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Water Matters

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A guide to integrated water management in Nebraska

Stream Depletion and Groundwater Pumping

Part Two: The Timing of Groundwater Depletions

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While the information presented in this article is technical in nature, it has been generalized to appeal to a broader audience. This article provides an overview of a very complex topic.

Introduction

In most areas of Nebraska, the groundwater system is in direct hydrologic connection with the surface water system. Therefore, the consumptive use of groundwater will have some impact on the amount of groundwater discharge (baseflow) to hydrologically connected streams. Reductions in baseflow due to groundwater pumping are not instantaneous, and may take many years or decades to be fully realized. The time lag between the start of pumping and the advent of streamflow depletions is largely dependant on the distance between the well and the stream, as well as the aquifer and streambed properties.

One factor that will affect lag time is the level of hydraulic conductivity of the materials in the aquifer. Hydraulic conductivity is a measure of the ease with which water travels through aquifer materials. Wells installed near a stream and/or in high hydraulic conductivity materials will have a quicker impact on the streams. Wells installed far from a stream and/or in lower hydraulic conductivity areas can take considerably longer to impact nearby streams (see figures 1a, 1b, and 1c on page 2).

Generally speaking, any consumptive groundwater pumping[1] in a hydrologically connected stream/aquifer system will eventually result in a similar level of stream depletion. However, in a large regional aquifer system such as the High Plains Aquifer in Nebraska (sometimes referred to as the Ogallala Aquifer), this stream depletion due to groundwater pumping during a given year will likely not be realized for many years.

The Timing of Stream Depletions

Stream depletions cannot be directly measured. Therefore, groundwater models are widely used to simulate past and predict future impacts to streams due to groundwater use. A calibrated groundwater model can be run with and without estimated past pumping rates. The difference between the baseflow to the streams for these two scenarios is referred to as stream depletion due to groundwater use. The model can then be run forward in time using similar scenarios

[1]Groundwater pumping in this document is intended to represent water that is pumped and consumed. The remainder will either return to the aquifer as recharge, or run off and become streamflow.

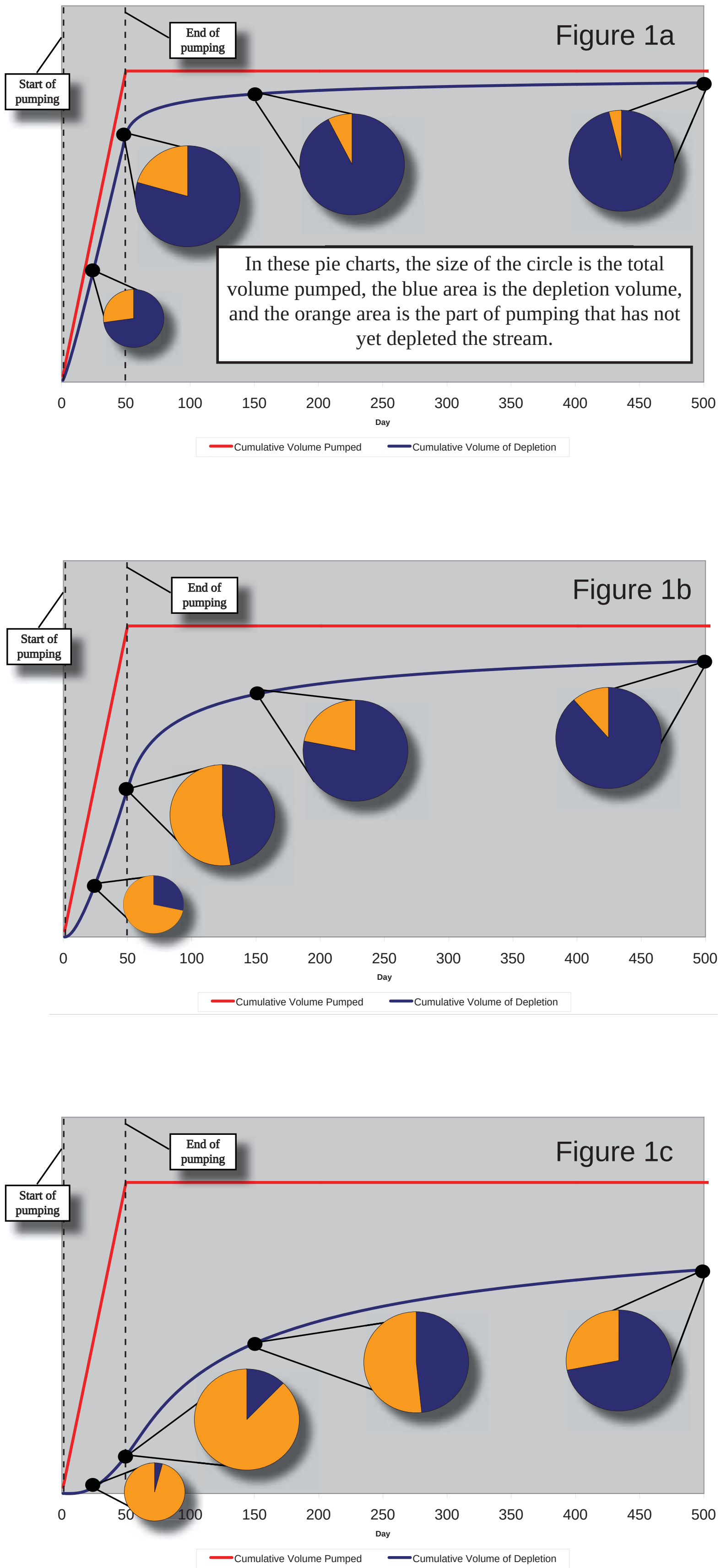
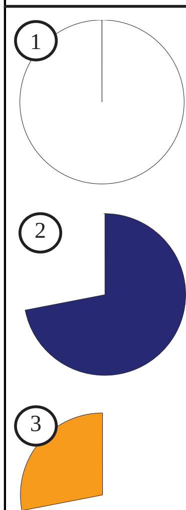


Figure 1 (a, b, c): Three hypothetical scenarios in which three different wells pump for 50 days. In all three of these scenarios, the wells pump the same volume of water. The red line shows the cumulative volume of groundwater that is pumped and the blue line represents the volume of depletion to streamflow. Again, in all three of these scenarios, the cumulative volume pumped is the same. However, the rates of depletion differ significantly. Even though the depletion rates differ, it is important to note that in all three scenarios, the volume of groundwater pumped and the volume of the depletion will eventually be nearly equal. This means that all pumping will eventually result in a near 100% depletion. However, the amount of time it takes for the depletion to be fully realized will differ depending on depletion rate. For example, in figure 1a, roughly 96% of the volume of groundwater pumped has depleted the stream after 500 days. In figure 1b, roughly 89% of the volume of groundwater pumped has depleted the stream after 500 days. And in figure 1c, roughly 72% of the volume of groundwater pumped has depleted the stream after 500 days. The pie charts show the volume of streamflow depletion relative to the volume of water pumped. The depletion rate (and therefore the depletion volume) will depend on many factors, such as aquifer properties and distance to the stream.

Explanation of Pie Charts in Figures 1a, 1b, and 1c



The pie charts in figures 1a, 1b, and 1c show the amount of streamflow depletion relative to the volume of water pumped. Here, pie chart 1 represents the height of the red line, which is the entire amount pumped. Pie chart 2 represents the height of the blue line, which is only the depletion due to groundwater pumping at day 500 in figure 1c. Note that the pie chart is incomplete: there is a portion of the full pie (which represents the volume of water pumped) that is missing. Pie chart 3 is that missing piece. The orange area represents the difference between pie charts 1 and 2, which is the distance between the red and blue lines. This is portion of the groundwater pumping that has not yet been realized as a depletion.

to estimate projected stream depletions due to past, current, and/or future groundwater use.

To better understand this long-term relationship between groundwater pumping and stream depletions, it is useful to separate streamflow depletions for a given basin into two components that are best understood in terms of some reference year (any appropriate year against which future depletions are measured). Relative to this reference year, there are residual impacts to streamflow from pumping that has occurred in the past and there are the lagged impacts of current pumping levels continuing into the future. Model scenarios can be used to illustrate the relative amount of each of these factors in the projected future streamflow depletions.

Residual Depletions

The scenario in figure 2 illustrates the residual impacts to streamflow from pumping that has occurred in the past (i.e. up to the reference year). It is important to note that in figures 1a, 1b, and 1c, *cumulative volumes* of pumping and depletion were shown. However, in the upcoming figures, pumping and *depletion rates* are shown. While cumulative volume measurements reflect the total volume of water pumped or depleted up to a given time, the rate is the volume of water pumped or depleted at one specific point in time.

The bars in figure 2 represent the amount of groundwater pumping during a given year (the rate of groundwater pumping), and the line represents the impact of this pumping on streamflow (this rate of streamflow depletion may be affected by pumping that has occurred in the past). The short term variability in the depletions curve is due to changes in year-to-year rainfall totals, which also affect the amount of streamflow. In this example, groundwater pumping has increased up to a given level through year six (the reference year in this scenario), after which all current pumping is set to zero. Despite the fact that no further pumping occurs beyond year six in this example, baseflow to the stream continues to be depleted due to continued effects of pumping that occurred during and before year six. This is referred to as the residual effect.

The residual effect has both a time component and a streamflow depletion component. The residual depletion is the streamflow depletion remaining during any given year after the reference year due to pumping that has occurred up to that reference year. The recovery time is the length of time after the reference year required for the residual depletions to approach zero.

The information on residual depletions and recovery time is compiled by running a groundwater model through this scenario. The model is run up to the reference year with groundwater use active, then it is run forward beyond the reference year with all pumping removed to quantify the recovery of baseflow to the streams. In this example, year six is the reference year, and the residual depletions approach zero sometime around year 41, for a recovery time of approximately 35 years (figure 2).

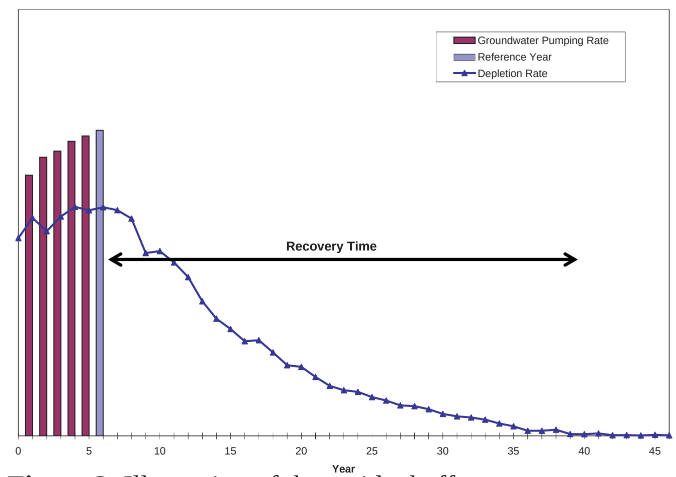


Figure 2: Illustration of the residual effect.

Lagged Depletions

Figure 3 illustrates a modeling scenario demonstrating the lagged impact to streamflow due to current levels of pumping. Here, groundwater pumping has been increasing until year six (reference year), at which time a hypothetical moratorium is placed on further well development in this basin, which is modeled as constant pumping for every year after the reference year (year six). This time, however, the model is run beyond the reference year with a constant level of pumping to assess the depletions to the stream due to past and current levels of water use. As in our first scenario, we observe short-term fluctuations due to the effects of annual precipitation variability. However, streamflow depletions will continue to increase despite the constant level of pumping. This is referred to as the lag effect. The depletions curve generated in this

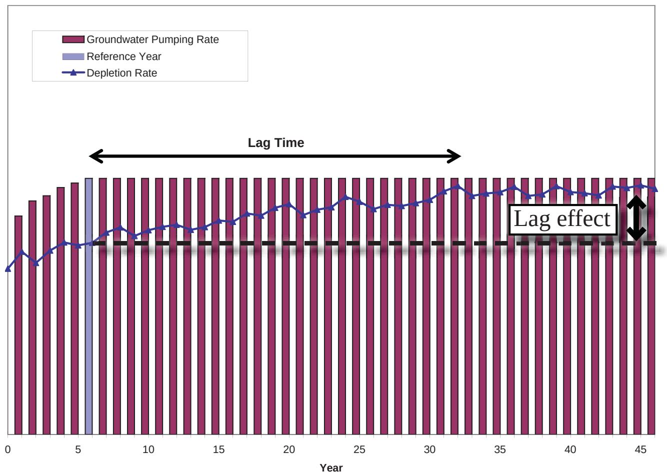


Figure 3: Illustration of the lag effect.

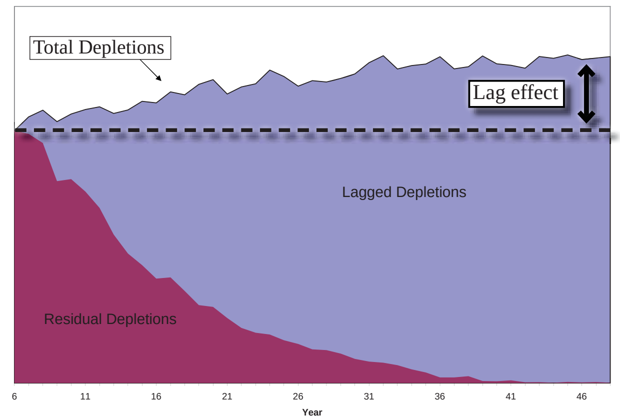


Figure 4: The residual and lagged components of total depletion beginning at the reference year (year 6).

scenario includes both the residual and lag depletions.

The lag effect also has a time and streamflow depletion component. The lag time is the length of time before the streamflow depletions come into equilibrium with continued groundwater pumping, and is defined in relation to a reference year. In this model scenario, the streamflow depletions appear to begin to reach equilibrium with respect to year six levels of pumping around year 36, for a lag time of approximately 30 years (figure 3). The lagged depletions for a given year are the difference between the residual depletions and the total depletions (figure 4).

Summary

The successful management of hydrologically connected waters requires an understanding of the complex effects of groundwater pumping on stream baseflow. The timing of the components of stream depletion are most easily discussed relative to points in time (a reference year) with an eventual realization of all consumptive groundwater withdrawals as stream depletions, years to centuries in the future. Understanding the timing of these effects and the response of hydrologically connected streams to groundwater pumping is critical in long–term management and planning.

This edition of *Water Matters* will be referenced and discussed in the October 2010 DNR newsletter.

Please contact the Nebraska Department of Natural Resources with questions or concerns about this publication at (402) 471-2363.

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