USGS science for a changing world

U.S. Environmental Protection Agency

Time of Travel as a New Criterion for Groundwater Sampling: Demonstrations of the Purge Analyzer Tool (PAT)

INTRODUCTION

Active pumping of monitoring wells prior to sampling requires purging to evacuate the water column and collect recent formation water. A general guideline, and an often-cited industry criterion is the evacuation of three-well-water volumes (often called volumetric sampling). Coincident with volumetric evacuation is the additional criterion that common measured field physiochemical (water-quality) parameters exhibit stability. Stabilization of water-quality parameters is also a criterion for low flow sampling. However, what is not considered in either volumetric or low flow groundwater sampling is the time of travel for water to flow from various open intervals of the well to the pump intake. This process is governed by well construction, well hydraulics, bulk hydraulic properties, pumping rate and intake position, and the degree of formation heterogeneity.

CONCEPTS

Unless the pump intake is placed adjacent to the highest permeability unit intersected by the well opening, vertical flow in the well will occur during pumping. Placing the pump inside the well casing ensures vertical flow in the well. Therefore, the vertical time of travel of groundwater from inflowing units to the pump intake is an important consideration in sampling and achieving chemical stability.

Vertical flow is dominant during many pumping conditions

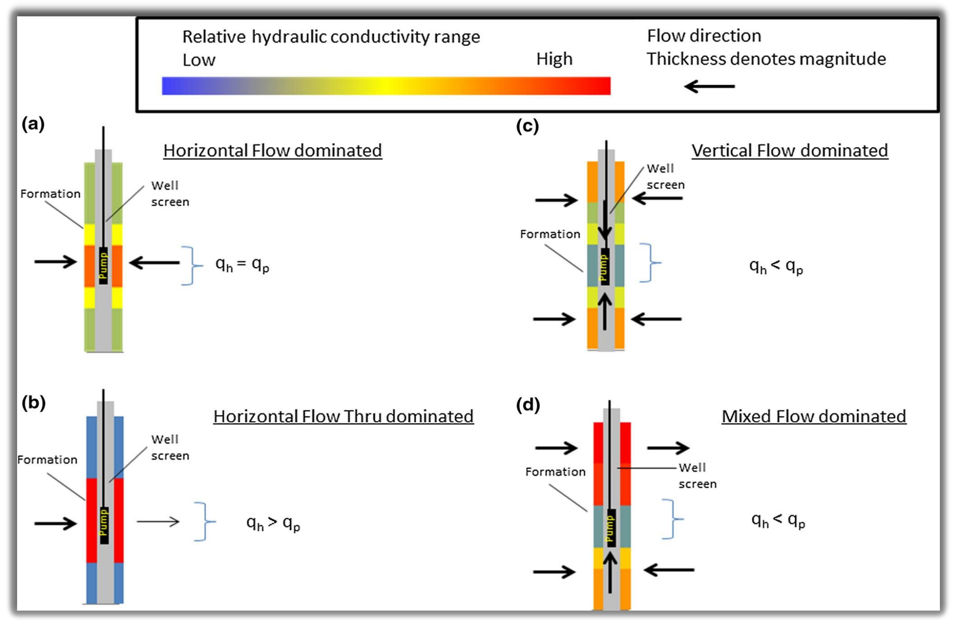


Figure 1 (above). Conceptualized groundwater flow in the well screen during lower rates of groundwater pumping (pump rate qp can be satisfied from a horizontal hydraulic conductivity equivalent to the symbol ; qh = horizontal flow rate near pump; gray denotes well screen). In many cases, inflow into the well screen will be induced along the entire well screen promoting converging flow toward the pump. Therefore, time-varying water chemistry is dependent on integration of vertical chemistry.

OPERATION

A Visual Basic for Applications (VBA) analytical model has been developed, called the Purge Analyzer Tool (PAT), that computes in-well time of travel. The PAT provides insight into optimal purging parameters (time, rate, and pump position) needed for the collection of representative groundwater samples. The PAT can be used to predict (forward mode) purge times required to flush existing well water. The PAT can also be used to analyze existing monitoring purge records (reverse mode) on well purging and physiochemical stability to assess the role of well hydraulics on water chemistry.

The PAT employs a water budget approach to solve for the Dupuit-Thiem equation. It then solves for time of travel from outside the pump intake zone (called mixing zone) assuming piston flow.

OPERATION-CONT

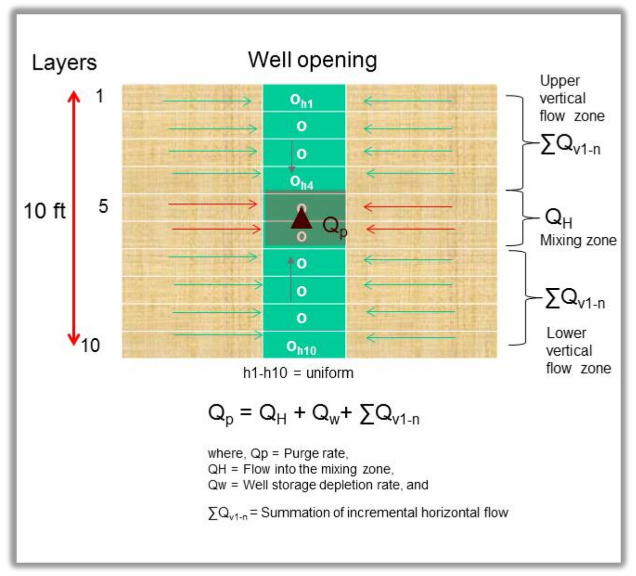


Figure 2 (left). Layering specified for the PAT simulation of in-well flow. The layering is used to divide inflow into the well and also used to compute vertical flow and time of travel to the pump. The water budget equation is also shown that is used in the PAT.

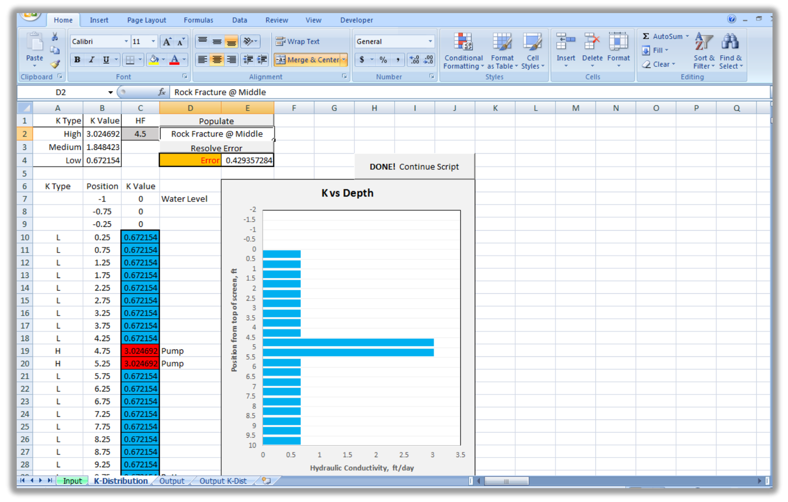


Figure 3 (right). Heterogeneity sheet of the PAT that allows for specification of layered hydraulic conductivity. In this example, the pump was set adjacent to a middle high hydraulic conductivity layer (middle fracture). Users can select different heterogeneity patterns from a drop-down menu.

PRE-SAMPLING TOOL

The PAT produces aquifer fraction graphs that illustrate the amount of inflowing groundwater captured during pumping. Time of travel is less sensitive to the amount of casing water than volumetric calculations once drawdowns are stabilized.

High Water Level-Large Amount of Casing Water

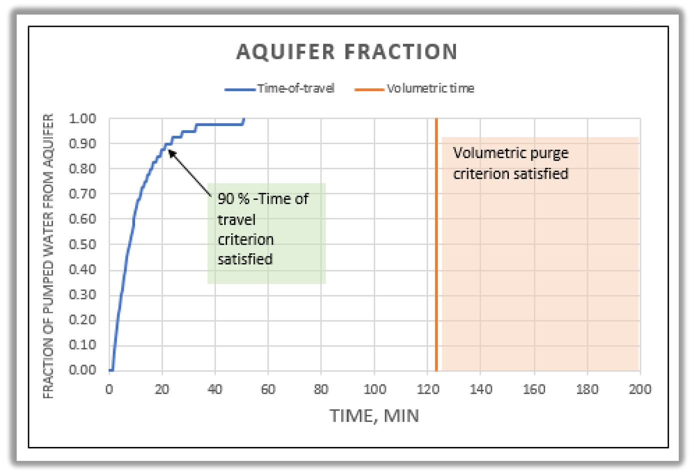
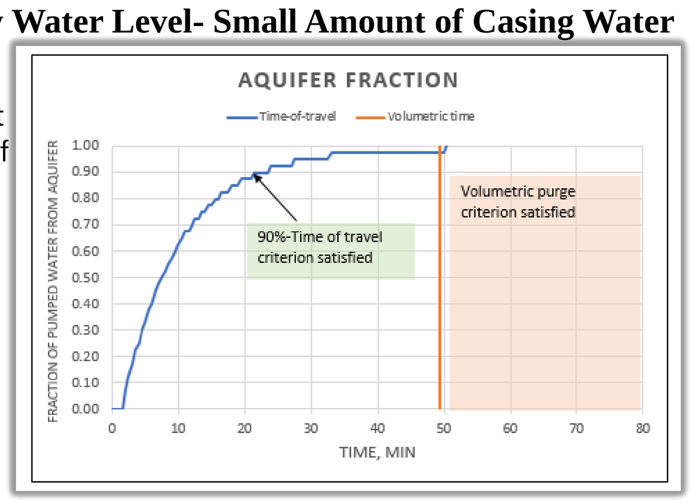
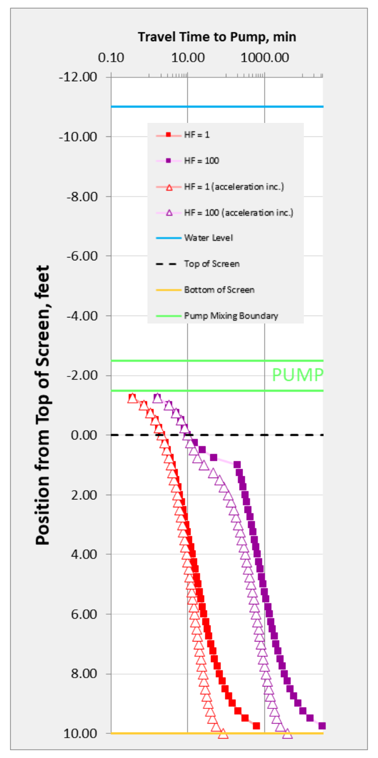


Figure 4. Aquifer fraction graphs that illustrate the ratio of pumped water captured from inflowing groundwater and existing well water for large (left), and small (right) amounts of casing water.

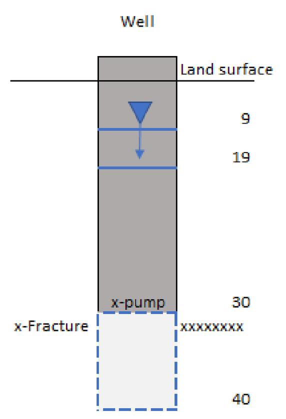
Low Water Level- Small Amount of Casing Water



A primary control on in-well time of travel is the relative distance between the pump intake and high hydraulic conductivity units of the aquifer. Time of travel from inflowing groundwater along a fracture to the pump is appreciably different if the fracture is located closer to the pump. Knowledge of this prior to sampling allows for determination of when water chemistry is likely to achieve stabilization and if adequate purging has been achieved.



Fracture at Top of Well Opening



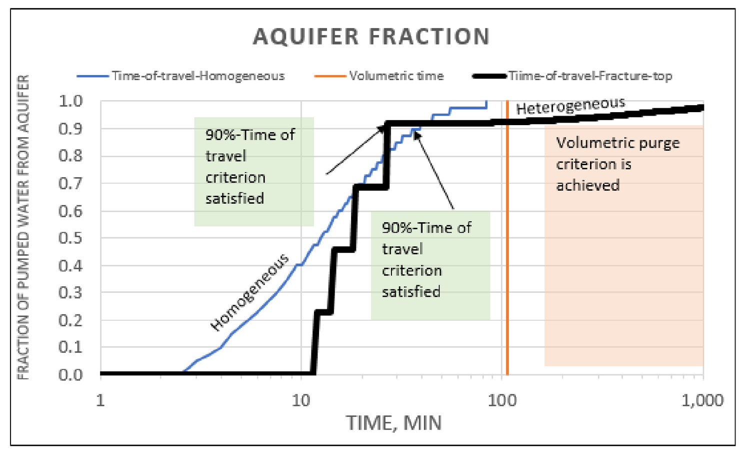
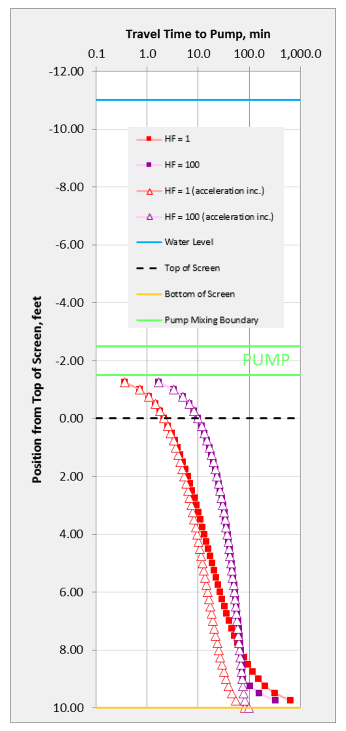


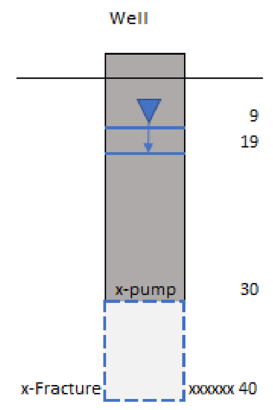
Figure 5. Time of travel in the well opening to the pump zone (left), schematic of pump and fracture location (upper middle), and aquifer fraction graph that illustrates ratio of pumped water captured from inflowing groundwater and existing well water (upper right). [Note elongated tail for heterogeneous line]

Reference
Harte, P.T., 2017, In-well time-of-travel approach to evaluate of monitoring wells: Environ. Earth Sci. (76)251. DOI 10.1007/s12665-017-6561-5

PRE-SAMPLING TOOL-CONT



Fracture at Bottom of Well Opening



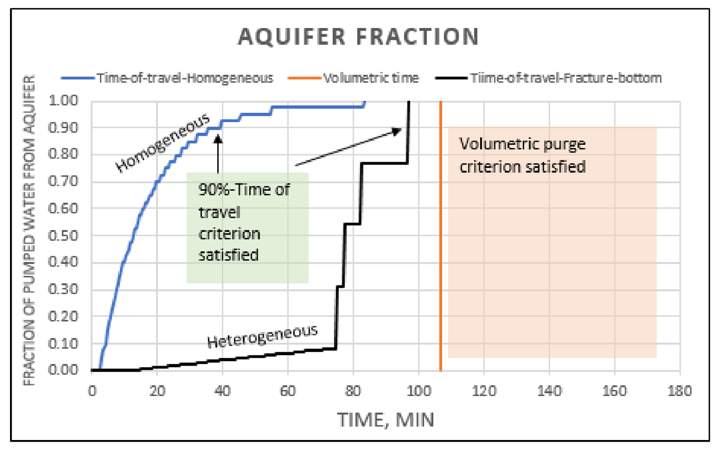
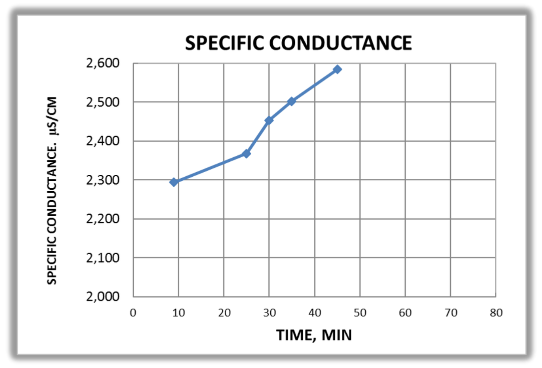


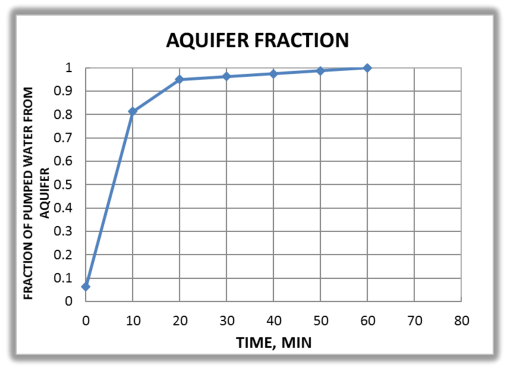
Figure 6. Time of travel in the well opening to the pump zone (left), schematic of pump and fracture location (upper middle), and aquifer fraction graph that illustrates ratio of pumped water captured from inflowing groundwater and existing well water (upper right). [Note rapid rise in groundwater captured for heterogeneous line]

POST-SAMPLING TOOL

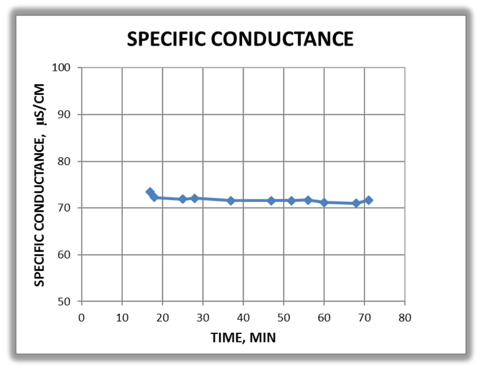
From data collected during purging and sampling, the PAT can be used to help determine the

- Bulk hydraulic conductivity of the aquifer
- Potential degree of heterogeneity
- Mixing
- Amount of pre-existing well water captured





Water chemistry analysis of groundwater from an alluvium well in New Mexico (left) indicated a mixed water type and field values of specific conductance showed instability during pumping. Predicted time of travel for this well indicated a likely heterogeneous inflow distribution with the potential of upward flow from the lowermost units of the well. In contrast, water chemistry from an Atlantic Coastal Plain well in North Carolina (right) indicated less mixing and field values of specific conductance showed rapid stability. Predicted time of travel for this well is rapid (< 10 mins).



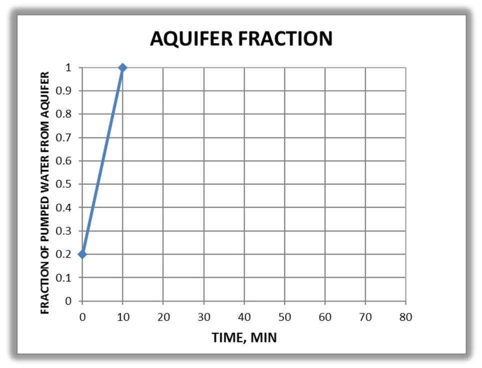


Figure 7. Field values of specific conductance collected during purging (upper graph) and predicted time of travel for heterogeneous conditions (lower graph), for a well in New Mexico.

Figure 8. Field values of specific conductance collected during purging (upper graph) and predicted time of travel for homogeneous conditions (lower graph), for a well in North Carolina.

CONCLUSIONS

Simulations of purge records show that the stability of field parameters can be tied to the rate of vertical in-well transport. This indicates that in-well vertical transport is a dominant process to consider when pumping wells for sampling. Calculations indicate that lateral transport or extent of interrogation into the formation from pumping are relatively small for many wells. Because of these small lateral transport dimensions, it's likely that vertical variability in water chemistry exceeds horizontal variability. Further, the position of the pump intake relative to the more permeable layers is particularly important for capture times and rate of vertical in-well transport.

Acknowledgements
This work was conducted in cooperation with the U.S. Environmental Protection Agency's Office of Superfund Remediation and Technology Innovation initiative on characterization of Fractured Rock under Interagency Agreement DW-014-92406101 with the U.S. Geological Survey. The authors would like to thank Edward Gilbert of EPA for his oversight on this initiative.

Philip T. Harte[1], Bradley Huffman[2], Herb Levine[3], Tomas Perina[4], and Daewon Rojas-Mickelson[3]

[1] U.S. Geological Survey, New England Water Science Center, ptharte@usgs.gov
[2] U.S. Geological Survey, South Atlantic Water Science Center
[3] U.S. Environmental Protection Agency, Region 9
[4] APTIM