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USE OF ELECTRICAL RESISTIVITY PROBE FOR DETERMINATION OF HYPORHEIC FLOW

Barton R. Faulkner, Victor A. Murray, Sam R. Hobson*

ABSTRACT: The hyporheic zone can play a significant role in nutrient behavior in watersheds. Conceptual models describe the behavior of nutrients and biota for the hyporheic ecotone, but site characterization is needed to quantify effects at the restoration reach scale (hundreds of meters). Hyporheic characterization includes quantifying the residence time distribution as well as the physical extent of the hyporheic zone within the fluvial system. Traditional methods rely on installing piezometer arrays, with data acquisition systems, at considerable time and expense. We developed and tested an inexpensive electrical resistivity probe for more rapid determination of parafluvial hyporheic flow. We tested the probe in a 125 m alluvial corridor of Big Sandy Creek, Tishomingo National Wildlife Refuge, Oklahoma (flow rate 359 L s^{-1}). A standard survey total station was used for real--time determination of capillary fringe elevation and areal location. Results were imported to a geographic information system and compared to a test area where a piezometer array was installed, surveyed, and synoptic water levels were taken. The error (due to the capillary fringe) ranged from 0 to 5 cm in coarse sandy regions (K=0.008 m s^{-1}), and up to 10 cm in regions containing sand mixed with organic material. The Modular Three-Dimensional Finite-Difference Model (MODFLOW) was calibrated using the probe data. The particle tracking code MODPATH was used to generate single--layer flow nets for the fluvial corridor. The results indicated hyporheic residence times ranging from 0 to 7 days, and flow paths up to 35 m in length within the 40-50 m wide fluvial corridor. These results show that for sandy alluvial streams, the electrical resistivity probe can be used for screening level determination of parafluvial hyporheic flow at scales important for stream restoration.
KEY TERMS: hyporheic zone, modflow, parafluvial

INTRODUCTION

Nutrient retention in watersheds can be strongly influenced by hyporheic exchange (mixing of stream water with adjacent ground water) along the stream corridor (e.g., Dahm et al., 1998; Carlyle and Hill 2001). Given basic knowledge of the geochemistry of the stream-hyporheic system, restoration projects can include manipulations to alter the hydraulic connection between the streams and adjacent ground water. Therefore cost-effective methods to characterize the degree of hyporheic exchange at the restoration reach scale are desirable for project planning. Tracer injection methods can provide lumped estimates of hyporheic residence time, but do not identify specific locations where the exchange is taking place. Piezometer arrays are costly to implement at the scale of interest to restoration planners, and are vulnerable to damage by floods. The purpose of this paper is to describe a rapid and inexpensive approach to screening level mapping of hyporheic flow using a hand-held electrical resistivity probe with a survey total station.

METHODS

Study Site

The Big Sandy Creek corridor, Tishomingo National Wildlife Refuge, Oklahoma, consists of an entrenched meander belt in sand and gravel. It exhibits riffle-pool morphology. The meander belt is approximately 40-50 m wide, bounded by silt and clay-rich deposits of the floodplain, and the study reach presented here is about 125 m in length. At the time of the current study the flow rate was 359 L s^{-1}. The slope of the water surface of the stream was found by survey to be nearly constant in the study reach and was about 0.0024.

* Respectively, Hydrologist, U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, 919 Kerr Research Dr., Ada, OK 74820, Sr. GIS Analyst\Surveyor- CSMoS, EPA Contractor- Shaw E&I, 919 Kerr Research Dr., Ada, OK 74820, Student, Physics Dept., East Central University, Ada, OK 74820, Phone: (580) 436-8530, Fax: (580) 436-8703, E-Mail: faulkner.bart@epa.gov.

Hyporheic Zone Survey

An electrical resistivity probe was constructed from a one-meter section of three-quarter inch schedule 80 PVC. It was fitted with two 18 gauge copper wires threaded so that they were exposed on either side of the bottom of the PVC pipe for about two cm. The pipe was filled up to about 15 cm from the bottom with epoxy resin, and plugged with a solid point, tooled on a lathe. The two wires were fed out the sides near the top of the probe to a standard digital ohmmeter with a range of about 200 Ω to 2 MΩ. The probe was capped so it could be tapped into the ground with a hammer. Twenty-eight piezometers were constructed from the same PVC material.

After setting up an automatic survey total station, the stream corridor was mapped by walking along transects of about 1.5 m in width. At about every 1.5 m, the probe was tapped into the alluvium while the resistance was monitored. When the resistance dropped by about three orders of magnitude, tapping was stopped and the top of the probe was surveyed, along with the ground surface elevation at the point of insertion. The survey was completed after 214 points were surveyed in this way, and 150 additional points were obtained, representing the areal perimeter of the stream. Approximately 400 additional survey points were obtained to represent the ground surface elevation and stream bathymetry. The survey took about 8 hours to complete.

Following the survey, the piezometers were installed in an approximately 3 m grid near the center of the surveyed area, and allowed to equilibrate. Water levels were recorded and the piezometer locations and elevations were surveyed with the total station. Standard pumping tests were conducted to estimate the hydraulic conductivity of the stream channel material using the Thiem-Dupuit method (Kruseman and de Ridder, 1990).

Post-Processing of Data

Results of the surveys were uploaded to a database and imported into a geographic information system. The water level surfaces obtained by each method were constructed by ordinary kriging.

In addition to developing the kriged surfaces, a single-layer MODFLOW (Harbaugh and McDonald, 1996) model was developed to determine parafluvial hyporheic flow. The model was discretized onto a one-meter grid. The bottom of the permeable channel material was everywhere assumed to be three meters below ground surface. Recharge was computed via the parameter estimation package (PEST) for MODFLOW (Doherty, 2000). Porosity was assumed to be 0.5. Horizontal anisotropy was assumed to be two. MODFLOW’s River Package was used on each edge of the stream (so central cells should be flooded), and perfect hydraulic connection was assumed between the stream and the porous medium. Figure 1 shows the model discretization and boundary conditions used. Calibration was accomplished using PEST tools for MODFLOW with surveyed water levels for the probe points as input. The particle tracking code MODPATH (Pollock, 1994) was used to generate a flow net for the site.

RESULTS AND DISCUSSION

Comparison of the kriged piezometric surfaces obtained by the probe with those obtained by the piezometers showed error ranging from 0 to 5 cm in the sandy alluvium, and up to 10 cm in a point bar region where seasonal vegetation was periodically buried. From the pumping tests, hydraulic conductivity was found to be about 0.008 m s^{-1}. PEST computed a recharge value of 3.69×10^{-6} m s^{-1}. Calibration results yielded a mean error between measured and simulated heads of –0.012 m, a mean absolute error of +0.106 m, and a root mean squared error of +0.145 m. The largest errors were seen in probe measurements taken very close to the river boundary. Results from MODPATH showed hyporheic residence times ranging from zero to about 7 days (Figure 1, right). A linear regression of observed heads on simulated heads showed all but 10 of the 214 probe observations were inside the 95% confidence limits (Figure 2).

CONCLUSION

Since the hyporheic zone can play in important role in nutrient dynamics and ecological function, restoration efforts should consider the basic geochemistry of the stream system to be managed, and characterize the locations where hyporheic exchange is occurring. Traditional methods for doing this are time consuming and expensive. This study used a simple electrical resistivity probe with a survey total station to obtain a rapid, screening level mapping of hyporheic exchange for a stream reach of about 125 m length. Error incurred from using this method, as compared to traditional piezometry, ranged from 0 to 5 cm in the alluvium, and up to 10 cm in soils containing buried vegetation. Results of using MODFLOW calibrated with the probe observations and MODPATH revealed a map of hyporheic exchange that can be useful, at the screening level, to guide restoration planning.

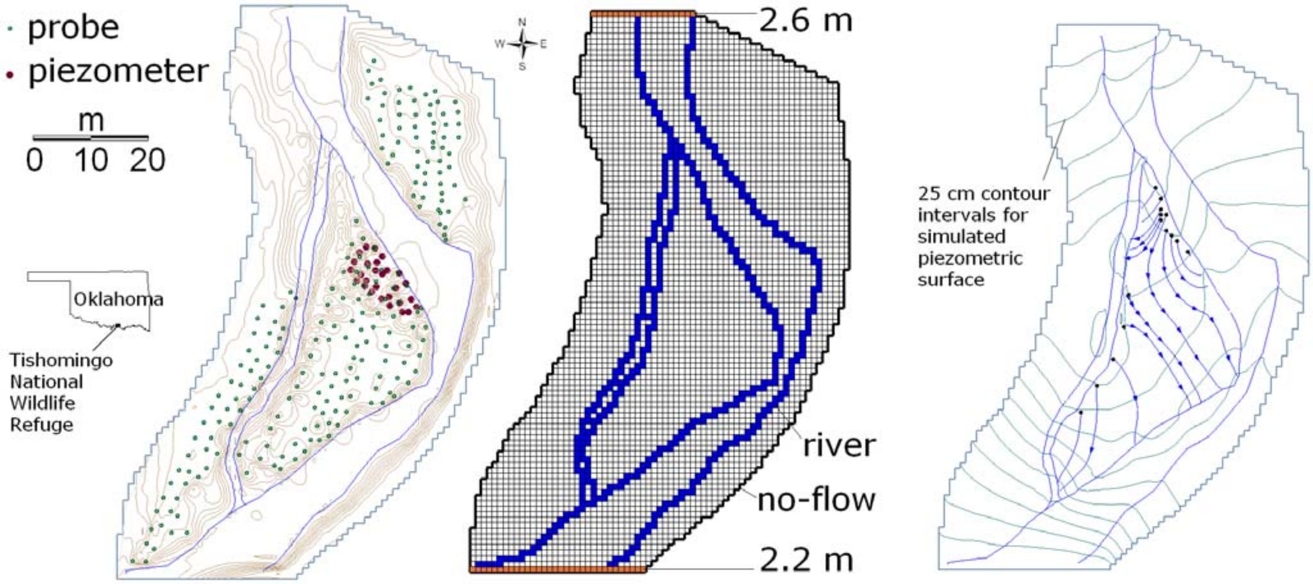

Figure 1. Left: Map of contoured elevations (10 cm intervals), probe locations, and piezometer locations, Middle: MODFLOW discretization, Right: Results displayed as flow net (arrows show 24–hr time intervals).

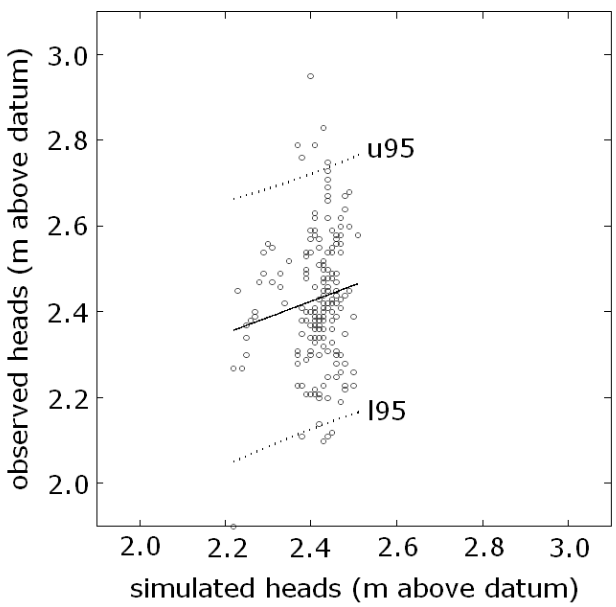

Figure 2. Plot of simulated versus probe-observed heads. Linear regression: $y = 1.53 + 0.37x$, $r^2 = 0.02$, $p = 0.05$. Upper and lower 95% confidence limits shown.

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NOTICE

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