Assessing the role of geology for nitrate fate and transport in groundwater beneath riparian buffers

by

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ABSTRACT

Riparian buffers have been shown to remove nitrate from groundwater, but the processes controlling removal are not well documented. Previous research at the Risdal Farm in the Bear Creek watershed in central Iowa suggests that geology influences groundwater velocity, residence time, denitrification rate, and ultimately how well the buffer functions. The research area for this study is the entire Bear Creek watershed, a 7,656 ha watershed with > 85 percent row crops. A multi-electrode electrical resistivity imaging system was used to characterize the extent and distribution of alluvial materials beneath buffers. Seven locations were selected for further groundwater investigations based on resistivity data and buffer maturity. A method for the construction, installation and monitoring of multilevel piezometers was developed for collection of hydrogeologic data in shallow alluvial sediments. Hydraulic gradient and hydraulic conductivity data from piezometers were used to assess controlling factors on nitrate removal in buffers. Buffers at the JRS, LSW, and TE sites both consistently removed over 95 percent of nitrate. The RRS and LSE sites often had little effect on nitrate removal, but occasionally achieved much higher removal rates. Nitrate removal was favored in locations with available dissolved organic carbon and low groundwater velocities (long residence time). Lack of dissolved oxygen in these locations suggests denitrification as the removal mechanism. Based on data from the 6 sites, the water quality benefits of buffers are most dependent on geology, groundwater residence time and geochemical environment and least dependent on the age of the buffer.

GENERAL INTRODUCTION

The application of supplemental nutrients to agricultural crops has been a common practice in the Midwest since the 1960's. Often, row crop agriculture extends to within several feet of streams, increasing the potential for contamination of both surface and groundwater. Of particular concern is contamination from nitrate (Spalding et al., 1978; Baker and Johnson, 1981). Nitrate has been associated with hypoxia in the Gulf of Mexico and such health problems as methemoglobinemia (Blue-Baby Syndrome) and gastro-intestinal transformation into nitrosamines, a suspected carcinogen. Riparian buffers along streams (i.e. re-established riparian zones) have been widely proposed as a means of increasing nutrient retention and improving water quality through the process of denitrification (Lowrance et al., 1984; Jacobs and Gilliam, 1985; Groffman et al., 1991; Haycock and Burt, 1993; Jordan et al., 1993; Osborne and Koviac, 1993; Hanson et al., 1994; Fennessy and Cronk, 1997; and Mengis et al., 1999).

The process of denitrification has been widely cited to improve water quality in shallow aquifers (Bradley et al., 1992; Smith et al., 1991; Hendry et al., 1983; Smith et al., 1996; Trudell et al., 1986). Denitrification is the dissimilatory reduction of nitrate by soil microorganisms (Knowles, 1982). Under anaerobic conditions, the metabolic processes of soil microbes, fueled by organic carbon, turn to nitrate as an electron acceptor (Knowles, 1982). During this process, nitrate (NO_3) is reduced to nitric oxide (NO) and nitrous oxide (N_2O), which may be further reduced to molecular nitrogen (N_2) (Wijler and Delwiche, 1954; Knowles, 1982; Korom, 1992).

Bear Creek Watershed

As in many areas of the Midwest, the Bear Creek watershed has suffered as a result of agricultural activity. Past and continuing influences have attributed to increased rates of erosion, peak flood discharges, and nutrient loading, while wildlife diversity has decreased. The native vegetation of the watershed consisted of tall grass prairie, prairie-wetland complexes, and forest prior to cultivation. However, over 85 percent of the greater than 7500 ha watershed is now devoted to row-crop agriculture (corn and soybeans). In an attempt to restore the natural function of riparian ecotones, a riparian management system was developed.

In 1990, the Agroecology Issue Team of the Leopold Center for Sustainable Agriculture and the Iowa State University Agroforestry Research Team began development of the Riparian Management System (RiMS)(Schultz et al., 1995). Initial efforts were conducted on the Ron Risdal farm north of Roland, Iowa. These efforts included re-establishment of riparian vegetation (multi-species riparian buffers), streambank stabilization, and the construction of small wetlands for interception of tile drainage. The overall goal of the project of to develop a process level understanding of the mechanisms of nitrate fate and transport in re-established riparian zones on previously cropped or pastured land and the effectiveness of riparian zone restoration as a Best Management Practice.

Purpose and Scope

The purpose of this thesis is to investigate the ability of multi-species riparian buffers to remove nitrate from groundwater, and particularly, to gain understanding of the affect that alluvial (and adjoining) geology has on this process. Buffers have been shown to be a source of carbon, which acts as an energy source in the microbial reduction of nitrate (denitrification), improving groundwater quality (Burford and Bremner, 1975; Parkin, 1987; Smith and Duff, 1988; McCarty and Bremner, 1992; Starr and Gillham, 1993; Starr et al., 1996). Previous research at the Bear Creek site has established that denitrification occurs primarily at the water table, where organic carbon is available and groundwater velocities are slow (Andress, 1999). However, it was also found that coarse sand units, deep below the buffer, may channel groundwater beneath the buffer at much higher velocities, effectively bypassing the functional zone of denitrification and diminishing the water quality effects of the buffer (Andress, 1999).

The objectives of this study are two-fold. The first objective is to develop efficient methods for the characterization and monitoring of hydrogeologic parameters in riparian areas. The second objective is to determine the role of geology in the removal of nitrate beneath multi-species riparian buffers. Methods include geological characterization with the use of electrical resistivity surveys, and the installation and monitoring of multilevel piezometers for the estimation of physical and chemical groundwater parameters. Data are used to assess the nitrate-removing ability of multi-species riparian buffers under varying conditions. This study constitutes a total method for the implementation, data collection, and analysis for investigating the nitrate removing abilities of re-established riparian buffers on a watershed scale.

Thesis organization

The thesis entitled "Assessing the role of geology for nitrate fate and transport in groundwater beneath riparian buffers" is composed of three papers for submission to scientific journals. The paper "Use of multi-electrode resistivity imaging to investigate the geology of riparian buffers" will be submitted to the Journal *Environmental and Engineering Geoscience*. The paper "Hydrogeology and nitrate removal efficiency beneath riparian buffers in the Bear Creek watershed" will be submitted to *Ground Water*. The paper "An improved multilevel piezometer system suitable for riparian buffer investigations" will be submitted to *Soil Science Society of America Journal*. The format and style of each paper follows that of the respective journal in which it is to be submitted. Tables and figures will follow the reference section of each paper and a General Summary will follow the third paper. Appendices and references cited in the General Introduction will follow the General Summary.

USE OF MULTI-ELECTRODE RESISTIVITY IMAGING TO INVESTIGATE THE GEOLOGY OF RIPARIAN BUFFERS

A paper to be submitted to *Environmental and Engineering Geoscience*

Timothy R. Wineland, Igor A. Beresnev, William W. Simpkins, Richard C. Schultz,
and Thomas M. Isenhart

Abstract

A multi-electrode electrical resistivity imaging system was used to characterize the extent and distribution of alluvial materials beneath riparian buffers in the Bear Creek watershed. Fifty-one measurements were taken along a 5 km portion of the creek. Resistivity values of geologic materials ranged from 5 to 3500 ohm-m. Loamy alluvium and till were found to have the lowest resistivities (<45 ohm-m) while coarse alluvial sand/gravel and limestone bedrock were consistently higher (90 to 300-plus ohm-m). Because of its ability to measure electrical properties characteristic of sediment texture, resistivity imaging was found to be an efficient method for characterizing alluvial sediments and their distribution. However, the technique often lacked the resolution necessary to identify all hydrogeologically significant materials, such as thin aquitards in riparian buffers.

Introduction

The application of supplemental nutrients to agricultural crops has been a common practice in the Midwest since the 1960's. In many locations, row crop agriculture extends to within several feet of streams, increasing the potential for contamination. Riparian buffers along streams (i.e. re-established riparian zones) have been proposed as a means of increasing nutrient retention and improving water quality (Lowrance et al, 1984; Groffman et al, 1991; Osborne and Kovacic, 1993; Schultz et al., 1995; Fennesy and Cronk, 1997). Hydrogeologic environments beneath buffers are suspected to be the key factors that control how well they work (Warwick and Hill, 1988; Cooper, 1990; Hill, 1996). However, many methods for investigating hydrogeology in complex environments are expensive and labor-intensive (Cherry et al., 1983). There is a need for more efficient ways to assess the geologic conditions that determine the potential of buffers to improve water quality.

Electrical-resistivity surveys have been used for determining geologic conditions in the near surface for several decades (Burger, 1992). Physical properties such as water content, porosity, clay content, and grain size have been shown to be the controlling elements in determining resistivity in geologic materials. This knowledge has led to the correlation of common geologic materials to commonly accepted ranges of resistivity (Burger, 1992), which provides the ability of interpreting geologic conditions from electrical resistivity surveys. Applications of electrical resistivity have included locating and mapping buried gravel deposits (Jakosky, 1950; Welkie and Meyer, 1983; Beresnev et al, 2002); estimation of aggregate volume and degree of weathering (Nowroozi et al, 1997); and estimation of common hydrogeologic parameters such as hydraulic conductivity (Zaarfran and Habberjam, 1983; Niwas and Singhal, 1985; Dassargues, 1997).

In the past, resistivity surveys have used a linear series of four electrodes in either expanding-spread (sounding) or constant-spread (profiling) sequences. Using Schlumberger and Wenner arrays, the two outer electrodes provide current while the two inner electrodes measure the potential difference at the surface (Burger, 1992). Apparent resistivity values obtained from these methods often lack the desired resolution, and data collection is slow due to repeatedly removing and re-installing electrodes along the profile.

The recent development of automated multi-electrode imaging systems has overcome many of the limitations of previous methods. These systems consist of multiple electrodes, a communication cable, and a field computer that controls the system and records the data. Readings are collected from all of the possible four-electrode combinations in one field transect utilizing both sounding and profiling. Apparent resistivity data can then be exported into a microcomputer where an inversion program provides a detailed, two-dimensional (2-D), true-resistivity section representing the geoelectrical properties of the subsurface.

In this paper, we present results from a multi-electrode resistivity imaging system for the characterization of geology beneath riparian buffers. Surveys were completed throughout the watershed in buffered and non-buffered sites. Findings were compared to core samples collected at drilling sites within several of the resistivity profiles.

Site Location and Description

Field investigations were performed in the Bear Creek Watershed in Story County, Iowa. The watershed is located within the Des Moines Lobe physiographic region (Figure 1). Bedrock geology consists of Mississippian limestone, dolomite, sandstone, and shale with the uppermost unit being the St. Louis Formation limestone (Witzke and Bunker, 1993). Previous work by Simpkins and Schultz (1993) has shown that depth to bedrock is less than 10 m in riparian areas and often less then 1.5 m below the stream channel. Pleistocene Alden and Morgan Member till of the Dows Formation overlie the bedrock, and Holocene alluvium of the DeForest Formation is encountered adjacent to Bear Creek and its larger tributaries. Johnston (1998) showed that till and Mississippian shale act as a confining unit between lower bedrock and upper alluvial flow systems in several locations within the watershed.

Surficial mapping by Quaid (2001) demonstrated variations in extent of alluvial (Holocene) and outwash (Pleistocene) sediments throughout the watershed (Figure 1).

Methods

Locations for electrical resistivity surveys were selected to sample the variety of geologic conditions that existed adjacent to Bear Creek. Surveys were conducted perpendicular to the creek. Transects were started as near to the creek as possible and continued through the buffer and into the adjoining crop field. Most surveys consisted of 24 electrodes at a 2 m spacing (46 m profile); however, where the buffer was wider, the survey transect was extended to cover the width of the buffer. Apparent resistivity data were collected using Wenner-Schlumberger geometry. A complete survey, including setup and removal of the electrode array, generally took 45 to 90 minutes to finish, depending on survey length and site vegetation. Fifty-one surveys were taken along a 5 km portion of the creek during summer 2000 (Figure 1).

Apparent resistivity readings were transferred from the field computer/data logger to a computer in the lab. The data were inverted using RES2DINV (Loke, 2000). The program uses a non-linear least squares optimization technique to estimate a true-resistivity profile of the subsurface (Loke, 2000). Inversion was generally completed within 8 to 12 iterations and in 10 to 15 seconds.

Fluctuation in soil moisture conditions could affect resistivity results; hence, we performed several surveys over time at a marked location for comparison. The first survey was conducted on June 8, 2000, toward the end of an extended period without precipitation. An additional survey was conducted on June 18, 2000, after a series of several precipitation events. As suspected, absolute resistivity values varied slightly between surveys, however, the relative positions of high and low resistivity values remained constant (Figure 2). Based on this comparison, it was decided that changes in moisture content of this magnitude during the data collection period would not prevent interpretation of geologic conditions from resistivity profiles.

In order to corroborate resistivity profiles, cores were obtained within electrical resistivity profiles, including seven where multilevel piezometers were installed. Continuous core was collected using a Giddings™ soil coring rig until bedrock or till was encountered. Samples were described (Appendix A) to determine geologic boundaries. Cores from locations where multilevel piezometers were installed were taken to the lab and analyzed for particle size using a pipette method (Gee and Bauder, 1986). Textural designations of sand, silt, clay, and loam were derived from relative sand, silt, and clay percentages and were adapted from USDA textural classifications (0.05 mm silt-sand break).

Geographic locations of resistivity profiles and borehole locations were recorded using a survey-grade global positioning system (GPS). Location and attribute data were collected on the GPS field computer and transferred to a laptop computer for GIS capabilities. All locations were collected to sub-meter accuracy and real-time differential correction allowed returning to previous locations with very good accuracy.

Results

Most resistivity surveys were conducted between late May and mid-June of 2000 and were completed with a 24-electrode line and a 2-m spacing. This configuration yielded about a 8-m-deep by 46-m-wide profile after inversion. Resistivity values ranged between 5 and

3500 ohm-m along Bear Creek with most materials yielding values less than 300 ohm-m. A transect of monitoring wells was installed at 3 sites (34, 36, and 37) which allowed for comparison of core samples with resistivity profiles. In addition, three profiles (1, 2, and 26) were selected to demonstrate the geologic diversity of the watershed.

Observed resistivity values at Site 34 (Figure 1) were low relative to many sites along Bear Creek. Values were lowest (<30 ohm-m) near the surface and at depths greater than 3 to 4 m (Figure 3a). At a depth of 1 to 3 m, a layer of slightly more resistive material can be seen through the central and right portions of the profile. Core samples were collected at two locations along the profile and are labeled N and M in the geologic interpretation of Figure 3a. These samples confirm that the low resistivity unit near the surface is a loam, the underlying unit (45 to 90 ohm-m) is a sand, and the deepest visible unit is a till. Although this site had a very small range of resistivities, the correlation between the resistivity profile and core analysis was very good.

The survey at Site 36 (Figure 1) indicated a relatively complex geology. The resistivity profile (Figure 3b) showed an area of high resistivity (>200 ohm-m) near the surface, underlain by a layer of low resistivity material (<30 ohm-m) and further underlain by a high resistivity material. Sediment analysis from core D (Figure 3b) suggests that the area of high resistivity near the surface is due to the presence of coarse channel sediments (coarse sand and gravel) within a layer of finer alluvium. Further examination of core indicated the middle layer of low resistivity sediment was till. Although deeper core was not available, the high resistivity material near the bottom of the profile probably represents weathered limestone bedrock.

A layer of low hydraulic conductivity not detected by the resistivity survey was found at 3 m within the coarse alluvium at Site 36. The material resembles till and it effectively separates the upper and lower portions of the alluvial aquifer. Use of a closer electrode spacing may have allowed the resistivity imaging to detect this layer. However, a closer electrode spacing would have resulted in a decrease in both survey length and depth and compromised the characterization.

At Site 37 (Figure 1), the resistivity profile indicated increasing resistivity with depth (Figures 3c). Resistivity was less than 30 ohm-m within several meters of the surface and exceeded 200 ohm-m with depth. Core samples were collected at three sites along the profile and are labeled A, B, and G in the geologic interpretation of Figure 3c. All three cores consisted of primarily loam to a depth of approximately 2 m. This corresponds to consistent values of less than 45 ohm-m on the resistivity profile. From 2 to 3 m, the core consisted primarily of sand and was found to have resistivity values of 45 to 90 ohm-m in survey results. All three boreholes encountered limestone residuum at about 3 m. At this depth, resistivity values ranged from 90 ohm-m near the contact with sandy alluvium to greater than 200 ohm-m where the bedrock was presumably less fractured or weathered. As with Site 36, a thin layer of loam was found at a depth of approximately 2 m in all three cores at Site 37. This layer was both overlain and underlain by sand layers showing higher resistivity.

Sites 1, 2, and 26 were chosen to demonstrate the geologic variability that exist in the watershed. All three surveys (Figure 4) were conducted perpendicular to the stream and were oriented so that Bear Creek lies to the left of each profile. Site 1 (Figure 4a), which appeared to be located outside of the meandering area of the creek, consisted almost exclusively of till, with the exception of some fine alluvial/colluvial mixed surface sediments near the creek. This area can be recognized on the left side of the resistivity profile by its slightly higher resistivity signature. The resistivity profile of site 2 (Figure 4b) was found to be very similar to that of Site 37. The surface consisted of low resistivity sediments but quickly changed with depth to significantly higher values. Coring revealed that loamy alluvium was directly underlain by limestone bedrock. As with Site 1, the survey at Site 26 (Figure 4c) also appeared to be located outside of the active meander of the creek. This survey showed an area of relatively low resistivity through the middle of the profile, which is assumed to be till, underlain by a slightly more resistive bedrock. Of particular interest in this profile is the material in the upper right corner with resistivity values exceeding 3000 ohm-m. This material, consisting of coarse gravel, was encountered adjacent to Bear Creek in several locations. Many of the other sites are identified as glacial outwash (Noah Creek Fm) by Quaid (2001). The absence of mapped outwash in this case (see Figure 1) demonstrates some advantages of resistivity over mapping surficial geology from soil surveys.

Throughout the watershed, a strong correlation was observed between sediment type and resistivity. Figure 5 demonstrates how resistivities observed on resistivity profiles strongly correlated to sediment types found in corresponding boreholes. Low resistivities (< 45 ohm-m) were associated with till and loam sediments. Higher resistivities (45 to 90 ohm-m) were found in areas of alluvial sand. Coarse sands and alluvial gravel were found to have resistivities ranging from 90 to 300 ohm-m.

Conclusions

Electrical resistivity imaging provides a fast and efficient method for the initial investigation of geologic materials in riparian environments compared to earlier 4-electrode sounding and profiling methods. Surveys consistently found normally accepted values of resistivity for near surface alluvial sediments as well as deeper glacial deposits and bedrock. Both loamy alluvium and till showed resistivity values less than 45 ohm-m in most situations. Alluvial sands were found to have resistivity values between 45 and 90 ohm-m. Coarse sands and gravel showed resistivity values of 300 ohm-m. Resistivities for limestone bedrock ranged from 90 to several hundred ohm-m depending on degree of weathering. Because bedrock and coarse alluvium both showed high resistivity, a comparison to core samples was generally required to distinguish them.

Comparison of actual core with resistivity profiles showed that electrical imaging was often unable to detect subtle, geologic heterogeneity at small scales, such as thin fine grained layers which have the potential to act as aquitards. The inability to detect these small differences could limit the potential of using this technology to predict hydrogeologic conditions underneath buffers, a key component to understanding how buffers improve water quality. Overall, however, this is a promising technique for assessing potential sites for riparian buffers.

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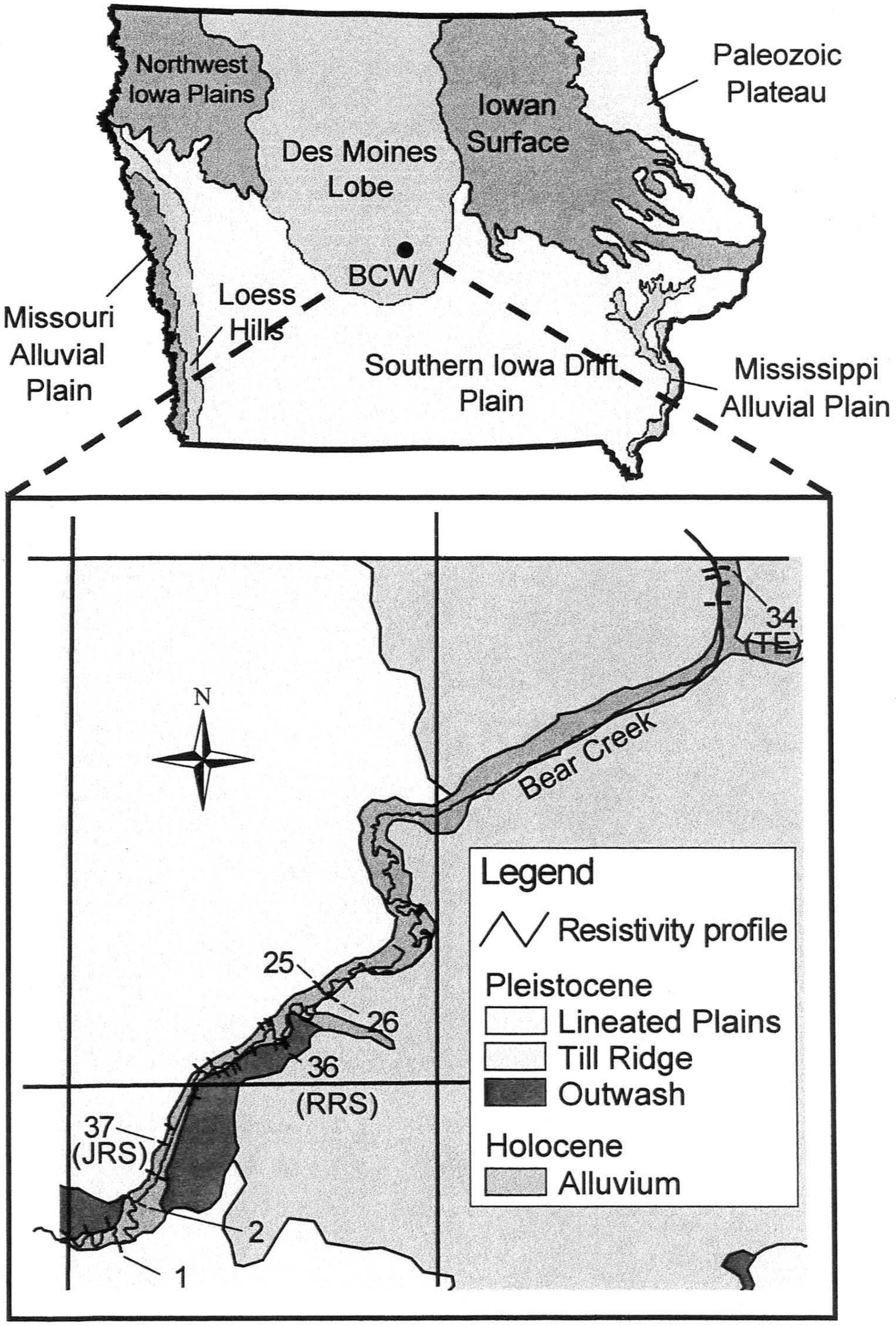

Figure 1. (a)Landform regions of Iowa showing location of Bear Creek Watershed (BCW). Diagram (b) shows electrical resistivity sites and surficial geology (Quaid et al, 2001) along a portion of Bear Creek. Groundwater sampling transects were later installed at locations JRS, RRS, and TE (Wineland, 2002).

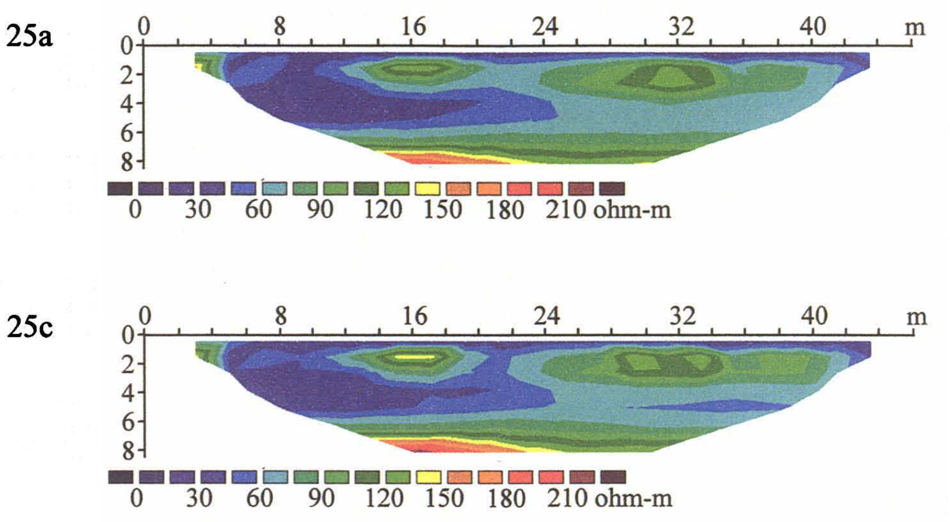

Figure 2. Comparison of resistivity profiles at site 25. Profile 25a (top) was produced on June 8, 2000. Profile 25c (bottom) was produced on June 18, 2000, after a series of precipitation events.

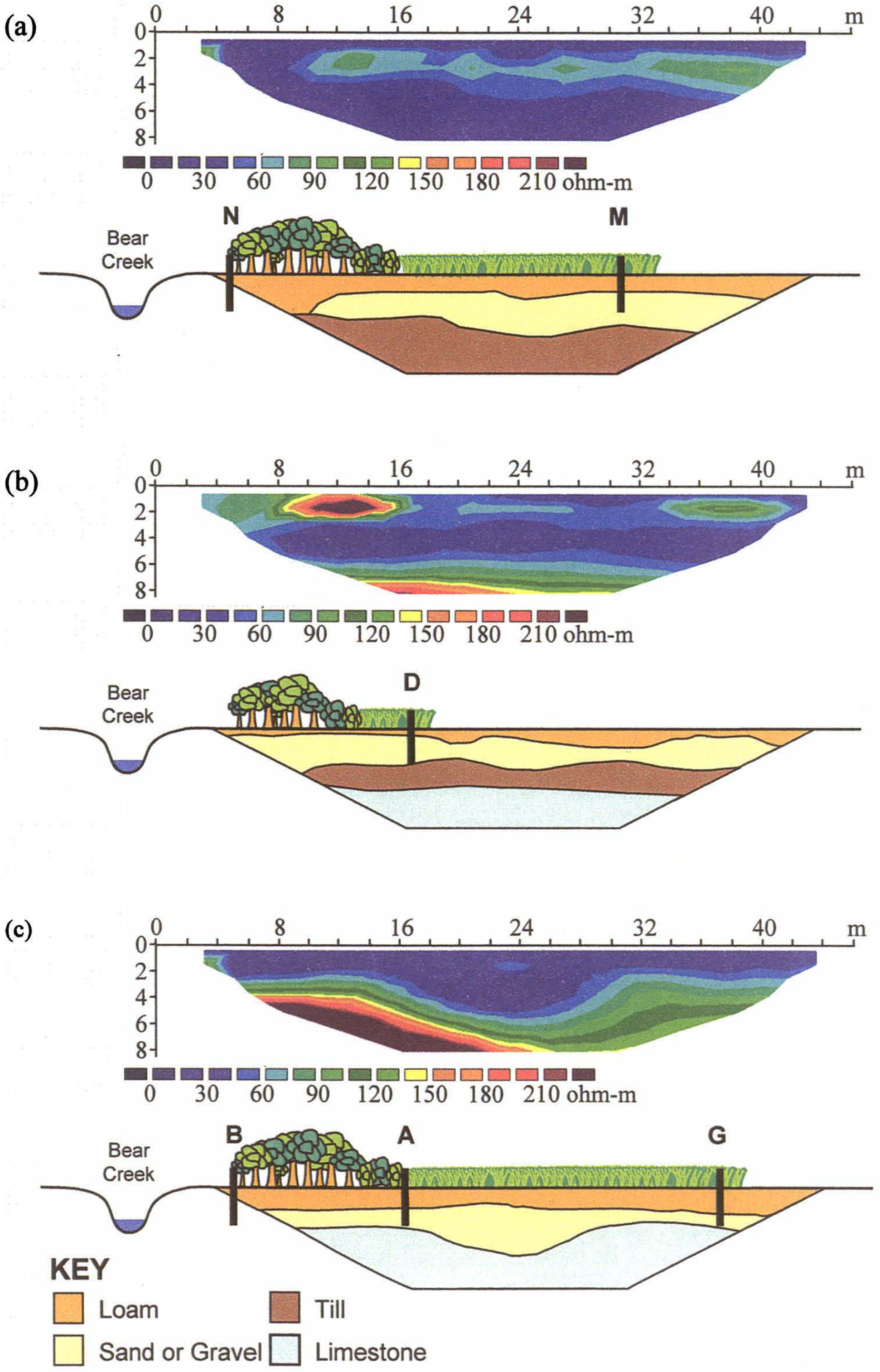

Figure 3. Resistivity profile and geologic interpretation at (a) sites 34, (b) 36, and (c) 37 (see Figure 1 for location).

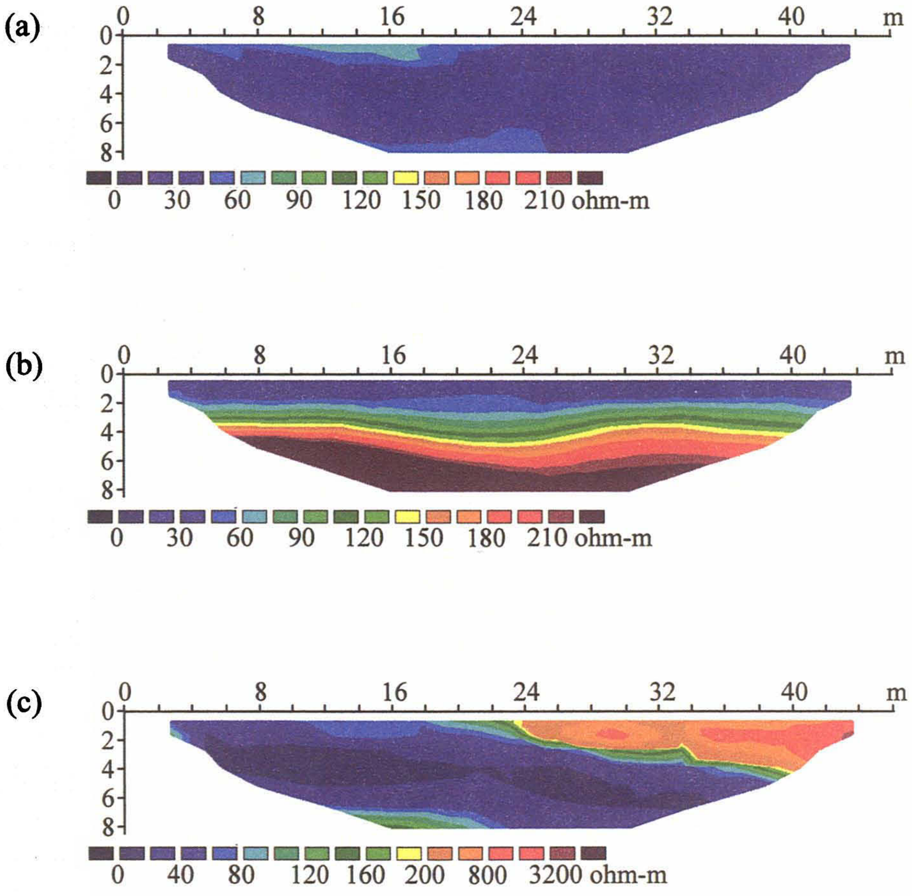

Figure 4. Resistivity profiles at sites (a) 1, (b) 2, and (c) 26 (see Figure 1) showing the variety of resistivity responses in sediments along Bear Creek. Creek lies to the left of all profiles.

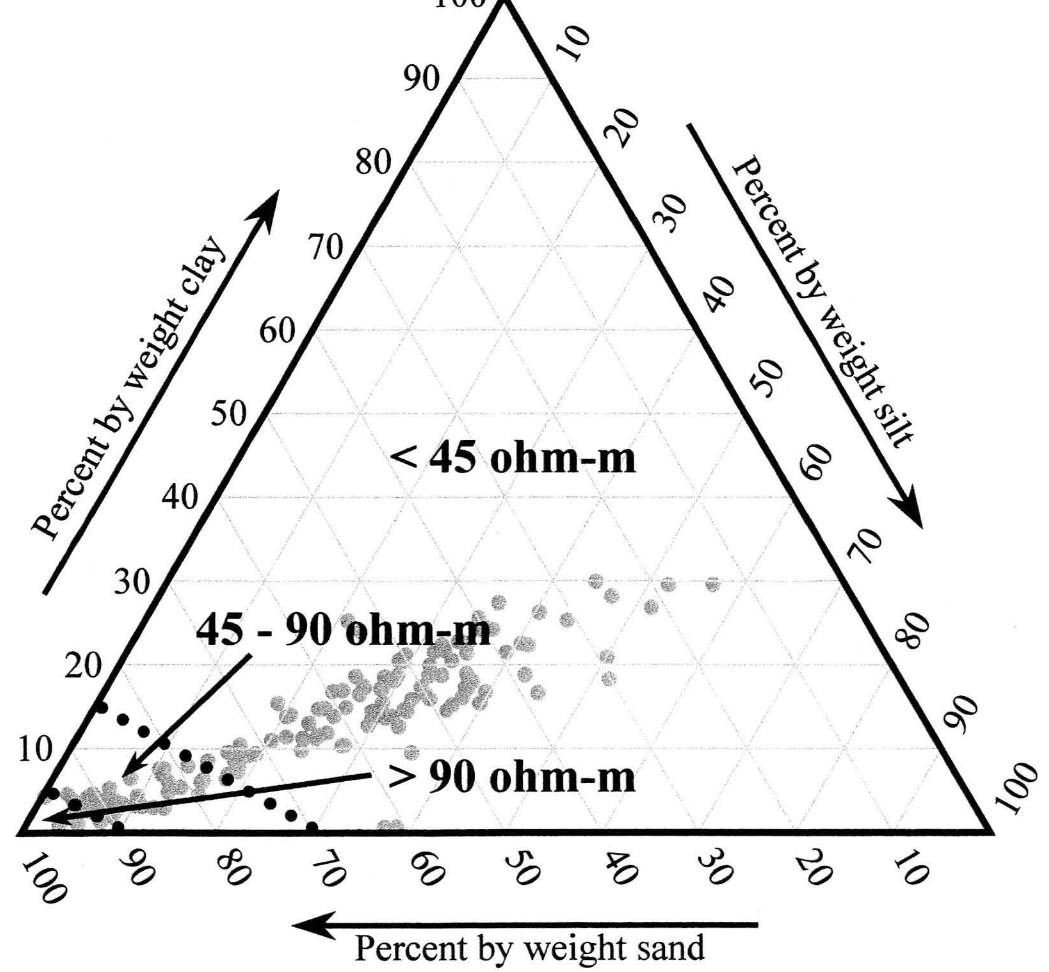

Figure 5. Soil textures and associated resistivity values observed in profiles for sediments at the study sites in the Bear Creek Watershed.

HYDROGEOLOGY AND NITRATE REMOVAL EFFICIENCY BENEATH RIPARIAN BUFFERS IN THE BEAR CREEK WATERSHED

A paper to be submitted to *Ground Water*

Timothy R. Wineland, William W. Simpkins, Richard C. Schultz, Thomas M. Isenhart and
Igor A. Beresnev

Abstract

Riparian buffers have been shown to remove nitrate from groundwater, but detailed hydrogeologic characterization of these systems is generally lacking. Previous research in the Bear Creek watershed in central Iowa suggests that geology influences groundwater velocity, location of groundwater flow, denitrification rate, and ultimately how well the buffer functions. The research area is the Bear Creek watershed, a 7,656 ha watershed with > 85 percent row crops. Reconstructed riparian buffers, consisting of 20-m-wide strips of grass, shrubs and trees, have been in place for up to 11 years. Hydraulic gradient and hydraulic conductivity data from multilevel and nested piezometers were used to assess controlling factors on nitrate removal in buffers. Data indicate that the distribution of nitrate concentrations in groundwater varies in the watershed. In some locations, high nitrate-N concentrations (>15 mg/L) coincide with high groundwater velocities (>1 m/d) in coarse sand units near the bottom of the alluvium beneath the buffer. In other locations, deeper sand units characterized by a lack of nitrate-N (<0.1 mg/L) are overlain by sediment with above-ambient concentrations (>5 mg/L) which is exposed to agricultural activity. Analysis of groundwater samples indicates a significant range in buffer effectiveness. Nitrate removal efficiency varies from 0 to 99 percent. Nitrate removal was highest in locations with abundant organic carbon and longer residence time. Correlations of low nitrate

concentrations with depletion of dissolved oxygen suggest the occurrence of denitrification at these sites. These data suggest that water quality benefits of buffers are primarily dependent on geologic controls that influence groundwater residence time and flow paths in underlying sediments.

Introduction

Previous Work

The application of supplemental nutrients to agricultural crops has been a common practice in the Midwest since the 1960's. Often, row crop agriculture occurs within several feet of streams, increasing the potential for contamination from nitrate (Spalding et al., 1978; and Baker and Johnson, 1981). Riparian buffers (i.e. re-established riparian zones) have been suggested as a means of improving soil and water quality where native vegetation has been removed by agricultural activities (Isenhart et al., 1997; Lowrance et al., 1984; Jacobs and Gilliam, 1985; Groffman et al., 1991; Haycock and Burt, 1993; Jordan et al., 1993; Osborne and Kovacic, 1993; Hanson et al., 1994; Fennessy and Cronk, 1997; and Mengis et al., 1999). Restored buffers are areas of perennial vegetation adjacent to streams that intercept and slow runoff, uptake pesticides and nutrients, stabilize streambanks, and provide wildlife habitat (Schultz, 1995). Riparian buffers, stream bank stabilization, tile-intercepting wetlands, boulder weirs, and rotational grazing comprise the Riparian Management System (RiMS).

Recently, interest has focused on the fate and transport of nitrate beneath riparian zones located in regions of intense agricultural activity. Mengis et al. (1999) discussed numerous geochemical and isotopic methods for assessing the elimination of nitrate in groundwater of shallow riparian aquifers near corn and winter wheat fields. Several researchers have documented the beneficial effects of riparian buffers regarding the removal of nitrate from groundwater (Haycock and Pinay, 1993; Addy et al., 1999; Spruill, 2000). Investigators have suggested that variations in groundwater flow-paths and residence time can significantly affect the water quality function of riparian zones (Gold et al., 1998; Simpkins et al., 2002). Andress (1999) demonstrated how stratigraphic variation within shallow alluvial aquifers, particularly the presence of coarse sands, could allow nutrient-laden groundwater to pass beneath buffers unaffected. Because of this, many believe that the hydrogeologic environments beneath buffers are the key factors that control how well they work (Warwick and Hill, 1988; Cooper, 1990; Hill, 1996).

Purpose and Scope

This study compliments a larger interdisciplinary study being conducted by the Agroecology Issue Team at Iowa State University. Since 1990, numerous multi-species riparian buffers have been established along portions of Bear Creek, north of Roland, Iowa. The sites generally consist of 20-m-wide areas along the creek planted in trees, shrubs and warm-season grasses. In addition to improvements in sediment retention, runoff detention, stream bank stability and wildlife diversity, buffers are believed to improve groundwater quality by promoting denitrification. This paper presents research on how efficient buffers of varying maturity and different hydrogeologic conditions are at lowering nitrate contamination in groundwater.

Site Location and Description

Field investigations were performed in the Bear Creek Watershed in Story County, Iowa (Figure 1). The native vegetation of the watershed consisted of tall grass prairie, prairie-wetland complexes, and forest prior to cultivation. As agriculture was introduced into the area, surface-water and groundwater hydrology was significantly changed with the draining of wetlands and the channeling of streams. Presently, over 85 percent of the watershed is devoted to row-crop agriculture (corn and soybeans). The watershed drains over 7500 ha and is a tributary of the South Skunk River. It is located within the Des Moines lobe physiographic region (Simpkins and Schultz, 1993). Bedrock geology consists of Mississippian limestone, dolomite, sandstone, and shale with the uppermost unit being the St. Louis Formation limestone (Witzke and Bunker, 1993). Previous work by Simpkins and Schultz (1993) has shown that depth to bedrock is less than 10 m in riparian areas and often only 1.5 m below the stream channel. Pleistocene Alden and Morgan Member till of the Dows Formation overlie the bedrock, and Holocene alluvium of the DeForest Formation is encountered at the surface adjacent to Bear Creek and its larger tributaries. The DeForest Formation generally contains the Gunder and Roberts Creek Members, consisting of loamy to coarse sands and loam, respectively. The Gunder Member is the upper sand aquifer. Johnston (1998) showed that till and shallow Mississippian shale act as a confining unit between lower bedrock and upper alluvial flow systems in several locations within the watershed. Several near surface sand and gravel deposits also exist in the watershed. Simpkins (1993) speculated that many of these units could represent fluvial surfaces active during or shortly after glaciation (Noah Creek Formation). Surficial mapping of Story County by Quaid et al. (2001) demonstrated variations in extent of alluvial and outwash sediments throughout the watershed (Figure 2).

Methods

Site Identification and Investigation

Groundwater monitoring locations were selected from a preliminary screening using 55 electrical resistivity profiles (Wineland et al., 2002). Profiles were generally 46 m in length and perpendicular to the channel of the creek. Buffers varied in age from 2 to 11 years. The method provided a fast and efficient method for delineating the relative locations of alluvium, till and bedrock near Bear Creek and demonstrated the heterogeneity of sediments that existed within the watershed (Wineland et al., 2002). Seven locations were selected for further groundwater investigation based on geological heterogeneity observed in electrical resistivity profiles and buffer maturity. Locations discussed include the JRS, RRS, LSE, LSW, and TE sites. Table 1 summarizes the physical setting of each location. Low water levels at the TW location often prohibited sample collection and alluvial heterogeneity prohibited the use of site LSS as a non-buffered control site.

Piezometer Installation

Monitoring sites were positioned at the edge of Bear Creek and adjacent to crop fields. Transects were oriented roughly perpendicular to the contour of the land and parallel to the presumed flow of groundwater. Two types of piezometer installations were implemented. In alluvial settings with coarse sediment (sand and gravel), a multilevel piezometer was installed (Wineland et al., 2002). In alluvial settings with fine sediment (silt, clay and till), piezometer nests consisting of small diameter (12.7 mm ID) PVC piezometers with 30-cm-screen-intervals were installed. Sixty-six sampling ports were installed at depths between 1.5 to 4 m throughout the Bear Creek watershed at seven different locations (Figure 1)(Appendix B). Particle size analysis (Gee and Bauder, 1986)(Appendix A) from the core was used to estimate mean particle size (Shirazi and Boersma, 1984; Shirazi et al., 1988; Rawls, 1983). Textural designations of sand, silt, clay, and loam were derived from relative sand, silt, and clay percentages and were adapted from USDA textural classifications with a 0.05 mm silt-sand break.

Measurements of hydraulic head were taken using electric water-level tapes. A meter with a small-diameter (3.2 mm) coaxial cable was used at locations with a multilevel piezometer. Water level depths were measured relative to the top of the piezometer. Relative height differences among piezometers at each sampling location were determined using a differential transit. Absolute elevation for the sampling locations was determined using a survey-grade GPS system with carrier-phase, differential correction. This allowed determination of absolute hydraulic head at all sampling locations (Appendix C) to an accuracy of approximately ± 0.1 m. The precision (accuracy) at each location is approximately ± 0.01 m.

Hydraulic conductivity (K) was estimated using two methods. At each piezometer, K was determined using a falling (variable) head test (Lambe and Whitman, 1979). Particle size was also used to estimate K of the sediment. The equation used to estimate K is as follows (Shepherd, 1989):

$$K = C_F \times d_{50}^{\,i}$$

K = hydraulic conductivity (ft/day)

C_F = shape factor (450 for alluvial material)

d_{50} = median grain size (mm)

i = exponent (1.65 for alluvial material)

Geochemical Analysis

Core samples collected during the installation of piezometers were analyzed for solid-phase Carbon and Nitrogen (Appendix A). Total Carbon was determined by the dry combustion method (Matejovic, 1997). Inorganic carbon was determined by a modified pressure calcimeter method (Wetterauer, 2001). Nitrogen was also found using the dry combustion method. Both analyses were conducted at the Department of Agronomy Soil and Plant Analysis Laboratory at Iowa State University and have an analytical precision of ± 1 percent.

Groundwater samples were collected from October of 2000 through November of 2001 on a 2 to 3 week interval. Dissolved O_2 was determined by pumping water through a flow cell containing a YSI 550-DO polarographic dissolved O_2 probe. Samples were also collected for lab analysis of nitrate-N, chloride, and dissolved organic carbon (DOC). Samples for nitrate-N were acidified with 20 μL of concentrated H_2SO_4 and analyzed with a spectrophotometer (Crumpton et al., 1992). Samples for chloride were analyzed with an ion specific electrode. DOC samples were analyzed using persulfate oxidation on a (Dohrman / Phoenix^{TM}) carbon analyzer. Analyses for nitrate-N, chloride, and DOC were performed at the Department of Natural Resource Ecology and Management, Water Quality Laboratory, Iowa State University (Appendix D). Analyses for nitrate-N and chloride have an analytical precision of ± 0.1 mg/L and ± 1 mg/L, respectively.

Chemical Flux Calculations

For each monitoring event and location, the efficiency of the buffer to remove nitrate from the alluvial aquifer was estimated. Water level data from each sampling event were used to calculate the horizontal hydraulic gradient at the water table. Estimates of K were used to calculate the average linear velocity of groundwater at depths corresponding to sampling ports and the residence time of groundwater as it passed beneath each buffer. Effective porosity was assumed to be 0.15 for all necessary calculations. Nitrate mass flux was estimated from average linear velocity, effective porosity, and nitrate concentration data. The equation used to estimate mass flux is as follows (Fetter, 1999):

$$F_x = v_x n_e C$$

F_x = mass flux (gm/day-m^2)
v_x = average linear velocity (m/day)
n_e = effective porosity
C = concentration (gm/m^3 or mg/L)

Total flux was then calculated for each depth interval in which a sampling port was positioned. A width of 10 m was chosen for the flux calculation to minimize the effects of heterogeneity within the buffer. Depth intervals were based on core analysis to group similar sediments. Mass flux was multiplied by the cross-sectional area to estimate total flux of nitrate-N. Mass either entering or leaving the buffer was summed from each vertical interval to calculate the mass crossing the arbitrary vertical border of the buffer (Figure 3). Quantities of nitrate entering and leaving the buffer from similar cross-sectional areas were then used to determine the relative efficiency of each location for a given sampling date.

In addition to analytical errors, incorrect estimations of hydraulic gradient constitute the significant source of error when estimating chemical fluxes into and out of the buffer. Horizontal hydraulic gradient was used to estimate average linear velocities near multilevels based K data. However, sediment changes between multilevels may have induced variability in horizontal hydraulic gradient and flow velocity along the flow path, contributing to erroneous calculations of hydraulic gradient and velocity. This error would further propagate in chemical flux estimations of the quantity of nitrate either entering or leaving the buffer.

Several methods of quantifying groundwater movement and chemical flux were investigated for the purposes of this project. One alternative to the methods used would consist of establishing numerous aquifer sections corresponding to sampling depths, treating each section as a different component of the aquifer. It would then be possible to find gradient from one point to a point of similar depth on the other side of the buffer. A calculation for hydraulic gradient, groundwater velocity, and chemical flux could then be determined for each individual section. However, lateral changes in lithology between ports would make this method difficult to implement. Another alternative would be to estimate one representative value of K for the buffer at each sampling area. This value could then be used with the hydraulic gradient of the water table to estimate groundwater velocity and chemical flux for the site as a complete unit. Again, the effects of heterogeneity would be lost in this approach.

Many of the errors that were introduced through the methods used could be reduced with additional multilevel piezometers at each sampling location. These would enable more refined estimations of flow direction and variable gradients that exist throughout the buffer, enabling calculation of groundwater velocity and chemical flux with greater accuracy.

However, the addition of several more multilevels at each monitoring location was time-prohibitive for the scale of this investigation.

Results and Discussion

Geology

Electrical resistivity surveys indicated that alluvial sediments along Bear Creek varied in both composition and extent (Wineland, 2002). Mapping by Quaid (2001) revealed that surficial geology, and particularly the extent of alluvium, varies throughout Story County (Figure 2). Alluvial sediments were up to 5 meters thick, and were often found as much as 50 m away from the existing channel. Cores from a Giddings™ rig were used to corroborate resistivity surveys and sampling piezometers were installed in several of the boreholes. Particle-size analyses of core samples revealed that the size distribution of alluvial sediments also varied throughout the watershed (appendix A). These data were used to assign stratigraphic units at study locations (Figure 4).

Analysis of resistivity profiles and borings helped develop geologic cross-sections in locations where sampling piezometers were installed. Loamy alluvium and till at the RRS site were found to have the lowest resistivities (<45 ohm-m) while coarse alluvial sand/gravel and limestone bedrock were consistently much higher (90 to 300-plus ohm-m) (Figure 5) (Wineland et al., 2002). Geologic cross sections of the JRS, LSE, LSW, and TE sites are shown in Figure 6.

Hydrogeology

Seasonal variations in recharge contributed to a fluctuating water table throughout the watershed. Water-table elevations varied as much as one meter during the monitoring period (Figure 7). Because hydraulic gradients control chemical flux, the data (Figure 7) suggest that the ability of the buffer to improve groundwater quality could vary by season as a result of changes in groundwater velocity and residence time beneath the buffer. Although vertical gradients were not dominant during the study, they were occasionally observed during short time periods in multilevel piezometers after precipitation events.

Values of K for buffer materials ranged between 3 x 10^{-8} to 1 x 10^{-3} m/s, with most alluvial sediments greater than 1 x 10-5 m/s. Groundwater velocities ranged between 0.1 to about 15 m/day. Lower velocities (< 1.0 m/day) occurred in near-surface loam sediments while highest velocities were generally found in coarse sands and gravels near the bottom of the alluvial aquifer.

Water Quality

Organic carbon

We initially hypothesized that there would be a correlation between buffer age and organic Carbon concentrations in buffer sediment (i.e., older buffer = more carbon). Concentrations of solid-phase organic Carbon in sediment varied throughout the watershed. At most locations, carbon concentration decreased with depth. However, carbon concentration was found to be higher in the 2 and 4 year old buffers than in the 11 year old buffer. The buffer at the Tesdal (4 yrs) site showed Carbon concentration greater than 2 percent, even to depths of 3 meters, while the buffer at the Ron Risdal South (11 yrs) site averaged carbon concentrations near 0.5 percent over a depth of 2 meters (Figure 8). It is suspected that the higher organic Carbon concentrations at depth in younger buffers may be due to the mixing of surface sediments during channelizing practices that occurred in the past. Consequently, organic Carbon was found to be abundant in all investigated locations, regardless of buffer maturity.

Nitrate and chloride

Nitrate-N concentrations in groundwater entering the buffer adjacent to Bear Creek varied greatly over the 14-month monitoring period. In nearly all locations, depth stratification of concentration is related to geology. Nitrate-N concentrations were greatest in shallow sampling ports of the JRS and RRS sites, often greater than 20 mg/L (Figure 9a, b). Thin, low-permeability layers at each site confined nitrate-contaminated water to the shallow portion of the aquifer, where nitrate-N concentrations ranged from 2.0 to over 20 mg/L (Figure 9a, b). Below this unit, nitrate-N concentrations rarely exceeded 1.0 mg/L.

Geologic controls at the LSE and LSW sites influenced vertical stratification of nitrate-N concentrations in alluvial sediments. However, rather than peak concentrations occurring near the top of the alluvial aquifer, they were observed in the deepest piezometer ports (Figure 9c, d). At these locations, high nitrate-N concentrations coincided with coarse alluvial sands and higher groundwater velocities. Nitrate-N concentrations at the TE site never exceeded 1 mg/L during the sampling period (Figure 9e). Only weak vertical trends were observed with slightly higher concentrations of nitrate in deeper sampling ports.

Peak nitrate concentrations also varied temporally in several locations. Time lags in peak nitrate concentration between shallow and deep portions of the alluvial aquifer further suggest that groundwater velocities influence nitrate delivery. This was seen at the JRS site during the summer of 2001 (figure 9a).

Elevated levels of chloride were often found to occur in conjunction with elevated levels of nitrate. Chloride concentrations at the RRS site were highest in the shallowest two ports, exceeding 20 mg/L in the 2.0-m-port (Figure 10). This was also observed at the LSW site where approached 18.0 mg/L in the 3.1-m-port (Figure 11). Both occurrences of peak Cl concentrations coincide with the location of peak nitrate concentration. Chloride concentration at the TE site remained below 7.0 mg/L for the duration of the sampling period (Figure 12). The lack of Cl and nitrate at the TE site suggests that the alluvial sediments beneath this buffer are less affected by agricultural activity.

In several locations, nitrate-N concentrations above background levels were collected down gradient during and after corn and soybean field rotations. This suggests that either distances (groundwater travel times) to nitrate source areas were long enough to allow continuous loading of nitrate to the buffers from upgradient, or that nitrification of nutrients applied nearby occurred up to 24 months after application.

Nitrate flux and buffer efficiency

Fifteen sampling events were conducted during the study period. Each event consisted of monitoring both physical and chemical groundwater variables at all 7 locations. For each monitoring event and location, the efficiency of the buffer to remove nitrate from the alluvial aquifer was estimated. Just as geologic controls had influenced where nitrate was located within alluvial aquifers, it also significantly affected the efficiency with which buffers removed nitrate from groundwater.

Analyses of sediment and groundwater samples collected on July 30, 2001, at the JRS site are shown in Figure 13. Between input and output points beneath the buffer, there was a slight increase in DOC in the lowest three sampling ports (Figure 13). Dissolved O_2 decreased near the water table, but remained essentially constant in the lower portions of the aquifer. Nitrate-N concentrations decreased from 18.4 mg/L in the sampling port at 1.85 m at the crop edge (Piezometer G) to less than 0.3 mg/L in all ports at the creek piezometer (B). As groundwater traveled beneath the buffer, Cl concentrations increased slightly from a range (vertical) of 14.2 to 15.1 mg/L in multilevel ports at the crop side to a range of 18.3 to 20.3 mg/L in ports at the creek side. The increase in Cl concentration may indicate mixing of groundwater with water of Bear Creek.

Hydraulic head measurements taken at the time of sampling indicated that a horizontal gradient of 0.004 exists toward Bear Creek below the buffer. Using K data, groundwater velocities beneath the buffer were estimated to be between 0.13 and 2.76 m/day, with residence times ranging from about 14 days near the bottom of the aquifer to about 130 days near the water table.

Nitrate-N mass entering the buffer through a 10-m wide strip was estimated at 11.2 g/day, while mass leaving the buffer was estimated at 0.02 g/day resulting in a 99.8 percent reduction in nitrate (Table 2). Although groundwater velocities at this location were higher in the lower portions of the alluvial aquifer, it appears that hydrogeology limited the flow of nitrate-contaminated groundwater to the upper portions of the aquifer near the water table where velocities were much lower.

Data collected from the RRS site on May 29, 2001, showed neither significant gains in DOC nor losses in dissolved O_2 (Figure 10). Data indicate that a significant portion of the nitrate which occurred in the upper portion of the aquifer was removed. A horizontal gradient of 0.026 toward Bear Creek indicated groundwater velocities between 3.3 and 15 m/day, with residence times nearing several days near the water table and up to a week near the base of alluvial sediments. However, these groundwater velocities seem anomalously high and may not represent ambient conditions.

Nitrate-N mass entering the buffer was estimated at 52.3 g/day, while mass leaving the buffer was estimated at 24.4 g/day, resulting in a 53.5 percent reduction in nitrate. So, in contrast to the JRS site, the RRS site removed only 50 percent of the nitrate that flowed beneath it. At this location, a low K unit effectively isolates the upper and lower portions of the alluvial aquifer. While nearly all nitrate was removed from the upper portion, the aquitard allowed nitrate to pass unaffected in the aquifer beneath the buffer.

Data for the LSE site for June 18, 2001, showed DOC concentrations increasing toward Bear Creek, while dissolved O_2 levels decreased toward Bear Creek. However, nitrate-N concentrations were considerably higher along Bear Creek than adjacent to crops, approaching 10 mg/L at the creek-side piezometer. A horizontal gradient of 0.026 outward from Bear Creek was recorded resulting in groundwater velocities beneath the buffer between 0.3 and 3.5 m/day. Residence times neared eighty days near the surface of the aquifer and as short as 7 days near the bottom of the aquifer. Groundwater flow away from Bear Creek could be due to beaver dams located just downstream from the monitoring site which would have artificially increased the stream stage. The dams were first noticed in the spring of 2001, and their arrival coincided with a decrease and occasional reversal of hydraulic gradients away from Bear Creek.

At LSE, nitrate-N mass leaving Bear Creak and entering the buffer was estimated at 21.6 g/day, while mass leaving the buffer was estimated at 9.5 g/day. This resulted in a 56 percent reduction in nitrate beneath the buffer. Nitrate removal in the lower portions of the alluvial aquifer appears to have been limited by the relatively short residence time. Although about 50 percent of nitrate was removed from this site, the data suggests that riparian buffers have the potential to remove nitrate in surface water, when the stream recharges shallow groundwater below buffers.

Groundwater data collected on July 30, 2001, at the LSW site showed dissolved O_2 concentrations decreased as groundwater flowed beneath the buffer toward Bear Creek (Figure 11). Although DOC concentrations never exceeded 1 mg/L, nitrate-N concentrations were found to decrease from 15 mg/L at the deepest piezometer near the crop (J), to below detection at the creek piezometers (K). Groundwater velocities beneath the buffer were estimated to be between 0.1 m/day near the surface of the aquifer and 3.8 m/day near the bottom of the aquifer, with residence times between 12 and 110 days.

Nitrate-N mass entering the buffer was estimated at 64.7 g/day, while mass leaving the buffer was negligible, thus effecting a near 100 percent reduction in nitrate. The efficient performance of this site may be in part due to the relatively slow groundwater velocities. Fine, loamy material (perhaps containing more carbon) encountered near the creek may have slowed flow enough for denitrification to occur.

At the TE site, analyses for July 30, 2001, showed DOC increasing from below 1 mg/L at all sampling levels in the crop piezometer nest (M) to between 11 to 26 mg/L in the creek piezometer nest (N) (Figure 12). Dissolved O_2 levels decreased from 5 to 7 mg/L near the crop to less than 3 mg/l near Bear Creek. Nitrate-N concentrations decreased from below

0.5 mg/L in all samples near the crop to below detection at Bear Creek. Groundwater velocities beneath the buffer ranged between 0.2 m/day near the surface of the aquifer and 6.2 m/day near the bottom. Residence times ranged between 8 and 18 days.

Nitrate-N mass entering the buffer was estimated at 0.90 g/day, while mass leaving the buffer was estimated at 0.03 g/day. The net effect was a 96.6 percent reduction in nitrate. Success of this buffer in removing incoming nitrate may be attributed to the relatively high contribution of DOC by the buffer. Although the amount of nitrate entering the buffer at this location was less than other sites in the watershed, the buffer is believed to have the potential to remove significantly more nitrate. The absence of nearby upland topographic relief at this location may indicate that a significant component of groundwater flow is occurring parallel to Bear Creek with only a small component of the flow occurring toward the creek. This may explain how such relatively small concentrations of nitrate are being detected at multilevel piezometer M, which lies within several feet of a cornfield.

Increases in DOC concentrations in many locations (JRS, RRS, LSE, and TE) suggest that buffers contribute organic matter to the shallow aquifer and act as a possible energy source for soil microorganisms. Decreased dissolved O_2 and nitrate-N concentrations suggest denitrification as a removal mechanism for nitrate in several locations. The best example is the JRS site, where decreases in nitrate concentration by over 95 percent coincided with increases in DOC and decreases in dissolved O_2 along the groundwater flow path. At this location, nitrate loss occurred in shallow sediments where groundwater residence times were over 100 days. Throughout the watershed, residence times were found to range from 5 to 10 days in coarse alluvium and up to 200 days in fine alluvium. Nitrate loss occurred when hydrogeologic controls influenced flow of nitrate contaminated groundwater to maximize residence time and contact with carbon sources. Table 3 summarizes conditions and relative efficiency of sites. Seasonal variation in buffer efficiency may also occur. While buffers at the JRS, LSW and TE sites consistently removed over 80 percent of groundwater nitrate (Figure 15, 17), buffer efficiency at RRS and LSE varied between no loss and up to 100 percent removal (Figure 16, 17).

Conclusions

Results of this research indicate that the variables controlling the efficiency of nitrate removal in riparian buffers vary greatly throughout the Bear Creek watershed. Nitrate-N concentrations within the watershed varied with location, depth, and time, with maximum concentrations greater than 15 mg/L. These variations are attributable to hydrogeologic conditions. Variations in the extent and texture of alluvial sediments contributed to groundwater velocities ranging from 0.1 to over several meters per day, resulting in buffer residence times ranging several days to well over 200 days. Often, low-K units contained within alluvial sediments divided the alluvial aquifer into distinct hydrogeologic units, which could often contribute to either the success or failure of a buffer to decrease nitrate concentrations. Geochemical parameters indicated that nitrate removal was often achieved when available carbon concentrations were high and dissolved O_2 concentrations were low, suggesting denitrification as a removal mechanism.

Buffers which consistently removed the most nitrate (>95 %) were characterized by having long residence times and geology that confined the flow of nitrate-rich groundwater to the shallow areas beneath of the buffer, where available organic carbon was plentiful and dissolved oxygen rates were low (Figure 18). Locations with deep aquifers and/or high groundwater velocities were found to be less efficient. Because hydrogeologic conditions proved to be a controlling factor in groundwater quality, it is important to note that only a relatively short stretch of Bear Creek was investigated. It is suspected that the geologic heterogeneity at the watershed scale would be even greater than observed in the study area.

Very little correlation was found between buffer efficiency and buffer maturity. This may be in part due to the channelizing of Bear Creek in locations where the youngest buffers are now located. This alteration to the alluvial aquifer may have artificially loaded the shallow sediment with carbon from either streambed or surficial sediments, thus increasing the potential for denitrification and removal of nitrate.

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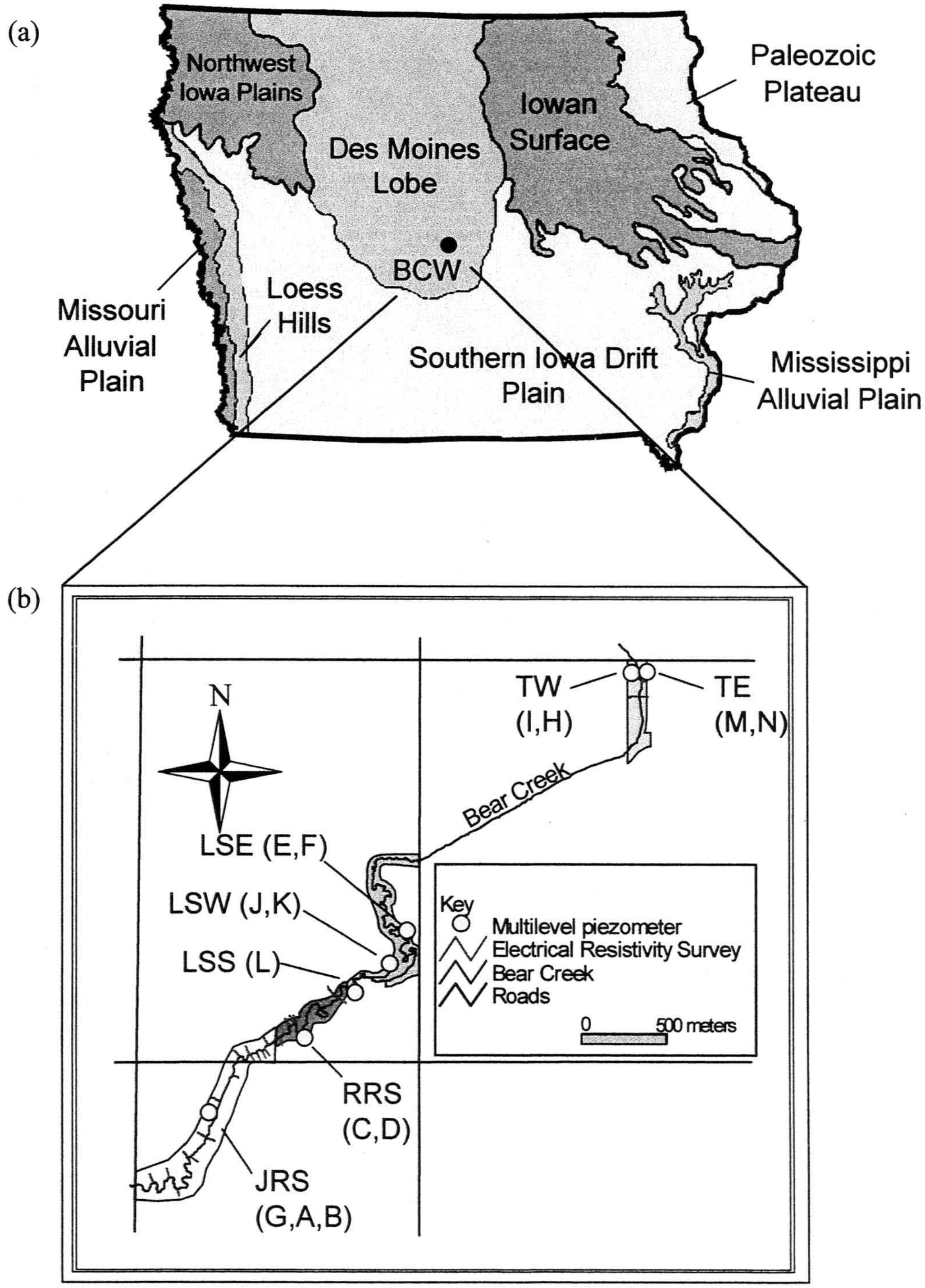


Figure 1. (a) Landform regions of Iowa showing location of Bear Creek Watershed (BCW). (b) Location of study sites along Bear Creek. Multilevel piezometers shown in parentheses (Wineland, 2002).

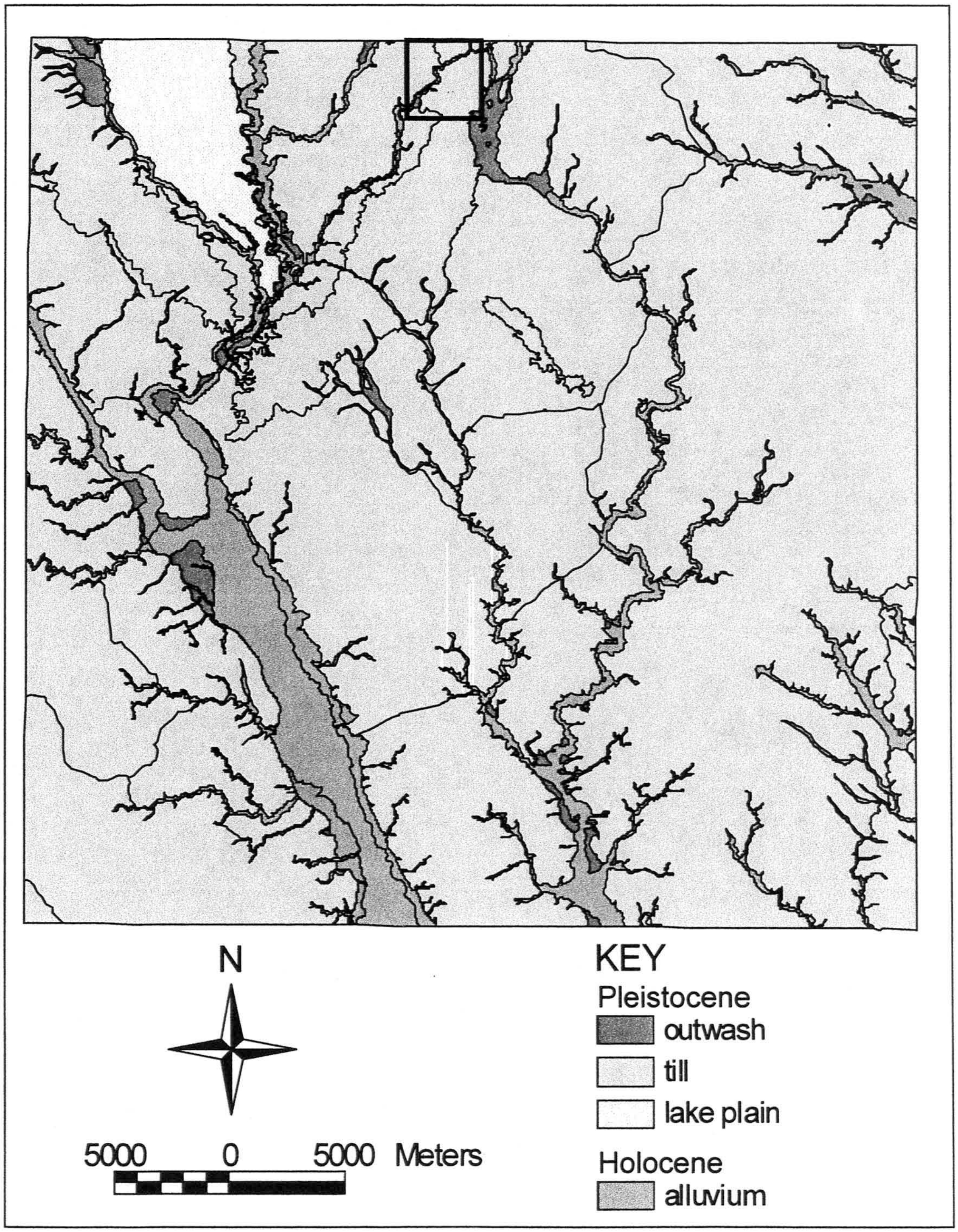


Figure 2. Surficial geology of Story County, Iowa. Research area indicated by box in top-center area of map (Modified from Quaid et al., 2001).

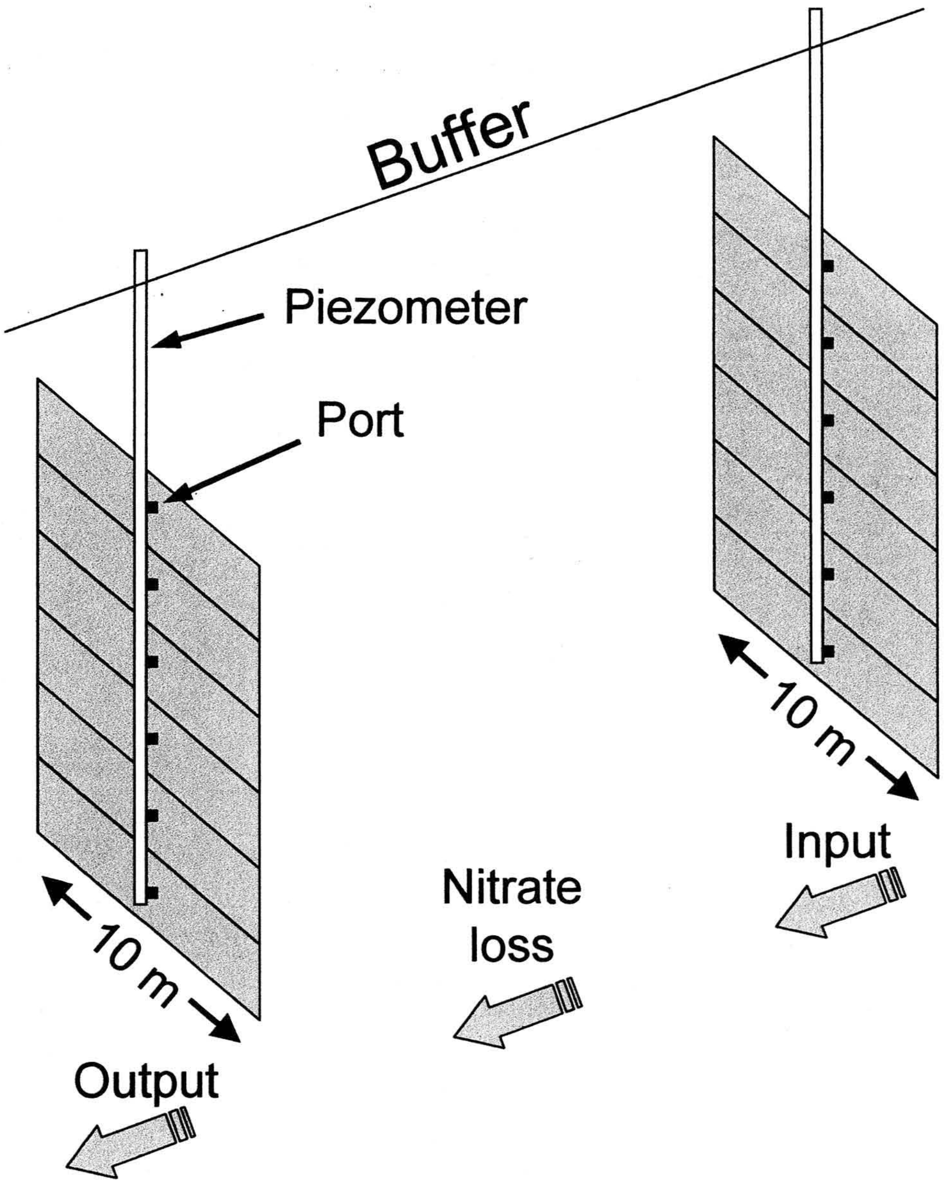


Figure 3. Diagram showing area used for calculation of chemical flux.

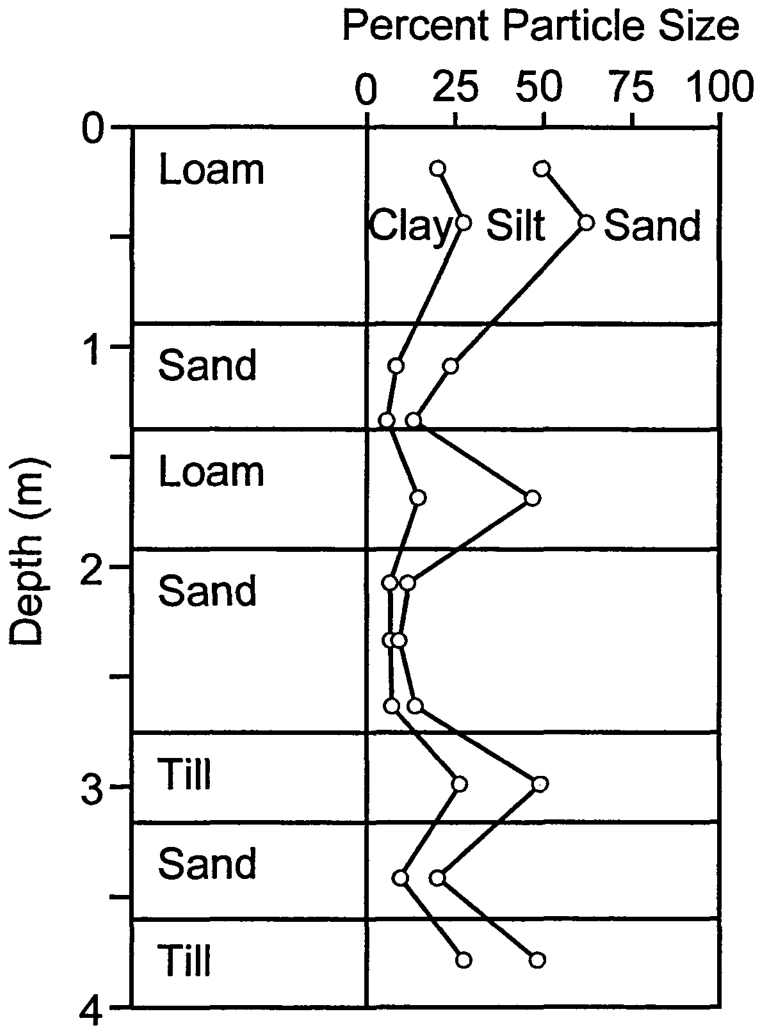


Figure 4. Particle-size distribution and sediment classification of core from piezometer D at the RRS site.

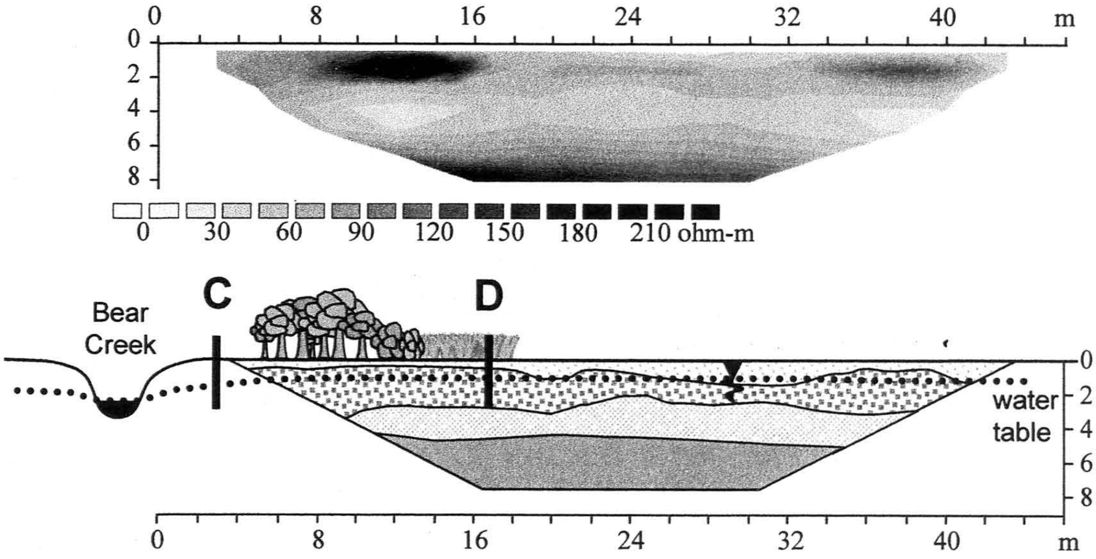


Figure 5. Resistivity profile and geologic interpretation at the RRS site. (C) and (D) indicate the locations of boreholes and multilevel piezometers. Area of high resistivity in upper-left portion of profile may represent coarse channel lag deposits.

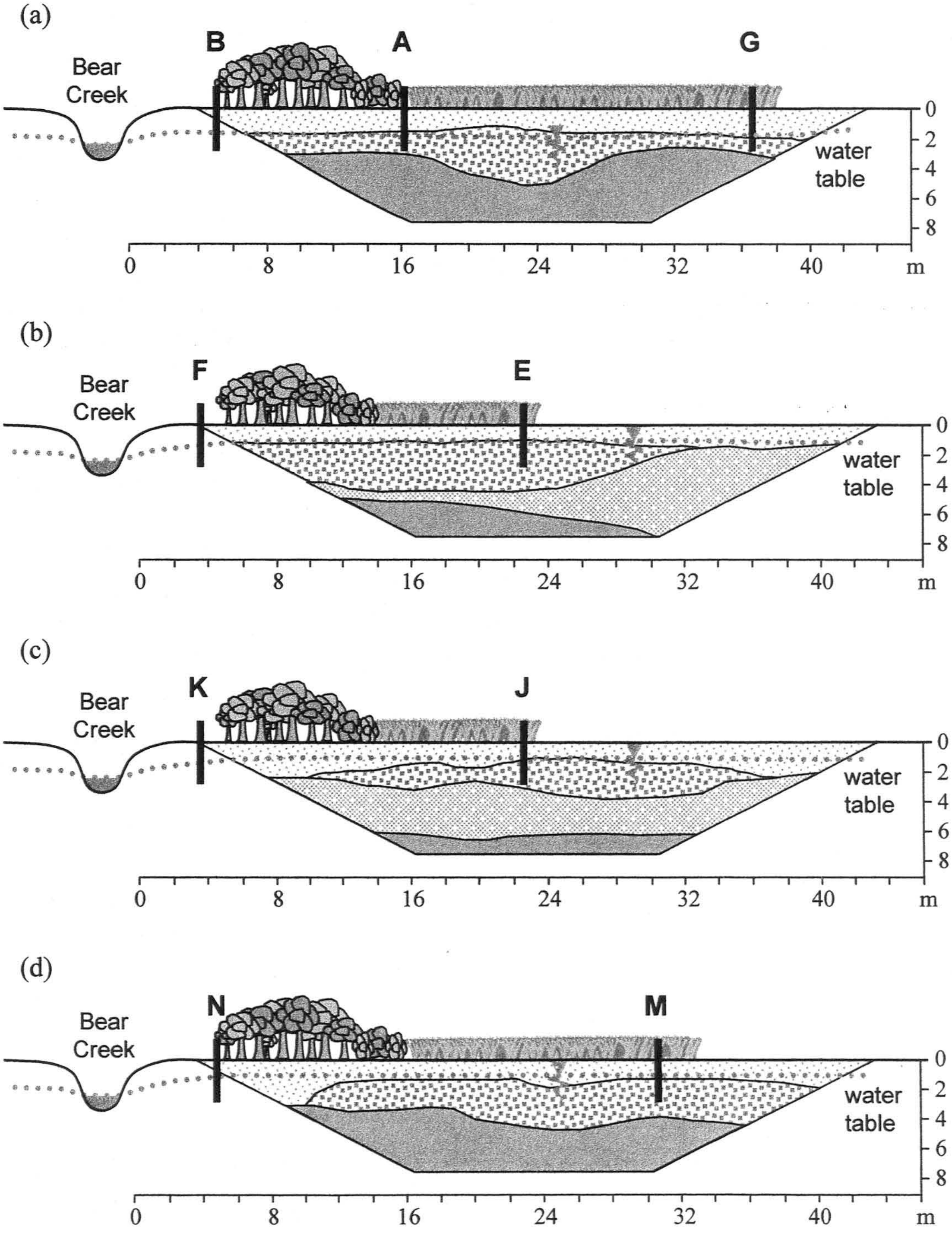


Figure 6. Resistivity-derived interpretations of buffer sediments at the JRS site (a), the LSE site (b), the LSW site (c), and the TE site (d). Piezometer nests indicated by letters.

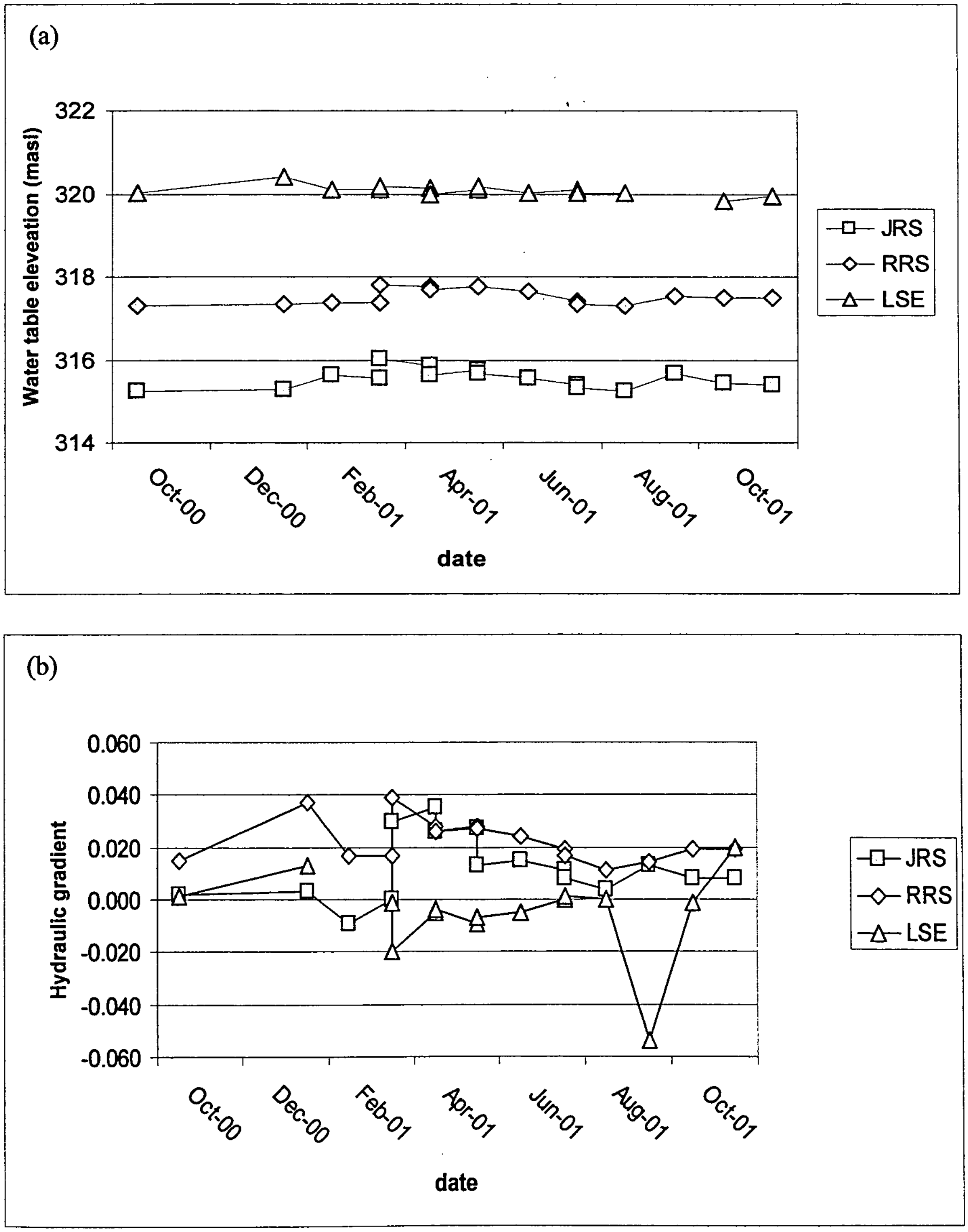


Figure 7 . Water-table elevation (a) and horizontal hydraulic gradients (b) for JRS, RRS, and LSE sites. Negative gradients indicate flow away from stream.

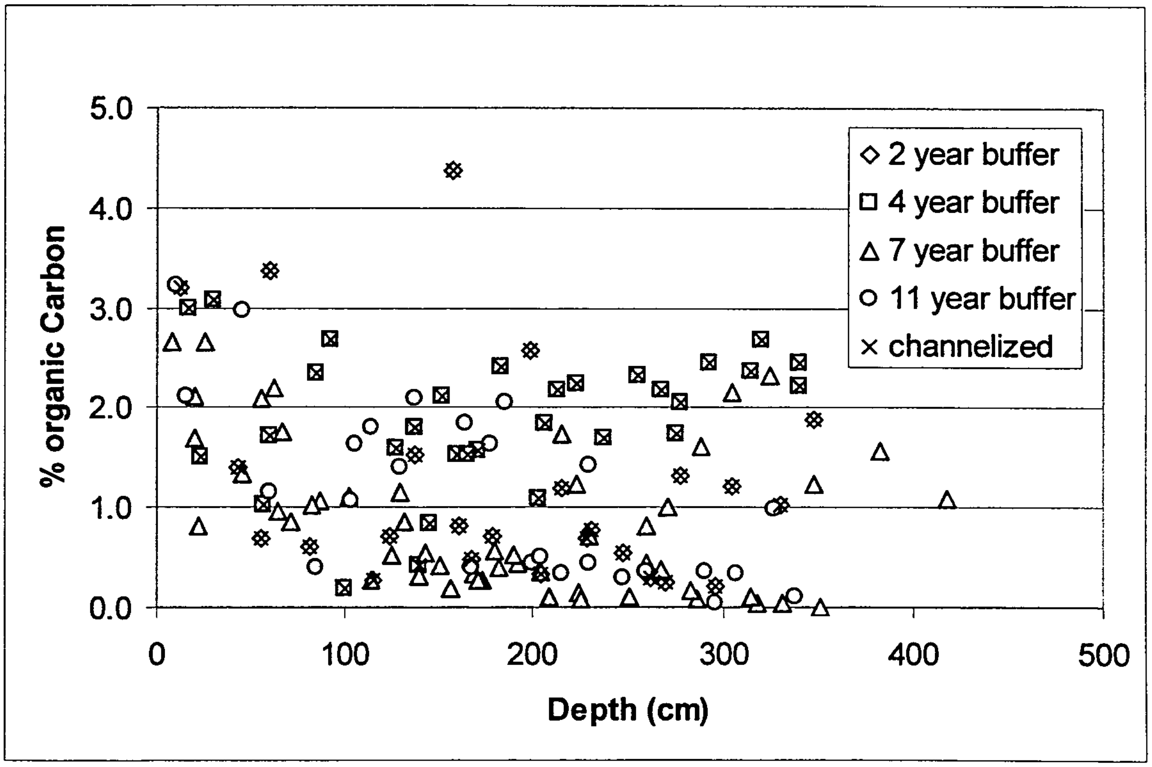


Figure 8. Weight percent of organic carbon in sediments vs. depth beneath buffers. Higher percents on channelized portions of Bear Creek may indicate that channelization provides organic carbon for near-creek and shallow sediments.

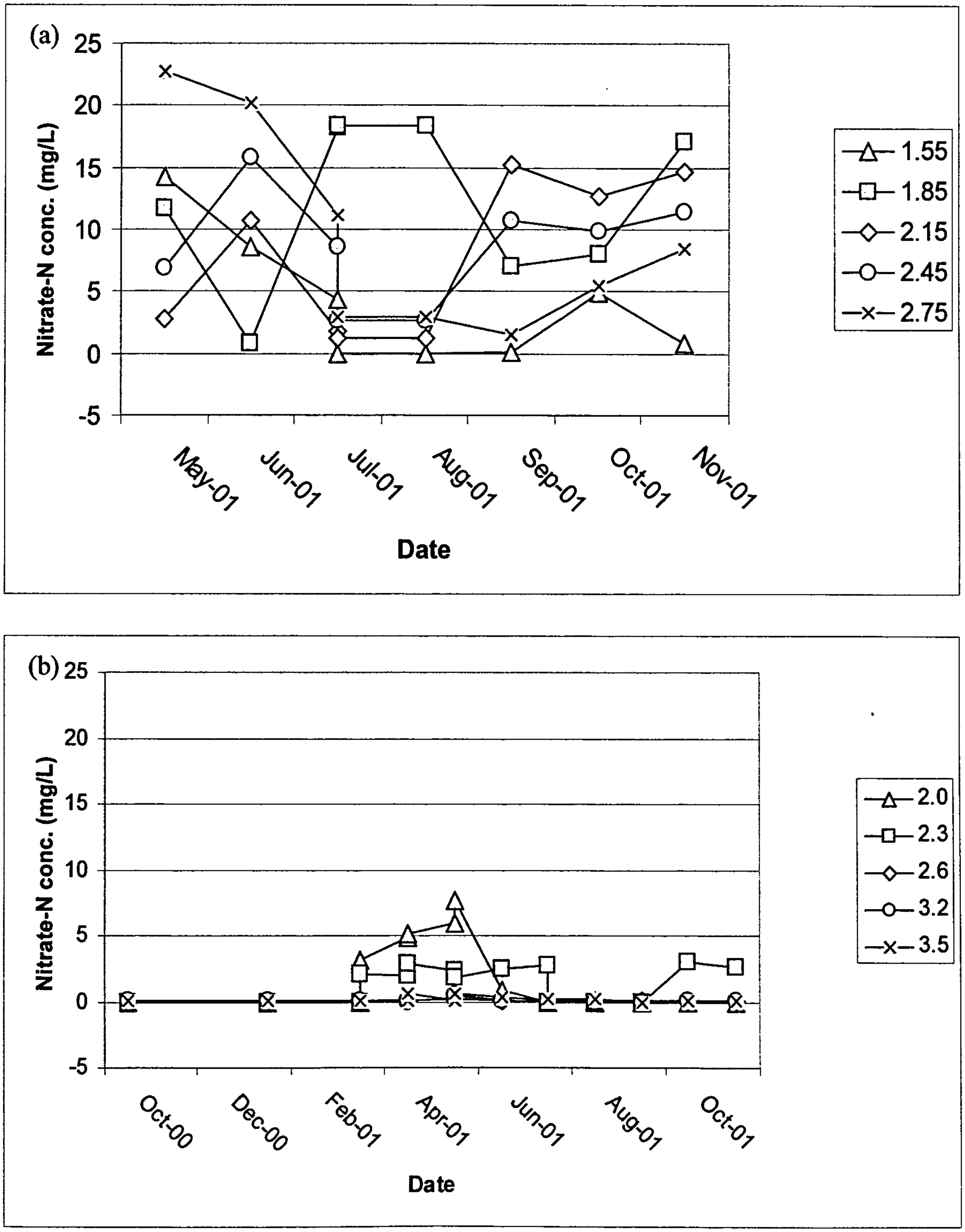
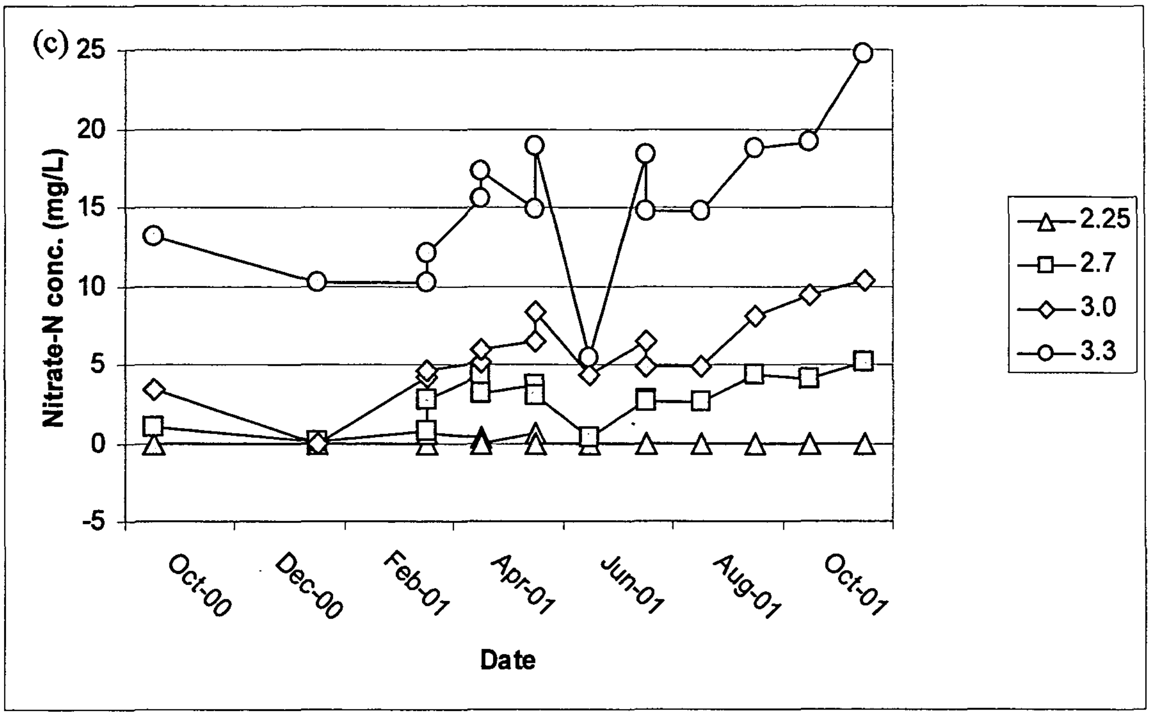
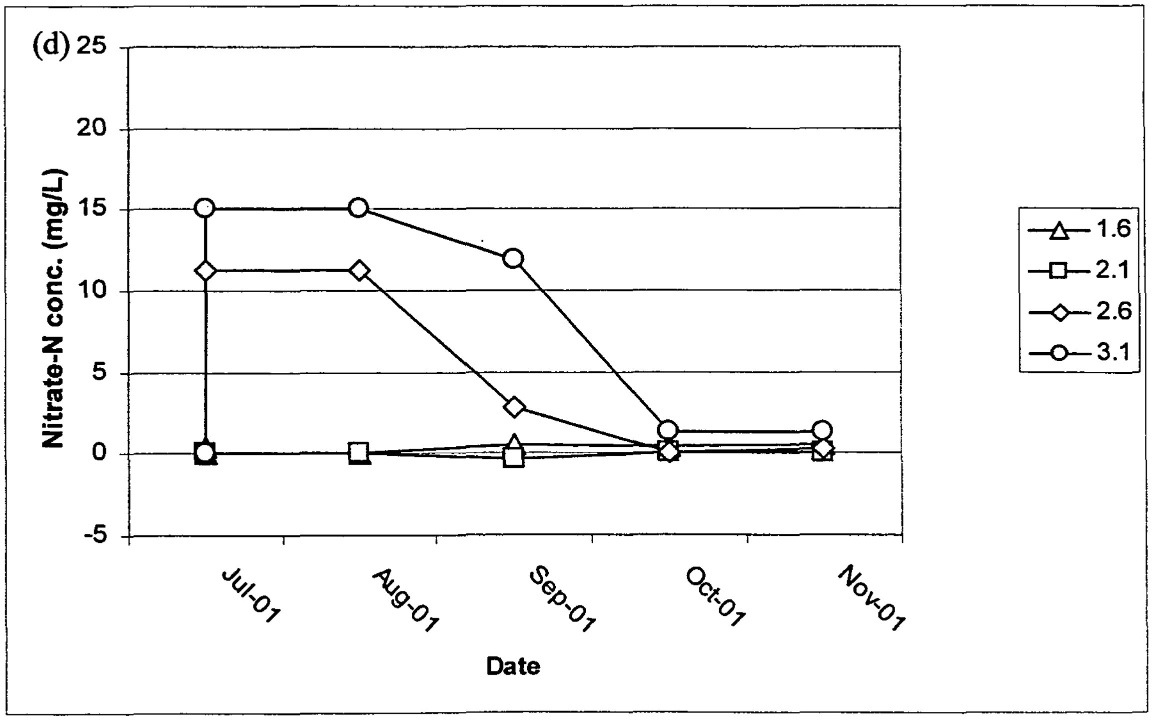
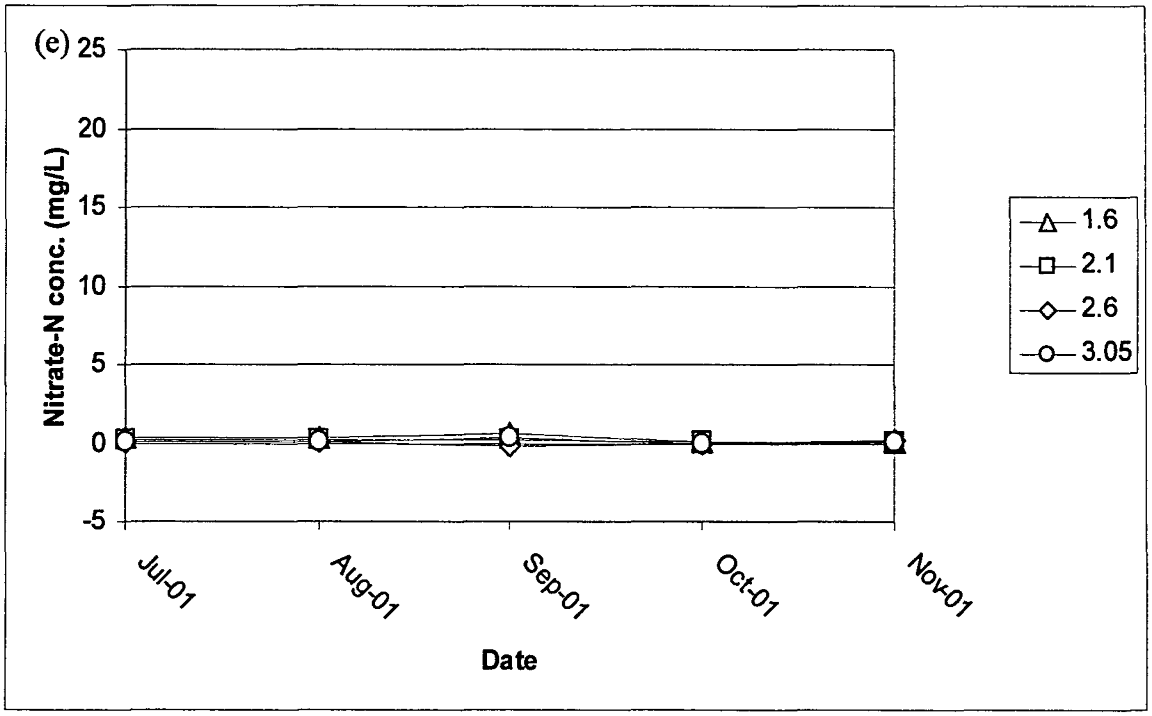


Figure 9. Nitrate-N concentrations at varying depths (m) in groundwater entering the buffers at the crop edge at the JRS site (a), the RRS site (b), the LSE site (c), the LSW site (d), and the TE site (e).


(c)
25
20
15
10
5
0
-5
Nitrate-N conc. (mg/L)
Oct-00
Dec-00
Feb-01
Apr-01
Jun-01
Aug-01
Oct-01
Date
2.25
2.7
3.0
3.3


(d)
25
20
15
10
5
0
-5
Nitrate-N conc. (mg/L)
Jul-01
Aug-01
Sep-01
Oct-01
Nov-01
Date
1.6
2.1
2.6
3.1


(e)
Nitrate-N conc. (mg/L)
25
20
15
10
5
0
-5
Jul-01
Aug-01
Sep-01
Oct-01
Nov-01
Date
1.6
2.1
2.6
3.05

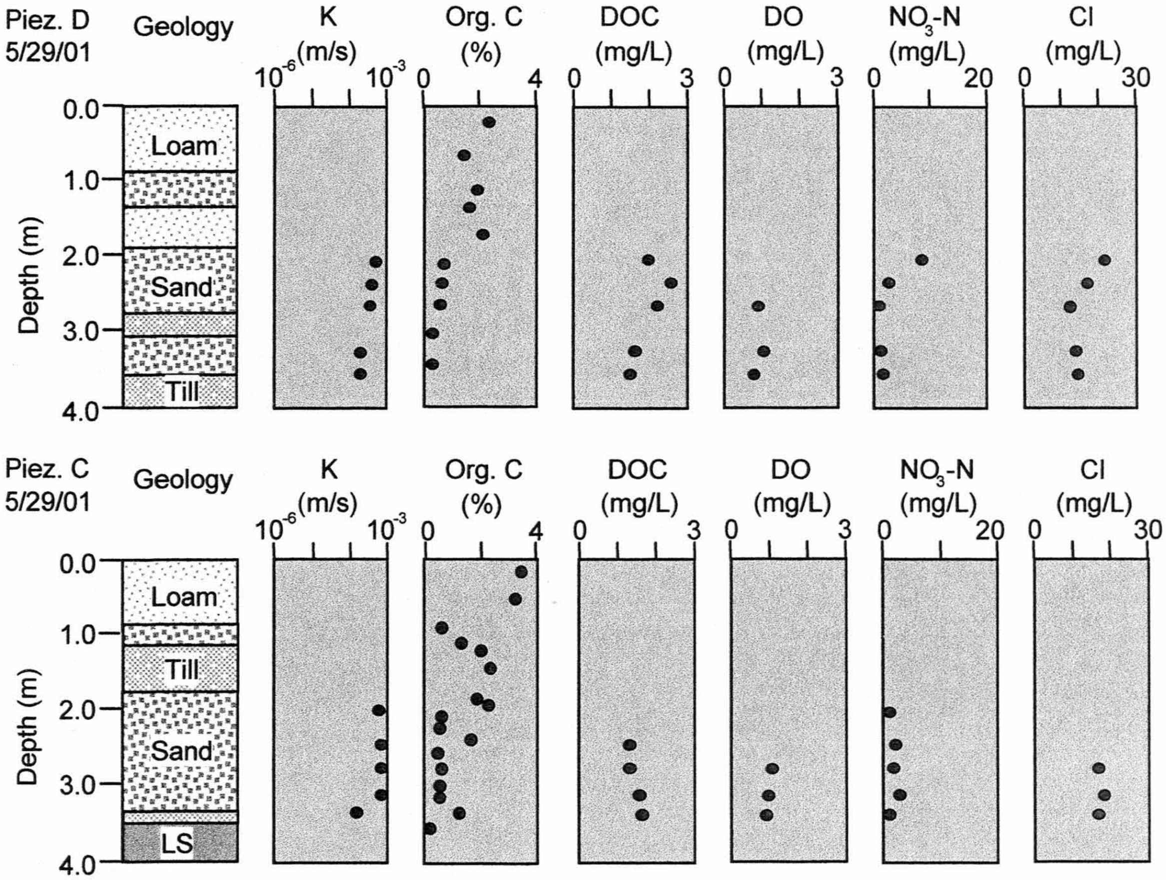


Figure 10. Vertical profiles of geochemical parameters collected from piezometers D and C on 5/29/01 at the RRS site (see Figure 5).

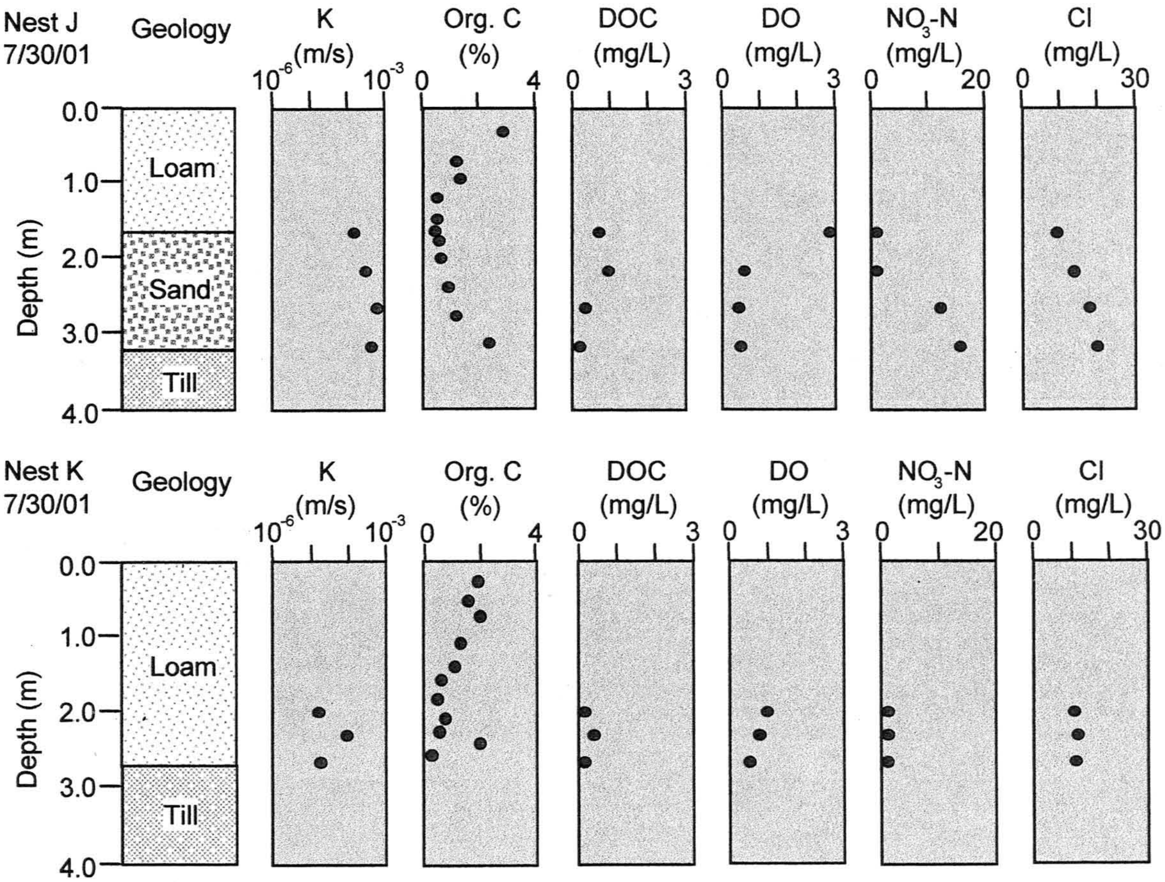


Figure 11. Vertical profiles of geochemical parameters collected for piezometer nests on 7/30/01 at the LSW site (see Figure 6c).

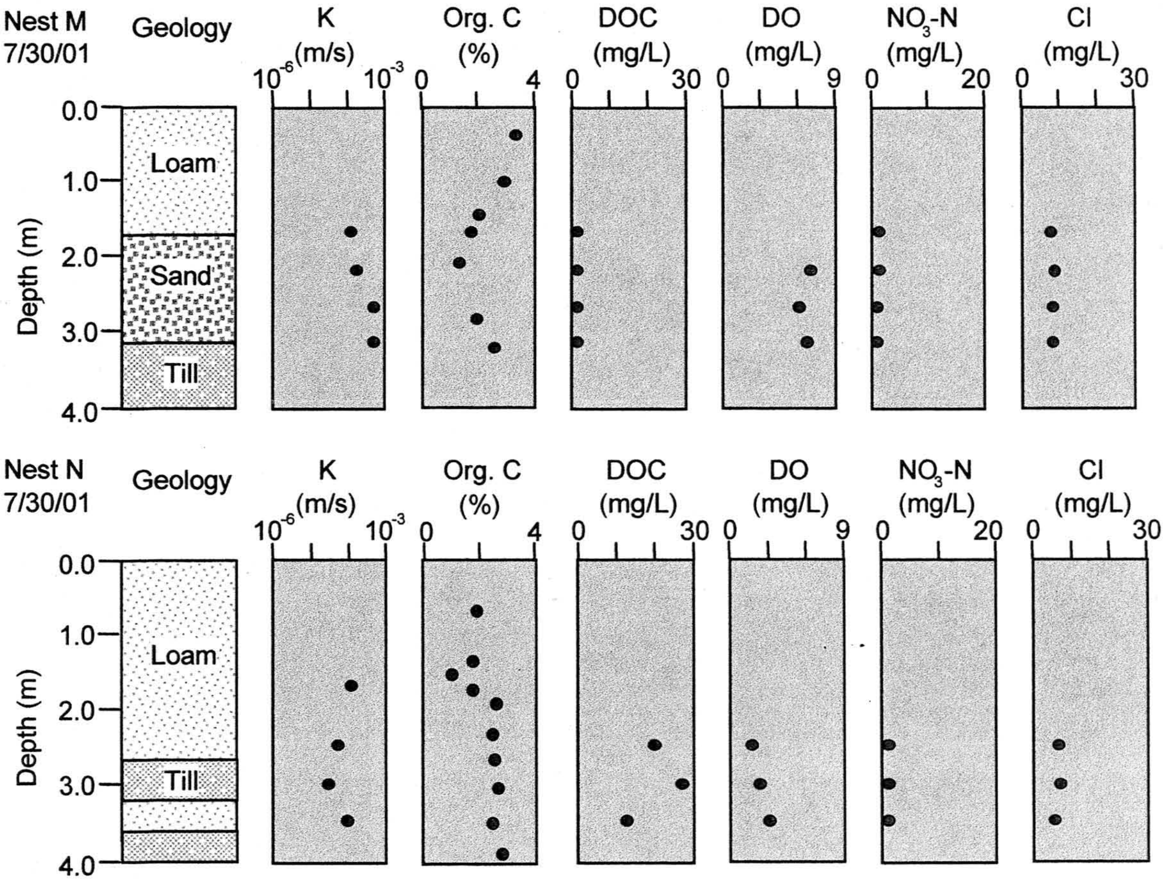


Figure 12. Vertical profiles of geochemical parameters collected from piezometer nests M and N on 7/30/01 at the TE site (see Figure 6d).

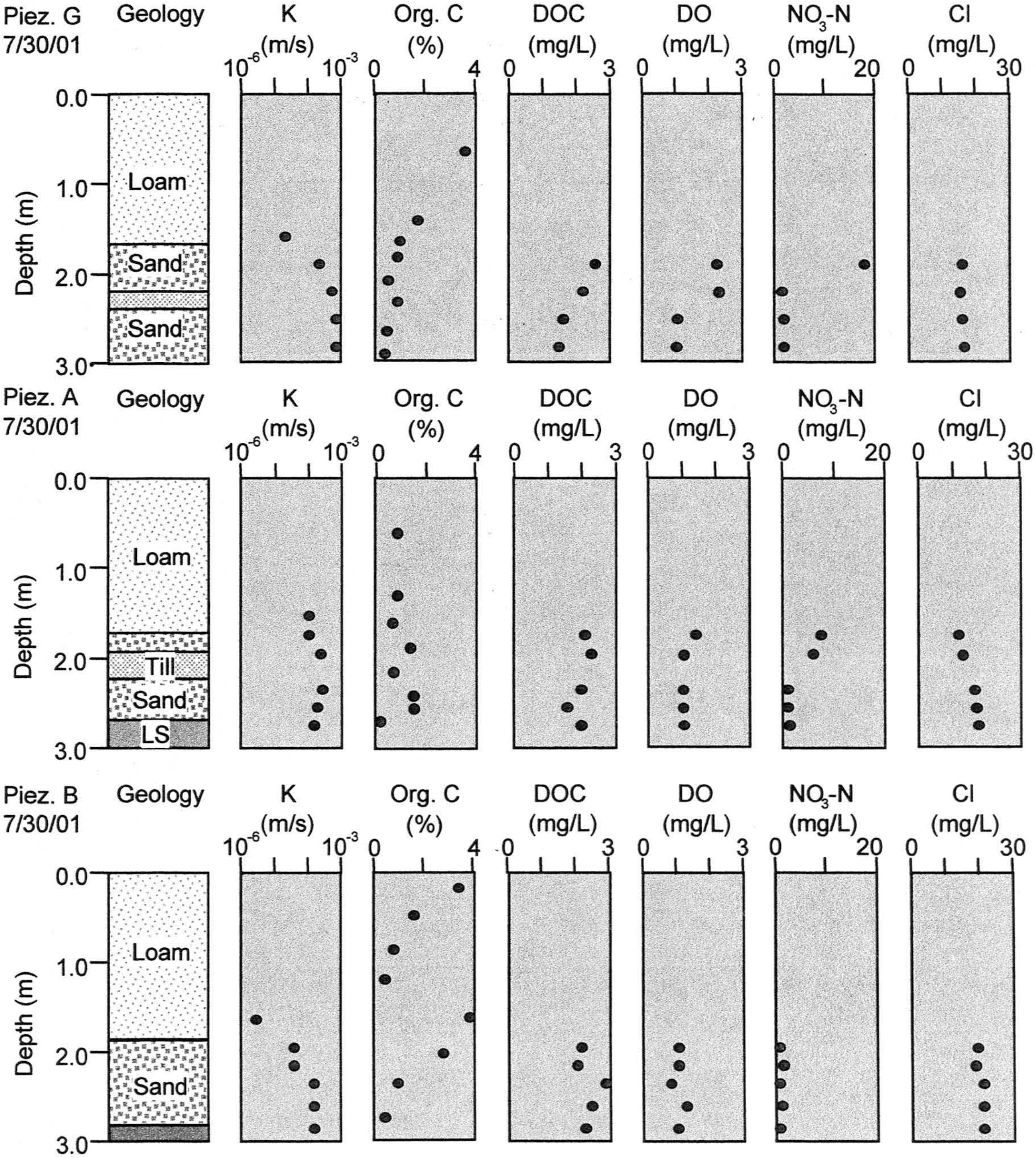


Figure 13. Vertical profiles of geochemical parameters collected from piezometers G, A, and B on 7/30/01 at the JRS site (see Figure 6a).

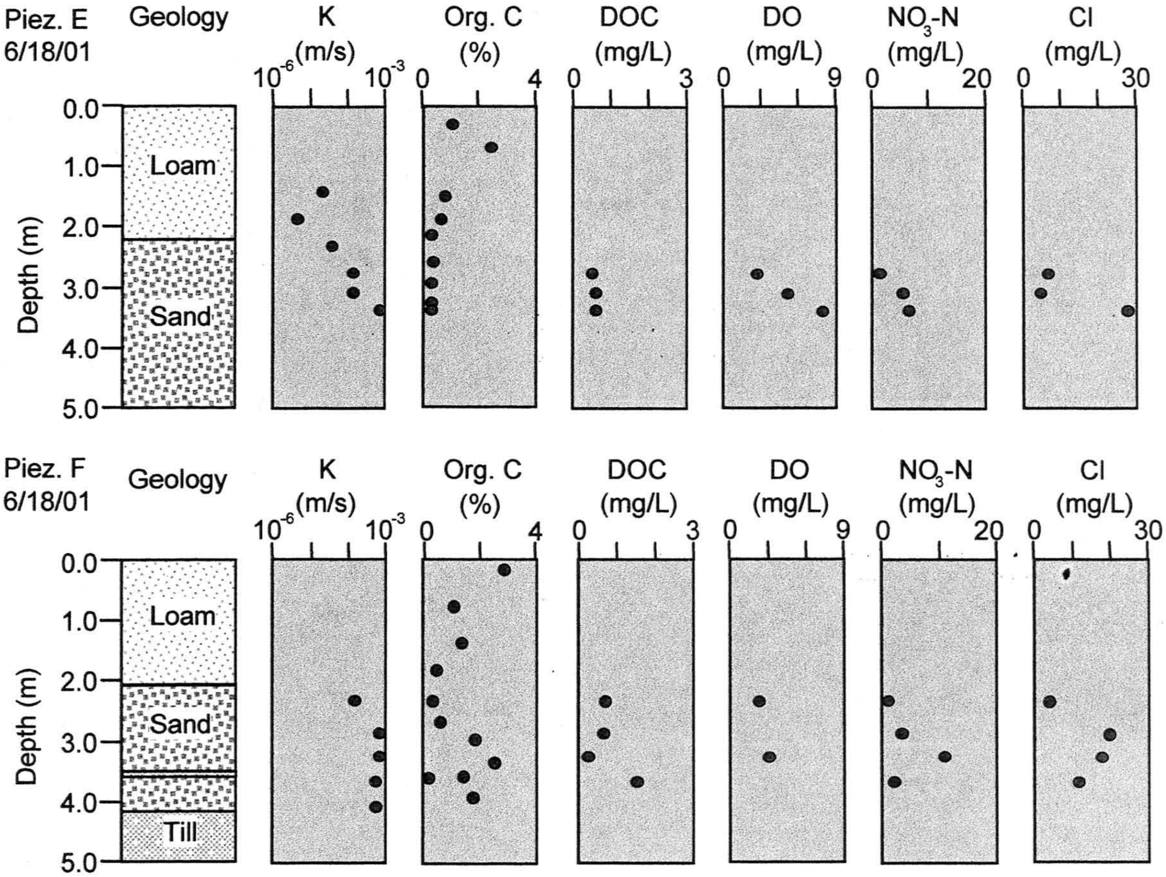


Figure 14. Vertical profiles of geochemical parameters collected from piezometers E and F on 6/18/01 at the LSE site (see Figure 6b).

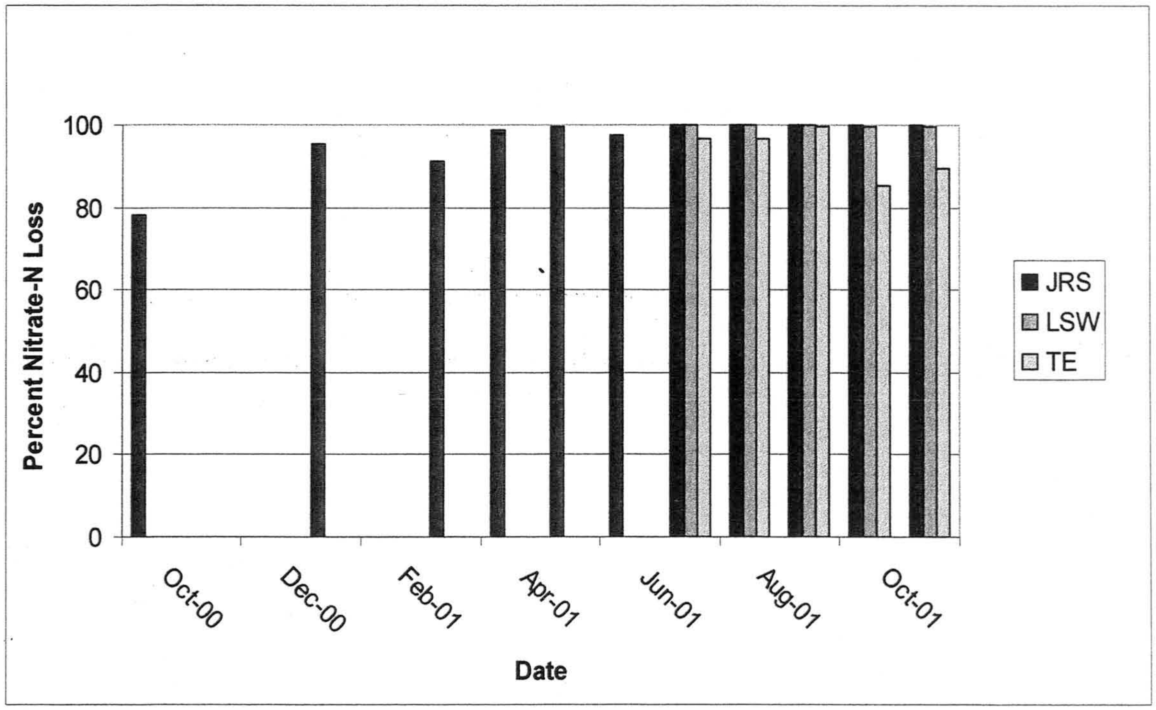


Figure 15. Percent nitrate-N removal at the JRS, LSW, and TE sites during the study.

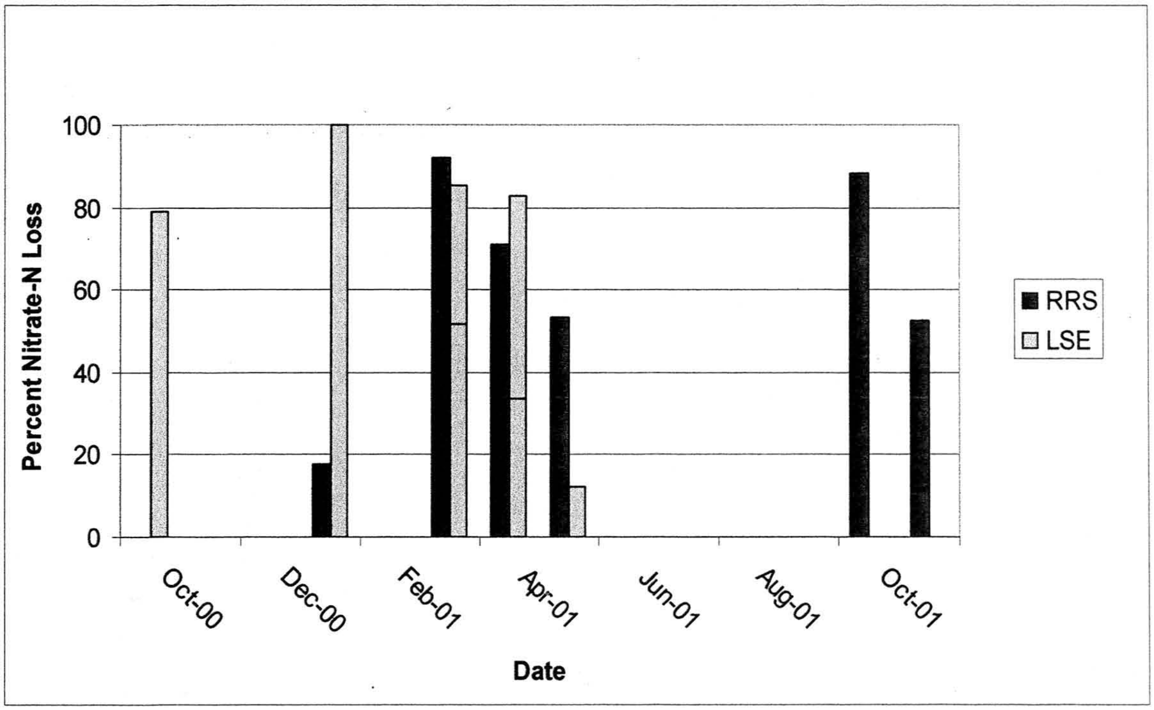


Figure 16. Percent nitrate-N removal at RRS and LSE during the duration of the study. No evidence of nitrate loss was observed during the summer of 2001 (June - August) at these sites.

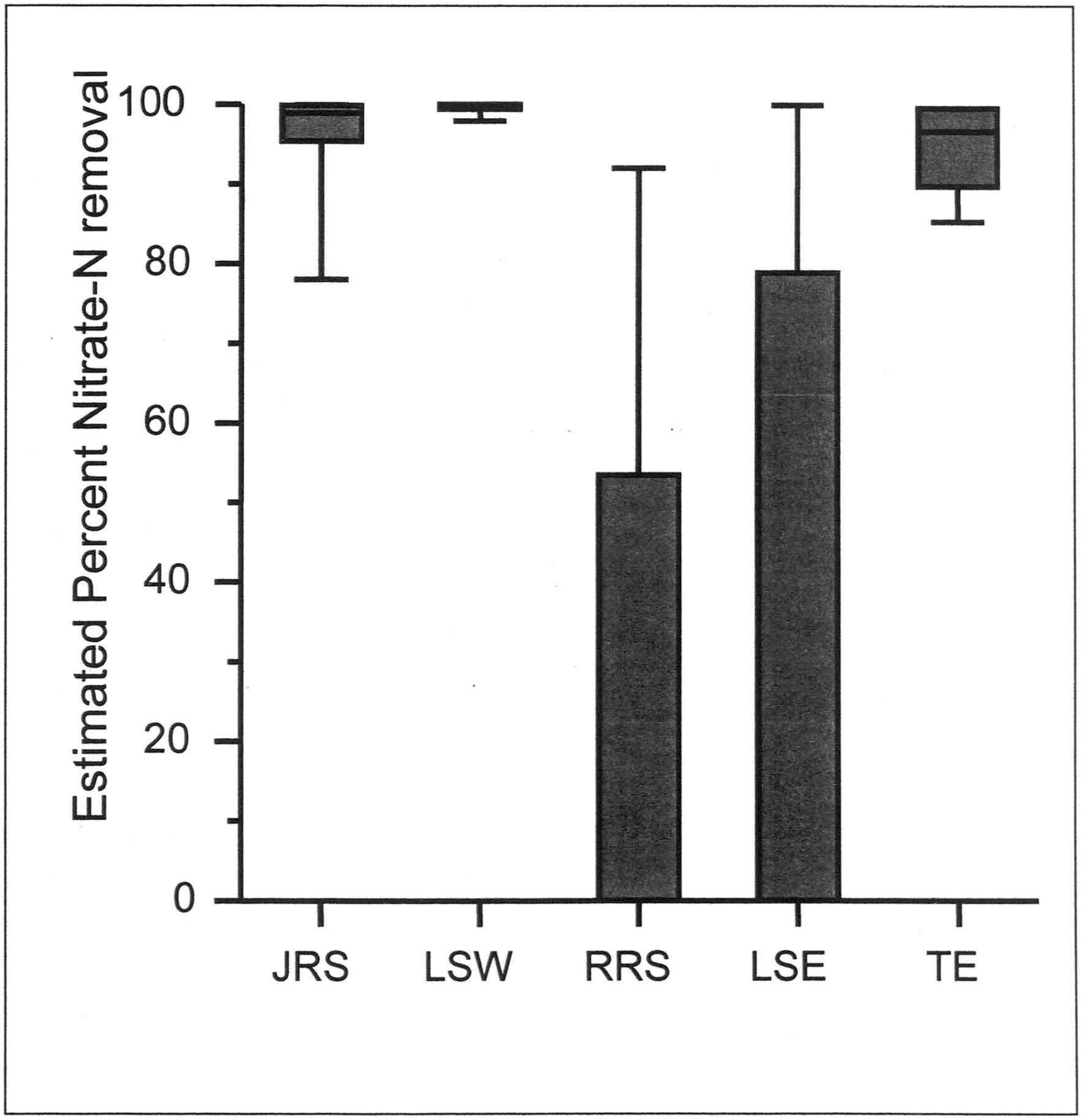


Figure 17. Box and Whisker plot showing median, quartiles, and minimum and maximum of estimated percent nitrite-N removal observed at the JRS, LSW, RRS, LSE, and TE locations during the study.

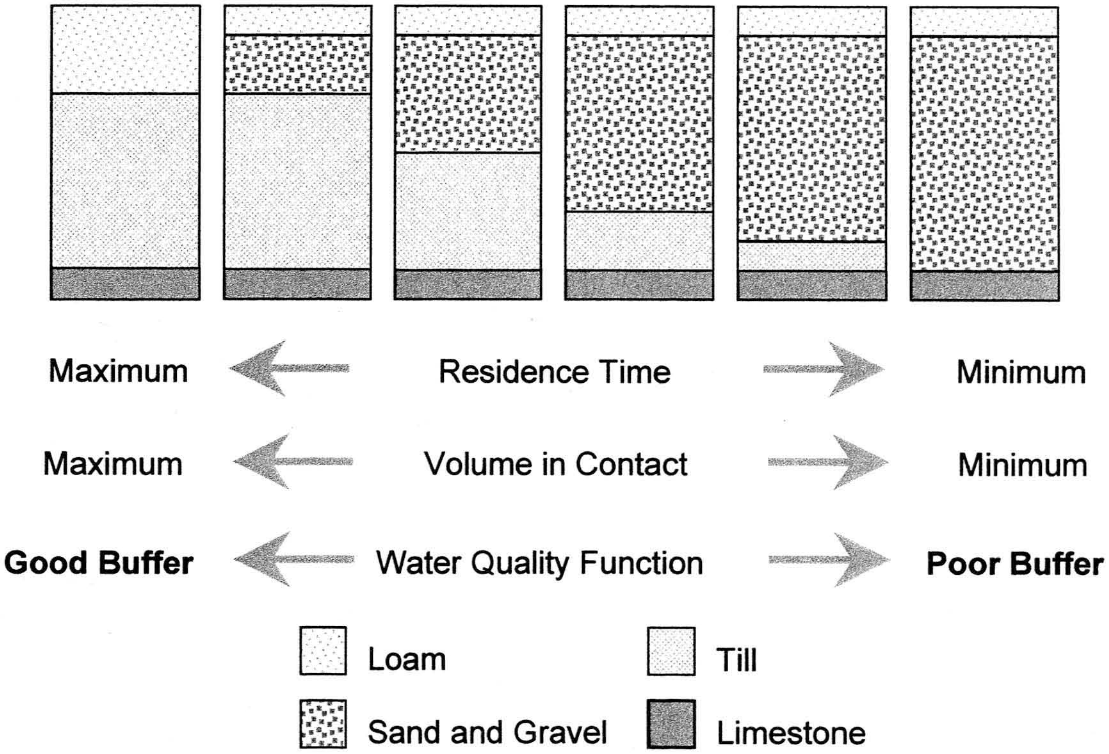


Figure 18. Diagram showing range of vertical geologic sequences encountered at Bear Creek, the residence time and volume of groundwater in contact with the shallow, buffer influenced portion of the alluvium, and the predicted ability of the buffer to improve water quality.

	JRS	LSW	RRS	LSE	TE
Buffer Age (yrs)	2	7	11	7	4
Buffer Width (m)	34	25	18	24	28
Alluvium Depth (m)	3	3	3.5	> 5	> 5
Alluvium Width (m)	> 46	40	45	30	> 46
Beneath Alluvium	limestone	till	till	till	till
Horizontal Gradient	0.012	0.006	0.022	0.001	0.013

Table 1. Summary of physical parameter estimates at each site.

At Crop:

MLP G Sampling Depth (m)	Horizontal gradient	K (m/s)	ALV (m/day)	NO3-N (mg/L)	Mass Flux [g/(day-m^2)]	Section width (m)	Section height (m)	**Total Flux** (g/day)
1.55	0.004	1.2E-05	0.03	–	–	10	0.3	–
1.85	0.004	1.7E-04	0.39	18.36	1.079	10	0.3	3.23606016
2.15	0.004	7.6E-04	1.75	1.27	0.334	10	0.3	0.10007194
2.45	0.004	1.2E-03	2.76	2.7	1.120	10	0.3	0.3359232
2.75	0.004	1.2E-03	2.76	2.89	1.199	10	0.3	0.35956224
								4.03161754

At Creek:

MLP B Sampling Depth (m)	Horizontal gradient	K (m/s)	ALV (m/day)	NO3-N (mg/L)	Mass Flux [g/(day-m^2)]	Section width (m)	Section height (m)	**Total Flux** (g/day)
1.6	0.004	3.4E-06	0.01	–	–	10	0.3	–
1.9	0.004	5.5E-05	0.13	0.01	0.000	10	0.25	0.00004752
2.1	0.004	5.5E-05	0.13	0.24	0.005	10	0.2	0.00091238
2.3	0.004	1.5E-04	0.35	0.01	0.001	10	0.225	0.00011664
2.55	0.004	1.5E-04	0.35	0.07	0.004	10	0.25	0.0009072
2.8	0.004	1.5E-04	0.35	0.01	0.001	10	0.25	0.0001296
								0.00211334

estimation of % NO3-N removed: 99.948

Table 2. Sample calculation of estimated nitrate loss over buffer for the JRS site.

	JRS	LSW	RRS	LSE	TE
Age (yrs)	2	7	11	7	5
DOC at crop (mg/L)	1.2	1.2	0.6	1.1	1.3
DOC at creek (mg/L)	1.5	1.0	0.8	1.3	9.3
Hydrogeology	Shallow confing layer	Low K, very little gradient	Complex alluvial / till	Deep sands (high K)	Low K near creek
High K residence time (days)	10	10	5	5	10
Low K residence time (days)	175	200	15	30	50
number of observations	15	6	15	15	5
Nitrate-N removed (%)	95.6	99.5	25.0	29.6	93.5

Table 3. Summary of conditions at each site. Values of DOC represent vertical and temporal mean for each piezometer. Values of residence time represent temporal mean for high and low K portions of the aquifer. Values for nitrate-N removed represent the mean value of percent removed at each location over the period of observation.

AN IMPROVED MULTILEVEL PIEZOMETER SYSTEM SUITABLE FOR RIPARIAN BUFFER INVESTIGATIONS

A paper to be submitted to *Soil Science Society of America Journal*

Timothy R. Wineland, William W. Simpkins, Richard C. Schultz, and Thomas M. Isenhart

Abstract

Vertical stratification of geochemical parameters in groundwater is usually determined by nested or multilevel piezometers. This paper describes a method for the construction, installation and monitoring of a multilevel piezometer design that provides an improved method of collecting hydrogeologic data in shallow alluvial sediments. A Giddings™ soil-coring rig is used to collect core and install a multilevel piezometer. Piezometers were constructed to site specific conditions, based on stratigraphic data from core. Two or more multilevel piezometers were positioned in a transect along the direction of groundwater flow allowing collection of individual values of hydraulic head at each sampling point and the calculation of both vertical and horizontal gradients. Falling-head slug tests and particle-size analysis of sediment cores were used to determine hydraulic conductivity. Groundwater samples from the multilevel piezometers showed detailed geochemical variation vertically and horizontally. The method uses inexpensive materials and causes minimal aquifer disturbance, while providing most of the benefits of multilevel piezometers installed with other methods.

Introduction

Groundwater investigations often require knowledge of the vertical stratification of contaminants and water quality parameters beyond what is provided by conventional monitoring wells. Methods have been developed to collect depth-specific samples from conventional monitoring wells (e.g. see Puls and Paul, 1997); however, vertical mixing of groundwater may occur in the sandpack. Multilevel piezometers have been used when groundwater samples are required from discrete depths. A hollow-stem auger is commonly used for installation (Smith et al., 1991; Cherry et al., 1983; Pickens et al., 1978), however, it requires a large drilling rig, which may cause concern for site access and disturbance. Pickens et al. (1978) developed an enclosed multilevel piezometer for use in shallow, cohesionless sediments. The piezometer was constructed of polypropylene tubes contained inside a PVC pipe. Sampling tips, which protruded the PVC at varying depths, were encased in fine mesh. Precise measurements of hydraulic head, however, required in-field use of a mercury manometer. Other methods (Stites and Chambers, 1991; Lee and Cherry, 1978) suggest the use of small, disposable drive-points for the installation of sampling ports. While easy to install and very economical, these methods do not allow for collection of core. Similarly, recent use of many direct-push groundwater sampling devices (Pitkin et al., 1999) are limited to blind sampling with no direct means of determining stratigraphy. Methods for collecting core with gas-powered jackhammers (Starr and Ingleton, 1992) have been developed to meet limited access needs, however they involve an extensive field setup including scaffolding, which sacrifices valuable field time. Andress (1999) used a Giddings™ soil coring rig for the installation of multilevel piezometer similar to those used by Lee and Cherry (1978) and Stites and Chambers (1991). This allowed for collection of core and the precise placement of sampling points based on stratigraphic data.

This paper describes the construction, installation, and monitoring of small multilevel piezometers which have been used to estimate hydraulic parameters and water-quality changes in groundwater beneath several re-established riparian buffers. The method allows for collection of core material, stratigraphically based positioning of sampling ports, and the ability to monitor both physical and chemical groundwater parameters. The installation technique described herein was used to install multilevel piezometers to depths of 2 to 4 meters in alluvial sediments along Bear Creek in Story County, Iowa. Piezometers were installed in transects perpendicular to the flow of Bear Creek to monitor groundwater quality changes beneath riparian buffers.

Methods

Boreholes were first made with a Giddings™ soil-coring rig mounted on the back of a tractor. A Giddings™ rig is a direct-push/rotary auger unit designed primarily for small diameter core sampling for agricultural and environmental applications. The initial borehole was made using 8.9 cm diameter soil coring tubes with a standard taper bit. A carbide-tooth bit was necessary at deeper depths. Core was collected and described during both of these methods and used for particle-size and chemical analysis. It was necessary to use a 8.9 cm double-flight auger to penetrate coarse alluvial gravel. In these cases, sediment samples were collected from the auger flights for analysis. The borehole was advanced until refusal in till or bedrock beneath the alluvial sediment. An "over-core" bit (9.5 cm OD diameter) was then installed along the length of the borehole to remove excess sediment. At this point, galvanized conduit (7.6 cm ID diameter) was inserted into the borehole. The conduit was available in 3.05 m lengths with 5.1 cm threaded areas on each end. Threaded couplings (7.6 cm) were used to produce lengths of approximately 1 to 5 m. The casing was firmly seated into the underlying till or bedrock and a small auger (5.1 cm diameter) was used to remove collapsed material from inside the casing. Core was described and taken back to the laboratory for further description and analysis. A multilevel piezometer was then constructed in the laboratory specifically for the location based on site geology.

Materials used in the construction of the piezometers were chosen specifically for their stability and non-reactivity. A PVC center pipe (12.7 mm ID diameter, Schedule 40) was used for vertical support. It spanned the entire borehole and extended 61 cm above the ground surface. Support for sampling tubes and ports was provided by brackets attached with epoxy at 25 to 30 cm intervals. Tubing brackets were constructed from solid, Type I, Grade I PVC (5.1 cm diameter) cut into 6-mm-thick discs and drilled out to 9.5 and 22.2 mm diameters to accept tubing and center pipe, respectively (Figure 1). Sampling ports consisted 12.7 mm (diameter) by 25.4 mm (length) screens manufactured for the tips of agricultural sprayers (*TeeJet* part no. 19845PP-50) (Figure 2). They are made of polypropylene and contain a screen of 50-size stainless steel mesh. Polyethylene tubing (6.35 mm ID diameter) connected the sampling ports to the surface. Ports and tubing were roughened with a brass-wire brush to aid adhesion with the epoxy. After attaching sampling screens to the tubing with epoxy, the tubing was thread through the tubing brackets from the bottom, positioning the sampling points at their desired depth based on the site stratigraphy. Up to six sampling ports were installed per piezometer. To minimize surface infiltration from moving vertically along the piezometer, an outer sleeve consisting of a 1.2 m section of PVC pipe (5.1 cm ID diameter, Schedule 40) was slid around the assembly. The sleeve extended 30.5 cm above the surface and 91.5 cm below the surface and was attached to the support brackets with epoxy. Nylon zip-ties held the ports to the center pipe and reduced the risk of damage during installation. To further protect the piezometers from surface contamination, covers were constructed by cementing PVC slip caps and couplings (5.1 cm) to opposite ends of a 30-cm-long section of PVC pipe (5.1 cm ID diameter, Schedule 40). The piece was then slid over the center pipe and tubes and onto the outer sleeve to protect the piezometer. An illustration of a completed multilevel piezometer is shown in Figure 3.

After construction in the laboratory, the piezometer was returned to the field and lowered into the temporary casing with the mast of the Giddings™ rig (Figure 4). The casing was then pulled from the borehole, making sure that the piezometer remained at the bottom of the borehole and was not withdrawn with the casing. In cohesionless sediment, collapse occurred around the piezometer. Where cohesive sediments were encountered, groundwater in the borehole was removed with a polyethylene tube using a peristaltic pump. Silica sand (2040) and bentonite (crumbles) were used as sandpack and sealant, respectively, to isolate sample intervals. After the shallowest port was covered with sand, bentonite was used to fill the remaining length of the borehole to within 15 to 20-cm of the surface. The remainder of the borehole was filled with on-site loamy material.

Values of hydraulic head were determined using an electric tape with a small diameter coaxial cable (3.2 mm). All measurements were taken relative to the top of the center pipe. Relative elevation between piezometers in each transect was determined with a differential transit. Absolute elevations for each transect were measured using with GPS's equipped with carrier-phase capabilities. The elevation measurements allowed for determination of an absolute hydraulic head at each sampling point, the vertical hydraulic gradient along each piezometer, and the horizontal hydraulic gradient across each transect.

Hydraulic conductivity (K) was estimated using two methods. A device was constructed to perform a falling (variable) head test (Lambe and Whitman, 1979) and consisted of a clear acrylic pipe (12.7 mm ID diameter) with graduations for measuring the water-level response to the introduction of a slug (Figure 5). However, in some locations, K values obtained from the falling head apparatus were not within the range of acceptable values based on stratigraphy. In locations where silica sand and bentonite were used to finish the annulus, values of K were approximately 5 x 10^{-4} m/s (Table 2). We hypothesized that the port screen was the limiting factor for flow during the K test. To test this hypothesis, the falling head apparatus was connected to a piezometer setup in the laboratory. The sampling ports of the piezometer were submerged in water and tests were conducted under a variety of water-table depths simulated by varying the height of the apparatus above the water level. Results showed the sampling port had an effective K of approximately 5 x 10^{-4} m/s, with only slight variations resulting from changes in apparatus height (Table 2). In intervals where K values from head tests were suspicious, particle size analysis (Gee and Bauder, 1986; Shirazi and Boersma, 1984) from the collected core was used to estimate the K of the sediment following the method of Shepherd (1989):

$$K = C_F \times d_{50}^{i}$$

K = Hydraulic Conductivity (ft/day)
C_F = Shape factor (450)
d_{50} = median grain size (mm)
i = exponent (1.65)

This method yielded K values similar to those for falling, variable head tests performed in finer alluvial sediments and also provided K data for coarser sediments (Table 1).

Groundwater samples were collected using a peristaltic pump on a 2 to 3 week schedule. Initially, ports were sampled simultaneously using a vacuum distribution manifold and filter flasks for each sampling port (Hitchman, 1988). However, due to the turbidity of groundwater samples, dissolved O_2 measurements were made using a dissolved O_2 meter with a polarographic probe. A flow cell was constructed for the probe and each port was then sampled individually (Figure 6).

Results

Eleven multilevel piezometers consisting of 58 sampling points were installed at seven sites in the watershed. Temporary vertical gradients ranging from 0.49 downward to 0.33 upward were recorded, however, horizontal gradients were dominant and showed groundwater flow to and from the stream. Hydraulic conductivity values from the falling head method ranged from approximately 1×10^{-6} to 5×10^{-4} m/s (the upper limit of the screened port). Values obtained from the particle-size analysis and Shepard (1989) calculations ranged from 1×10^{-5} to 9×10^{-3} m/s. Average linear velocities of groundwater were estimated to range from 0.09 to greater than 3 m/day beneath the buffers. The installed multilevel ports were used to collect in-field measurements of dissolved O_2 and samples for laboratory analysis of dissolved organic carbon, chloride, and nitrate (Figure 7). The ports succesfully showed vertical stratification in geochemistry Ultimately, these methods allowed for the observation of nitrate removal rates as high as 99 percent in shallow groundwater beneath buffers (Wineland et al., 2002). Installation was generally very successful and only one port was broken during the installation process. Sampling locations were sampled successfully from October 2000 through November of 2001 without complication.

Conclusions

Multilevel piezometers were designed for use in constructed riparian buffers in alluvial environments. Piezometers were installed with a Giddings^{TM} soil-coring rig, allowing for collection of core at each site. Multilevel piezometers were constructed based on site stratigraphy for each location, positioning sampling ports in specific stratigraphic locations. Improvements over previous multilevel piezometer systems include the use of inexpensive agricultural spray screens as sampling ports, support brackets on the center pipe, and multiple methods of K determination. Methods of installation were adapted to fit a variety of alluvial environments from fine alluvial sediments to very coarse alluvial sand and gravel. This method provided the flexibility and accuracy to efficiently estimate hydraulic parameters within shallow alluvial aquifers. However, the use of larger screen areas for sampling ports would allow for K determinations in a wider range of sediment types without significantly altering the methods of piezometer construction and installation. Canister-style strainers, also used for agricultural spraying are available with significantly larger screen areas and may improve the method for K determinations. If site access is not a problem, the installation of the multilevel piezometer could be done with a hollow-stem auger.

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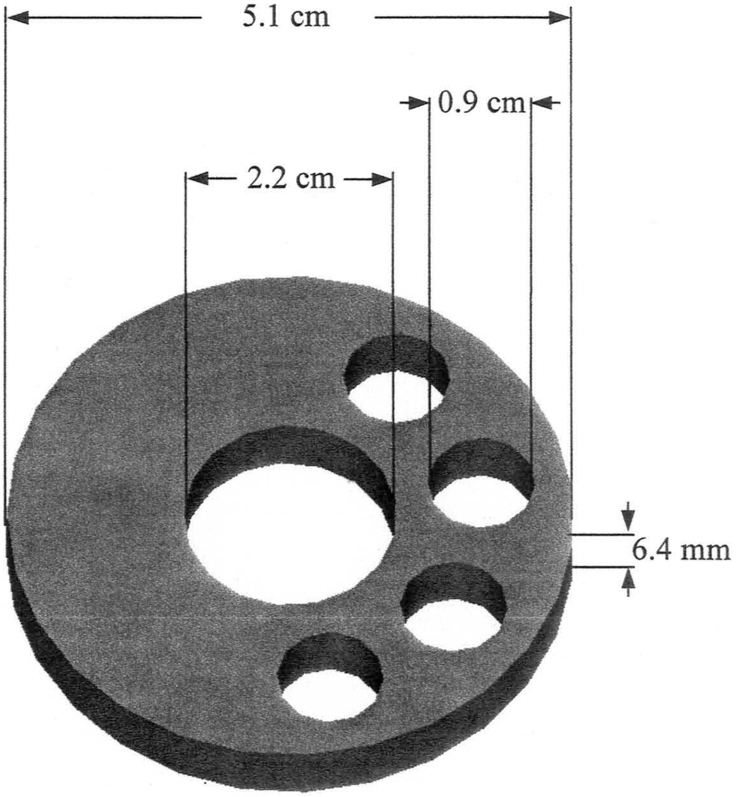

Figure 1. Tubing bracket used for support of polypropylene tubing around center pipe in the multilevel piezometer.

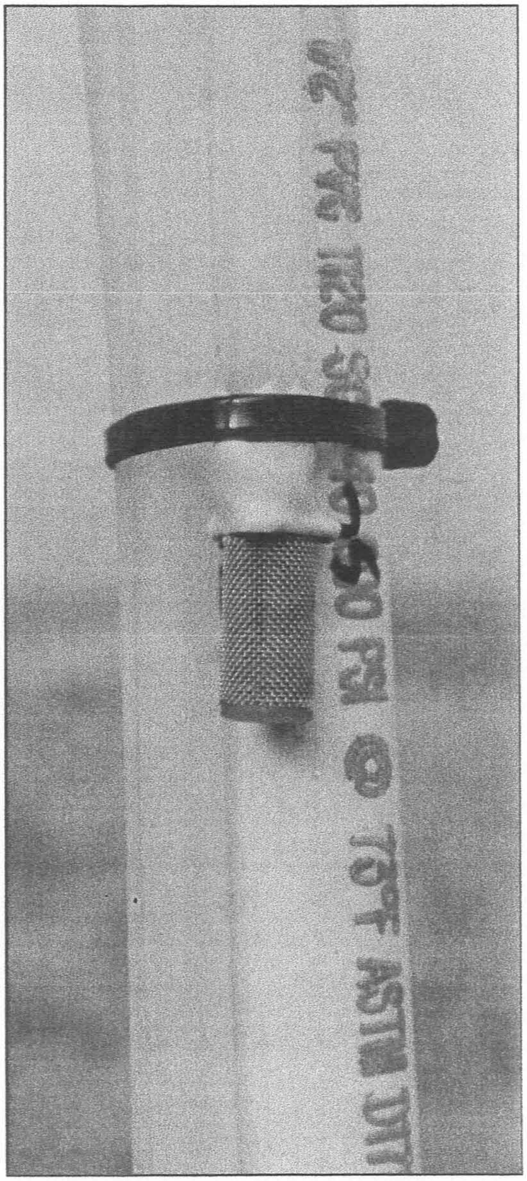

Figure 2. Photograph of sampling port showing the 50 mesh screen attached to tubing with epoxy. A nylon zip-tie attaches the tubing to the center pipe during installation.

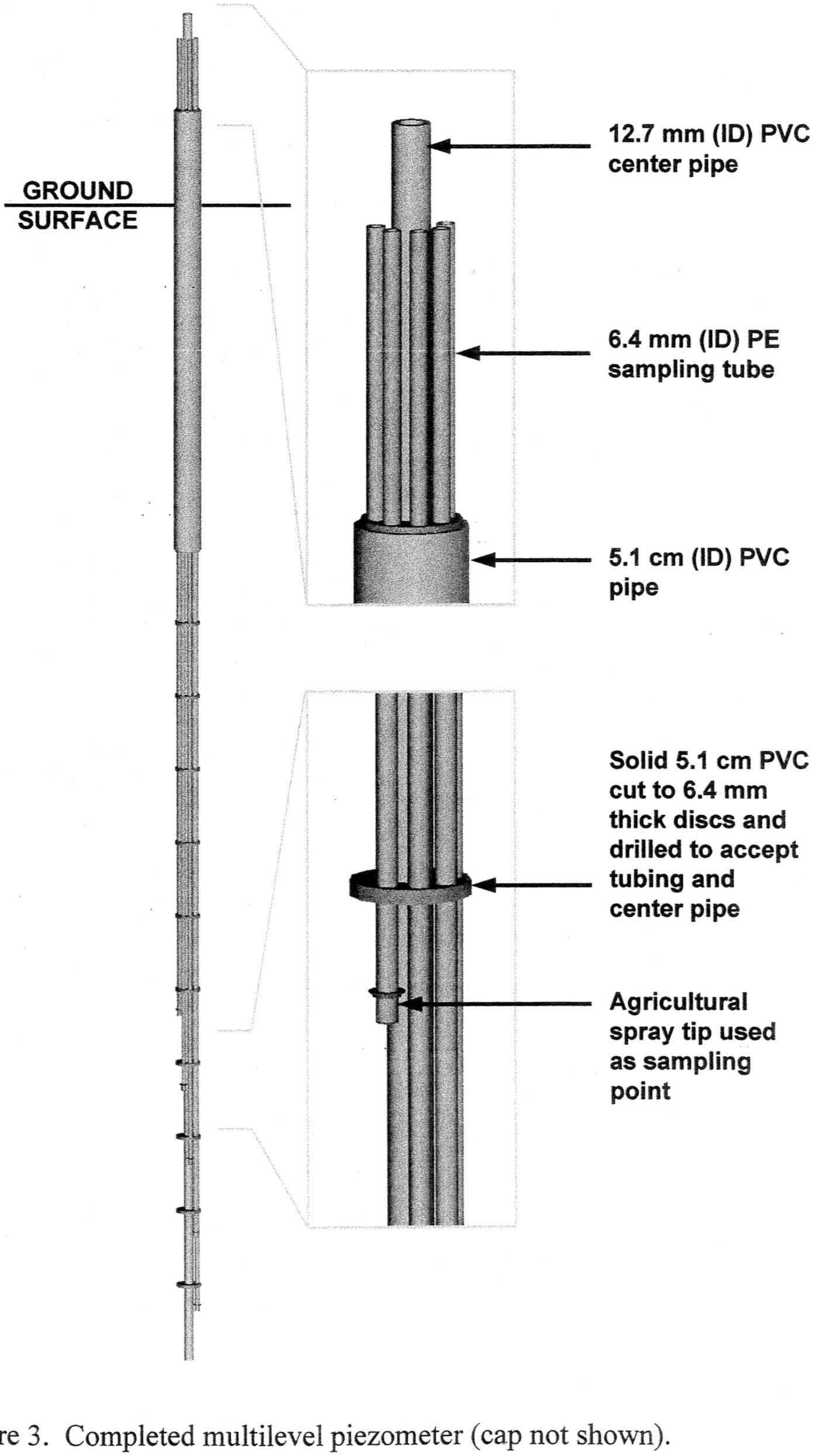

Figure 3. Completed multilevel piezometer (cap not shown).

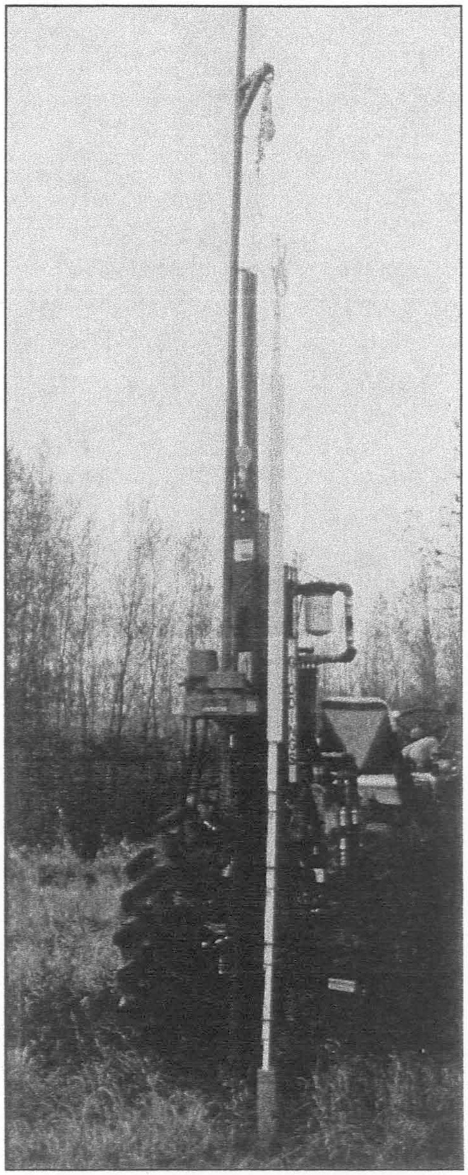

Figure 4. Giddings™ soil-coring rig shown lowering a multilevel piezometer into a borehole.

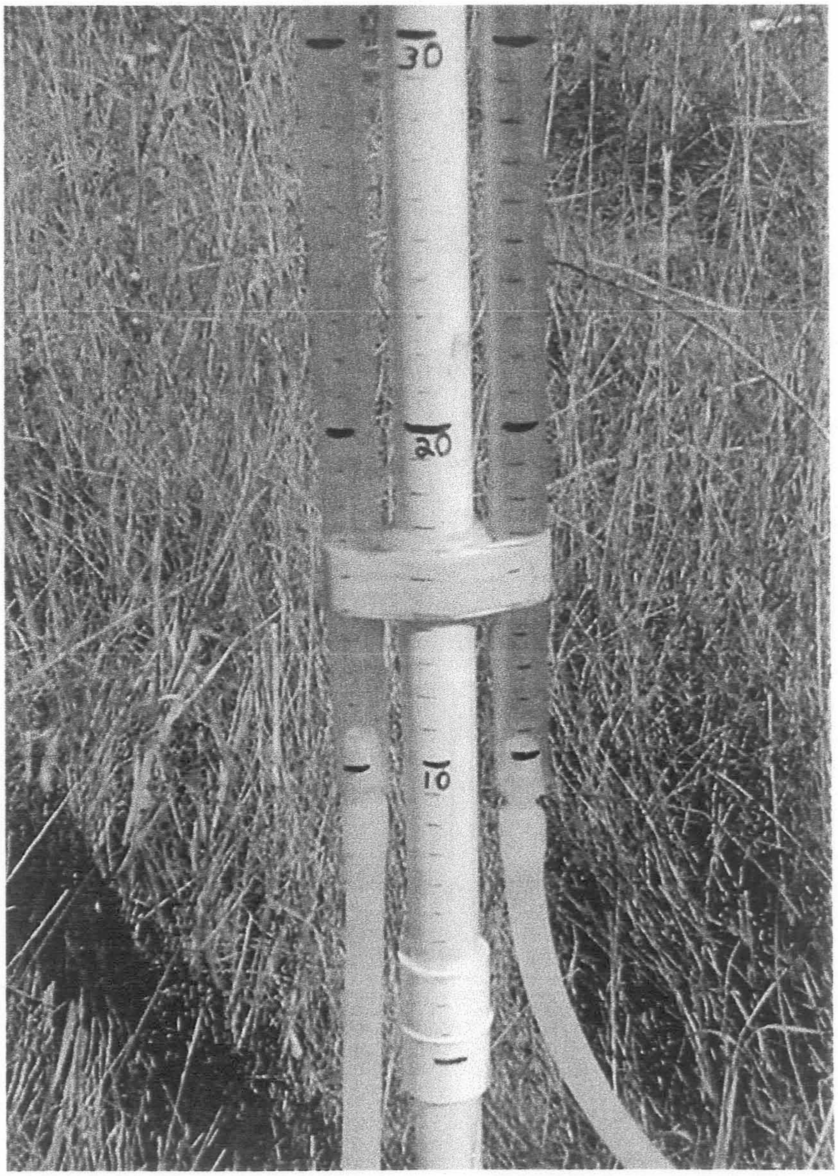

Figure 5. Apparatus used for variable (falling) head test for estimate of K (Lambe and Whitman). Measurements were recorded relative to the top of the center pipe with a maximum head difference range of 80 cm.

Figure 6. Flow cell built for measurement of dissolved O_2. Probe fits snuggly into the top of the unit forcing groundwater to flow across the membrane.

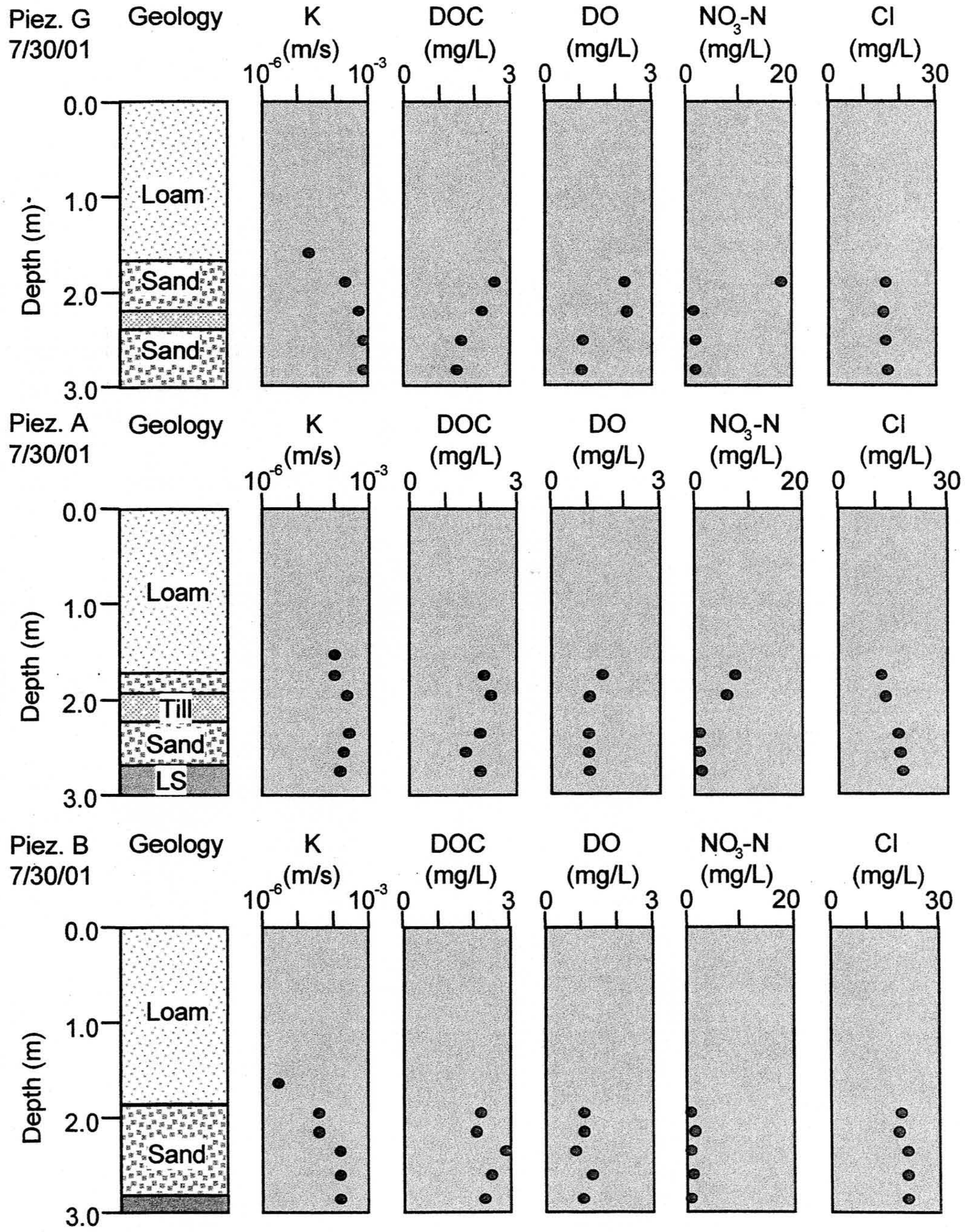

Figure 7. Sample geochemical data collected from three multilevel piezometers in a transect (Wineland 2002). In most cases, good geochemical stratification was identified using this method.

		Gee & Bauder			Shirazi & Boersma	Shepherd	Lambe & Whitman	
Piezometer	depth (cm)	% Sand	% Silt	% Clay	Mean Dia (mm)	K (m/s)	t (sec)	K (m/s)
A	137-172	66	20	14	0.17	8.5E-05	< 1	4.1E-04
A	172-193	84	13	3	0.52	5.4E-04	5.3	8.0E-05
A	193-223	89	8	3	0.63	7.4E-04	4.7	8.9E-05
A	223-246	79	13	8	0.38	3.2E-04	4.0	1.0E-04
A	246-269	67	22	11	0.22	1.3E-04	96.0	4.1E-06
B	185-210	57	29	14	0.13	5.5E-05	< 1	3.7E-04
B	210-251	62	37	1	0.24	1.5E-04	6.9	5.8E-05
B	251-281	61	38	1	0.24	1.5E-04	80.0	4.3E-06
C	255-280	93	4	3	0.77	1.0E-03	< 1	3.2E-04
C	280-300	86	10	4	0.56	6.1E-04	< 1	3.2E-04
C	315-340	74	18	8	0.30	2.2E-04	< 1	3.2E-04
D	244-275	89	6	5	0.58	6.5E-04	< 1	3.1E-04
D	316-360	82	10	7	0.41	3.6E-04	277.3	5.5E-07
E	258-313	72	19	9	0.28	1.9E-04	< 1	3.2E-04
E	323-340	96	0	4	0.85	1.2E-03	6.0	5.6E-05
F	207-240	62	28	10	0.19	1.0E-04	4.8	1.1E-04
F	274-302	91	7	1	0.72	9.2E-04	500.0	9.0E-07
F	302-347	91	7	2	0.72	9.2E-04	80.0	5.8E-06
F	352-412	91	7	3	0.69	8.6E-04	14400.0	3.1E-08
G	167-190	72	17	10	0.26	1.7E-04	< 1	4.0E-04
G	190-219	90	8	2	0.64	7.6E-04	< 1	4.0E-04
G	238-286	96	3	1	0.83	1.2E-03	< 1	4.0E-04

	Height (cm)						t (sec)	K (m/s)
Lab test	71	–	–	–	–	–	2.1	3.90E-04
	71	–	–	–	–	–	2.2	3.90E-04
	71	–	–	–	–	–	2.3	4.00E-04
	43	–	–	–	–	–	2.2	4.80E-04
	43	–	–	–	–	–	2.7	4.80E-04
	43	–	–	–	–	–	1.5	4.30E-04
	21	–	–	–	–	–	2.2	6.40E-04
	21	–	–	–	–	–	2.4	6.70E-04
	21	–	–	–	–	–	2.5	6.60E-04

Table 1 . Calculations of K from particle size analysis and from variable (falling) head tests. Shaded values are port locations in cohesive sediment (natural collapse did not occur) finished with silica sand where K values may be compromised by limited screen area. Data at bottom show K of the sampling port screen from laboratory simulations. Values of t represent the time for water in the test apparatus to fall 80 cm.

GENERAL SUMMARY

The purpose of this thesis was to investigate the ability of multi-species riparian buffers to remove nitrate from groundwater, and particularly, to gain understanding of the affect that alluvial (and adjoining) geology has on this process. More than 50 electrical resistivity surveys were completed and 14 multilevel piezometers were installed and monitored along Bear Creek. Multilevel monitoring enabled characterization of physical and chemical parameters beneath buffers. Hydraulic head and hydraulic conductivity data enabled estimation of vertical and horizontal gradients, flow velocities, and residence time of groundwater as it flowed beneath riparian buffers. Groundwater sampling provided information on nitrate, dissolved O_2, dissolved organic carbon and chloride for groundwater as it entered buffers near agricultural fields and again as water was discharged into Bear Creek.

Electrical resistivity surveys indicated that alluvial sediment in the Bear Creek Watershed varied in both sediment size and extent. This heterogeneity resulted in a great deal of variation in the depth and velocity with which groundwater flowed beneath buffers. Nitrate removal was found to occur in locations where organic carbon was present and groundwater velocities were slow. Depletion of dissolved O_2 in these locations suggests denitrification as a removal mechanism. Analysis of samples indicated that nitrate levels decreased by up to 99 percent as groundwater passed beneath buffers in several locations. However, nitrate removal was diminished under certain conditions where residence time was too low or groundwater flow by-passed carbon fuel sources.

Rather than buffer maturity, as earlier suspected, geologic conditions were found to be the determining factor of how well a buffer functioned to remove nitrate. In areas with deep alluvial aquifers, nitrate-laden groundwater was observed to flow well below the functional zone of the buffer toward Bear Creek. In locations with coarse alluvium, low groundwater residence times were found to limit the effectiveness of the buffer. Often, thin units of low-permeability sediment were found to function as aquitards, effectively partitioning alluvial units into two or more distinct hydrogeologic units. These units were observed to both help and hinder the water quality effects of riparian buffers. When nitrate was confined below the aquitard, buffer vegetation had little effect on nitrate removal. However, when nitrate was confined above the aquitard, contact with buffer supplied carbon provided for effective nitrate removal. The ideal geology for nitrate removal is suspected to be one where residence time beneath the buffer is maximized and groundwater flow is restricted to the near surface where contact with buffer materials is maximized. In the Bear Creek watershed, the alluvial aquifer was nearly always separated from the underlying bedrock aquifer by either till and/or weathered limestone.

Results from this study suggest that riparian buffers may be very effective in locations where alluvial sediments are absent or early in development. In prominent drainage ways and first-order streams, fine sediments reduce groundwater velocities and often restrict flow to the near surface. Restoration of riparian vegetation in these areas could provide an effective method for reducing nitrate contamination of surface waters.

APPENDIX A

SOIL DATA

Piezometer	depth (cm)	sand (%)	silt (%)	clay (%)	Organic C (%)	Total N (%)
JRS - A	0-112	50.25	29.32	20.43	0.6917	< 0.010
JRS - A	112-137	56.89	26.65	16.46	0.7013	< 0.010
JRS - A	137-173	65.93	20.33	13.74	0.4900	< 0.010
JRS - A	173-193	83.96	13.21	2.83	1.1995	< 0.010
JRS - A	193-223	59.52	23.67	16.81	0.5537	< 0.010
JRS - A	223-232	89.48	7.85	2.67	1.3270	< 0.010
JRS - A	232-241	91.27	5.91	2.82	1.2150	< 0.010
JRS - A	241-250	78.96	13.12	7.92	1.0353	< 0.010
JRS - A	250-259	92.02	5.49	2.50	1.8880	< 0.010
JRS - A	259-269	67.12	21.52	11.36	-0.6290	< 0.010
JRS - B	0-25	30.10	51.67	18.24	3.2045	0.2585
JRS - B	25-61	58.40	24.71	16.89	1.4010	0.0635
JRS - B	61-102	65.35	20.63	14.02	0.5970	0.016
JRS - B	102-130	82.20	10.89	6.91	0.2654	< 0.010
JRS - B	130-185	21.48	51.69	26.84	4.3725	0.242
JRS - B	185-211	56.63	28.94	14.43	2.5800	0.14
JRS - B	211-251	62.29	37.16	0.55	0.7829	< 0.010
JRS - B	251-282	61.05	38.39	0.56	0.2515	< 0.010
JRS - B	252	78.61	15.42	5.98	3.2120	0.261
JRS - B	267	74.18	18.61	7.22	2.9650	0.2105
JRS - B	282	75.36	17.76	6.89	0.4040	< 0.010
RRS - C	0-20	37.02	40.47	22.50	1.0714	< 0.010
RRS - C	20-70	39.81	35.72	24.47	1.7960	< 0.010
RRS - C	70-98	54.26	28.67	17.07	2.0870	< 0.010
RRS - C	98-108	86.19	10.77	3.04	1.6255	< 0.010
RRS - C	108-120	85.07	12.02	2.90	2.0430	< 0.010
RRS - C	120-175	50.01	33.54	16.46	0.4297	< 0.010
RRS - C	175-180	57.88	29.41	12.71	0.3341	< 0.010
RRS - C	180-190	79.66	15.99	4.35	1.4305	< 0.010
RRS - C	190-210	91.26	4.58	4.16	0.2965	< 0.010
RRS - C	210-220	75.88	17.83	6.29	0.3958	< 0.010
RRS - C	220-240	71.36	19.31	9.34	0.3490	< 0.010
RRS - C	240-255	93.65	4.25	2.09	0.3347	< 0.010
RRS - C	255-280	93.02	3.85	3.14	0.9908	< 0.010
RRS - C	280-300	86.06	9.69	4.25	-1.3657	< 0.010
RRS - C	300-315	92.95	3.36	3.69	--	--
RRS - C	315-340	73.92	17.70	8.38	2.1035	0.1515
RRS - C	340-353	56.57	29.63	13.80	1.1550	0.065
RRS - D	0-30	52.58	29.34	18.08	1.6370	< 0.010
RRS - D	30-89	39.96	34.48	25.56	1.3940	0.019
RRS - D	89-122	78.19	15.57	6.24	1.8375	< 0.010
RRS - D	122-137	88.72	7.53	3.75	0.4937	< 0.010
RRS - D	137-192	54.83	32.61	12.56	0.4385	< 0.010
RRS - D	192-216	90.63	4.89	4.49	0.3544	< 0.010
RRS - D	216-244	93.13	2.36	4.51	0.0497	< 0.010
RRS - D	244-275	88.54	6.31	5.15	0.0984	< 0.010
RRS - D	275-316	53.00	23.03	23.96	0.8193	< 0.010
RRS - D	316-360	82.18	10.32	7.49	2.1955	0.1495
RRS - D	360+	53.72	21.03	25.24	0.5525	0.0285
LSE - E	0-44	81.60	10.80	7.60	0.4073	< 0.010

Piezometer	depth (cm)	sand (%)	silt (%)	clay (%)	Organic C (%)	Total N (%)
LSE - E	44-80	44.37	37.59	18.05	0.1032	< 0.010
LSE - E	122-164	45.55	37.16	17.29	0.1125	< 0.010
LSE - E	164-200	30.89	43.83	25.28	0.0742	< 0.010
LSE - E	200-216	61.43	23.82	14.75	0.0499	< 0.010
LSE - E	244-258	76.64	14.90	8.46	0.0352	< 0.010
LSE - E	258-313	72.19	18.71	9.11	2.6645	0.201
LSE - E	313-323	88.17	8.44	3.38	--	--
LSE - E	323-340	95.63	0.19	4.17	0.8647	0.0295
LSE - F	0-16	29.01	50.14	20.85	1.1550	0.048
LSE - F	16-26	#N/A	#N/A	-4.03	0.2717	0.01
LSE - F	26-116	25.61	44.45	29.93	0.1560	< 0.010
LSE - F	122-138	24.88	46.99	28.13	0.4387	0.013
LSE - F	138-207	13.64	56.79	29.58	1.6083	< 0.010
LSE - F	207-240	61.55	28.14	10.32	2.3215	< 0.010
LSE - F	244-274	38.51	42.73	18.76	1.2360	< 0.010
LSE - F	274-302	91.38	7.30	1.33	0.0000	< 0.010
LSE - F	302-347	91.23	6.64	2.13	1.5620	< 0.010
LSE - F	347-350	60.93	25.26	13.81	1.0825	< 0.010
LSE - F	350-352	93.82	5.14	1.05	3.3780	0.2235
LSE - F	352-412	90.70	6.68	2.62	1.5225	0.061
LSE - F	412-425.5	56.00	26.53	17.46	0.8071	0.016
JRS - G	0-120	39.16	36.64	24.20	0.7019	0.014
JRS - G	120-155	40.72	35.09	24.19	0.3303	< 0.010
JRS - G	155-167	46.63	31.85	21.52	0.6975	< 0.010
JRS - G	167-190	72.34	17.25	10.42	0.2959	< 0.010
JRS - G	190-219	89.90	8.29	1.81	0.2141	< 0.010
JRS - G	219-238	66.33	23.93	9.74	--	--
JRS - G	238-286	95.86	3.30	0.84	2.9990	0.24
JRS - G	286-305	89.17	8.25	2.58	1.0293	0.059
TW - H	0-33	38.19	45.17	16.65	0.1898	< 0.010
TW - H	33-80	39.12	39.40	21.48	0.4213	< 0.010
TW - H	80-120	50.05	32.66	17.29	1.5680	< 0.010
TW - H	120-160	61.88	27.84	10.28	-0.1790	< 0.010
TW - H	160-181	55.00	35.54	9.45	1.8375	< 0.010
TW - H	181-188	64.14	24.69	11.16	1.6870	< 0.010
TW - H	188-225	45.39	37.47	17.14	2.0455	< 0.010
TW - H	225-250	54.82	31.36	13.81	0.7299	< 0.010
TW - H	250-305	51.82	32.37	15.81	2.4545	< 0.010
TW - H	250-305	85.70	7.92	6.38	1.5105	0.1055
TW - H	305-375	44.92	39.69	15.38	2.3490	< 0.010
TW - I	0-1.5	54.35	28.55	17.10	2.1075	< 0.010
TW - I	1.5-4	53.20	32.22	14.58	2.1690	< 0.010
TW - I	4-6	55.63	30.23	14.14	2.1740	< 0.010
TW - I	6-8	55.70	30.67	13.62	2.6870	< 0.010
TW - I	8-9.5	73.81	18.40	7.79	2.6545	0.192
TW - I	9.5-11.5	63.57	24.88	11.55	0.9660	0.0335
LSW - J	0-52	36.39	41.28	22.33	1.0740	0.0445
LSW - J	52-76	33.25	40.48	26.27	0.2626	< 0.010
LSW - J	76-96	45.30	34.23	20.47	0.3066	< 0.010
LSW - J	96-132	43.47	33.72	22.81	0.1855	< 0.010

Piezometer	depth (cm)	sand (%)	silt (%)	clay (%)	Organic C (%)	Total N (%)
LSW - J	132-148	43.63	39.61	16.76	0.3259	< 0.010
LSW - J	148-164	65.46	23.34	11.20	0.4420	0.016
LSW - J	164-174	93.97	4.18	1.85	0.7026	< 0.010
LSW - J	174-209	47.88	32.22	19.91	0.9994	< 0.010
LSW - J	209-250	82.64	12.66	4.70	2.1445	< 0.010
LSW - J	250-290	93.88	4.51	1.61	--	--
LSW - J	290-320	91.20	6.02	2.78	1.7005	0.1115
LSW - K	0-40	49.88	34.17	15.95	1.3315	0.0855
LSW - K	40-50	66.00	18.59	15.40	1.7630	0.1075
LSW - K	50-83	42.69	34.86	22.45	1.1160	0.055
LSW - K	83-122	45.49	32.80	21.71	0.8578	0.0375
LSW - K	122-141	43.08	34.25	22.67	0.4179	< 0.010
LSW - K	141-160	53.27	28.25	18.48	0.2630	< 0.010
LSW - K	160-182	36.94	35.68	27.37	0.5150	< 0.010
LSW - K	182-198	44.59	36.51	18.90	0.3505	< 0.010
LSW - K	198-210	62.13	23.16	14.70	1.7315	< 0.010
LSW - K	210-220	86.94	9.95	3.10	0.0839	< 0.010
LSW - K	220-230	63.94	23.05	13.01	2.1160	0.178
LSS - L	0-40	47.23	34.06	18.72	2.0875	0.153
LSS - L	40-70	48.60	32.71	18.70	1.0180	0.0585
LSS - L	70-95	50.80	28.72	20.48	0.5130	0.011
LSS - L	95-155	51.80	29.49	18.71	0.5750	< 0.010
LSS - L	155-205	52.52	29.39	18.08	1.2360	< 0.010
LSS - L	205-240	55.00	29.54	15.46	0.3794	< 0.010
LSS - L	240-295	89.57	6.65	3.78	--	--
TE - M	0-60	18.33	52.09	29.58	3.0715	0.2395
TE - M	60-125	43.31	35.33	21.35	2.6770	0.1705
TE - M	125-150	68.88	20.19	10.93	1.7935	0.0845
TE - M	150-170	74.09	16.43	9.49	1.5310	0.058
TE - M	170-235	82.00	11.87	6.13	1.0901	0.015
TE - M	235-315	90.58	7.03	2.39	1.7400	< 0.010
TE - M	315 +	53.01	32.57	14.42	2.3715	0.015
TE - N	0-120	45.42	32.23	22.35	1.7185	0.089
TE - N	120-135	56.20	25.21	18.60	1.5795	0.0745
TE - N	135-155	59.12	26.00	14.89	0.8416	0.0205
TE - N	155-175	73.75	17.51	8.74	1.5350	< 0.010
TE - N	175-200	81.09	13.59	5.32	2.4035	0.01
TE - N	200-245	57.04	29.39	13.57	2.2445	< 0.010
TE - N	245-265	46.41	37.50	16.08	2.3295	< 0.010
TE - N	265-320	47.88	36.92	15.20	2.4445	< 0.010
TE - N	320-360	62.64	25.50	11.85	2.2240	< 0.010
TE - N	360-400	48.83	36.65	14.52	2.6040	< 0.010
LSW - K	244-275	49.76	29.08	21.16	0.8259	0.033
LSW - K	275-300	73.13	18.14	8.73	0.1608	< 0.010
LSW - K	300-330	55.99	26.72	17.29	0.1038	< 0.010

APPENDIX B

PIEZOMETER COORDINATES

Coordinates

System: UTM
Zone: 15 North
Datum: NAD 1983 (Conus)

		Northing	Easting
JRS	**A - mid-buffer**	4670526.74	458979.84
	B - near creek	4670520.74	458993.22
	G - near crop	4670534.94	458961.37
RRS	**C - near creek**	4670977.70	459498.77
	D - near crop	4670961.78	459508.93
LSE	**E - near crop**	4671570.56	460110.94
	F - near creek	4671550.40	460100.34
TW	**H - near creek**	4673046.49	461426.33
	I - near crop	4673034.97	461381.70
TE	**M - near crop**	4673052.42	461484.83
	N - near creek	4673051.21	461441.31
LSW	**J - near crop**	4671374.37	460024.28
	K - near creek	4671371.00	460029.34
LSS	**L - near creek**	4671246.99	459781.32

APPENDIX C

WATER LEVEL DATA

Head	(masl)	10/25/00	01/10/01	02/27/01	03/03/01	03/27/01	04/10/01
JRS							
	A - mid-buffer						
	A 1.5	dry	dry	315.500	315.546	316.427	316.361
	A 1.7	315.263	315.327		315.284	316.453	316.362
	A 1.9	315.234	315.329		315.177	316.604	316.363
	A 2.3	315.263	315.307	315.646	315.570	316.043	315.939
	A 2.5	315.257	315.314	315.635	315.572	316.029	315.940
	A 2.7	315.259	315.304		315.575	315.958	315.941
	B - near creek						
	B 1.6	dry	dry	dry	315.543	316.011	315.868
	B 1.9	315.229	315.281	315.626	315.569	315.940	315.805
	B 2.1	315.229	315.278	315.624	315.565	315.940	315.807
	B 2.3	315.227	315.279	315.624	315.575	315.941	315.806
	B 2.55	315.336	315.283	315.639	315.571	315.903	315.767
	B 2.8	315.256	315.301	315.701	315.584	315.754	315.686
	G - near crop						
	G 1.55						
	G 1.85						
	G 2.15						
	G 2.45						
	G 2.75						
RRS							
	C - near creek						
	C 1.95	dry	dry	dry	dry	317.816	317.776
	C 2.4	dry	317.347	317.380	317.374	317.814	317.774
	C 2.7	317.283	317.355			317.837	317.790
	C 3.05	317.282	317.350	317.388	317.385	317.836	317.794
	C 3.3	317.283	317.358	317.392	317.385	317.837	317.791
	D - near crop						
	D 2.0	dry	dry	dry	dry	318.520	318.278
	D 2.3	dry	dry	dry	dry	318.343	318.275
	D 2.6	317.555	318.011	317.680	317.686	318.341	318.278
	D 3.2	317.656	318.101	317.794	317.797	318.390	318.335
	D 3.5	317.759	317.853	317.897	317.838	318.440	318.395
LSE							
	E - near crop						
	E 1.35	dry	dry		dry	dry	dry
	E 1.8	dry	dry		dry	dry	dry
	E 2.25	dry	dry		dry	320.642	320.248
	E 2.7	319.979	320.088		320.128	320.668	320.288
	E 3.0	321.021	320.038		320.103	320.681	320.283
	E 3.3	322.353	320.012		320.125	320.954	320.684
	F - near creek						
	F 2.25	320.012	320.392	320.106	320.101	320.162	320.123
	F 2.8	320.026	320.399	320.080	320.083	320.238	320.173

Head (masl)		**10/25/00**	**01/10/01**	**02/27/01**	**03/03/01**	**03/27/01**	**04/10/01**
	F 3.2	320.104	320.397	320.096	320.096	320.123	320.053
	F 3.6	319.916	320.404	320.220	320.209	320.176	320.077
	F 4.0	319.421	320.419	320.071	320.076	320.214	320.184
TW							
	H - near creek						
	H 1.3						
	H 1.7						
	H 2.4						
	H 2.6						
	H 2.9						
	I - near crop						
	I 1.6						
	I 2.2						
	I 2.8						
TE							
	M - near crop						
	M 1.6						
	M 2.1						
	M 2.6						
	M 3.05						
	N - near creek						
	N 1.6						
	N 2.4						
	N 2.9						
	N 3.4						
LSW							
	J - near crop						
	J 1.6						
	J 2.1						
	J 2.6						
	J 3.1						
	K - near creek						
	K 1.95						
	K 2.25						
	K 2.6						
LSS							
	L - control						
	L 1.5						
	L 2.0						
	L 2.5						
	L 2.85						
	L 3.0						

Head	(masl)	**04/28/01**	**05/09/01**	**05/29/01**	**06/11/01**	**07/10/01**	**07/30/01**
JRS							
	A - mid-buffer						
	A 1.5	316.013	316.105	316.016	315.889	315.600	315.486
	A 1.7	316.012	316.104	316.016	315.888	315.600	315.486
	A 1.9	316.012	316.104	316.012	315.886	315.599	315.484
	A 2.3	315.753	315.867	315.850	315.756	315.555	315.423
	A 2.5	315.752	315.866	315.849	315.755	315.553	315.419
	A 2.7	315.750	315.865	315.848	315.754	315.552	315.418
	B - near creek						
	B 1.6	315.644	315.729	315.689	315.568	dry	dry
	B 1.9	315.618	315.708	315.697	315.587	315.384	315.303
	B 2.1	315.617	315.712	315.695	315.586	315.382	315.304
	B 2.3	315.622	315.710	315.697	315.578	315.381	315.303
	B 2.55	315.596	315.692	315.688	315.578	315.390	315.302
	B 2.8	315.544	315.652	315.671	315.572	315.410	315.308
	G - near crop						
	G 1.55			316.144	316.064	315.746	315.562
	G 1.85			316.065	316.064	315.749	315.560
	G 2.15			316.165	316.064	315.748	315.563
	G 2.45			316.166	316.091	315.845	315.629
	G 2.75			316.099	316.098	315.845	315.629
RRS							
	C - near creek						
	C 1.95	dry	317.785	317.780	dry	dry	dry
	C 2.4	317.675	317.787	317.777	317.651	317.435	317.327
	C 2.7	317.691	317.797	317.793	317.665	317.442	317.336
	C 3.05	317.692	317.804	317.796	317.665	317.444	317.338
	C 3.3	317.694	317.804	317.794	317.670	317.444	317.338
	D - near crop						
	D 2.0	318.138	318.287	318.270	318.082	dry	dry
	D 2.3	318.139	318.286	318.251	318.085	317.772	dry
	D 2.6	318.140	318.287	318.245	318.087	317.782	317.638
	D 3.2	318.220	318.367	318.345	318.210	317.925	317.780
	D 3.5	318.302	318.453	318.456	318.339	318.092	317.938
LSE							
	E - near crop						
	E 1.35	dry	dry	dry	dry	dry	dry
	E 1.8	dry	dry	dry	dry	dry	dry
	E 2.25	dry	320.330	dry	dry	dry	dry
	E 2.7	320.068	320.329	320.351	320.126	320.093	320.013
	E 3.0	320.070	320.327	320.349	320.118	320.090	320.010
	E 3.3	320.112	320.331	320.346	320.133	320.089	320.011
	F - near creek						
	F 2.25	319.968	320.116	320.176	320.009	320.083	320.036
	F 2.8	320.003	320.119	320.171	320.013	320.095	320.041

Head

(masl)	04/28/01	05/09/01	05/29/01	06/11/01	07/10/01	07/30/01
F 3.2	319.958	320.105	320.166	320.013	320.094	320.036
F 3.6	320.001	320.102	320.166	320.021	320.096	320.040
F 4.0	320.136	320.120	320.116	320.097	320.085	320.077
TW						
H - near creek						
H 1.3			dry	dry	dry	dry
H 1.7			dry	dry	dry	dry
H 2.4			326.270	326.235	325.962	325.822
H 2.6			326.258	326.244	325.956	325.824
H 2.9			326.254	326.247	325.954	325.832
I - near crop						
I 1.6					328.322	dry
I 2.2					328.321	328.126
I 2.8						328.129
TE						
M - near crop						
M 1.6						325.937
M 2.1						325.927
M 2.6						325.934
M 3.05						325.879
N - near creek						
N 1.6						dry
N 2.4						325.568
N 2.9						325.570
N 3.4						325.582
LSW						
J - near crop						
J 1.6					319.415	319.354
J 2.1					319.440	319.376
J 2.6					319.454	319.390
J 3.1					319.442	319.390
K - near creek						
K 1.95				319.026	319.282	319.279
K 2.25				319.237	319.231	319.279
K 2.6				319.399	319.293	319.271
LSS						
L - control						
L 1.5						dry
L 2.0						318.789
L 2.5						318.848
L 2.85						318.837
L 3.0						318.867

Head	(masl)	08/19/01	09/10/01	10/01/01	11/13/01
JRS					
	A - mid-buffer				
	A 1.5	dry	316.057	315.609	315.607
	A 1.7	315.363	316.059	315.608	315.607
	A 1.9	315.357	316.051	315.606	315.604
	A 2.3	315.320	315.707	315.514	315.524
	A 2.5	315.320	315.706	315.513	315.523
	A 2.7	315.318	315.748	315.512	315.523
	B - near creek				
	B 1.6	dry	315.668	dry	dry
	B 1.9	315.244	315.666	315.418	315.408
	B 2.1	315.247	315.664	315.417	315.406
	B 2.3	315.247	315.664	315.414	315.405
	B 2.55	315.247	315.648	315.411	315.408
	B 2.8	315.256	315.604	315.412	315.416
	G - near crop				
	G 1.55	dry	316.096	315.678	315.670
	G 1.85	315.397	316.095	315.680	315.669
	G 2.15	315.399	316.095	315.677	315.672
	G 2.45	315.438	315.833	315.691	315.684
	G 2.75	315.431	315.830	315.691	315.686
RRS					
	C - near creek				
	C 1.95	dry	dry	dry	dry
	C 2.4	317.295	317.547	317.510	317.511
	C 2.7	317.301	317.553	317.524	317.520
	C 3.05	317.299	317.555	317.522	317.521
	C 3.3	317.300	317.554	317.521	317.518
	D - near crop				
	D 2.0	dry	dry	dry	dry
	D 2.3	dry	317.800	317.854	317.861
	D 2.6	317.496	317.805	317.857	317.862
	D 3.2	317.670	317.927	317.972	317.971
	D 3.5	317.847	318.114	318.160	318.151
LSE					
	E - near crop				
	E 1.35	dry	dry	dry	dry
	E 1.8	dry	dry	dry	dry
	E 2.25	dry	dry	dry	dry
	E 2.7	320.020	323.073	319.865	dry
	E 3.0	320.015	323.073	319.861	319.455
	E 3.3	320.019	323.073	319.862	319.158
	F - near creek				
	F 2.25	320.024	321.766	319.837	319.936
	F 2.8	320.036	321.766	319.838	319.945

Head

(masl)	08/19/01	09/10/01	10/01/01	11/13/01
F 3.2	320.028	321.766	319.837	319.936
F 3.6	320.034	321.766	319.836	319.672
F 4.0	320.061	321.766	320.054	321.766

TW

H - near creek

H 1.3	dry	dry	dry	dry
H 1.7	dry	dry	326.086	326.100
H 2.4	325.677	326.115	326.270	326.058
H 2.6	325.676	325.582	326.264	326.058
H 2.9	325.679	326.115	326.268	326.032

I - near crop

I 1.6	dry	328.169	328.166	dry
I 2.2	327.986	328.104	328.123	328.098
I 2.8	327.989	328.104	328.123	328.101

TE

M - near crop

M 1.6	325.818	326.257	326.089	326.034
M 2.1	325.808	326.253	326.088	326.027
M 2.6	325.806	326.258	326.090	326.029
M 3.05	325.797	326.263	326.074	326.007

N - near creek

N 1.6	dry	325.988	325.690	325.619
N 2.4	325.492	326.007	325.705	325.632
N 2.9	325.494	325.988	325.728	325.631
N 3.4	325.518	326.055	325.729	325.661

LSW

J - near crop

J 1.6	319.330	319.909	319.439	319.586
J 2.1	319.370	319.891	319.453	319.611
J 2.6	319.393	319.869	319.460	319.616
J 3.1	319.393	319.866	319.463	319.613

K - near creek

K 1.95	319.291	319.529	319.324	319.452
K 2.25	319.292	319.529	319.340	319.499
K 2.6	319.290	319.555	319.354	319.512

LSS

L - control

L 1.5	dry	dry	dry	319.499
L 2.0	318.795	318.982	319.096	319.500
L 2.5	318.822	321.299	319.096	319.495
L 2.85	318.801	318.994	319.102	319.505
L 3.0	318.799	318.992	319.104	319.504

APPENDIX D

GROUNDWATER CHEMISTRY DATA

Nitrate-N (mg/L)	**10/25/00**	**1/10/01**	**3/3/01**	**3/27/01**	**4/10/01**	**4/28/01**
JRS						
A - mid-buffer						
A 1.5	dry	dry	0.72	0.37	1.41	2.63
A 1.7	dry	dry	0.14	0.23	1.22	2.82
A 1.9	0.10	0.27	0.34	0.13	1.12	1.97
A 2.3	0.04	<0.01	0.18	0.06	0.03	0.08
A 2.5	0.02	<0.01	0.21	<0.01	0.10	0.07
A 2.7	0.09	0.04	0.14	0.39	0.00	0.43
B - near creek						
B 1.6	dry	dry	0.13	0.16	0.04	0.07
B 1.9	dry	0.05	0.14	0.13	0.01	0.07
B 2.1	0.14	0.04	0.22	0.04	0.03	0.01
B 2.3	0.03	<0.01	0.27	0.02	0.02	0.07
B 2.55	0.07	<0.01	0.16	0.04	0.03	0.09
B 2.8	0.03	<0.01	0.22	0.00	0.01	0.06
G - near crop						
G 1.55						
G 1.85						
G 2.15						
G 2.45						
G 2.75						
RRS						
C - near creek						
C 1.95	dry	dry	dry	0.07	0.00	dry
C 2.4	dry	<0.01	0.17	0.12	1.08	2.99
C 2.7	0.29	0.03	0.22	0.04	0.03	1.38
C 3.05	0.46	<0.01	0.12	<0.01	<0.01	0.93
C 3.3	2.41	0.04	0.13	0.04	0.29	1.31
D - near crop						
D 2.0	dry	dry	dry	3.08	4.87	5.13
D 2.3	dry	dry	dry	2.03	1.91	2.88
D 2.6	<0.01	0.05	0.03	0.06	0.02	0.08
D 3.2	0.03	0.01	0.04	0.05	0.00	0.07
D 3.5	0.00	0.06	0.04	0.07	0.03	0.61
LSE						
E - near crop						
E 1.35	dry	dry	dry	dry	dry	dry
E 1.8	dry	dry	dry	dry	dry	dry
E 2.25	dry	dry	dry	0.59	0.34	dry
E 2.7	0.97	0.08	0.71	2.78	4.33	3.16
E 3.0	3.34	N/A	4.18	4.60	5.14	5.89
E 3.3	13.16	10.21	10.20	12.13	15.50	17.23
F - near creek						
F 2.25	0.45	<0.01	0.07	1.45	2.95	0.76
F 2.8					1.66	2.75
F 3.2	1.71	0.01	1.47	6.17	0.46	8.81
F 3.6	1.17		0.09		<0.01	0.01

Nitrate-N (mg/L)	**10/25/00**	**1/10/01**	**3/3/01**	**3/27/01**	**4/10/01**	**4/28/01**
F 4.0						
TW						
H - near creek						
H 1.3						
H 1.7						
H 2.4						
H 2.6						
H 2.9						
I - near crop						
I 1.6						
I 2.2						
I 2.8						
TE						
M - near crop						
M 1.6						
M 2.1						
M 2.6						
M 3.05						
N - near creek						
N 1.6						
N 2.4						
N 2.9						
N 3.4						
LSW						
J - near crop						
J 1.6						
J 2.1						
J 2.6						
J 3.1						
K - near creek						
K 1.95						
K 2.25						
K 2.6						
LSS						
L - control						
L 1.5						
L 2.0						
L 2.5						
L 2.85						
L 3.0						

Nitrate-N (mg/L)	**5/10/01**	**5/29/01**	**6/18/01**	**7/10/01**	**07/30/01**	**8/20/01**
JRS						
A - mid-buffer						
A 1.5	2.92	8.55	1.91	12.07	dry	dry
A 1.7	3.13	8.55	6.99	12.68	7.07	7.07
A 1.9	2.67	7.34	5.99	12.11	5.39	5.39
A 2.3	0.02	0.10	0.17	<0.01	<0.01	<0.01
A 2.5	0.03	0.14	<0.01	<0.01	<0.01	<0.01
A 2.7	0.07	0.19	0.17	0.44	0.16	0.16
B - near creek						
B 1.6	0.90	0.26	0.09	dry	dry	dry
B 1.9	0.04	0.18	0.26	0.05	<0.01	<0.01
B 2.1	0.03	0.22	0.12	0.06	0.24	0.24
B 2.3	<0.01	0.23	10.84	<0.01	0.01	0.01
B 2.55	0.03	0.69	0.14	<0.01	0.07	0.07
B 2.8	0.19	0.29	0.52	0.30	0.00	0.00
G - near crop						
G 1.55		14.31	8.65	4.30	dry	dry
G 1.85		11.69	0.73	18.16	18.36	18.36
G 2.15		2.80	10.71	1.75	1.27	1.27
G 2.45		6.89	15.83	8.56	2.70	2.70
G 2.75		22.75	20.18	11.10	2.89	2.89
RRS						
C - near creek						
C 1.95	2.89	0.11	dry	dry	dry	dry
C 2.4	2.59	0.90	2.00	0.33	0.71	0.71
C 2.7	1.58	0.71	0.45	1.51	0.46	0.46
C 3.05	0.84	1.55	1.49	2.25	2.15	2.15
C 3.3	1.33	0.12	1.31	1.68	1.97	1.97
D - near crop						
D 2.0	5.94	7.71	0.82	dry	dry	dry
D 2.3	2.38	1.82	2.52	2.72	dry	dry
D 2.6	0.15	0.21	0.08	<0.01	0.02	0.02
D 3.2	0.24	0.46	0.13	<0.01	<0.01	<0.01
D 3.5	0.06	0.60	0.31	0.01	0.15	0.15
LSE						
E - near crop						
E 1.35	dry	dry	dry	dry	dry	dry
E 1.8	dry	dry	dry	dry	dry	dry
E 2.25	0.55	dry	dry	dry	dry	dry
E 2.7	3.62	2.96	0.28	2.73	2.63	2.63
E 3.0	6.53	8.28	4.35	6.49	4.88	4.88
E 3.3	14.83	18.82	5.39	18.27	14.73	14.73
F - near creek						
F 2.25	1.29	0.07	<0.01	0.70	2.79	2.79
F 2.8	3.42	3.00	2.28	6.37	10.26	10.26
F 3.2	9.78	13.41	9.87	14.59	12.62	12.62
F 3.6	3.19	0.91	1.06	0.13		

Nitrate-N	(mg/L)	5/10/01	5/29/01	6/18/01	7/10/01	07/30/01	8/20/01
	F 4.0						
TW							
	H - near creek						
	H 1.3				dry	dry	dry
	H 1.7				dry	dry	dry
	H 2.4				<0.01	1.03	1.03
	H 2.6				0.05	<0.01	<0.01
	H 2.9				<0.01	<0.01	<0.01
	I - near crop						
	I 1.6				1.10	dry	dry
	I 2.2				4.45	5.05	5.05
	I 2.8				<0.01	0.88	0.88
TE							
	M - near crop						
	M 1.6					0.29	0.29
	M 2.1					0.19	0.19
	M 2.6					0.04	0.04
	M 3.05					0.01	0.01
	N - near creek						
	N 1.6					dry	dry
	N 2.4					<0.01	<0.01
	N 2.9					0.00	<0.01
	N 3.4					0.05	0.05
LSW							
	J - near crop						
	J 1.6				0.39	0.08	0.08
	J 2.1				<0.01	0.03	0.03
	J 2.6				<0.01	11.22	11.22
	J 3.1				<0.01	15.01	15.01
	K - near creek						
	K 1.95		<0.01		0.05	<0.01	<0.01
	K 2.25		0.20		<0.01	0.01	0.01
	K 2.6		7.61		<0.01	<0.01	<0.01
LSS							
	L - control						
	L 1.5					dry	dry
	L 2.0					1.09	1.09
	L 2.5					N/A	N/A
	L 2.85					<0.01	<0.01
	L 3.0					<0.01	<0.01

Nitrate-N (mg/L)	**9/11/01**	**10/02/01**	**11/14/01**
JRS			
A - mid-buffer			
A 1.5	3.75	5.00	5.67
A 1.7	6.92	6.89	6.82
A 1.9	5.43	5.32	5.15
A 2.3	0.03	<0.01	0.24
A 2.5	<0.01	0.02	0.14
A 2.7	1.23	0.05	0.36
B - near creek			
B 1.6	dry	dry	dry
B 1.9	0.19	0.02	0.04
B 2.1	<0.01	<0.01	0.02
B 2.3	<0.01	0.04	<0.01
B 2.55	<0.01	0.03	<0.01
B 2.8	<0.01	0.07	0.07
G - near crop			
G 1.55	0.06	4.88	0.78
G 1.85	7.04	8.01	17.13
G 2.15	15.22	12.64	14.70
G 2.45	10.75	9.84	11.40
G 2.75	1.57	5.50	8.50
RRS			
C - near creek			
C 1.95	dry	dry	dry
C 2.4	0.08	0.14	0.28
C 2.7	<0.01	0.07	0.01
C 3.05	<0.01	<0.01	0.51
C 3.3	0.26	0.06	0.09
D - near crop			
D 2.0	dry	dry	dry
D 2.3	dry	3.03	2.65
D 2.6	0.04	0.12	0.04
D 3.2	<0.01	0.10	0.05
D 3.5	<0.01	0.11	0.02
LSE			
E - near crop			
E 1.35	dry	dry	dry
E 1.8	dry	dry	dry
E 2.25	dry	dry	dry
E 2.7	4.29	4.06	5.18
E 3.0	8.06	9.44	10.34
E 3.3	18.68	19.13	24.70
F - near creek			
F 2.25	0.17	2.35	6.06
F 2.8	9.72	12.38	19.72
F 3.2	14.89	17.33	21.89
F 3.6	1.10	0.55	0.86

Nitrate-N	(mg/L)	**9/11/01**	**10/02/01**	**11/14/01**
	F 4.0			
TW				
	H - near creek			
	H 1.3	dry	dry	dry
	H 1.7	dry	dry	dry
	H 2.4	2.13	0.25	0.15
	H 2.6	<0.01	<0.01	<0.01
	H 2.9	3.00	<0.01	0.02
	I - near crop			
	I 1.6	dry	dry	dry
	I 2.2	2.08	4.13	5.55
	I 2.8	10.67	1.33	2.62
TE				
	M - near crop			
	M 1.6	0.62	0.01	0.08
	M 2.1	0.23	0.04	0.08
	M 2.6	<0.01	<0.01	0.14
	M 3.05	0.28	<0.01	0.06
	N - near creek			
	N 1.6	<0.01	<0.01	0.06
	N 2.4	<0.01	0.01	0.04
	N 2.9	<0.01	<0.01	0.01
	N 3.4	0.01	<0.01	0.01
LSW				
	J - near crop			
	J 1.6	0.58	0.39	0.50
	J 2.1	<0.01	0.06	0.02
	J 2.6	2.86	0.06	0.32
	J 3.1	11.92	1.25	1.37
	K - near creek			
	K 1.95	<0.01	<0.01	<0.01
	K 2.25	0.00	0.04	0.15
	K 2.6	<0.01	0.01	<0.01
LSS				
	L - control			
	L 1.5	dry	dry	1.94
	L 2.0	3.06	0.65	0.36
	L 2.5	<0.01	0.77	0.03
	L 2.85	1.98	<0.01	<0.01
	L 3.0	<0.01	<0.01	<0.01

Chloride (mg/L)	**10/25/00**	**1/11/01**	**3/3/01**	**3/27/01**	**4/10/01**	**4/28/01**
JRS						
A - mid-buffer						
A 1.5	dry	dry	11.3	12.9	14.4	10.1
A 1.7	dry	dry	20.4	20.7	11.7	8.6
A 1.9	18.9	17.1	11.6	12.6	10.9	9.2
A 2.3	18.1	23.3	20.6	19.8	19.1	15.3
A 2.5	23.3	23.4	20.3	48.4	46.3	14.1
A 2.7	17.5	18.4	13.8	18.1	23.2	15.3
B - near creek						
B 1.6	dry	dry	14.5	17.4	16.0	12.0
B 1.9	dry	23.9	30.3	15.3	17.9	15.8
B 2.1	19.5	25.9	22.1	22.2	45.6	16.7
B 2.3	10.1	22.8	39.9	21.3	19.9	16.4
B 2.55	9.2	26.0	26.2	20.5	24.0	17.1
B 2.8	31.3	26.5	22.9	23.5	25.4	21.0
G - near crop						
G 1.55						
G 1.85						
G 2.15						
G 2.45						
G 2.75						
RRS						
C - near creek						
C 1.95	dry	dry	dry	22.1	23.4	dry
C 2.4	dry	59.4	16.7	17.5	24.0	18.3
C 2.7	21.4	13.0	15.3	13.1	70.6	15.8
C 3.05	22.4	12.6	12.2	14.7	27.3	22.0
C 3.3	18.5	13.5	10.7	N/A	27.4	17.0
D - near crop						
D 2.0	dry	dry	dry	18.1	28.8	18.9
D 2.3	dry	dry	dry	18.9	20.7	16.4
D 2.6	15.0	14.5	13.6		17.2	13.2
D 3.2	12.5	16.8	15.1	16.8	15.5	13.4
D 3.5	13.7	15.1	20.1	15.3	16.2	13.7
LSE						
E - near crop						
E 1.35	dry	dry	dry	dry	dry	dry
E 1.8	dry	dry	dry	dry	dry	dry
E 2.25	dry	dry	dry	dry	dry	dry
E 2.7	25.9	15.2	14.8	14.6	18.4	11.9
E 3.0	24.2		14.5	14.8	17.9	12.6
E 3.3	17.7	15.5	14.3	14.7	18.8	16.8
F - near creek						
F 2.25	12.3	12.6	12.0	19.5	16.1	10.9
F 2.8					20.7	10.7
F 3.2	14.4	15.2	14.4	14.6	12.4	11.1
F 3.6	18.3		16.8		11.9	7.5

Chloride	(mg/L)	**10/25/00**	**1/11/01**	**3/3/01**	**3/27/01**	**4/10/01**	**4/28/01**
	F 4.0						
TW							
	H - near creek						
	H 1.3						
	H 1.7						
	H 2.4						
	H 2.6						
	H 2.9						
	I - near crop						
	I 1.6						
	I 2.2						
	I 2.8						
TE							
	M - near crop						
	M 1.6						
	M 2.1						
	M 2.6						
	M 3.05						
	N - near creek						
	N 1.6						
	N 2.4						
	N 2.9						
	N 3.4						
LSW							
	J - near crop						
	J 1.6						
	J 2.1						
	J 2.6						
	J 3.1						
	K - near creek						
	K 1.95						
	K 2.25						
	K 2.6						
LSS							
	L - control						
	L 1.5						
	L 2.0						
	L 2.5						
	L 2.85						
	L 3.0						

Chloride (mg/L)	**5/9/01**	**5/29/01**	**6/18/01**	**7/10/01**	**7/31/01**	**8/20/01**
JRS						
A - mid-buffer						
A 1.5	9.3	6.9	5.4	11.5	dry	dry
A 1.7	8.6	7.9	3.1	10.8	10.5	10.1
A 1.9	9.7	8.1	5.3	14.0	11.5	8.6
A 2.3	16.9	12.3	21.1	16.5	15.1	12.3
A 2.5	17.5	15.6	18.2	17.9	16.1	11.4
A 2.7	20.1	14.6	4.9	17.8	16.7	11.3
B - near creek						
B 1.6	16.3	14.8	7.2	dry	dry	dry
B 1.9	18.5	15.0	13.2	17.0	18.3	11.9
B 2.1	18.7	15.8	6.7	18.2	17.9	13.8
B 2.3	19.2	16.2	15.9	20.1	20.2	14.8
B 2.55	19.0	17.7	8.2	20.2	20.3	16.3
B 2.8	21.0	21.1	8.7	20.1	19.9	15.7
G - near crop						
G 1.55		10.1	14.1	14.8	dry	dry
G 1.85		10.1	11.6	12.9	15.0	10.0
G 2.15		16.8	12.6	21.9	14.2	10.3
G 2.45		12.8	5.3	16.1	14.6	12.1
G 2.75		15.0	6.6	26.2	15.1	12.7
RRS						
C - near creek						
C 1.95	18.9	dry	6.5	dry	dry	dry
C 2.4	18.2	dry	6.9	18.8	17.2	12.4
C 2.7	17.1	15.0	5.1	20.9	19.5	21.7
C 3.05	16.7	16.7	5.9	20.8	24.6	15.8
C 3.3	18.1	15.5	5.2	20.7	18.3	14.8
D - near crop						
D 2.0	24.4	20.1	6.4	dry	dry	dry
D 2.3	20.6	15.3	28.2	19.2	dry	dry
D 2.6	13.4	10.7	4.0	13.1	12.2	10.6
D 3.2	14.8	12.3	4.6	14.3	13.7	10.0
D 3.5	14.3	12.9	12.9	13.4	12.8	10.1
LSE						
E - near crop						
E 1.35	dry	dry	dry	dry	dry	dry
E 1.8	dry	dry	dry	dry	dry	dry
E 2.25	dry	dry	dry	dry	dry	dry
E 2.7	13.3	dry	5.2	9.1	8.2	8.0
E 3.0	16.2	9.8	2.8	10.7	8.4	10.8
E 3.3	16.0	25.4	25.8	20.3	16.8	12.0
F - near creek						
F 2.25	10.6	8.6	2.8	9.1	9.3	6.8
F 2.8	10.0	7.2	18.1	10.7	13.0	11.2
F 3.2	10.0	8.4	16.2	14.8	14.0	10.4
F 3.6	8.6	6.8	10.1	8.5	8.5	

Chloride	(mg/L)	**5/9/01**	**5/29/01**	**6/18/01**	**7/10/01**	**7/31/01**	**8/20/01**
	F 4.0						
TW							
	H - near creek						
	H 1.3			dry	dry	dry	dry
	H 1.7			dry	dry	dry	dry
	H 2.4			10.3	3.9	2.8	2.0
	H 2.6			1.9	4.2	2.5	2.1
	H 2.9			1.0	5.2	2.5	2.1
	I - near crop						
	I 1.6				4.3	dry	dry
	I 2.2				7.6	10.0	6.1
	I 2.8				14.8	9.6	8.2
TE							
	M - near crop						
	M 1.6					6.1	4.4
	M 2.1					7.0	4.8
	M 2.6					6.6	3.9
	M 3.05					6.5	4.8
	N - near creek						
	N 1.6					dry	dry
	N 2.4					5.3	4.1
	N 2.9					5.5	2.2
	N 3.4					4.3	1.9
LSW							
	J - near crop						
	J 1.6				8.8	7.5	8.1
	J 2.1				11.0	12.3	11.7
	J 2.6				14.5	16.5	15.3
	J 3.1				16.7	18.1	16.0
	K - near creek						
	K 1.95			5.9	11.7	9.1	6.8
	K 2.25			6.1	11.4	10.4	8.9
	K 2.6			10.9	10.9	9.7	7.2
LSS							
	L - control						
	L 1.5					dry	dry
	L 2.0					8.5	6.6
	L 2.5						
	L 2.85					5.4	4.1
	L 3.0					5.2	3.7

Chloride (mg/L)	**9/11/01**	**10/2/01**	**11/16/01**
JRS			
A - mid-buffer			
A 1.5	7.4	7.9	12.8
A 1.7	9.3	8.4	12.6
A 1.9	15.3	8.9	12.6
A 2.3	19.2	19.7	18.2
A 2.5	16.9	55.3	18.2
A 2.7	18.3	17.9	21.2
B - near creek			
B 1.6	dry	dry	dry
B 1.9	28.1	23.4	16.9
B 2.1	31.3	26.7	22.8
B 2.3	23.9	24.6	26.7
B 2.55	21.1	24.4	20.6
B 2.8	25.8	24.1	21.2
G - near crop			
G 1.55	2.0	6.6	15.1
G 1.85	19.5	9.4	13.8
G 2.15	14.9	56.4	17.9
G 2.45	18.1	14.5	18.4
G 2.75	23.8	18.5	17.4
RRS			
C - near creek			
C 1.95	dry	dry	dry
C 2.4	23.2	20.7	21.6
C 2.7	28.9	19.7	18.7
C 3.05	28.7	16.9	15.9
C 3.3	28.6	16.8	16.3
D - near crop			
D 2.0	dry	dry	dry
D 2.3	dry	35.1	25.1
D 2.6	19.5	27.4	20.9
D 3.2	13.3	20.7	17.3
D 3.5	13.7	19.2	18.7
LSE			
E - near crop			
E 1.35	dry	dry	dry
E 1.8	dry	dry	dry
E 2.25	dry	dry	dry
E 2.7	6.8	8.3	13.7
E 3.0	10.3	11.6	14.9
E 3.3	29.9	27.9	27.9
F - near creek			
F 2.25	13.1	12.3	18.3
F 2.8	18.4	21.3	29.0
F 3.2	16.1	22.3	27.4
F 3.6	8.3	10.5	10.9

Chloride

	(mg/L)	9/11/01	10/2/01	11/16/01
	F 4.0			
TW				
	H - near creek			
	H 1.3	dry	dry	dry
	H 1.7	dry	dry	dry
	H 2.4	1.8	1.5	1.8
	H 2.6	1.8	1.5	1.9
	H 2.9	1.5	1.5	1.9
	I - near crop			
	I 1.6	dry	dry	dry
	I 2.2	7.2	9.2	9.0
	I 2.8	10.1	10.7	11.8
TE				
	M - near crop			
	M 1.6	5.8	8.2	6.6
	M 2.1	5.5	6.5	5.1
	M 2.6	4.2	4.8	4.9
	M 3.05	4.6	6.0	4.9
	N - near creek			
	N 1.6	2.1	2.1	4.2
	N 2.4	1.7	4.0	3.0
	N 2.9	4.6	2.2	3.7
	N 3.4	0.8	0.9	2.8
LSW				
	J - near crop			
	J 1.6	8.5	16.3	15.3
	J 2.1	23.1	21.9	18.9
	J 2.6	43.9	18.1	16.9
	J 3.1	21.7	13.9	10.7
	K - near creek			
	K 1.95	14.3	19.9	25.2
	K 2.25	7.0	45.2	17.5
	K 2.6	8.7	10.9	14.7
LSS				
	L - control			
	L 1.5	dry	dry	9.0
	L 2.0	8.8	6.2	7.6
	L 2.5	4.6	4.8	6.1
	L 2.85	5.0	3.2	4.7
	L 3.0	5.3	3.4	6.7

Dissolved O_2	(mg/L)	7/30/01	8/20/01	9/10/01	10/1/01	11/13/01
JRS						
	A - mid-buffer					
	A 1.5	dry	dry	4.57	0.62	1.39
	A 1.7	1.30	0.69	1.67	0.38	0.66
	A 1.9	0.90	1.18	1.14	0.37	1.51
	A 2.3	0.80	0.22	0.28	0.27	0.73
	A 2.5	0.80	0.31	0.31	0.30	0.56
	A 2.7	0.90	0.29	0.34	0.32	0.67
	B - near creek					
	B 1.6	dry	dry	dry	dry	dry
	B 1.9	0.90	1.40	0.57	0.40	1.67
	B 2.1	0.90	0.45	0.37	0.38	0.72
	B 2.3	0.75	0.28	0.32	0.39	1.20
	B 2.55	1.15	0.35	0.47	0.48	0.60
	B 2.8	0.85	0.40	0.33	0.33	0.44
	G - near crop					
	G 1.55	dry	dry	2.60	3.54	7.07
	G 1.85	2.15	0.60	1.70	1.54	1.91
	G 2.15	2.20	0.63	1.11	1.98	1.25
	G 2.45	0.90	0.32	0.35	1.10	1.38
	G 2.75	0.85	0.33	0.34	0.73	1.10
RRS						
	C - near creek					
	C 1.95	dry	dry	dry	dry	dry
	C 2.4	1.80	1.51	0.48	0.42	1.20
	C 2.7	0.90	0.75	0.42	0.38	1.14
	C 3.05	0.80	0.45	0.44	0.30	1.42
	C 3.3	0.75	0.40	0.40	0.28	0.93
	D - near crop					
	D 2.0	dry	dry	dry	dry	dry
	D 2.3	dry	dry	dry	0.60	1.61
	D 2.6	0.75	0.45	0.47	0.40	1.50
	D 3.2	0.90	-	0.32	0.36	0.39
	D 3.5	0.65	0.40	0.37	0.28	0.42
LSE						
	E - near crop					
	E 1.35	dry	dry	dry	dry	dry
	E 1.8	dry	dry	dry	dry	dry
	E 2.25	dry	dry	dry	dry	dry
	E 2.7	2.25	0.95	1.74	1.85	2.31
	E 3.0	4.75	5.76	4.27	3.90	3.21
	E 3.3	7.40	4.53	7.89		7.83
	F - near creek					
	F 2.25	1.85	0.95	1.39	0.65	0.91
	F 2.8					
	F 3.2	2.65	1.85	2.76	2.84	2.64

Dissolved O_2

	(mg/L)	7/30/01	8/20/01	9/10/01	10/1/01	11/13/01
	F 3.6					
	F 4.0					
TW						
	H - near creek					
	H 1.3	dry	dry	dry	dry	dry
	H 1.7	dry	dry	dry	dry	dry
	H 2.4	4.33	1.60	2.60	2.13	1.91
	H 2.6	4.70	1.15	0.93	0.87	1.09
	H 2.9	2.70	0.35	0.71	0.73	0.78
	I - near crop					
	I 1.6	dry	dry	dry	dry	dry
	I 2.2	3.93	6.45	3.20	5.16	7.71
	I 2.8	2.94	4.32	2.14	0.99	1.76
TE						
	M - near crop					
	M 1.6	dry	2.43	0.81	0.36	0.82
	M 2.1	6.60	0.81	0.70	0.87	1.32
	M 2.6	5.70	0.38	0.30	0.33	0.61
	M 3.05	6.20	0.41	0.26	0.23	0.49
	N - near creek					
	N 1.6	dry	dry	dry	3.70	7.10
	N 2.4	1.20	1.67	0.83	2.14	3.05
	N 2.9	1.80	1.45	0.91	1.50	2.01
	N 3.4	2.65	1.10	0.65	0.75	1.25
LSW						
	J - near crop					
	J 1.6	2.78	2.68	1.10	1.65	1.55
	J 2.1	0.45	0.66	0.99	0.50	1.05
	J 2.6	0.30	0.68	0.56	0.63	0.91
	J 3.1	0.35	0.52	0.71	0.31	0.49
	K - near creek					
	K 1.95	0.83	0.46	0.43	0.32	0.79
	K 2.25	0.60	1.15	0.72	0.89	1.56
	K 2.6	0.35	1.75	0.43	0.28	0.60
LSS						
	L - control					
	L 1.5	dry	dry	dry	dry	3.02
	L 2.0	1.30	0.95	1.57	0.42	1.67
	L 2.5			0.43	0.34	0.82
	L 2.85	2.30	0.31	0.46	0.31	1.57
	L 3.0	0.51	0.27	0.31	0.26	1.62

DOC (mg/L)	3/27/01	4/10/01	4/24/01	5/8/01	5/29/01	6/5/01	6/19/01
JRS							
A - mid-buffer							
A 1.5	1.61	1.57		1.87			1.11
A 1.7	1.23	1.52		1.94			0.99
A 1.9	1.48	1.40		2.07			0.95
A 2.3	0.86	1.08		1.74			0.74
A 2.5	0.93	1.14		1.60			0.49
A 2.7	0.84	0.82		1.05			0.25
B - near creek							
B 1.6	3.26	2.38		2.39	4.17		1.82
B 1.9	1.47	1.82		1.78	2.89		0.67
B 2.1	1.90	1.86		1.67	2.42		0.43
B 2.3	1.61	1.69		1.60	2.74		1.02
B 2.55	1.69	3.24		2.20	2.31		1.49
B 2.8	0.87	1.18		1.31	1.72		0.95
G - near crop							
G 1.55					5.67		1.94
G 1.85					4.46		2.04
G 2.15					4.35		1.31
G 2.45					2.18		0.01
G 2.75					1.17		0.01
RRS							
C - near creek							
C 1.95	1.52	1.88		1.77	dry		0.59
C 2.4	0.52	0.66		1.05	1.17		0.29
C 2.7	0.42	1.53		1.18	1.17		0.16
C 3.05	0.64	0.68		0.90	1.40		0.35
C 3.3	1.10	0.79		0.87	1.47		0.57
D - near crop							
D 2.0	0.88	1.02		1.02	1.88		0.09
D 2.3	0.82	1.45		0.94	1.49		0.47
D 2.6	0.46	0.77		0.74	1.27		0.19
D 3.2	0.41	0.94		0.84	1.55		0.16
D 3.5	0.64	0.71		0.87	1.49		0.17
LSE							
E - near crop							
E 1.35	dry	dry		dry	dry		dry
E 1.8	dry	dry		dry	dry		dry
E 2.25	1.63	dry		dry	dry		dry
E 2.7	1.45	1.22		1.50	dry		0.37
E 3.0	1.33	1.23		1.06	1.67		0.44
E 3.3	0.79	1.18		1.01	1.43		0.43
F - near creek							
F 2.25	1.01	0.88		1.71	2.18		0.58
F 2.8		3.67		3.07	2.13		0.53
F 3.2	0.43	0.96		1.72	1.83		0.11
F 3.6		1.69		4.79	3.03		1.37

DOC

	(mg/L)	3/27/01	4/10/01	4/24/01	5/8/01	5/29/01	6/5/01	6/19/01
	F 4.0							
TW								
	H - near creek							
	H 1.3							
	H 1.7							
	H 2.4							
	H 2.6							
	H 2.9							
	I - near crop							
	I 1.6							
	I 2.2							
	I 2.8							
TE								
	M - near crop							
	M 1.6							
	M 2.1							
	M 2.6							
	M 3.05							
	N - near creek							
	N 1.6							
	N 2.4							
	N 2.9							
	N 3.4							
LSW								
	J - near crop							
	J 1.6							
	J 2.1							
	J 2.6							
	J 3.1							
	K - near creek							
	K 1.95							
	K 2.25							
	K 2.6							
LSS								
	L - control							
	L 1.5							
	L 2.0							
	L 2.5							
	L 2.85							
	L 3.0							

DOC (mg/L)	**7/10/01**	**7/30/01**	**8/19/01**	**9/10/01**	**10/2/01**	**11/13/01**
JRS						
A - mid-buffer						
A 1.5	1.79	dry	dry	0.64	1.64	
A 1.7	1.96	1.95	dry	1.69	1.34	
A 1.9	2.02	2.13	1.44	1.80	1.53	
A 2.3	1.71	1.80	1.31	1.49	1.41	
A 2.5	1.92	1.39	0.94	0.75	0.85	
A 2.7	1.63	1.80	1.36	0.45	1.01	
B - near creek						
B 1.6	dry	dry	dry	dry	dry	dry
B 1.9	1.23	1.99	1.33	1.04	0.93	< 0.01
B 2.1	1.01	1.90	1.30	0.87	1.27	< 0.01
B 2.3	0.98	2.72	1.52	0.65	1.34	0.06
B 2.55	1.02	2.29	1.15	1.14	1.21	0.30
B 2.8	0.78	2.11	1.29	0.66	0.97	0.05
G - near crop						
G 1.55	1.61	dry	dry	2.46	2.52	0.58
G 1.85	1.68	2.42	2.28	1.68	2.21	0.54
G 2.15	1.13	2.06	1.77	0.98	1.90	0.48
G 2.45	0.45	1.48	0.78	0.40	0.71	0.54
G 2.75	0.74	1.36	0.73	< 0.01	0.62	-0.01
RRS						
C - near creek						
C 1.95	dry	dry	dry	dry	dry	dry
C 2.4	0.31	1.50	0.73	< 0.01	0.47	< 0.01
C 2.7	0.45	1.99	0.92	< 0.01	0.64	< 0.01
C 3.05	0.46	1.47	0.65	0.08	0.83	< 0.01
C 3.3	0.37	1.12	0.63	< 0.01	0.98	0.08
D - near crop						
D 2.0	dry	dry	dry	dry	dry	dry
D 2.3	0.51	dry	dry	dry	1.15	0.15
D 2.6	0.33	1.31	0.66	< 0.01	0.55	< 0.01
D 3.2	0.46	1.74	1.20	< 0.01	0.72	< 0.01
D 3.5	0.41	1.45	0.74	0.13	0.98	0.04
LSE						
E - near crop						
E 1.35	dry	dry	dry	dry	dry	dry
E 1.8	dry	dry	dry	dry	dry	dry
E 2.25	dry	dry	dry	dry	dry	dry
E 2.7	0.79	2.27	1.13	1.73	0.56	1.21
E 3.0	0.55	1.52	0.83	0.34	0.60	< 0.01
E 3.3	0.51	1.37	0.53	< 0.01	1.34	0.12
F - near creek						
F 2.25	0.51	1.61	0.83	0.04	0.82	0.17
F 2.8	0.87	2.16	0.94	2.46	0.94	0.14
F 3.2	0.37	1.37	0.52	< 0.01	0.47	< 0.01
F 3.6	0.71	4.01	1.00	2.24	1.57	0.82

DOC

(mg/L)	7/10/01	7/30/01	8/19/01	9/10/01	10/2/01	11/13/01
F 4.0						
TW						
H - near creek						
H 1.3	dry	dry	dry	dry	dry	dry
H 1.7	dry	dry	dry	dry	dry	dry
H 2.4	1.81	2.44	1.87	0.58	1.36	< 0.01
H 2.6	1.87	3.17	2.50	1.81	2.18	1.39
H 2.9	3.21	4.13	4.15	2.27	2.34	1.45
I - near crop						
I 1.6	2.95	dry	dry	dry	dry	dry
I 2.2	0.22	1.00	0.66	< 0.01	0.42	< 0.01
I 2.8	3.93	3.58	3.31	1.05	1.61	0.81
TE						
M - near crop						
M 1.6		0.53	2.03	3.43	1.80	0.64
M 2.1		0.50	2.90	2.66	2.90	0.96
M 2.6		0.10	1.51	0.99	1.08	0.34
M 3.05		< 0.01	1.43	1.15	1.11	0.49
N - near creek						
N 1.6		dry	dry	2.53	3.96	2.32
N 2.4		18.57	14.82	6.30	4.17	1.25
N 2.9		25.61	29.24	4.94	6.18	3.91
N 3.4		11.14	24.90	9.72	6.18	3.70
LSW						
J - near crop						
J 1.6	1.85	0.54	1.44	0.10	1.70	0.56
J 2.1	3.52	0.84	1.83	0.46	1.76	0.22
J 2.6	5.35	0.19	1.74	0.56	1.44	0.16
J 3.1	1.35	0.04	1.63	< 0.01	1.33	0.14
K - near creek						
K 1.95	1.20	< 0.01	2.06	0.34	1.16	0.35
K 2.25	1.89	0.25	2.74	0.42	1.51	0.35
K 2.6	3.14	< 0.01	2.06	0.01	1.22	0.36
LSS						
L - control						
L 1.5		dry	dry	dry	dry	0.61
L 2.0		2.73	1.25	< 0.01	0.67	< 0.01
L 2.5				1.44	0.97	< 0.01
L 2.85		1.37	0.97	< 0.01	2.51	< 0.01
L 3.0		1.46	1.05	< 0.01	0.50	< 0.01

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