-06E	107	+3 to -13	E. Fork Issaquah Creek/300 ft
Issaquah #2	1000	M/27-24N-06E	97	+12 to -3	E. Fork Issaquah Creek/300 ft
Issaquah #4	250	B/28-24N-06E	112	-11 to -36	Main Stem Issaquah Creek/500 ft
Issaquah #5	1000	B/28-24N-06E	412	-266 to -338	Main Stem Issaquah Creek/500 ft
SPW&SD #7	2000	A/28-24N-06E	151	-12 to -77	N. Fork Issaquah Creek/100 ft
SPW&SD #8	3500	A/28-24N-06E	190	-31 to -105	N. Fork Issaquah Creek/100 ft
SPW&SD #9	2000	E/27-24N-06E	303	-116 to -141	N. Fork Issaquah Creek/900 ft.

Table 2 - Summary of Municipal Water Rights Certificates

	Certificate	Date	Qi gpm	Qa ac-ft/yr	
Issaquah #1	G1-08632C	3/28/69	630	1000	
Issaquah #2	G1-10071C	10/8/70	1200	1600	
Issaquah #4	G1-24809C	3/10/86	250	200	
Issaquah #5	G1-24633C	4/2/85	1000	1600	Qa is Supplemental
Gun Club #1	G1-22733C	9/1/76	300	120	Qa is Supplemental
Gun Club #2	G1-22734C	9/1/76	500	645	Qa is Supplemental
SPW&SD 7&8	G1-00289C	1/20/72	3,200	936	Wells 7 and 8 on same certificate
SPW&SD 7&8	G1-25428P	4/24/89	2,300	1,738	November-May operation only.
SPW&SD 9	G1-26014P	12/25/90	2,000*	1,608*	November-May operation only. Both Qi and Qa supplemental to Wells 7 & 8. *(limited to Qi and Qa not used under G1-25428P.)

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

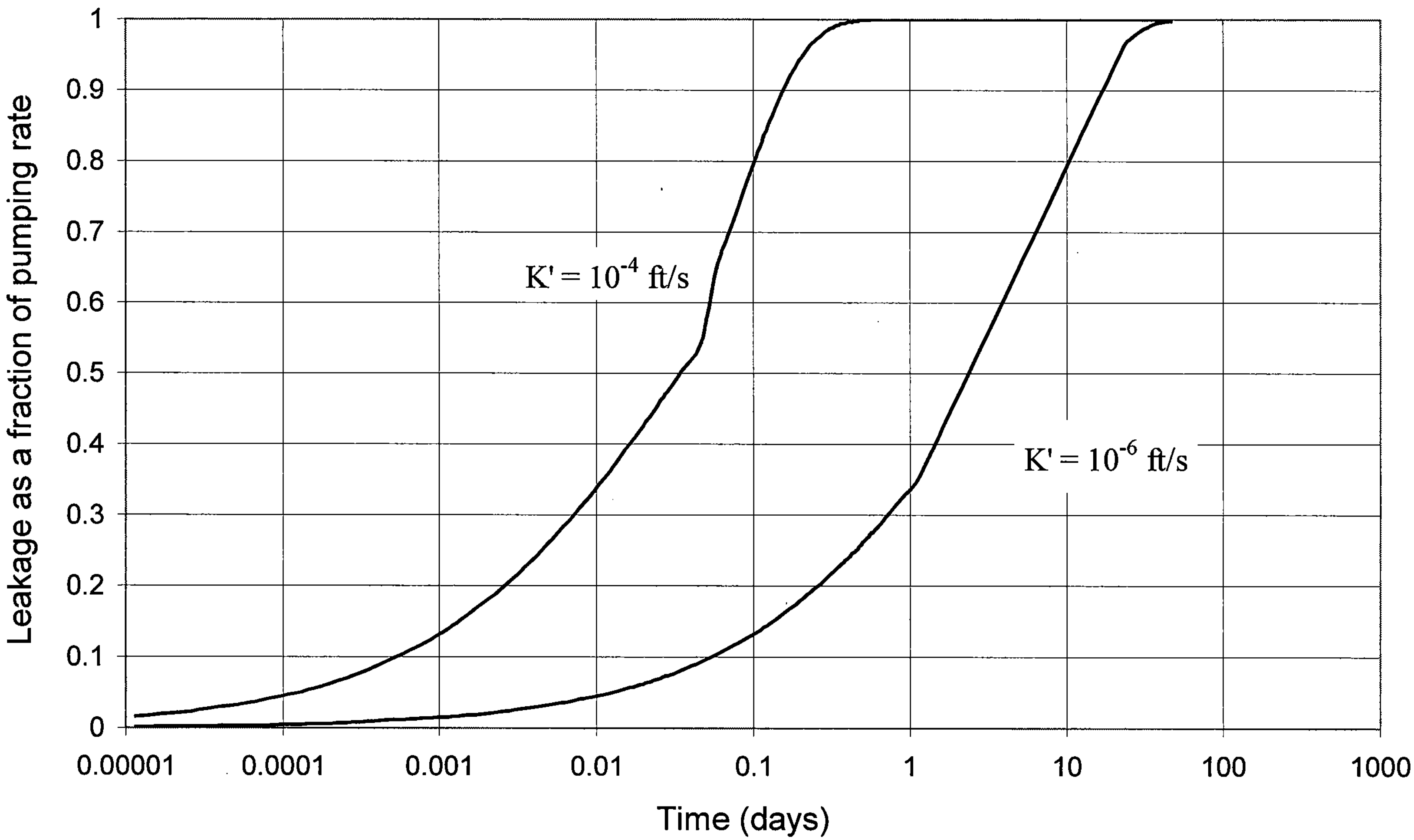

Figure 2 - Relative Discharge at Stream for Confined Aquifers

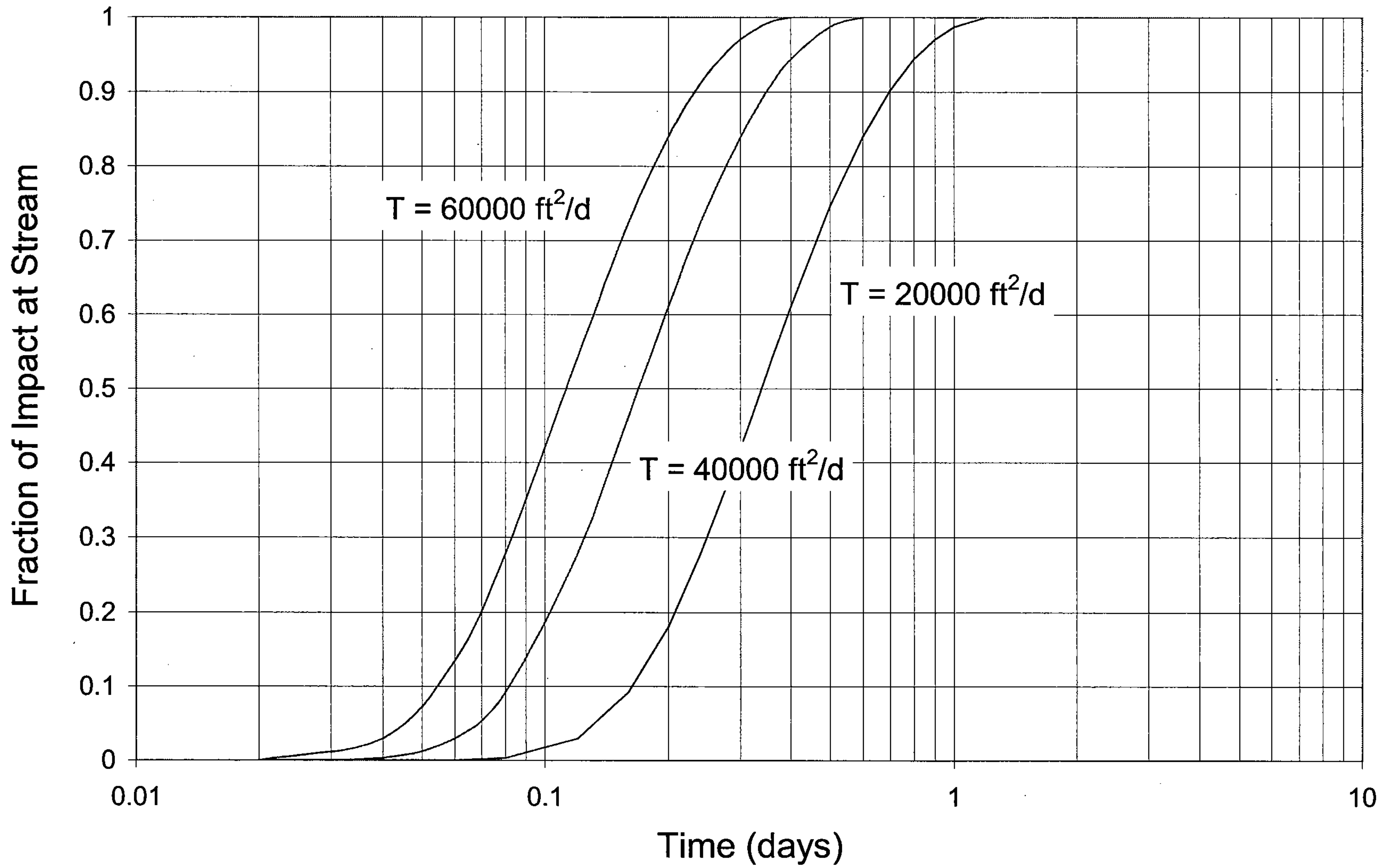

Figure 3 - Relative Discharge at Stream for Unconfined Aquifers