Using Available Resources to Enhance the Teaching of Hydrogeology

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ABSTRACT

Teaching the concepts and fundamentals of hydrology and hydrogeology, particularly to undergraduates who have limited field experience, presents a challenge. Many innovations from working models to computer simulations have been used to improve visualization of the subject and to add a practical applied component to training. Recently, as a result of a partnership with private firms, two monitoring wells were completed on the University of Wisconsin-Green Bay campus to augment several previously installed porous-cup lysimeters. These enabled a graduate student to sample vadose and ground and surface water from a variety of streams, ponds, and seeps and to characterize the surface and subsurface water resources of the 700-acre campus. The investigation revealed a number of relationships such as the high sulfate concentrations in one of the monitoring wells, elevated concentrations of chloride in several surface water bodies, and an unexpectedly low concentration of ions in a pond on the campus golf course.

The results of the study, and the convenient sampling sites available on the campus, are being used to strengthen the science curriculum. Students now have opportunities to obtain practical experience with water-quality sampling and analysis instruments and to improve their applied technical skills. They may also develop an appreciation of the difficulties involved with field sampling and measurement, and an understanding of the importance of proper handling of samples and accountability issues of sample collection and analysis.

Keywords: Apparatus; field trips and field study; hydrogeology and hydrology.

Introduction

Presenting the concepts and fundamentals of hydrology and hydrogeology to undergraduate students poses a number of challenges for instructors. Theoretical aspects are not only challenging but also difficult to frame in a practical applied manner. Working models such as stream tables and groundwater tanks allow valuable observation and visualization of otherwise obscure relationships and processes; however, they provide little training in the complexities and limitations of sample collection, handling, and analysis (Gates, and others, 1996; Knadle and Udaloy, 1994). Computer models are powerful simulators of natural systems, but they also may seem contrived when disconnected from the source of the data (Hudak, 1996). Data can be obtained from the literature, drawn from the instructor's research, or invented for the course, but those data seem unreal to students because in a classroom exercise they are not involved with all phases of a project from data collection through interpretation. In such cases, students manipulate and apply the data, but they do not appreciate the importance of the source or quality of the data.

Many examples of efforts to improve the effectiveness of instruction at various levels of sophistication have been published (Fletcher, 1994; Rahn and Davis, 1996; and Tabidian, 1996). In this article, we describe activities that strengthen and integrate science education and training at the University of Wisconsin-Green Bay beyond individual courses and that include several disciplines at different levels in the science curriculum. We also review the benefits of a partnership between the University and private firms that resulted in improved educational opportunities for students.

Background

The University of Wisconsin-Green Bay campus, which includes the 290-acre Cofrin Arboretum, is located on nearly 700 acres of gently rolling topography along the east shore of Green Bay in northeastern Wisconsin (Figure 1). Most of the campus lies on outwash and till overlying the predominantly shaly Upper Ordovician Maquoketa Formation, west and below the Niagara Escarpment formed of Lower Silurian dolostones (Need, 1985; Krohelski, 1986). The glacial sediments were reworked during higher levels of the bay. The campus encompasses an interesting topographic variability with a prominent post-Pleistocene shore terrace and an array of water bodies that includes ponds, streams, and springs as well as Green Bay itself. Much of the campus was previously farmed; another segment was part of an 18-hole golf course that was reduced to nine holes when the academic buildings were constructed.

Although numerous students have studied and sampled the plants, insects, soils, and surface waters of the campus, little systematic work had been completed on the water quality and none related to subsurface water quality. In an effort to remedy that situation, two porous-cup suction lysimeters were installed by Rimal, Stieglitz, and James Wiersma, another UW-Green Bay professor, in the fall of 1996 to sample soil water. In the spring of 1997, arrangements were finalized with two private environmental firms to drill and install a pair of shallow monitoring

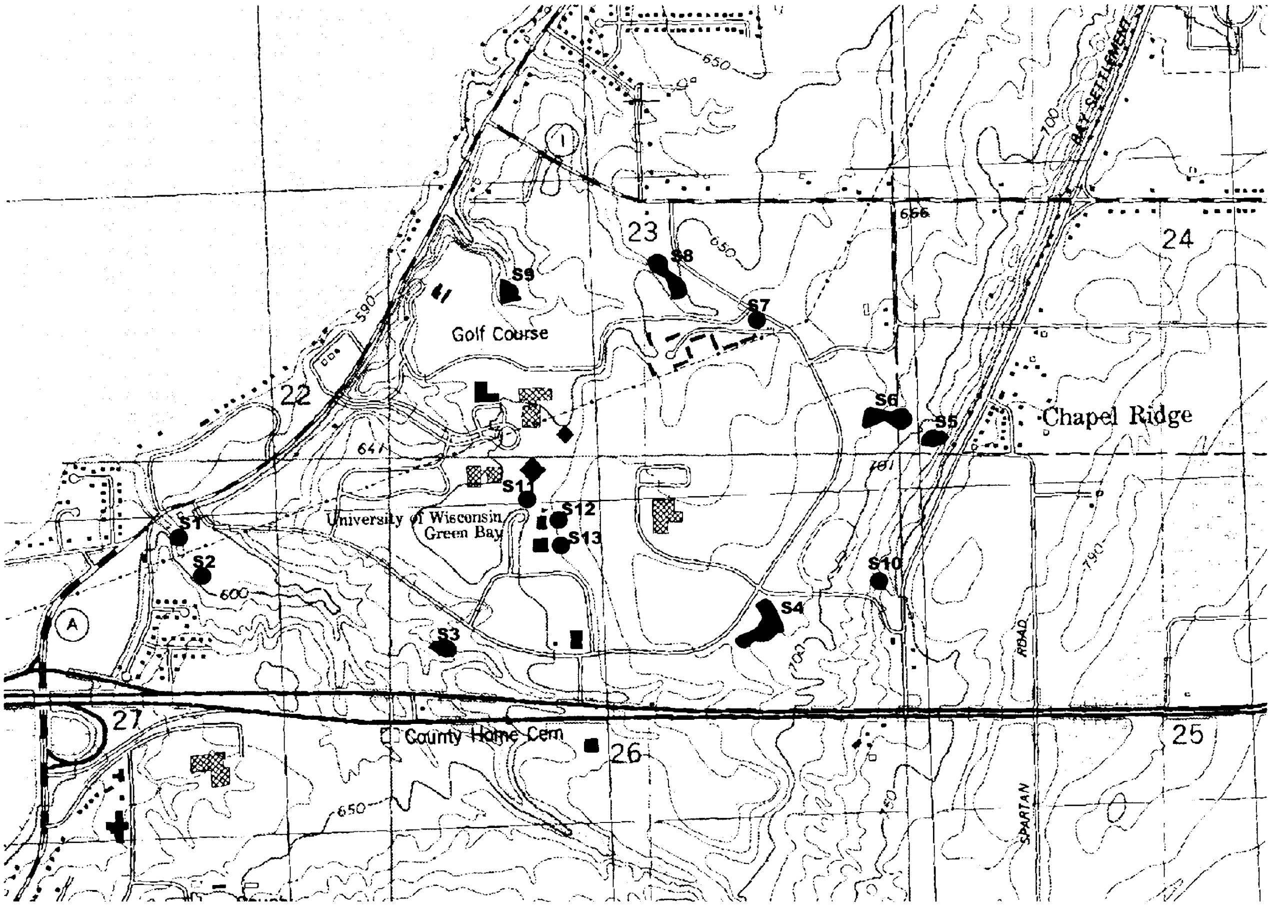

Figure 1. Study site and sampling locations on the University of Wisconsin-Green Bay campus.

wells to provide access to the ground water. Environmental Drilling Services (EDS) of DePere, Wisconsin provided the drilling equipment and crew and donated all the materials needed for the wells. A hydrogeologist from Natural Resources Protection Consultants (NRP) of Green Bay supervised the installation. The wells were sited near the Laboratory Sciences Building and the lysimeters to facilitate sampling and to allow comparisons of the vadose and ground water. One well was screened to monitor the fluctuations of the water table. The second well was completed as a piezometer and screened just above the bedrock surface. The sediments were described and the numbers of blows needed to drive the sampler were recorded as the holes were advanced. In addition, we collected samples for size analysis in the laboratory. Rimal then began a study of the water resources of the campus. His goals were to investigate the quality of the surface, soil, and ground waters on the campus, to use the information to characterize the different water systems and select distinctive sampling sites, and to determine how to better incorporate the sites into the related science courses.

FEATURE	SAMPLE NUMBER
STREAMS AND SEEPS	
Mahon Creek Lower	S1
Mahon Creek Upper	S2
Ledge Creek	S6
Housing Drainage Ditch	S7
Escarpment Seep	S10
PONDS	
Prairie Pond	S3
Upahaki Pond	S4
New Pond	S5
Tadpole Pond	S8
Golf Course Pond	S9
SUBSURFACE SITES	
Lysimeter	S11
Shallow Well	S12
Piezometer Well	S13

Table 1. Sampling sites related to sample numbers.

Water-Quality Sampling and Analysis

We collected water samples from the lysimeters, monitoring wells, Mahon Creek, several springs, five ponds, and a small artificially channelized stream during the spring, summer, and fall of 1997 to 1998 (Table 1). Surface sites were chosen to obtain samples from streams, a variety of ponds, and of newly emergent groundwater from the springs. Rimal analyzed

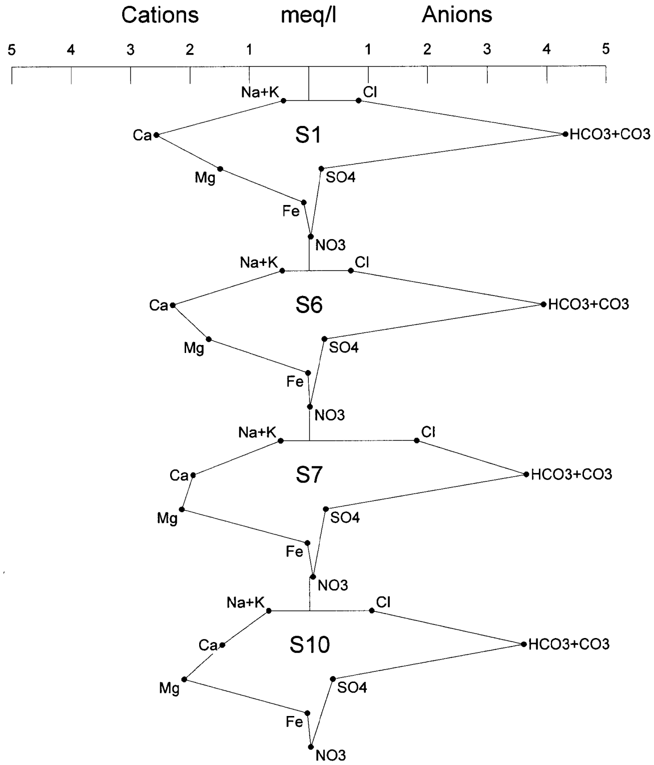

Figure 2. Stiff diagrams for flowing surface water samples.

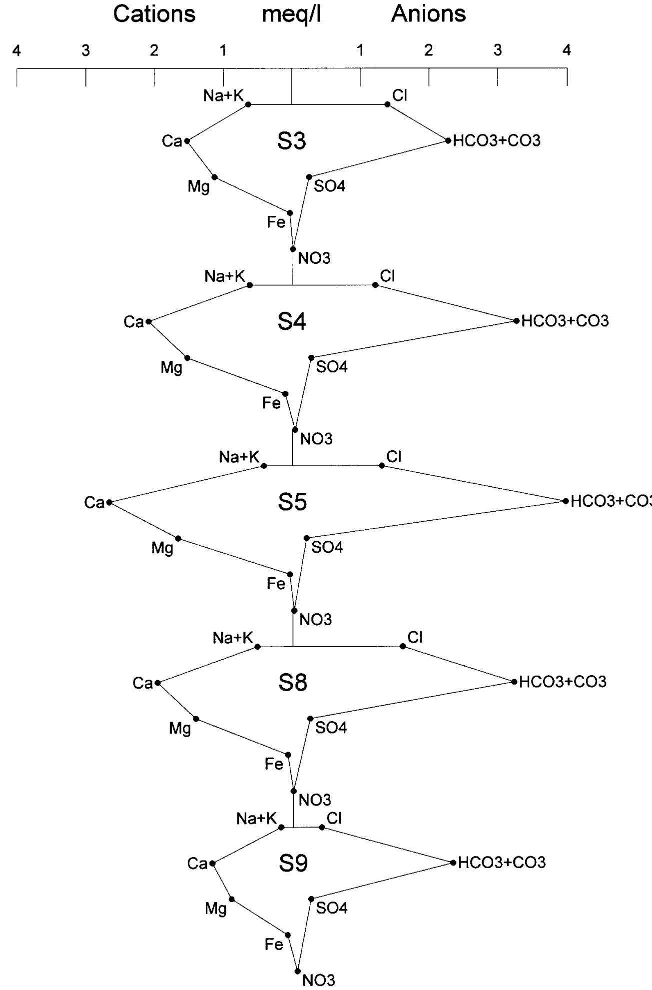

Figure 3. Stiff diagrams for the pond samples.

the samples for calcium, magnesium, sodium, potassium, iron, chloride, sulfate, nitrate-nitrogen, and bicarbonate in the university laboratories. Samples that were not analyzed within a few hours were stored in a walk-in cooler. All analytical procedures followed the standard methods of the American Public Health Association (1992). We also monitored the water levels in the two wells.

Results

We tabulated and graphed the water-level measurements and analytical results for each site. A complete description of techniques and results can be found in Rimal (1998). We prepared several types of graphs. For example, the concentrations of the ions were plotted against the sampling dates to provide a time series graph for each site. The concentrations were also plotted on Stiff and Piper diagrams and displayed as box plots (Freeze and Cherry, 1979, p. 247-254).

Stiff diagrams show the absolute and relative concentrations of the four most abundant cations and the four most abundant anions. The cations are plotted on the left of the diagrams and the anions on the right. Because they are based on the ionic concentration of the water in milliequivalents/liter, the relative size of the diagram corresponds to the conductance of the water. These diagrams help to visualize the distinctive patterns of water from different sources. The Stiff diagrams for the surface water sampling sites are shown in Figures 2 and 3. Several conclusions and interpretations can be drawn from the diagrams. First, as expected, calcium is the dominant cation and bicarbonate the dominant anion in all of the ponds, Mahon Creek, and Ledge Creek. Magnesium is the dominant cation in the drainage ditch and the Niagara escarpment seep, reflecting the effects of the water recently passing through the Silurian dolo- stones of the escarpment (Figure 2). Magnesium is also relatively high, but not the most abundant cation, in Mahon Creek, Ledge Creek, and several of the ponds, again reflecting contributions from water flowing through the dolostones. Nitrate is very low at all sites, less than 10 mg/L, despite the agricultural history of the land and the presence of agriculture nearby. Chloride is relatively high in several ponds, but is notably high in the drainage-ditch samples where concentrations reached 80 mg/L (Figure 2). Elevated nitrate and chloride levels usually indicate contributions from human activities. The relatively high chloride concentrations are thought to result from the runoff of salt from campus roads near the water bodies.

Stiff diagrams of four of the five ponds appear quite similar in shape and size (Figure 3). The diagram for golf-course pond is markedly different, showing smaller concentrations of all of the major ions. This anomalous pattern is explained by the fact that the golf course has a bedrock well from which water is pumped into the pond during the summer to maintain an adequate supply for watering greens. While no construction record is available for the well, it appears

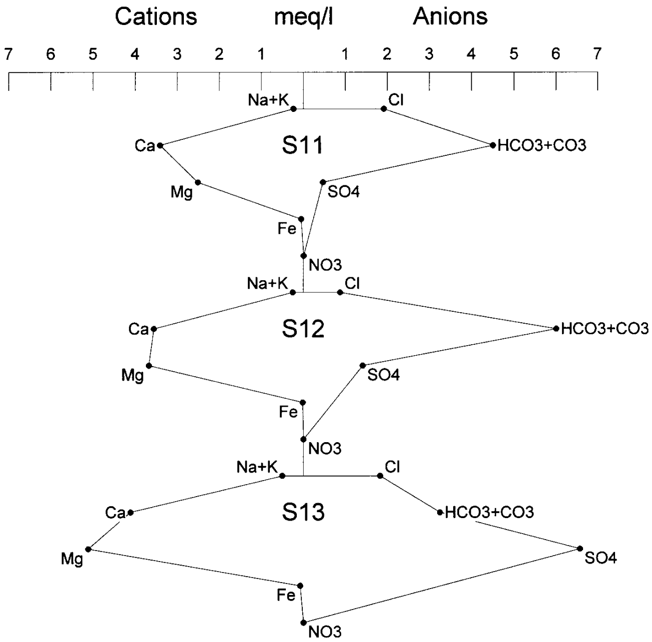

Figure 4. Stiff diagrams for soil and ground-water samples.

to extend into Cambrian sandstone since it is yielding water with significantly lower concentrations of calcium, magnesium, and bicarbonate.

The Stiff diagrams for the lysimeters and the monitoring wells are shown in Figure 4. Not only do they differ from those of the surface water, but the three diagrams also show an interesting relationship that can be used to illustrate the effects of the source and mixing of water. The diagram of the water from the lysimeter reveals relatively low concentration of all of the major ions with the exception of calcium. In addition, there is an interesting progression shown in the three diagrams of increasing magnesium and sulfate until they become the dominant ions in the water from the deeper piezometer. The overall increase in the ion concentration can be explained by the longer contact time of the water from the wells with the sediment and bedrock. Plotting of the heads in the two wells indicates an upward gradient, and the high concentrations of magnesium and sulfate in the piezometer are attributed to solution of gypsum nodules known to occur locally in the Maquoketa Formation. The intermediate concentrations of magnesium and sulfate in the water from the monitoring well may be due to solution of dolomite clasts in the glacial materials or to the mixing of infiltrating water with water moving upward from below. In any case, the variation of concentrations with depth provides an interesting and convenient problem for our students to recognize and explain.

Similarly, Piper diagrams (Figure 5) can be used to determine the hydrochemical facies of the water from the several sampling sites (Freeze and Cherry, 1979). Hydrochemical facies are defined by the dominant ions present in the water. The cations and anions are plotted in separate parts of a Piper diagram and are then projected onto the third part of the figure. The water from the piezometer is distinctly different from all others in sulfate concentration.

COURSE	APPLICATION
Introduction to Earth Science	Lecture Examples
Physical Geology	Examples/Demonstrations
Environmental Geology	Demonstrations/Sampling
Geological Field Methods	Sampling/Mapping
Hydrology	Sampling/Projects
Hydrogeology	Sampling/Projects
Environmental Chemistry	Analysis of Samples
Environmental Systems	Demonstrations/Sampling
The Soil Environment	Sampling/Projects
Groundwater Resources	Demonstrations/Sampling
Independent Study	Projects

Table 2. Courses and applications of the water-quality information.

The means and ranges of the average concentrations of the major ions were also plotted as box plots (Figure 6). The distinction between the composition of water from surface and subsurface sampling sites is evident, and subtle differences among the various surface sites are also apparent. Rimal (1998) used simple statistical analysis to test the significance of the differences among the parameters and as an aid to select sampling sites that best illustrate the instructional purposes of a number of different courses (Table 2).

Discussion

The campus of the University of Wisconsin-Green Bay is favorably located with respect to water-quality training opportunities. Not only are Green Bay and the Fox and East Rivers adjacent to or near the campus, but a variety of surface water bodies occur within its boundaries. With the installation of the shallow monitoring wells and lysimeters, students can be introduced to a broad range of water-sampling situations in a field setting. Exercises are constructed to emphasize the principles and techniques of investigation of surface, soil, or ground water individually or in any combination. The installation of the subsurface sampling points and the characterization of the different water resources on the campus provide a convenient and effective way for instructors to demonstrate, and for students to learn, fundamental concepts of hydrology and hydrogeology.

Students are introduced to, and can gain experience with, a variety of sampling and monitoring instruments. Water-sampling techniques, such as the use of a bailer or submersible pump to first purge and then to sample a monitoring well, are introduced in the field. Students are shown how a hand-held vacuum pump is used to draw water into and to expel water from a porous-cup lysimeter and that lysimeters can be effective tools to integrate ground water and vadose-zone monitoring and to understand the extent of pollution migration and attenuation processes. The elevation of the water in the wells is determined with water-level recorders and used to

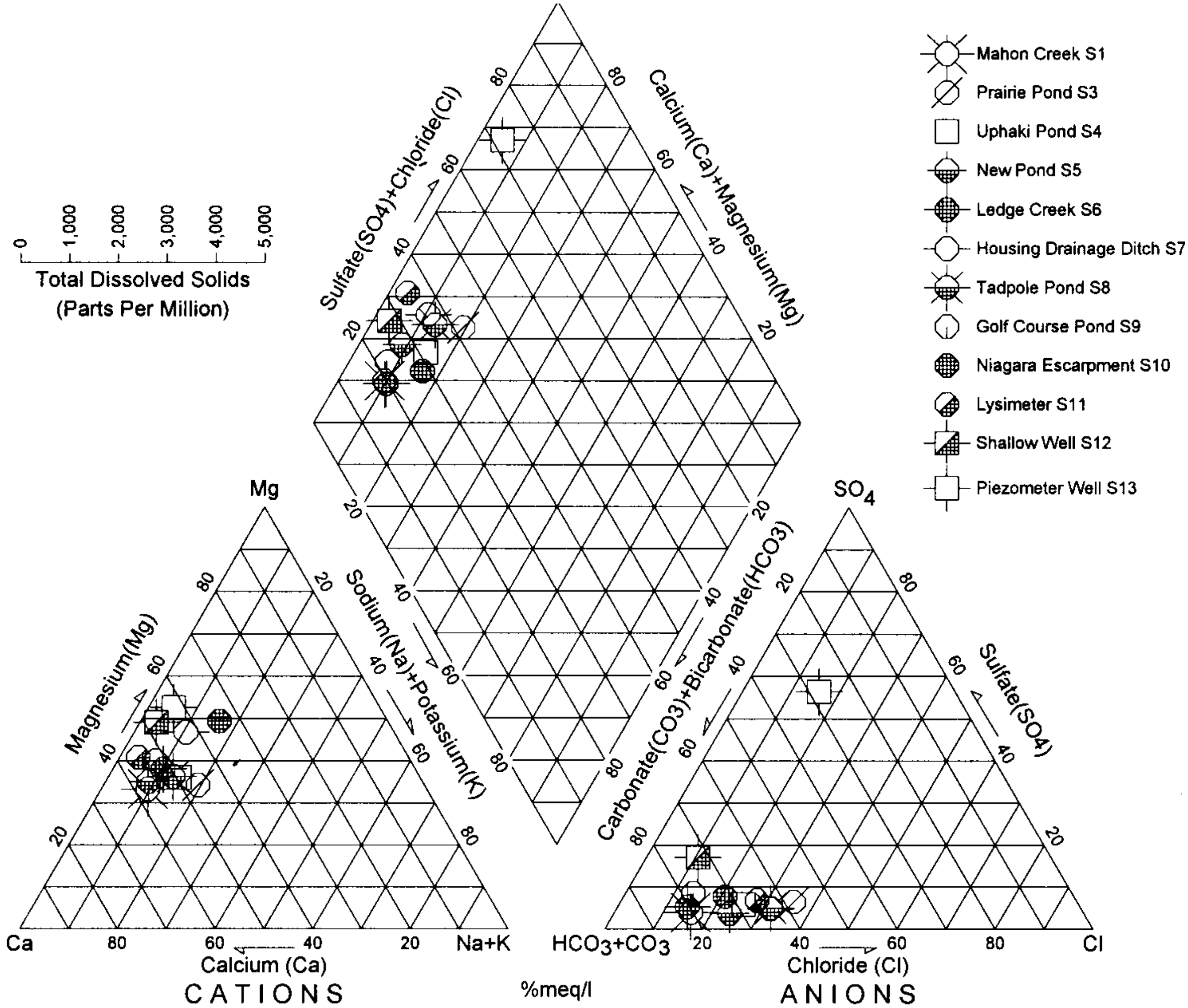

Figure 5. Piper diagram for all sites. (Sample numbers refer to sites shown on Figure 1.)

calculate the vertical gradient at the site. Students also gain experience in the techniques and difficulties involved with the measurement of conductivity, pH, and dissolved oxygen using field meters. The significance of such measurements cannot be overemphasized because calculation of chemical relationships and determination of the species present are strongly affected by the presence and quality of such data.

Water samples collected from the field sites are analyzed in the laboratory or provided to students in an Environmental Chemistry class, for example, to simulate the role of a commercial laboratory. The entire process makes students aware of the precautions necessary to collect, handle, transport, and analyze samples in order that uncontaminated and unbiased results are obtained that represent the quality of the water and whose validity cannot be challenged.

Exercises are being developed to use the data collected in the field or from the laboratory analysis of samples with computer software packages to simulate site evaluations, source impacts, surface and subsurface interactions, and resource estimations. Statistical packages will also be used to graph and plot the data as discussed earlier to assist students in visualizing relationships, trends, or anomalies. It might still be necessary to supplement the data set for larger problems; however, the hands-on component remains and adds to the reality of the exercise.

Because little has been done regarding the water quality on the campus, the wells, lysimeters, and the characterization of the water bodies will not only be helpful for instruction but also will be valuable for monitoring environmental conditions on the campus and in the adjacent Cofrin Arboretum. This can be achieved by assigning class projects in undergraduate and graduate courses that include sampling and monitoring as part of a semester-long effort. In this way, students can gain an appreciation for the temporal variations of water quality, and a long time-series of information can be developed.

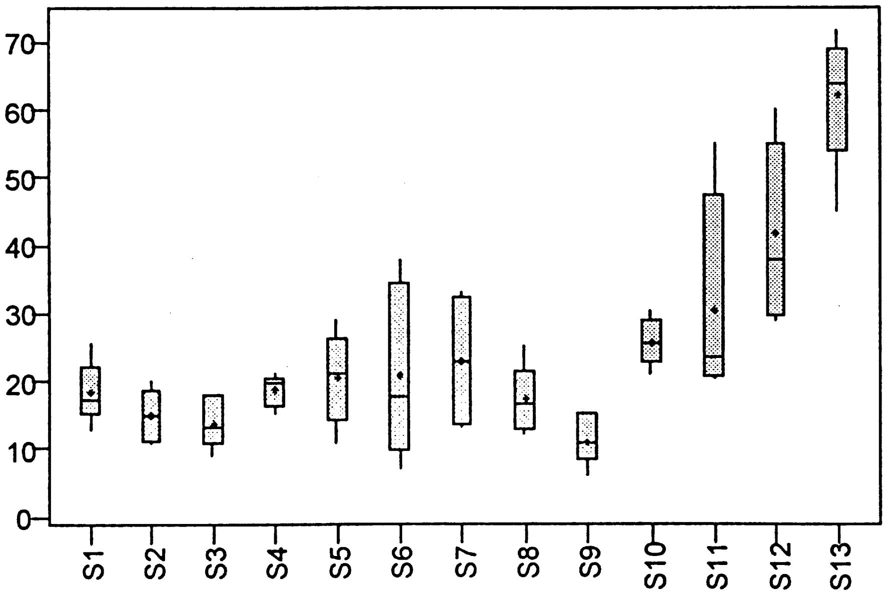

Figure 6. Boxplots of S1-S13. Analysis of variance of magnesium (mg/L) for all sites. Means are indicated by solid circles.

Conclusions

The combination of a Master's degree research project and a partnership with a private company that provided invaluable services and materials allowed the assessment of the water resources on the University of Wisconsin-Green Bay campus. The investigation developed information useful for instructional purposes and it strengthens the applied field and laboratory components of the science curriculum. For example, Mr. Rimal's work revealed that there is little, if any, residual effect on the soil and ground water from the agricultural use of the land before the University was established. It further indicates a significant difference in the composition of the vadose water, shallow ground water, and the ground water moving near the bedrock surface. The effect of the two different bedrock types is reflected by the composition of the water from the subsurface and the surface springs. Differences among the surface water bodies result from runoff or dilution with well water as in the case of the golf-course pond.

Each of these examples can serve as the basis for a simple but significant exercise with a specific question to be addressed and answered. Larger-scale and longer-term projects and exercises are also possible. The work reported here produced multiple benefits. It served to train a graduate student, determined the water quality on the University's campus, and pointed out existing and potential impacts to those resources that could affect the Cofrin Arboretum. Finally, the information forms the basis for a variety of applications in undergraduate and graduate courses. The increased opportunities for practical experiences with water-quality methods should increase student interest and involvement, and improve their technical and interpretive skills.

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