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Basis of Groundwater Levels

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Introduction

This report is intended to describe and explain some of the basic principles of using groundwater levels to manage a stream-aquifer system with the goal of permitting the maximum amount of groundwater pumping that is consistent with maintaining a certain minimum streamflow. It is based on issues raised in discussions of the Advisory Committee of the Walnut Creek Intensive Groundwater Use Control Area. Although the report is presented in non-technical general terms, its goal is to provide a basis for deciding whether pumping controls based on groundwater levels is an approach that deserves further consideration and a more technical analysis.

Recharge-based management

There is a strong tendency for people involved in Kansas groundwater use to think of recharge estimation as the preferred approach to determining how much water can be withdrawn from an aquifer. This is because the traditional definition of the "safe yield" of an aquifer is "the average long-term recharge." We now understand that this is not necessarily a good definition in cases where surface water and groundwater interact, but it is a reasonable first approximation of how much water might be withdrawn from an aquifer on a sustainable basis, in the absence of any other criteria or limitations. When it is necessary to maintain natural groundwater discharge (to satisfy surface water rights or minimum streamflow requirements) or specific groundwater elevations (for example, to keep existing municipal or domestic wells from going dry), the practical "safe yield" will be less than that estimated from recharge alone. This complex and important topic is the subject of an edited book currently in preparation by KGS, with contributions from personnel at various state water research and management agencies (Sophocleous, in press).

Even without the complications of other restrictions on groundwater withdrawal, recharge is a notoriously difficult quantity to measure or estimate accurately. It depends in a complex fashion on various factors -- precipitation (intensity as well as amount), land use and land cover, soil and aquifer characteristics, depth to water, etc. All of these are likely to exhibit considerable variability over space, and some are variable over time as well. An example is the long-term study of recharge in the Great Bend Prairie aquifer by Sophocleous (1992; 1993). After 8 years of collecting rainfall, soil moisture and water level data at 10 sites he was able to develop a predictive relationship and estimate regional recharge -- but the estimates still contained a significant level of uncertainty. Recharge estimation requires either tolerance of substantial uncertainty or a very extensive -- and expensive -- program of data collection and analysis.

Groundwater levels and streamflow

When there is a requirement to maintain a specified flow in a stream that relies heavily on baseflow, the issue of estimating recharge becomes of secondary importance. Baseflow will occur only when there is a water table gradient toward the stream and the elevation of the water table is above the elevation of the bottom of the stream channel. Figure 1 shows an example in which the water table gradient is exaggerated for the purposes of illustration. In any given location the requirement for flow can be translated directly into a minimum acceptable groundwater elevation by some reasonably straightforward measurements and calculations. The height of the water table above this minimum elevation can be used to calculate the amount of water in storage that could be available for pumping without unacceptable reductions in streamflow. While it might be nice to have an estimate of recharge to better understand the system and for long-range planning, it is relatively simple and conservative to manage the aquifer like a business bank balance -- we may not be able to predict the times and amounts of income, so we control expenditures to make sure there is always enough of a balance to cover the known obligations.

It's worth pointing out why this is simple compared to management by recharge estimates. If we measure rainfall and determine soil type and land use at two points a few miles apart on the land surface, we still have substantial uncertainty about using those measurements to predict or estimate what is happening in between the points, because the factors that control recharge vary in time and space. By comparison, if we measure the water table elevation at two points in a continuous aquifer, and are careful to pick a time when there have been no major local recharge events or pumping, we can predict what the water table looks like in between those points with a high degree of accuracy.

A simple management example

To start out, let's consider a very simple system, such as is illustrated in Figure 2. Here we have an alluvial aquifer contained in a valley in bedrock that does not contribute any significant amount of groundwater. There is a short reach of stream flowing through the alluvium, and we want to be sure that some minimum flow rate is maintained -- but we also want to use ground water to irrigate crops as much as possible consistent with maintaining streamflow. To begin with, we'll pretend that we can make up our rules and regulations as we go along and that there are no prior water rights.

We survey the elevation of the stream channel. This gives us the minimum water table elevation required for the stream to transmit water without loss to the aquifer. By measurement or calculation we determine the additional elevation required to maintain the minimum desired discharge and baseflow. At this point in the discussion we are ignoring the complications introduced by runoff-derived streamflow, variability, etc.; some of these points are discussed below. In this simplified example, if we know something about the historic variation in water levels, we can decide how much groundwater can be pumped on average, and we might issue permits for pumping, conditioned on the water level at the beginning of the season. These initial

rules will have to be adjustable in subsequent seasons, to take advantage of what we learn about the relationships between pumping and water level change..

Figure 2 has some examples of how this might work. Suppose that we decide that the elevation required for the desired minimum flow is about a foot above the bottom of the stream channel, and that long-term average predevelopment water level is about one foot above that -- or two feet above the channel bottom datum. So we issue permits for amounts that total up to a drawdown of one foot over the aquifer, but with the condition that the irrigators can pump their full amounts only as long as the pre-season level is a foot or more above the streamflow control level (2' above channel bottom). When the water table is at or below one foot above channel bottom there is no pumping permitted, and in the 1-2' range allocations are proportionately reduced. We might imagine that because a small fraction of a normal allocation is not much good to anybody, the users would organize a water banking system that might use either a market process, a rotating priority, or a lottery system to redistribute the reduced allocations in an equitable but useful way.

Before going on to some of the real-life complications that would need to be addressed, we can consider the basic management process. Clearly we would want to have streamflow measurements -- not only at the outflow, but also at additional locations if it is a long or complicated stream we are managing. We would also need a network or transects of wells to determine water levels -- it would be good to have dedicated piezometers installed in a pattern designed to obtain the necessary coverage while avoiding the effects of local pumping, but working wells could be used in many cases. It would be important to be able to "tune" the management system by adjusting the threshold elevation limits -- overall, or by area if necessary. And, of course, there would have to be an acceptable program of measurement, notification, and reporting.

Less simplicity, more reality

The discussion above presented the basic idea, but it made some simplifying assumptions and didn't consider the realities of Kansas water law, or of dealing with an existing problem rather than a fresh start. While the intention is not to go all of the way to a final proposal, we can take a look at some of the issues that will have to be considered in the Walnut Creek case, or in other similar situations. Some may be problems, some just complications, and a few may be advantages.

1. Seasonal flow variations: Streams don't flow uniformly the year around, and there are a wide variety of approaches to characterizing stream stages, flow duration curves, etc. Basic decisions will need to be made about acceptable rates and durations of flow, and the frequency of low-flow or dry periods that can be tolerated. In considering these questions it is good to have a specific practical goal of the management, such as the need to ensure usable delivery of the annual allocation to the Cheyenne Bottoms diversion point. With that as a target, the analysis of streamflow characteristics has a focus. An advantage of periodically adjusting the water level-pumping relationship on the basis of stream flow is that it automatically compensates for the hydrologic effects of changes in land use, climate, etc.

Although this will somewhat complicate the level-flow relationship and pumping rules compared to the simplified case discussed above, it provides a useful practical basis for defining minimum stream flow in terms of time distribution as well as amount. There may be potential for making more water available on an episodic basis if KDWP can take their allocation early in the year during a high-runoff winter or spring, or if it can voluntarily forego some of its allocation in years when a large quantity has been carried over in storage. Alternatively, if seasonal variations in water level and flow are inconveniently large, it might be possible to augment streamflow with pumped groundwater at some times.

2. Distance from stream: Where the alluvial aquifer is relatively wide, it may be possible to lower the water table below the stream channel near the valley wall as long as a suitable gradient is maintained closer to the stream. The distribution as well as the total amount of pumping can be important, and it may be possible to protect the stream flow without restricting all wells to the same absolute water level, or by moving points of diversion.

3. Differences between reaches: There will not be a single consistent rate of baseflow seepage at every point in the stream. Use, recharge, and aquifer characteristics will also not be uniformly distributed. This means that there will be no "one-size-fits-all" water elevation that can be applied as a single standard for pumping management throughout the system. Because of the local variations in geology, topography, recharge, and water use, some stretches will be net producers while others will have to be managed simply to minimize losses in transmission. This almost certainly means organization into multiple measurement and management units; to some extent the framework for this already exists in the Walnut Creek because of DWR's program of streamgauging and well measurements at additional sites.

4. Classes of water rights: Vested, senior, and junior rights must be treated differently, but uniformly within each class. That means system-level management to achieve the desired overall stream behavior, since we probably can't establish different rules for different reaches.

5. Need for refinement: As was indicated in the discussion of the simple case, there will need to be an ongoing review of the adequacy of the measurements and the appropriateness of the rules, preferably with a built-in mechanism for making reasonable adjustments on an administrative basis. Monitoring and modeling studies combined can explore the sensitivity of the system to various factors and test the possible effects of management plan refinements such as stream corridors. The important point is that a water-level management system is one that can be put in place with reasonable estimates and progressively refined based on experience. This provides a much surer approach to optimizing all of the yields than trying to calculate the whole thing correctly the first time.

Advantages and disadvantages

One of the main advantages is that this is a conceptually simple approach that addresses the problem by looking directly at the source of both the pumped water and the streamflow. It should be easier to understand and justify than the recharge-based approach. It also can be set up to deal automatically with changes or variations in climate or other factors that might invalidate the values used to design a recharge-oriented approach.

For the water users, it will essentially remove restrictions at times when there is ample water, and it should be able to make at least as much water available over the long term.

A disadvantage for the user is that he will probably have less long-range planning ability than under the existing system, and a potentially shorter lead time for making and implementing decisions. It would be possible to build some kind of year-in-advance buffer into this approach by making and annually updating short-term (2-3 year) predictions based on historic trends, but it would complicate the management scheme, would potentially result in a greater frequency of flows lower than the surface water right, and might reduce total water availability compared to the "use it when it's there" approach.

From the technical standpoint, this will require some design and development by the state regulatory and research agencies. This is not a management approach for which Kansas has a ready model or experience, so design and implementation will take some time and effort.

What's next?

The first step is to determine if there is sufficient interest in the idea to justify more detailed consideration of this conceptual preproposal. If there is, and if a two-year extension of the existing Walnut Creek IGUCA arrangement is granted, then the first year should be devoted to design and development of a prototype management system (including obtaining necessary additional data, such as elevation surveys, and basic stream-aquifer calculations using the models already developed and tested). If the product appears acceptable to all parties, then the second year could have a trial run (with no actual management implementation of the findings) to experiment with the process and see what kind of results it would deliver. The reviewed and refined system could then be considered for adoption at a hearing.

The initial assessment activity would be to review the data on streamflow, water levels, and steam-aquifer hydrogeology for adequacy, to scope the critical needs of the water right holders that would have to be met, and to draft a proposed system design for review. An important part of this would be reviewing historic flow patterns and the anticipated needs of the surface right holder so that a realistic picture of a minimum acceptable flow pattern could be developed. During or following this process, some of the existing stream-aquifer models could be used to help identify the management reaches, design the measurement strategy, and start predicting water-level/streamflow relationships under various scenarios. The KGS Geohydrology section is prepared to assist with advice and review, or to take a more active role in design and development if suitable arrangements can be made.

References

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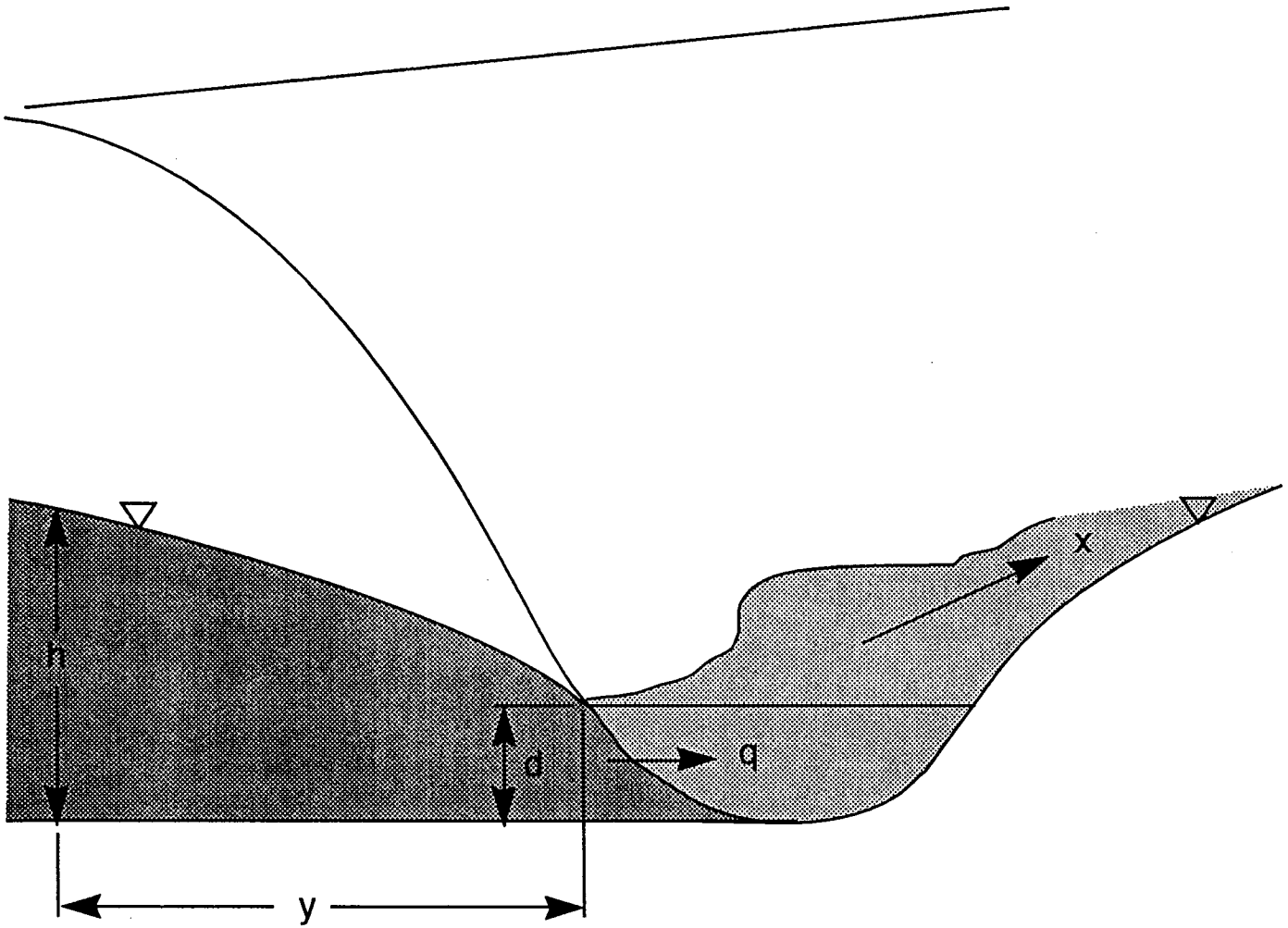

Figure 1. A sketch to show the relationship of baseflow and groundwater levels

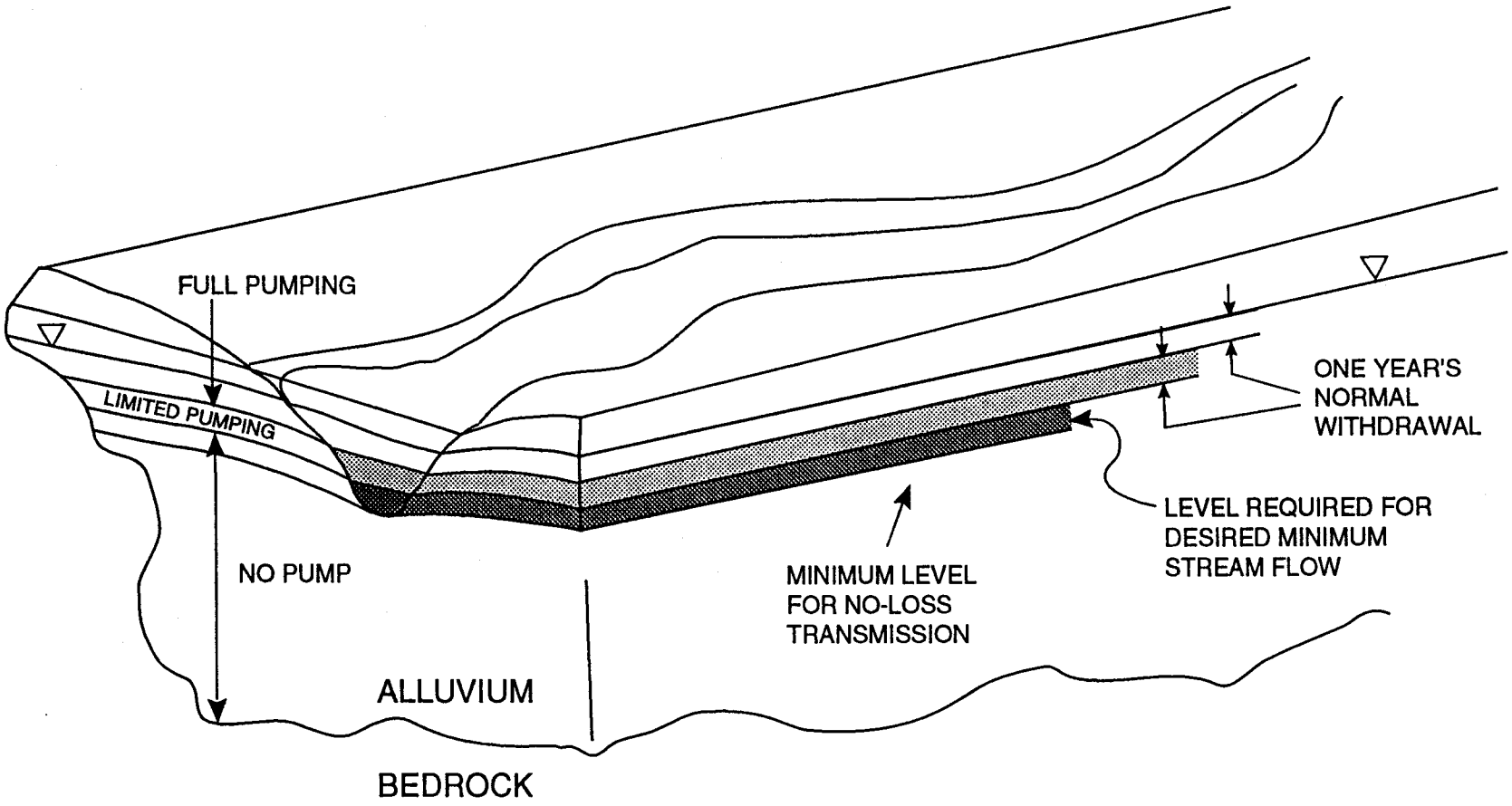

Figure 2. A simplified stream-aquifer system showing a system of pumping management to control streamflow by water level.