Exploring Dynamic Interactions Between
Surface Water and Groundwater
at a Point Bar System
in the Muskegon River Watershed

Introduction

The quality of critical surface water resources is linked to the ability of stream ecosystems to reduce the concentrations of supplied nutrients. The hyporheic zone is a region of intensive exchange between surface water and groundwater, where reactions of nutrients are known to be enhanced. Despite this region's importance for water quality, the dynamics of surface and ground-water interactions are very complex and not well understood (Sophocleous, 2002). According to Woessner (2000), the larger-scale hydrologic exchange of groundwater and surface water in a landscape is controlled by:

1) The distribution and magnitude of hydraulic conductivity, both within the channel and the associated alluvial-plain sediments;
2) The relation of stream stage to the adjacent groundwater level; and
3) The geometry and position of the stream channel within the alluvial plain.

However, very little data exists on the exchange between these regions and associated reactions, particularly on a local scale. Furthermore, it is unclear how important this region is for nutrient removal relative to wetlands in regional Michigan watersheds, as there has been little research on flow and transport dynamics in this area.

Project Description

A significant amount of research has been conducted to evaluate the impact of nutrients and other contaminants on the quality of groundwater and streams. Such research indicates that high nutrient concentrations can be related to agricultural inputs (Wayland et al., 2003; Welty et al., submitted). There has been far less research on the details of hyporheic zone exchange and associated reactions that are known to reduce the concentrations of nutrients in surface water. The proposed research was designed to improve knowledge of the flow and transport mechanisms within the hyporheic zone. It is hoped that this research will provide a basis for future extramural proposals that will both measure and predict fluxes and reactions through large regions of exchange between surface water and groundwater. Such
research will provide a foundation for management plans designed to protect ecological and human health in regional watersheds.

The proposed research was designed to address the following hypotheses:

1) Hyporheic zone exchange between groundwater and surface water can be evaluated to an extent that was previously not possible by tracking an injected plume of high electrical conductivity water with three dimensional ground penetrating radar (GPR) surveys.

2) Spatial variations in exchange between groundwater and surface water can be evaluated with minimal cost and effort using a grid of thermistors to track an injected plume of warm water.

3) The hyporheic zone exchange of water is most active across point bar deposits, with enhanced flux from surface water to groundwater on upgradient sides of these bars, and exchange back into streams on the downgradient side of such bars.

Research Approach

The primary study site is located on a point bar system on Cedar Creek, which is a major tributary to the Muskegon River where a great deal of supporting hydrology, chemistry, and ecology data are available from intensive ongoing studies by MSU, U of M, and GVSU researchers.

Field Work

The first step was to characterize the heterogeneous sediments across the study region using both geophysical and hydrologic methods. A network of 21 ground-water monitoring wells, three stream gauging stations, three soil moisture probes, three soil temperature probes, and a weather station were installed at the site. The sediment samples were logged to provide a lithologic description and selected intervals are scheduled to be tested for permeability and porosity. Odyssey data loggers were installed in selected wells and the stream gauging stations to record temperature and pressure (water levels) across the site.

Sediment Borings/Monitoring Wells.

The borings were advanced using a GeoProbe® direct push drill rig. Soil samples were collected continuously as the boring advanced using a 4 foot long, clear plastic sleeve. Selected samples were retained for further testing. Earlier borings (MW-1D) indicated that the aquifer was
only 16 to 20 feet thick and underlain by a thick clay seam. However, subsequent borings indicated that the clay layer thins and disappears to the southeast. One boring, MW-5D, was advanced to a depth of 80 feet, the maximum depth of the GeoProbe, without encountering the bottom of the aquifer.

Upon completion, the borings were converted to monitoring wells. Using the GeoProbe, a 3-1/4 – inch diameter hollow rod was driven to the desired depth and the well was set. The wells were constructed from a 1-foot long, 2-inch diameter PVC well screen and sufficient riser to reach the surface. Clean silica sand was emplaced in the annulus around the well screen to a depth approximately one foot above the top of the screen and then sealed with a 1 to 2 foot layer of bentonite. The remainder of the annulus was backfilled with clean silica sand mixed with bentonite pellets. In many cases, a second, “shallower” well was installed within several feet of the first well. After developing the wells, Odyssey Data Loggers were installed in select wells. The data loggers were set to record temperature and pressure (water levels) every ½ hour.

Stream Gauging Stations

Three stream gauging stations were installed at the site – one on each end of the point bar and one up-stream approximately ¼ mile in an attempt to evaluate the groundwater flux into and out of the stream. An Odyssey data logger was installed in each and set to record temperature and pressure every ½ - hour. Periodically, measurements were collected using a Marsh – Birney flow meter. These will be used to calibrate the gauging stations.

Soil Moisture Probes

Three soil moisture probes were installed at the site. The probes are set at a depth approximately 18 inches below the ground surface. One is located in the open near the stream, one along the tree line and one in the forested area of the site. The probes were set to collect and store the soil moisture data once every ½ hour. It is our intention to add additional soil moisture probes as additional funds become available.

Temperature Probes

Three temperature probes were installed at the site, adjacent to the soil moisture probes.
Weather Station

An Onset (Hoboware) weather station was installed at the site. The station has the ability to collect wind speed, wind direction, barometric pressure, temperature, relative humidity, precipitation, solar radiation, photosynthetic radiation, and soil moisture data. Readings are collected every 2 minutes, and the average value stored every 15 minutes.

Installation of all of the equipment associated with the hydrogeologic study was completed by the middle of June.

This infrastructure is in place for completion of a pilot study with a dynamic tracer test, which will provide a strong basis for future proposals to EPA, NSF, and other granting agencies.

In August of 2004, a pilot geophysical study was conducted at the site using ground penetrating radar system. The information provided us with an initial characterization of the heterogeneous properties across the site, and provides initial data for developing a preliminary groundwater flow model which will be used to design an intensive tracer test which will demonstrate the nature of hyporheic zone exchange in point bars.

Once the additional wells are installed, we plan to:

- Conduct in-situ hydraulic conductivity tests in each well to examine the variations in permeability across the site.
- Conduct tracer tests using heated, saline water to examine the affects of heterogeneity on groundwater flow through the system.
- Image a saline plume in three dimensions through time as it moves from the point bar into the stream system.
- Conduct infrared mapping of the stream channel to determine areas of groundwater discharge and recharge.
- Collect velocity and thermal profiles at various locations around the point bar.

- Measure differences in diurnal water level fluctuations in areas of differing land cover across all four seasons.

Laboratory measurements

During the course of the investigation, selected soil samples will be tested in the laboratory for permeability, porosity, and grain size distribution.

All of the data will be used to develop detailed groundwater flow models
for the site, which will be used to evaluate characteristics and mechanisms (e.g. soil texture, soil moisture, vadose zone thickness, etc.) that affect groundwater – surface water interactions and associated ecological effects.

Publications

Potential publications based on newly gathered data would include:

- Estimating Evapotranspiration Rates in Near Stream Regions Using Diurnal Fluctuations in Groundwater Levels And Stream Flows
- Evaluation of Hyporheic Zone Exchange Across A Point Bar Using Thermal and Saline Fluids.
- The Influence of Heterogeneity on Exchanges Between Groundwater and Surface Water, as Measured Using Thermal Tracer Tests.
- Estimating Hydraulic Conductivity in Three Dimensions Using a Coupled Inversion of Hydrologic and Geophysical Data

Proposals

This research funding contributed to a successful National Science Foundation Grant: High-resolution Dynamic Characterization of Transport Pathways: Providing New Insights into Subsurface Processes, $450,000 to three Universities, $151,645 to MSU, Co-PI's: Dr. Remke van Dam (Michigan State University), Drs. James Butler, Gaisheng Liu, and Geoffrey Bohling (University of Kansas), and Drs. Chunmiao Zheng, and Geoffrey Tick, (University of Alabama), 3/1/2008 -2/29/2011.

In addition, the research supported by this funding, will be used to establish proposals to:
- Hydrologic Sciences Program of the National Sciences Foundation, and Environmental Protection Agency

The NSF proposal will further develop the hydrogeophysical inversion methods for saline tracer plumes in a range of environments from hyporheic zones, to regions where groundwater flows into large lakes such as Lake Michigan.

The EPA proposal will use the pilot data developed in this study to design follow up tracer experiments where nutrients were injected along with thermal and saline plumes. This would allow detailed characterization of hyporheic zone reactions.

References

The proposed research was designed to instrument a field site and collect pilot datasets for evaluating the properties that are critical to hyporheic zone flow, transport, and reactions. This research will provide a basis for proposals to measure and predict fluxes and reactions in various regions of exchange between surface water and groundwater. We have been collecting water temperature and groundwater level data at the site for approximately two years to provide the basis for design of this research. The proposed additional funds would allow us to install additional deep monitoring wells, collect sediment samples for permeability testing, conduct aquifer testing within the wells, and perform preliminary tracer studies which will be imaged in three dimensions using ground penetrating radar. The information gained will provide proof of concept data and models necessary for submission of proposals for additional funds to the EPA and NSF. In addition, a number of private funds are available that are interested in sponsoring this type of research, including the Nestle’s Fund for Environmental Research, and the Ford Foundation.