

Method for Assessing Affected Water User Groundwater Withdrawal Impacts on Surface Water Flow – For Review and Comment

Introduction

Wells completed in formations that possess hydraulic connection to surface water bodies have the ability to reduce the flows to or in the surface water bodies. In order to discuss how to determine if surface water flow is affected by groundwater pumping, it is useful to discuss the basics of the hydraulic connections. Figure 1 depicts a very common groundwater scenario for New Hampshire rivers and streams during the very low flow periods: the groundwater surface (the piezometric surface) slopes towards a stream. In this type of simplified system, groundwater ultimately discharges to the stream, and therefore a portion of the streamflow originates as groundwater.

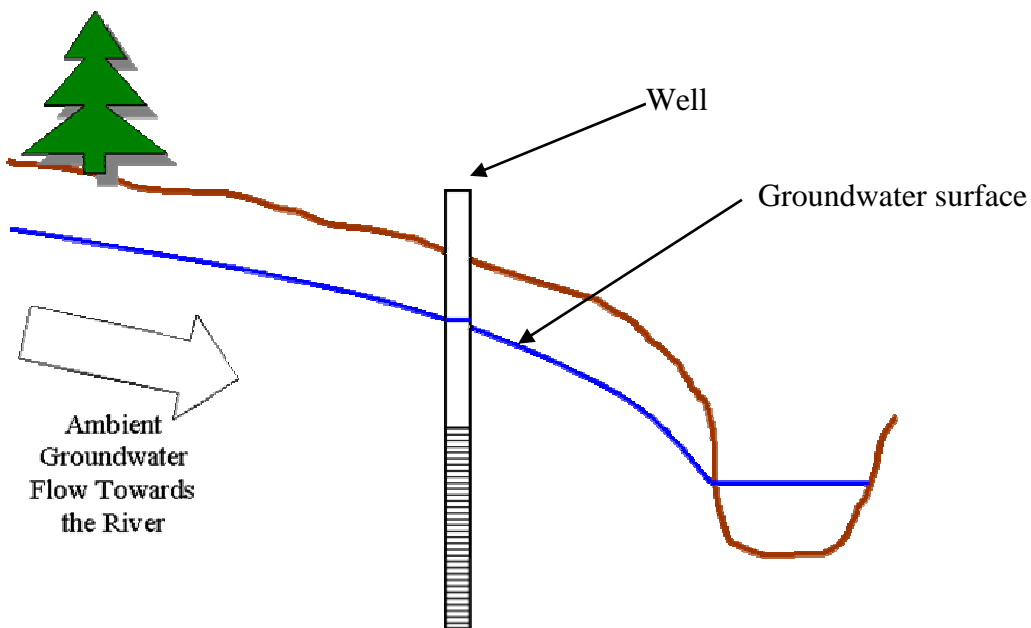


Figure 1. Non-pumping well in the groundwater flow field of a gaining stream.

In Figure 2, the well is pumped at a rate at which some of the groundwater flowing to the stream is captured, yet groundwater still flows to the stream. In this case, the well does not directly capture water from the stream (known as induced recharge), but the water pumped from the well ultimately would have reached the stream and therefore streamflow is reduced by the well pumping. When the pumping rate of the well increases, it may not only capture all of the ambient groundwater flow moving towards the stream, but it may also induce recharge (Figure 3). Clearly in both of these cases, the well has affected streamflow. Similarly, Figure 4 depicts a short-screened well to demonstrate that such wells may also affect streamflow. These scenarios set the stage for the data needs required to employ methods of assessing groundwater pumping impacts on surface water flow.

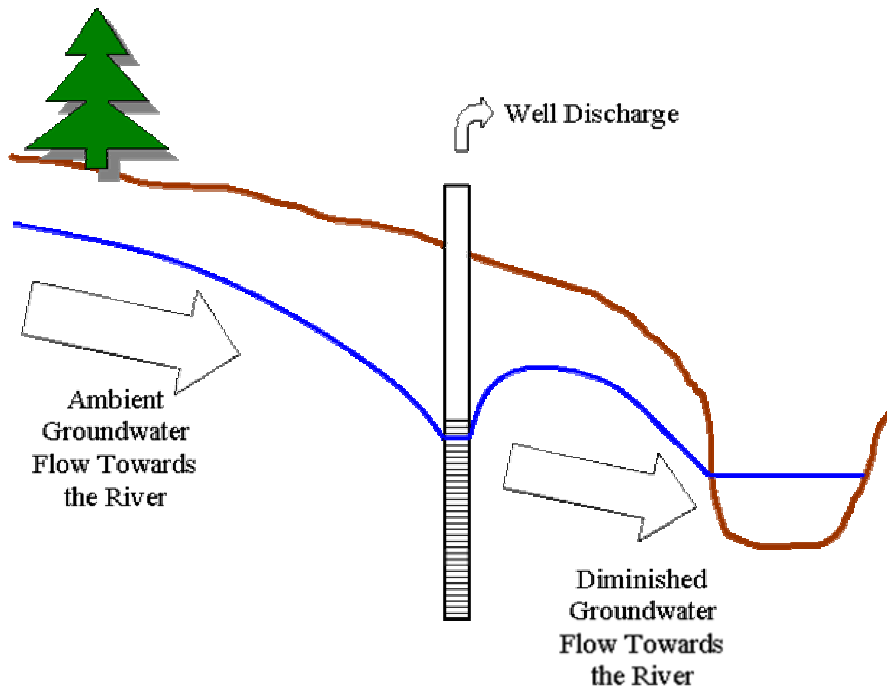


Figure 2. Pumping well in the groundwater flow field of a gaining stream.

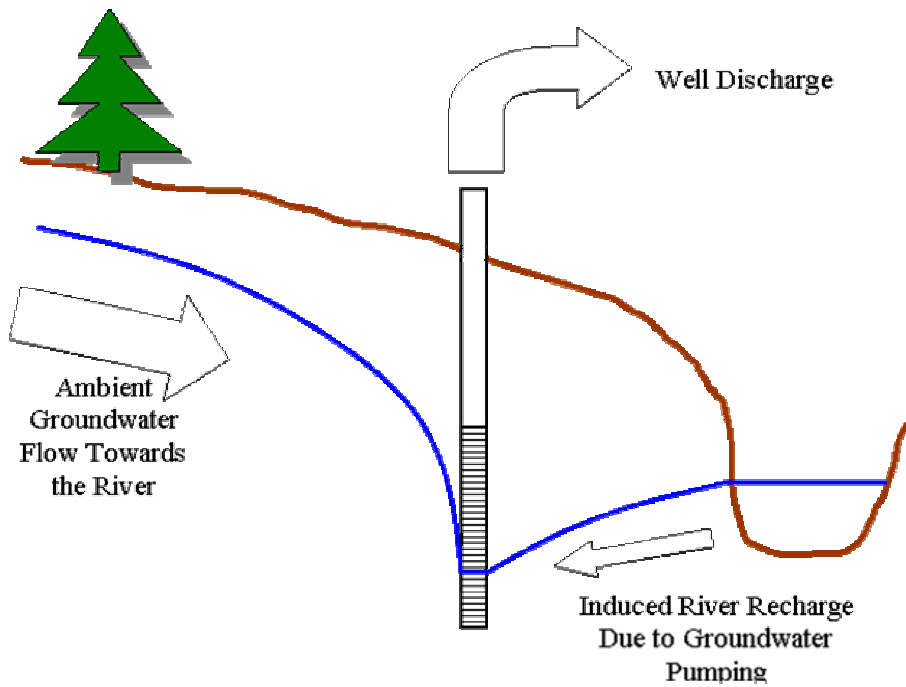


Figure 3. Pumping well in the groundwater flow field of a gaining stream that induces river recharge.

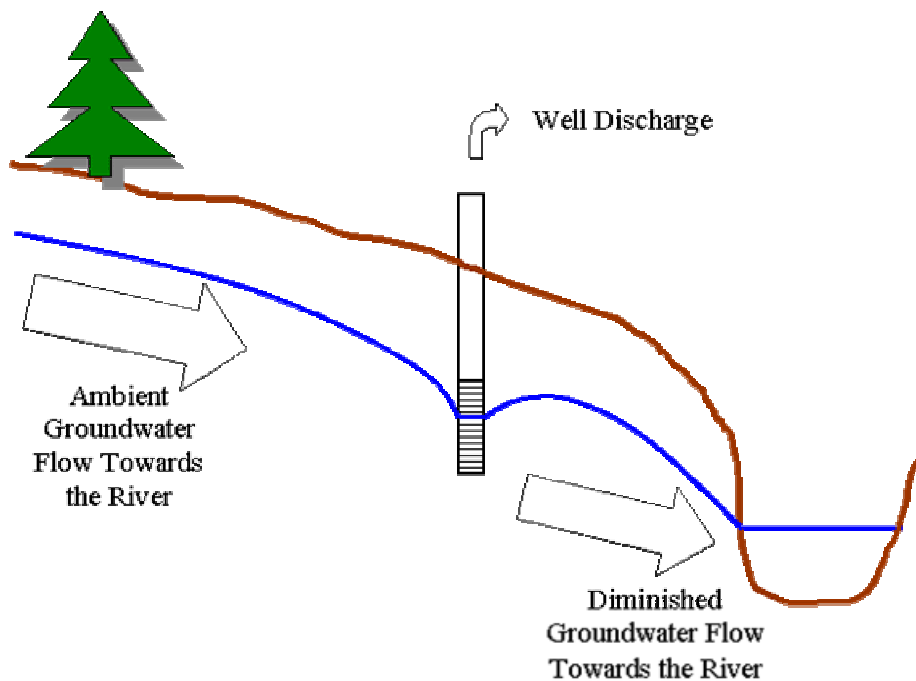


Figure 4. Pumping well, with screen located higher than the river stage, in the groundwater flow field of a gaining stream.

Data Needs

In order to determine and quantify the nature of groundwater withdrawals on the Souhegan River, first and foremost reliable data needs to be secured. Data needs categories include: the well, the formation, and the user. Although not all data is available at every well, a nearly exhaustive list of desirable data follows. Information needs concerning the well include: a well completion report/design, well depth, well diameter, screen/open interval location, casing depth, static water level, dynamic water level, pump location, type of pump and motor, distance to surface water, wellhead elevation, ground elevation, and horizontal coordinates. Formation data needs include: lithology, stratigraphy, material classification, grain size distribution, hydraulic conductivity, saturated thickness, transmissivity, specific yield, storage coefficient, pumping test drawdown data, monitoring well network, water level information (time histories), piezometric map, well head protection study, aquifer recharge study, groundwater temperature, and ground water chemistry. Finally, data needs about the user include: pumping schedule, pumping rates, return flows (septic systems, infiltration basins, etc.), and consumptive use.

Methods Considered to Assess Groundwater Withdrawal Impacts on Surface Water Flow

The categories of methods to estimate the amount of surface water entering groundwater wells are divided into the following four categories: physical barrier, analytical model,

numerical model, and field measurement. In each category there are various methods, and these methods will be described in the next sections.

Physical Barrier

As delineated in Env-Ws 1903.04 - Procedure for Determining No Hydraulic Connection, there are various physical constraints that would indicate that groundwater wells are not removing surface water when the wells are pumped. Such physical barriers include:

- the formation in which the well is completed is physically not connected to the surface water body, and
- the riverbed is sealed with impermeable materials.

Without a physical hydraulic connection, the well cannot be tapping surface water or water destined to be discharged at surface waters (there is the possibility that groundwater could discharge as a spring which then flows overland to the surface water in question, and this case needs to be addressed by inspecting surface water hydrography and geologic maps).

Analytical Model

There are a variety of mathematical equations that describe the fraction of surface water pumped by groundwater wells when the formation containing the well and surface water body has a hydraulic connection. These equations go back to the 1940's when some of the great names in groundwater hydraulics attacked the issue (Theis, Jacobs, Glover, and Hantush). The most recent and simplest to understand of the methods was presented by Jenkins (1968). The advantage of simplicity in the analytical models can be lost due to the many simplifications used to obtain the equations. The most important of these assumptions is that before pumping starts, the groundwater table (piezometric surface) is flat. Figures 1 through 4 depict the more realistic sloping water table of natural systems. Why this one assumption is so important is because their solutions yield the fact that once pumping starts, as time increases and the system achieves steady state (drawdown stabilizes in the pumping well and at all locations in the aquifer), all water pumped from the well is derived from the stream. Figures 2 and 4 clearly show that this is not the case when there is a slope to the water table. Therefore in using these analytical methods, one would obtain an upper bound on the amount of surface water flow pumped by the well (induced recharge).

Both the rules (Env-Ws 1900) and the RFP seem to be concerned at delineating the amount of induced recharge from the Souhegan River (Figure 3) rather than the totality of intercepted flow ((figures 2 and 4) plus induced recharge. In the RFP, this was termed, "effective surface water withdrawal due to wells". Therefore as a first pass, a relatively simple question to ask and answer is whether a pumped well will create induced stream recharge. To do this, basic groundwater hydraulics theory is used to identify if the steady state cone of depression reaches the river sufficiently to induce recharge. Figure 5 displays the system of Figure 2, and in addition identifies a point known as the stagnation point. The stagnation point is a divide whereby water on one side flows to the well and the other side flow to the stream. As the well pumping rate increases, the stagnation point moves towards the river. When the stagnation point reaches the river, the system is at incipient induced recharge: any increase in pumping will induce recharge. A coarse estimate (and an overestimate at that) of the amount of induced recharge would be the difference in the actual well pumping rate minus the pumping rate when the stagnation point just reaches the stream. If the difference is zero or negative, there is no

induced recharge. If the difference is positive, that is a conservative estimate of the induced recharge. This is a conservative estimate because by increasing the well discharge over that discharge when the stagnation point just reaches the stream, the cone of depression increases. The increased pumping rate is derived not only from induced recharge, but the well is also capturing more groundwater flowing from upgradient locations.

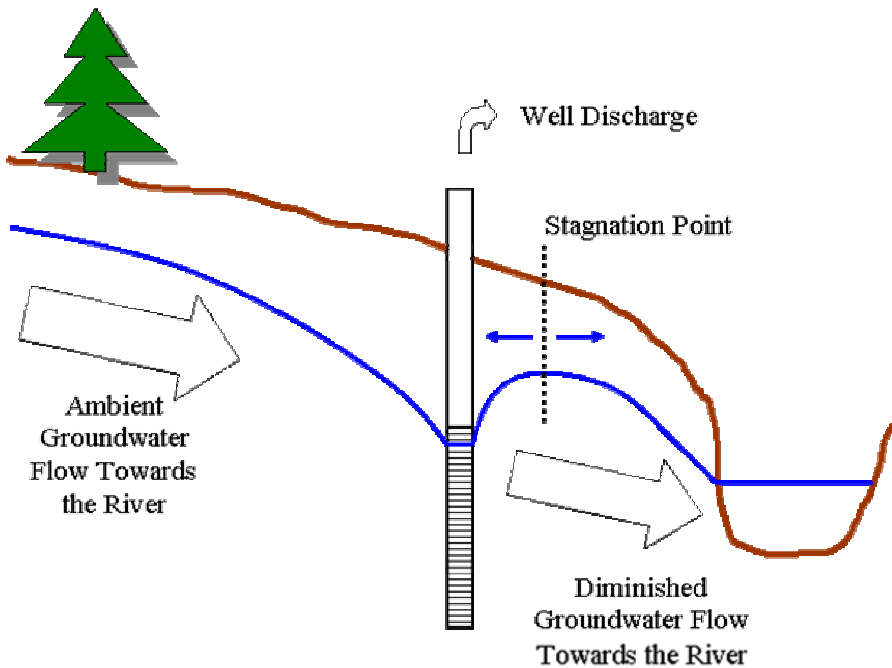


Figure 5. Pumping well in the groundwater flow field of a gaining stream and location of the stagnation point.

The hydraulic theory behind the stagnation point location for a well in a uniform groundwater flow field can be found in most introductory groundwater textbooks (for example, McWhorter and Sunada, 1977) as well as numerical codes (WHPA). The distance (in feet) from the well to the stagnation point (x_s) is:

$$x_s = \frac{Q}{2\pi Ti} \quad \text{Eq. 1}$$

where: Q = well pumping rate (cubic feet per day), T = aquifer transmissivity (feet per day) and i = the slope to the groundwater table (dimensionless). Equation 1 can be used to compute x_s or by knowing the distance between the well and the stream and setting this equal to x_s , it can be used to determine the flow at which the stagnation point just reaches the stream.

Numerical Model

At this writing there are a substantial number of numerical groundwater codes that can be employed to quantify induced recharge. Popular models include: MODFLOW, FLOWPATH, WHPA, WhAEM, and GMS. Some of these models are public domain and others must be purchased through vendors. The advantage of the numerical models to more accurately

determine the induced flow is lost by the significant degree of model input requirements as well as for trained personnel to calibrate, validate, verify, and use the model. The data requirements for numerical models are non-trivial: not only are aquifer geometries and hydraulic characteristics needed, but also boundary conditions, initial conditions, and calibration data. Not uncommonly, induced recharge is a calibration parameter for numerical models rather than the variable computed by the models.

Numerical groundwater modeling can also be coded into spreadsheet software. However these user developed codes have no less input and user requirements than the more widely-available models.

Field Measurements

To measure induced recharge with field observations, very often the induced flow itself is not measured, but inferred or computed from other observation variables. The two most commonly measured variables for assessing induced recharge are groundwater levels and dissolved chemical species. In the case of groundwater levels, monitoring wells or piezometers between the stream and the pumping well can delineate the groundwater table (as depicted in Figures 1 through 5). These water levels can then be interpreted to yield the groundwater slope (the gradient). Coupling the gradient, the hydraulic conductivity, and an areal extent then yields the induced recharge. It is incumbent that sufficient wells exist to determine: the existence of a stagnation point, the areal extent of induced recharge, and the gradient between pumping well and stream. The monitoring requirements can be inexpensive if miniature piezometers or wells are used at the streambed. Well installation can occur manually, data taken as frequently as desired, and the wells can be easily removed if so desired. More permanent well installations can be used if induced recharge needs to be monitored more carefully of the long term.

When using chemical parameters to identify and quantify induced recharge, samples are required of: groundwater upgradient of the pumping well, the pumped water, and the stream. By knowing the total flow from the well and the three identified water concentrations, two mass balance equations (one for flow and one for concentration) are employed to solve for the two unknowns: groundwater pumped and the pumped induced recharge. For these types of studies, conservative markers are best (markers that do not change to due biogeochemical processes or reactions such as sorption, biodegradation, dissolution, etc.). Common markers for these methods are halides (Chloride, Bromide, etc.) anions (nitrate, etc.) or introduced dyes (Rhodamine, etc.). Other exotic markers can be used (environmental isotopes, chlorofluorocarbons, etc.) however the analytical expenses increase dramatically, plus these markers may be much more variable than a simple snapshot sampling event may reveal.

Another technique for estimating induced recharge is to measure streamflows upstream and downstream of the well pumping effects. The difference between upstream and downstream flows is then assumed to be the induced recharge. Major complications with this method are the accuracy of the streamgaging method, the fraction of induced recharge compared to streamflow, and the fact that infiltration or exfiltration can be occurring on the opposite side of the river from the well.

Recommended Method to Assess Groundwater Withdrawal Impacts on Surface Water Flow

In lieu of site specific studies of induced recharge at the AWU groundwater wells defined in the RFP, a tiered approach is recommended based upon the data available for each site. This approach employs both analytical and field measurement techniques. The first step in the entire approach is data collection. Each AWU will be contacted and visited. They will be asked about relevant and pertinent reports and data for their wells. In addition, published reports and data, as well as file information, will be requested from: NH DES, USGS UNH, consulting firms, US EPA, towns, planning commissions, etc. Based upon this data, the following methods are recommended.

1. Existing Study

If an existing study was performed that estimated induced recharge, the study will be reviewed, critiqued, and the conclusions accepted or modified. Modifications may be required due to any of the following factors: changes in conditions since the report was written (for example pumping rate), or newer data that necessitate changes to the original report methods (for example aquifer hydraulic characteristics). As a check of the estimating capabilities of the following two methods and if the data exists, the induced recharge from this first method will be compared to estimates of induced recharge from the next two presented methods.

2. Analytical Estimation

If there is sufficient data, Equation 1 will be used to identify if induced recharge occurs. If it does, then Equation 1 will also be used to estimate the amount of induced recharge by using the method outlined in the Analytical Model section. The USGS stratified drift aquifer studies possess a substantial amount of data to employ this method for many of the wells of interest in the Souhegan study.

3. Field Measurements - Office

If data exists (water level or chemistry), the techniques outlined in the Field Measurements section will be employed to compute induced recharge. In the case of water levels, flow from the river to the well will be computed using a direct application of Darcy's Law: transmissivity/hydraulic conductivity from reports, width of flowpath from the water level information, and gradient from the water level information. In the case of chemical markers, the two mass balance equations (water flow and chemical) will be used to compute the induced recharge: chemistry from reports, well pumping from AWU records.

4. Field Measurements – Miniature Piezometers.

If there is insufficient data to make an estimate of induced recharge by any of the three previous methods, at selected sites miniature piezometers will be installed at the Souhegan River bed closest to the wells in order to obtain data to perform a water level field measurement estimate of induced recharge. This estimate can be greatly aided if the well owners agree to turn off then turn on their wells while the miniature piezometers are in place. Sites will be selected by prioritizing all the wells that fit in this class (inability to use the other three methods) and installing the miniature piezometers at sites from the highest priority and moving down the list. Only two or three sites were originally planned to be studied this way. Prioritization variables

include: well production rate, distance to the Souhegan River, well screen depth, capability to install the miniature piezometers, and access.

References

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