A Tracer Technique For Measuring Regional Groundwater Velocities from a Single Borehole

Summary of Principal Findings

Peter L. Monkmeyer†
Robert H. B. Netzer‡

A cost-efficient determination of the prevailing regional groundwater velocity is a vital element of many groundwater projects. For example, problems involving contaminant transport and remediation, groundwater resource evaluation, groundwater recharge and storage planning, interpretation of groundwater monitoring data, and design of dewatering and collection systems, are only a few examples. The regional flow velocity is one of the principle background factors that a hydrogeologist or groundwater engineer must evaluate when solving these problems. To ignore it would be like ignoring the flow velocity of a river when designing a dam or bridge. The focus of this study is on a method for measuring regional velocity that uses only a single borehole. Our goals were to correct inherent errors in an existing single-borehole method, and to expand the usefulness of this method to more complex cases. Our principal results to date are a procedure for analyzing the data obtained from such a method to compute the regional velocity. Given the simplicity and low cost of the single borehole tracer test as a field tool, it is expected that our corrected method of data analysis will replace the erroneous method presently available. Future work, not yet completed, includes increasing the accuracy of this method by relaxing some of the assumptions, which are sometimes unrealistic, that are made in the theoretical analysis, and then expanding its applicability to a wider range of field conditions.

---

† Dept. of Civil and Environmental Engineering, University of Wisconsin–Madison, 1415 Johnson Dr., Madison, WI 53706.

‡ Computer Sciences Dept., University of Wisconsin–Madison, 1210 W. Dayton St., Madison, WI 53706.

The primary objective of this research is to develop a valid method for determining regional groundwater flow velocities by applying a technique that requires only a single borehole. The method relies on data obtained when a tracer (such as a dye) is released from the borehole, is allowed to drift with the regional flow velocity, and is retrieved by means of a pump operating in the same borehole. The use of a single well is attractive since the cost of setup and operation is incurred for only a single well. Other methods which use multiple wells operate by releasing the tracer at one well and either sampling or pumping at another. These methods require the construction of two boreholes, and also an independent method of estimating the direction of flow. The additional wells required for these methods add to their cost. Consequently, a single-well method is preferable, especially when only one such well or borehole is available.

Although the single-borehole method was originally proposed over two decades ago, early approaches were applicable only to certain field conditions, such as low-velocity flow. These approaches were based on a theoretical analysis that assumed the regional velocity had little impact when the tracer was retrieved by pumping. A more recent approach attempted to account for higher-velocity flows. However, this method was found by us to be erroneous. We have therefore developed a new and correct equation with which one can calculate the regional groundwater flow velocity. The equation is

$$t_a - t_p = \frac{Q}{2\pi b n v^2} \ln\left(\frac{Q}{Q - 2\pi b n v^2 (t_p - t_i)}\right) - (t_p - t_i)\,,$$

where the data obtained in the field is

Q = constant pumping rate (in *cfs*)

t_i = time at which tracer is injected into the well (s)

t_p = time at which pumping begins (s)

t_a = time at which tracer arrives back at the well (s)

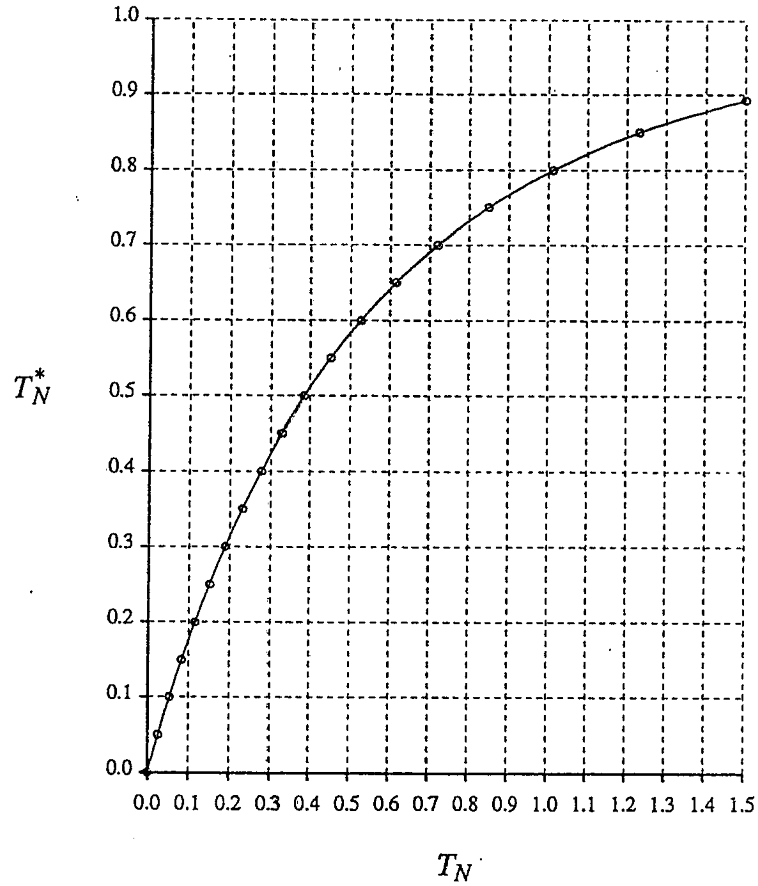
n = effective porosity (–)

b = aquifer thickness (ft)

and the variable to be evaluated is

v = regional groundwater flow velocity (ft/s)

This equation does not appear to have an explicit closed-form solution for v. However, with the aid of a graphical representation of the formula in the form of a universal curve (shown below), it is possible to make the calculation.



In order to use this graph one simply uses the field data, i.e., the first three variables described above, to calculate

$$T_N = \frac{t_a - t_p}{t_p - t_i} .$$

Then one enters the graph to find

$$T_N^* = \frac{2\pi bnv^2(t_p - t_i)}{Q} .$$

And finally one evaluates v, the regional flow velocity, with the aid of the remaining field variables:

$$v = \left(\frac{QT_N^*}{2\pi bn(t_p - t_i)}\right)^{1/2}.$$

Additional objectives of this research are to broaden the usefulness of the existing method beyond the simple case to which it presently applies. These extensions include accounting for different aquifer and well configurations and accounting for the effect of pump startup.