1-1-2007

Environmental studies: Interdisciplinary research on Maine lakes

Philip J. Nyhus
Colby College, pjnyhus@colby.edu

F Russell Cole
Colby College, frcole@colby.edu

David H. Firmage
Colby College, dhfirmag@colby.edu

Daniel Tierney

Susan W. Cole
Colby College, swcole@colby.edu

See next page for additional authors

Authors
Philip J. Nyhus, F Russell Cole, David H. Firmage, Daniel Tierney, Susan W. Cole, Raymond B. Phillips, and Edward H. Yeterian

Chapter 13

Environmental studies: Interdisciplinary research on Maine lakes

Philip J. Nyhus, F. Russell Cole, David H. Firmage, Daniel Tierney, Susan W. Cole, Raymond B. Phillips, and Edward H. Yeterian

Since the late 1980s, students in Colby College's Problems in Environmental Science (PES) course have been conducting studies of lakes and watersheds that surround their campus. Colby is located in central Maine, in the center of the state's lake district (figure 1).

The lakes are easily accessible to residents and tourists alike and are estimated to generate over $1.8 billion for the Maine economy each year. Their popularity, however, is contributing to their declining water quality, as housing and road construction have accelerated. A growing number of lakes now experience regular algal blooms resulting from excessive nutrient runoff from surrounding watersheds. This lake degradation has potentially serious implications for water quality as well as for the fishing and recreation sectors of Maine's economy.

Professors Russ Cole and David Firmage designed and teach the PES course to provide a common research experience for environmental science majors and to build on previous coursework in

Figure 1. Students in the Problems in Environmental Science course in the Environmental Studies Program at Colby College studied this map showing the location of lakes in central Maine.
Data courtesy of the Maine Office of GIS, and USGS.

ecology and environmental science.[1] Each year, the class assumes the role of a consulting firm and the students engage in real-world research. They problem-solve collaboratively and have ample opportunities to express themselves orally and in writing. They employ research methods commonly used in the field of environmental science and develop an understanding of relevant state and local regulations and their applications.

This course also exemplifies service learning in action, engaging the college and the environmental studies program with the local community (Firmage and Cole 1999, pp. 25–37). Which lakes are studied each year depends on incoming requests from local lake associations and the state Department of Environmental Protection (DEP). The course culminates in a public presentation and a major research report of class findings. In previous years, the students' final products have been used by the lake associations to guide management decisions and by the DEP to develop lake management strategies.

One iteration of the Problems in Environmental Science course

In autumn 2004, PES students investigated the water quality and related factors in the watershed of Togus Pond near Augusta, Maine. Situated close to the state capital, residential development along the lake's shoreline has been rapid in recent years and the lake experiences annual algal blooms. Understanding what causes algal blooms was only one component of the PES course, though. Students also investigated shoreline development and surrounding land-use and land-cover change, and modeled erosion potential and site suitability for septic systems. In each case, GIS was used to organize and analyze the environmental data, and we will briefly highlight details of these analyses.

Algal blooms respond to a lake's flushing rate, or its ability to self-clean. To understand flushing rates, the students conducted a descriptive spatial inventory of the lake. Using boat surveys, the class measured the lake's depth at more than 100,000 points and generated a bathymetric map.[2] With bathymetric data in hand, the students could derive vital statistics that described the lake, including its average depth (5.4 meters), deepest point (15.7meters), and relative distribution of shallow- and deep-water areas.

The students then pinpointed locations in the lake where the depth could jeopardize environmental health or make that location susceptible to an ecological threat. For example, one quarter of the pond is more than 8 meters deep, making it vulnerable to anoxia (a condition when little or no oxygen is available) (figure 2). Anoxic conditions are directly detrimental to many fish species and contribute to the growth of algae (by prompting release of phosphorus from sediments and increased phosphorus loading into the water column, which may stimulate algal growth near the water surface). During summer stratification, the students found anoxic areas in the deepest sections of the lake. The bathymetric analysis also showed that half the lake is susceptible to invasion by exotic macrophytic plants that prefer to colonize water shallower than five meters. This type of information is particularly important for scientists and lake association members trying to understand thresholds for lake water quality and working to develop water quality management strategies.

In addition, students conducted a survey of shoreline residences by boat and surveyed the buffer of vegetation that separated each house from the lake. They used GPS to locate the approximate

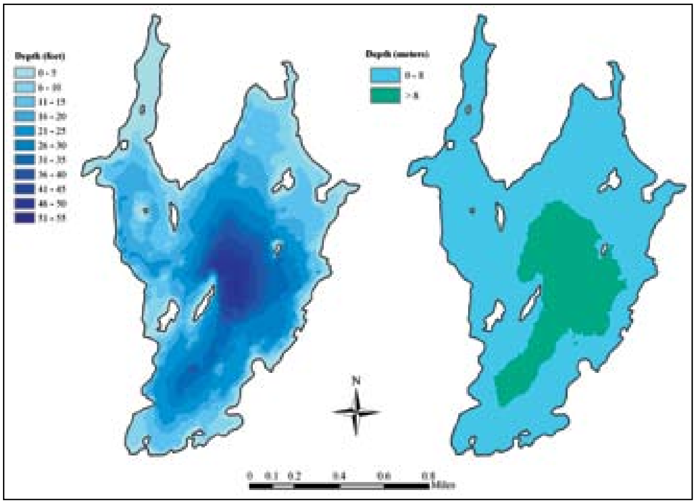

Figure 2. Bathymetry map for Togus Pond with depth measured in feet (left). Depth points were acquired using a Lowrance LCX-15MT, which consists of a boat-mounted sonar device and a GPS unit. The area below a depth of 8 meters (26 feet) where anoxic conditions are common is shown in green (right).
Data courtesy of the Maine Office of GIS.

center of each residential lot; and for each house, estimated lot length and buffer slope, vegetative cover, and depth. They made note of dense residential development areas, poor-quality roads adjacent to the shoreline that might contribute to soil erosion, and the quality of shoreline vegetative buffers surrounding the lake (figure 3).[3]

Because changes in land use and land cover have tremendous impacts on water quality, students digitized aerial photographs from 1954 and 2002 to create land-use data layers.[4] The students identified unique land covers for both years, including agriculture, disturbed forest, forest, commercial and municipal, residential, and wetlands, and made these into ArcGIS feature classes (figures 4 and 5).

They used the GIS to calculate the difference between the 1954 and 2002 images and quantified the changes on a map. Like much of the rest of Maine, forest cover has remained relatively stable in the area, accounting for just over 60 percent of the

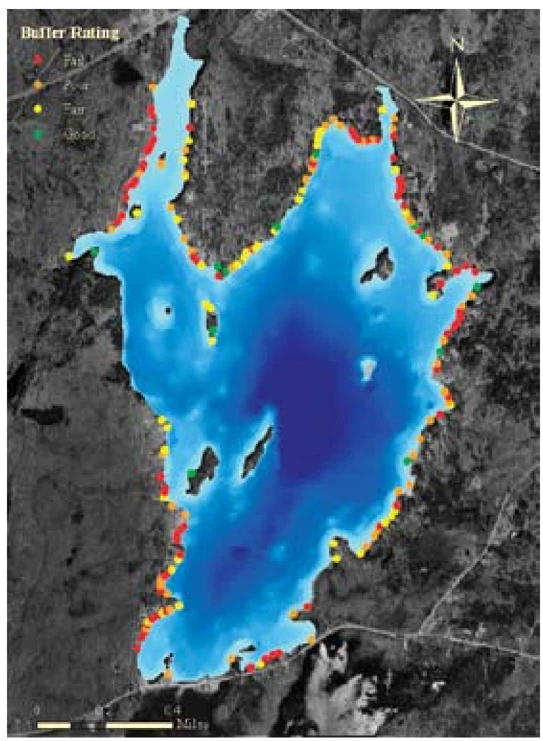

Figure 3. Buffer evaluation map for Togus Pond. Points correspond to developed house lots evaluated by students using a boat survey of all lakeshore lots.
Data courtesy of the Maine Office of GIS.

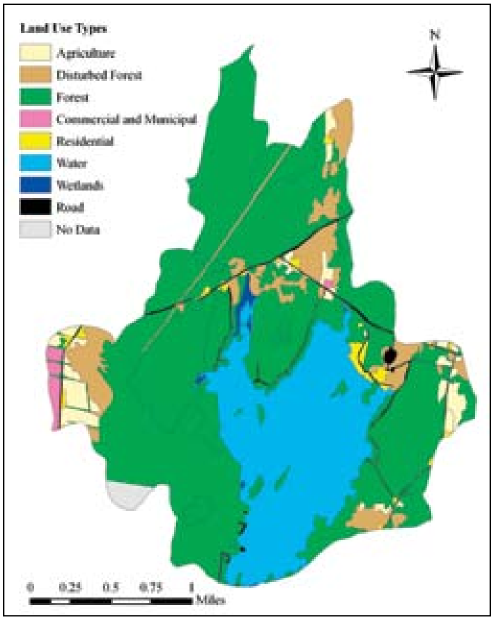

Figure 4. Land-use patterns for the Togus Pond watershed in 1954. Land-use types were determined using aerial photographs. Students digitized roads from the photographs because no road maps were available from that time.

Data courtesy of Colby College 2004 Problems in Environmental Sciences class

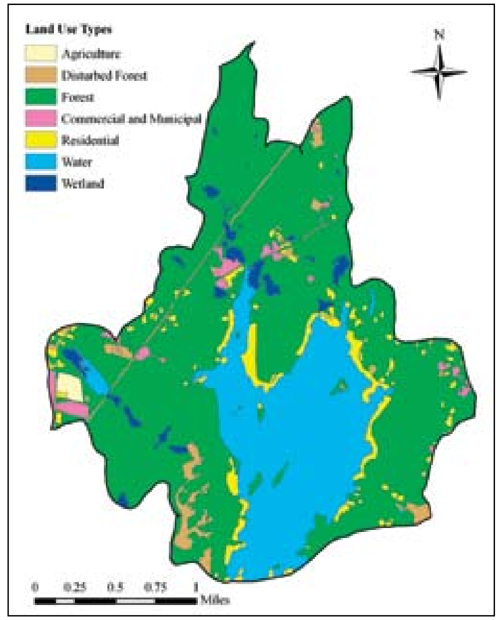

Figure 5. Land-use patterns for the Togus Pond watershed in 2002. Land-use types were determined using aerial photographs. In 2002, students were unable to differentiate mature from transition forest, so only one forest class was used. No cropland was present.

Data courtesy of Colby College 2004 Problems in Environmental Sciences class

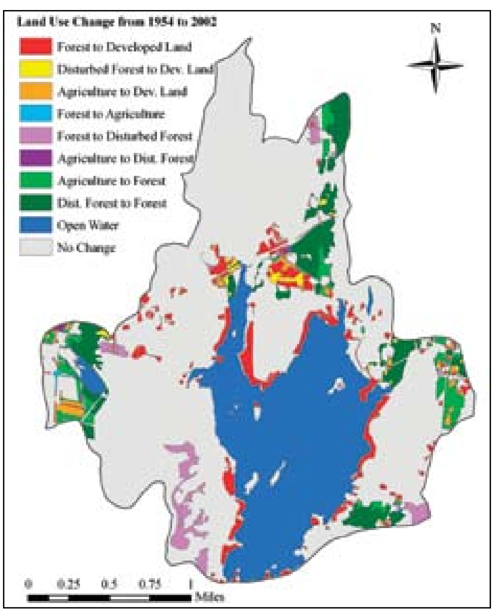

Figure 6. Land-use change in the Togus Pond watershed, 1954 to 2002.

Data courtesy of Colby College 2004 Problems in Environmental Sciences class total land area. Agricultural land decreased, while residential and commercial land use increased, particularly near the water (figure 6).

Students used the derived data to develop a model that predicted total phosphorus levels in the lake. The model is based on average rainfall, runoff data for different land-use types (adjusted for total area covered by each land-use class), the area and volume of the lake, and the amount of water flowing into the lake over a year's time. The class also projected future phosphorus inputs based on probable future changes in land use, and we plan to make these predictive models spatially explicit in the future.

The students developed a second model that combined four factors (slope, soil type, proximity to the lake, and land-use type) to calculate an area's erosion potential and suitability for septic systems.[5] For erosion potential, the students weighted their overlay model to favor slope as the most significant input (40 percent), followed by soil type (25 percent), land cover (25 percent), and distance from the lake (10 percent). Each factor was classified on a scale of 1 (low) to 9 (high). The final model showed areas with relatively more or less erosion potential (figure 7). They developed a

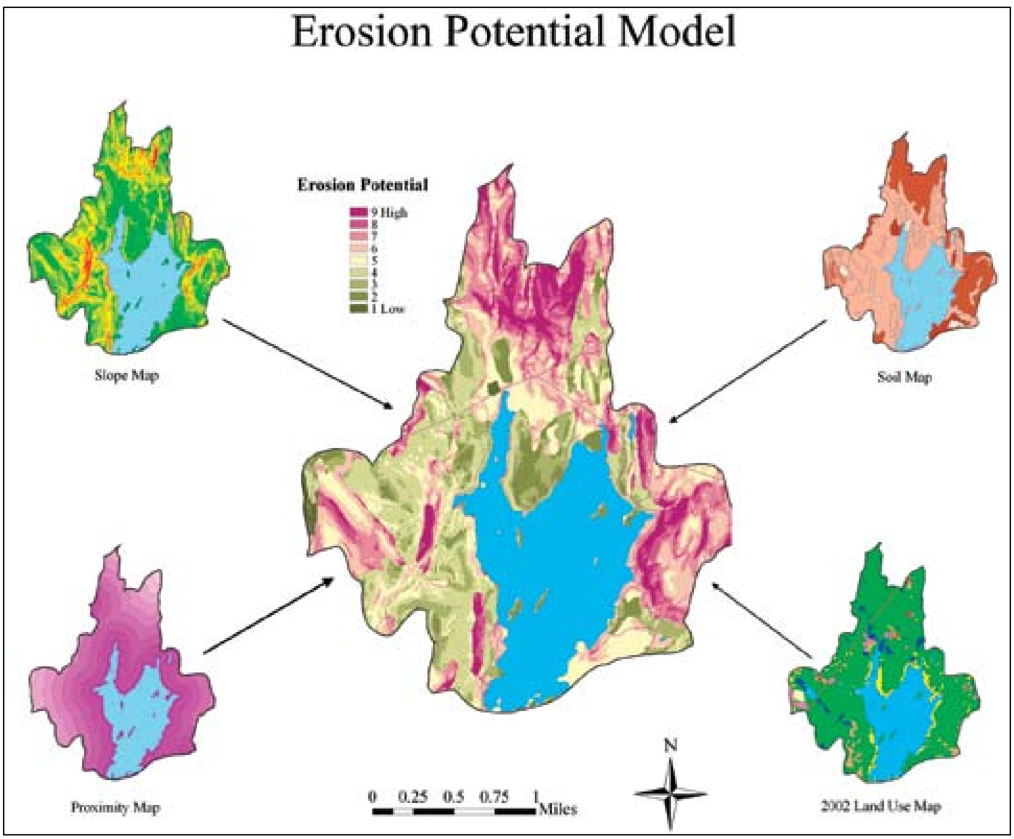

Figure 7. Erosion potential map for Togus Pond watershed derived from slope, soil, land use, and proximity to lake. Purple represents higher erosion potential and green represents lower erosion potential.
Data courtesy of Colby College 2004 Problems in Environmental Sciences class

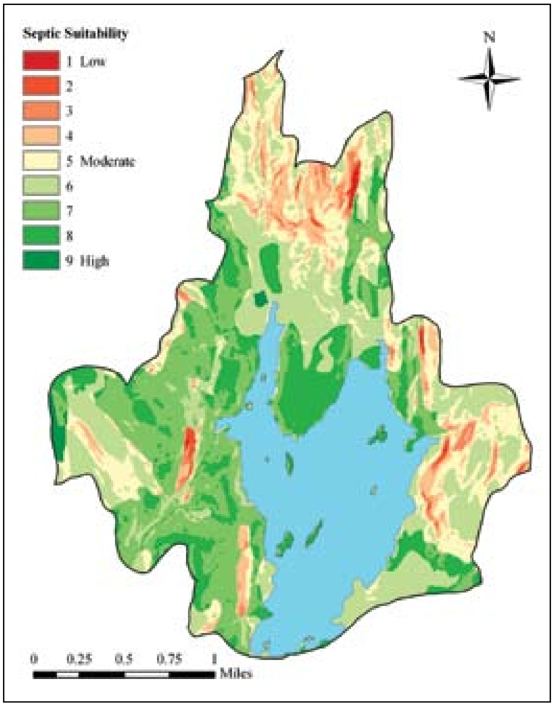

Figure 8. Results of a model showing septic suitability of the Togus Pond watershed based on soil septic limitations and slope. Areas with low septic suitability are shown in red.
Data courtesy of Colby College 2004 Problems in Environmental Sciences class

similar model, with modifications to the input values, to show which areas were more or less suitable for household septic systems (figure 8).

Impact of GIS on teaching and learning

Collectively, these GIS analyses have had a substantial impact on what and how students learn in the course, and on the impact this course has had well beyond the classroom (Nyhus et al. 2002). Student evaluations have consistently been very positive, and many students have used these experiences, and their GIS skills, to pursue employment and graduate study in related fields. Since the first studies by this course in 1988, students' models have become much more sophisticated, a development that has been concurrent with other progress in our field (such as our ability to measure phosphorus more accurately). The software's usability has increased sufficiently to enable students, some of whom have never been exposed to GIS before, to generate relatively sophisticated GIS land-use models in just one semester (figure 9).

Digital data has become more available and more refined. Increasingly, data is available through the State of Maine and other public sources. Students can download a wide range of thematic layers, such as soil types, rather than painstakingly digitizing the data as they had to do in earlier years. This has enabled students to spend more time on in-depth data analysis and modeling rather than repetitive data preparation. The students, building on methodologies and results of past student projects (available through old reports archived in the laboratory and the library), have a much better perception of what they can accomplish and how important it will be to the Department of Environmental Protection (DEP), the lake associations, and local landowners. This year the DEP incorporated some of the class data (with appropriate credit and acknowledgments) into a Total Maximum Daily Load (TMDL) study they were undertaking.

GIS has improved our ability to communicate effectively and professionally. As the reputation of our course and students' work has became known to state agencies, lake associations, and local land holders, students' expertise has been sought after by citizens and government officials. By 2005, sixteen different lakes had been studied, several of them by other classes or independent projects, and much of

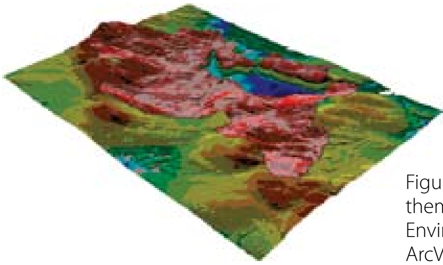

Figure 9. Erosion risk theme draped over topographic theme created in 2000 by students in Problems in Environmental Science class. This was the first year ArcView was used by students in this course.

this research has been enhanced by GIS. The professional quality of the analyses and resulting images created compelling visual displays that engaged the audience and lent credibility to the studies during the class's public presentations. The bathymetry, shoreline, land cover, and suitability maps provided unique insight into the biophysical dynamics of the watershed basin. They highlight high-risk areas that would benefit from short-term and long-term remediation. These conclusions informed not only the students, but also local watershed, regional, and statewide management, planning, education, and policy. Furthermore, students often present their research at local, regional, and national meetings (figure 10).

Expanding the use of GIS within environmental studies

Our PES course is one of several in the environmental studies program that use GIS and other geospatial technologies. Colby College recently hired a new environmental studies faculty member, Philip Nyhus, with expertise in both environmental policy and GIS, adding a strategic resource that benefits several disciplines. A new environmental policy senior capstone course now mirrors the environmental science capstone; both require students to complete a GIS project. For the first time, we are now offering a midlevel course that teaches GIS and remote sensing skills as its primary focus, which is distinctive from other courses that teach with GIS and only apply the tool as needed. This

Figure 10. Students in Problems in Environmental Science class carrying out water quality studies on a Maine lake.
Photo by David Firmage.

course, designed primarily for environmental studies majors but available to students across the campus, allows students to work on projects with community partners and generates a regular series of student Web projects under the broad title of An Atlas of Maine.[3]

Lessons learned implementing campuswide GIS

From its early roots in the environmental studies program and the department of geology, the body of GIS users and the use of GIS in the Colby curriculum continues to expand. Some of the key lessons we have learned from our experience building GIS capacity in our environmental studies program and across campus include the following:

- GIS can promote interdisciplinary teaching, research, and collaboration. Many of the world's most pressing problems are interdisciplinary and are influenced by complex factors operating at multiple scales and levels. In our experience, GIS has been a highly effective teaching and research tool for students to use in investigating local, regional, and global environmental problems. In environmental studies, we have found GIS to be an ideal tool to support studies at a watershed level, because it can incorporate and be used to analyze a wide range of data at varying scales. As the amount and quality of spatial data increases, and as the scope and user friendliness of GIS increases, we expect our ability to use GIS to help students explore these issues will only improve. Moreover, the universal visual language of maps provides a unique opportunity for interdisciplinary curricular initiatives and engagement of students and faculty across departments and academic divisions. The utility of incorporating interdisciplinary GIS analyses into environmental studies inquiry-based courses and some civic engagement courses has been pronounced, and we are replicating the environmental studies model in other curricular initiatives.
- GIS can promote active learning styles. Hands-on activities, inquiry-based learning, and action-oriented investigation represent three successful and highly touted educational approaches, and have each been encouraged by the National Science Foundation, the National Research Council, and the American Association for the Advancement of Science. Emerging geospatial technologies encourage and support these approaches across the curriculum. As one of these technologies, GIS facilitates student engagement in the collection, analysis, and presentation of spatial data. Involving students in real-world problem-solving exercises generates considerable enthusiasm among students, faculty, and staff, as well as outside collaborators and other constituents. Students are motivated to learn and apply GIS—and correspondingly to work hard on the problems they are trying to solve—when the connections are real. Other students in turn are motivated to learn this powerful tool when they see the results obtained by their peers.
- GIS can be used effectively in numerous courses. Interest in GIS is emerging across the campus at Colby. The enhanced functionality of modern GIS software enables students to complete sophisticated projects within a single semester. Undeniably, the learning curve is steep for students with no background in GIS or who are not accustomed to thinking about a problem spatially. But we have found that the abundance of ready-to-use data, increasingly user-friendly software, and publicly available training modules support GIS as a tool that can be used actively in virtually any course across the curriculum. Benefits also exist from a more passive form of use—through increased

exposure and access to maps or from the derived products of GIS analyses completed by others. In either case, students benefit by having additional opportunities to think about things from a spatial perspective.

- Faculty and students in the departments of biology, geology, chemistry, government, and economics are now using GIS, and several new courses and research projects that will use GIS are under development. For example, chemistry students are conducting detailed assessments of lakes from which local towns obtain their drinking water. Economic students are working with a faculty member to help the local city government integrate GIS-based census data with local tax and real estate information. Moreover, the GIS activities are not limited to Maine. Students in government and environmental studies are helping faculty members use GIS to better understand spatial factors relating to social justice, civil society, and democracy in Buenos Aries, Argentina. Also, environmental studies students have worked with a faculty member to develop maps of suitable tiger habitat in Indonesia and China. Many of these problems would have been difficult to investigate due to practical and time constraints if GIS resources were not readily available across campus.[6]
- Libraries can and should play important roles in expanding GIS across campuses. Colby's library played a central role in GIS growth on campus. For the PES course, the science librarian prepared a guide presented every semester that identifies sources of spatial data, including datasets, data clearinghouses, and mapping projects. The library has become a central repository for archiving GIS projects, developing and posting subject guides, and maintaining the Colby GIS Web page. The science librarian and the government documents librarian have been instrumental in coordinating a campuswide GIS users' group.
- GIS is just one of many new technologies being introduced to faculty and students. Libraries are uniquely positioned to support these new technologies because they serve all departments and programs on campus and they can leverage data, software, and expertise acquired by one department or faculty member to benefit the campus as a whole. GIS projects, like other digital data, can and should be archived within the library and included in institutional repository initiatives. These initiatives are gaining momentum within the library community.
- Technology support and leadership make a difference. Campuswide technical coordination and support by Information Technology staff are crucial for expanding GIS beyond single departments. For example, efficiencies are generated through consortium-wide software licenses and support from national organizations such as NITLE (*www.nitle.org*), from campuswide network support staff, from standardized hardware and software strategies, and from broad on- and off-campus training opportunities. Strategic maintenance of infrastructure is fundamental to enabling students and faculty to integrate GIS into innovative teaching and research projects.
- Strong administrative support matters. The successful growth and application of GIS across campus requires dedicated core faculty and committed departments and programs, but ultimately is not possible without strong support by the administration. By starting with a vision—in our case a campuswide strategic plan—the president and the dean of faculty were able to effectively mobilize external funds, support a new faculty line, and fund the expansion of GIS hardware, software, and human resources.

In conclusion, GIS is a particularly valuable tool to support environmental studies teaching, research, and outreach. At Colby, enthusiastic support of GIS by faculty, staff, students, and administrators is helping to integrate the technology into a spectrum of courses in the Environmental Studies Program and across the campus. The PES course demonstrates how GIS can support broader pedagogical goals, including supporting active inquiry-based learning, civic engagement, and interdisciplinary research and collaboration. We have been very satisfied with GIS and look forward to expanding its use in the future.

Acknowledgments

We gratefully acknowledge support we have received from ESRI for software, the National Science Foundation, the Andrew W. Mellon Foundation, President William Adams and the Board of Trustees of Colby College, staff of Colby's ITS Department, and the students enrolled in the Environmental Studies Program at Colby College. Multiple NITLE workshops were influential in the development of our GIS programs at Colby. Diana Sinton, Jennifer Lund, and an anonymous reviewer provided helpful advice on earlier drafts of this chapter.

Notes

1. Before taking this course, students are exposed to lake ecology concepts, study typical lake flora and fauna, learn field methodology, and are introduced to elementary GIS and GPS through the introductory ecology courses. These efforts help them to make connections among theory, field work, and geospatial analysis. A new GIS and remote sensing course was recently added to the environmental studies curriculum to provide more in-depth exposure to geospatial concepts and tools.
2. More than one hundred thousand depth points and their corresponding GPS coordinates were gathered using a high-end sonar coupled to a GPS receiver carried on one of the college's boats. Students cruised the perimeter of the lake and then made multiple transects of the lake on four different days, combining these efforts with water sampling efforts. Data points (simultaneous GPS and sonar readings using a Lowrance instrument) were taken every two seconds. Students generated a map of the completed transects so it was relatively easy to identify areas that required more coverage. Individual points were uploaded into ArcGIS software and converted into a raster grid where each pixel represents a unique depth.
3. A good-quality buffer was defined as covering the entire width of the shoreline associated with the property, having a mix of shrubs and trees, and having a depth of at least 50 feet (ideal is 75 feet). Most buffers lacked that kind of depth and some only covered a part of the shoreline.
4. Nine black-and-white aerial photographs (1":1000' scale) were used for the historic land-cover maps. Fourteen color aerial photographs with greater resolution (1":750' scale) were used for the current land-cover estimates. For both sets, photographs were rectified to digital orthophotos and control points on vector layers derived from thematic layers available through the Maine Office of GIS.

5. Soil was classified into nine classes based on data from the National Cooperative Soil Survey. The erosion potential factor (k) for each soil type was provided by the local Soil and Water Conservation District. This enabled the students to differentiate between soils that are less likely to erode (e.g., clay soils and soils commonly found in bogs and wetlands) and more likely to erode (e.g., sandy and silty soils). Slope was derived from a digital elevation model. Each land-cover class was weighted by erosion risk from low erosion potential (e.g., forests and wetlands) to high erosion potential (e.g., residential land, cleared land, and dirt roads). Proximity to the lake was included as a factor to account for the greater likelihood that soil or nutrients would enter the water from lands closer to the lake. A series of concentric 200-foot buffers were created from an initial 200-foot buffer close to the water extending out to the watershed boundary.
6. Colby participates in a consortium of Maine colleges and universities that provides educational discounts for ESRI software, including a campuswide license for ArcGIS and most ArcGIS extensions.

References

An Atlas of Maine. www.colby.edu/environ/courses/ES212/atlasofmaine.

Firmage, David H. and F. Russell Cole. 1999. Service Learning in Environmental Studies at Colby College. *Acting Locally: Concepts and Models for Service-Learning in Environmental Studies.* ed. H. Ward. Washington, D C.: American Association of Higher Education.

Nyhus, Philip J., F. Russell Cole, David H. Firmage, and Phoebe S. Lehmann. Enhancing Education through Research in the Environmental Studies Laboratory: Integrating GIS and Project-Based Learning at Colby College. *Council on Undergraduate Research Quarterly* 34 (September 2002).

About the authors

F. Russell Cole, Oak Professor of Biological Sciences, is a member of the Department of Biology at Colby College. He previously served as chair of the Department of Biology, the Division of Natural Sciences, and is currently director of the Environmental Studies Program. He is one of the core faculty who teach Problems in Environmental Science.

Susan W. Cole has been the science librarian at Colby College since 1978, where she provides library instruction for science classes, develops resource guides for individual classes and projects, and is spearheading Colby's library GIS program.

David H. Firmage, Clara C. Piper Professor of Environmental Studies, is a member of the Department of Biology and the Advisory Committee for the Environmental Studies Program at Colby College. He has served as chair of the Department of Biology, as director of the Environmental Studies Program, and as chair of the Interdisciplinary Studies and Natural Science Divisions. He is one of the core faculty who teach Problems in Environmental Science.

Philip J. Nyhus is assistant professor of Environmental Studies at Colby College, where he teaches courses in GIS and environmental policy. As a postdoctoral fellow funded by a National Science Foundation Award for the Integration of Research and Education to Colby College he was active in early efforts to develop GIS in the Problems in Environmental Science course.

Raymond B. Phillips is director of Information Technology Services and is an assistant professor in the Department of Biology. He and his staff have been responsible for implementation of GIS hardware and software infrastructure at Colby.

Daniel Tierney is a former teaching associate in the Biology Department at Colby College. He was GIS supervisor for the department and coordinated the GIS activities for the Problems in Environmental Science research course, independent study projects, and honors projects.

Edward H. Yeterian serves as vice president for Academic Affairs and dean of Faculty at Colby College. He has been a member of the Department of Psychology since 1978 and for many years has supported efforts to develop and expand GIS capacity at Colby.

Environmental assessments and watershed studies represent complex chemical problems, requiring integrated biological, geological, hydrologic, chemical, and demographic analyses (Harbor 1997). This chapter describes a project in which students at Denison University in Granville, Ohio, used GIS both as a visualization tool and as a means to further their interpretation of their lab-generated analytical results. GIS helped students assess a real-world spatial problem (lake sediment deposition as indicated by measuring concentrations and locations of lead in the sediments) and to visualize relationships between the factors that affect the patterns (soil types and land cover, for example).

Our collaboration began in 2000 with a chemistry senior honors project. Undergraduate student Shelie Miller wanted to apply her advanced analytical skills in a field experiment that would tie in with her environmental studies concentration. Brigitte Ramos, her chemistry advisor, and Karl Korfmacher, her environmental studies advisor, guided her work.

Brigitte and Karl were also interested in replicating this problem-solving approach in Brigitte's environmental chemistry course. As initially conceived, students in the chemistry course would collaborate with students taking Karl's Advanced GIS course to collect field data, create a GIS database and conduct spatial analyses, and use the results to make watershed management recommendations. These collaborations highlight the interdisciplinary links between the two sciences, expanding the learning experiences of both courses. Unfortunately, the collaborative pedagogical component of our project never reached its full potential, as we no longer teach at the same institution. Though we have begun our efforts anew at other schools, this chapter will focus first on Shelie's honors project, then Brigitte's subsequent effort to incorporate the project into her environmental chemistry class.