DESIGN, IMPLEMENTATION, AND ASSESSMENT OF AN UNDERGRADUATE INTERDISCIPLINARY WATERSHED RESEARCH LABORATORY

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ABSTRACT

In 1999 Shippensburg University established the Burd Run Interdisciplinary Watershed Research Laboratory. The Laboratory uses a local watershed to provide intensive undergraduate field training in the collection and analysis of environmental data, which are then compiled into a comprehensive statistical and spatial watershed database. Geographic information systems serve as the project's organizational focus, providing a powerful tool for data display, analysis and sharing. We emphasize a systems approach that links disciplinary perspectives across courses in geology, geography, biology, and teacher education. Important linkages among watershed characteristics, water quality, and aquatic ecology are emphasized over several semesters, allowing students to build and integrate scientific skills throughout their education using the watershed as a common case study. The Burd Run Interdisciplinary Watershed Research Laboratory provides an easily adaptable conceptual model for improving environmental science education at teaching-oriented institutions nationwide. Its success is largely attributable to three factors: (1) the project is student-centered and goal specific; (2) the selected watershed is accessible, diverse, and at a manageable scale; and (3) the 17-member Laboratory Advisory Board provides for continuous revision, adaptation, and improvement.

Keywords: Education-Geoscience; Education-Undergraduate; Education-Graduate; Education- Laboratory; Field Trips, Field Study, Summer Field Courses.

INTRODUCTION

Educators increasingly recognize watershed-based field laboratories as an effective means for improving undergraduate environmental science curricula (Ferreri et al., 1997; Kirk et al., 1997; Lindsey and Jewett, 1997; Woltemade and Blewett, 2000). The National Science Foundation (NSF) strongly supports this approach through its Course, Curriculum, and Laboratory Improvement - Adaptation and Implementation (CCLI - A & I) grant program, in which educators are encouraged to adapt and implement exemplary projects developed and tested at other institutions. Despite the success of such projects, few descriptions have been published in widely available journals. Accordingly, this paper reviews the design, implementation, and assessment of the Burd Run Interdisciplinary Watershed Research Laboratory at Shippensburg University of Pennsylvania, a project typical of those funded under NSF's CCLI - A & I program. Like many state-supported teaching universities, Shippensburg University has limited funding available for equipment and research, a situation that we hope makes our review especially pertinent.

The Burd Run Interdisciplinary Watershed Research Laboratory, conceptually developed over 18 months and then funded by NSF in 1999, is a cooperative effort among 13 faculty from the Departments of Geography-Earth Science, Biology, and Teacher Education. It uses a local watershed to provide intensive undergraduate field training in the collection and analysis of environmental data, which are then compiled into a comprehensive statistical and spatial watershed database using geographic information systems (GIS). These accumulated data are then made available on the University's web site (www.ship.edu/~geog/burdrun) for further student investigations in a wide variety of environmentally related courses across the curriculum. A 17-member advisory board, representing a broad cross-section of environmental professionals, provides project monitoring and assessment.

BACKGROUND

In a recent self-study Shippensburg University (SU) recognized four areas for improving undergraduate education common to most teaching universities: greater use of technology, increased support for student-faculty research, emphasis on innovative teaching strategies, and enhanced interdisciplinary study. Within these general goals, we identified six specific objectives for improving environmental education at SU: (1) strengthen hands-on field and laboratory learning by emphasizing instrumentation, data collection, field research, and environmental monitoring; (2) enhance students' quant- itative skills through the analysis of environmental data; (3) improve the teaching of complex, interdependent environmental systems by linking a variety of scientific perspectives to a common case study throughout students' undergraduate education; (4) engage students in the long-term monitoring of environmental change and impacts of human disturbance; (5) improve the earth and space science and biology education curricula by providing pre-service teachers intensive training in scientific methods applied in a field and laboratory learning environment; and (6) provide field opportunities otherwise unavailable for a wide range of users, including public school systems and related university programs targeting women and minorities in science.

Our review of the pedagogic literature indicated that the watershed approach, emphasizing complexly related environmental systems, was the most appropriate method for meeting those goals. The emphasis on environmental systems mirrors national trends in both natural resources management and ecological sciences. Watershed scientists have emphasized linkages between upland and downstream environments and between land use and water resources (Brooks et al., 1991). Similarly, ecologists are calling for management that integrates the physical, chemical, biological, and social environments (Taylor et al., 1995). The EPA (1996) has stressed the development of projects that coordinate natural resources management within entire watersheds, rather than focusing on components of hydrology, ecology, or pollution.

Approaches emphasizing integrative, interdisciplinary studies of watersheds exist at several other institutions, including Pennsylvania State University (Ferreri et al., 1997), Skidmore College (Kirk et al., 1997), and Indiana University-Purdue University Indianapolis (Lindsey and Jewett, 1997). Similarly, the SU project was designed to use an easily accessible local watershed, facilitating involvement of local experts and planners in student learning. This approach is supported by research indicating that students are more likely to retain information when theories and methods discussed in the classroom have been applied to “real world” situations

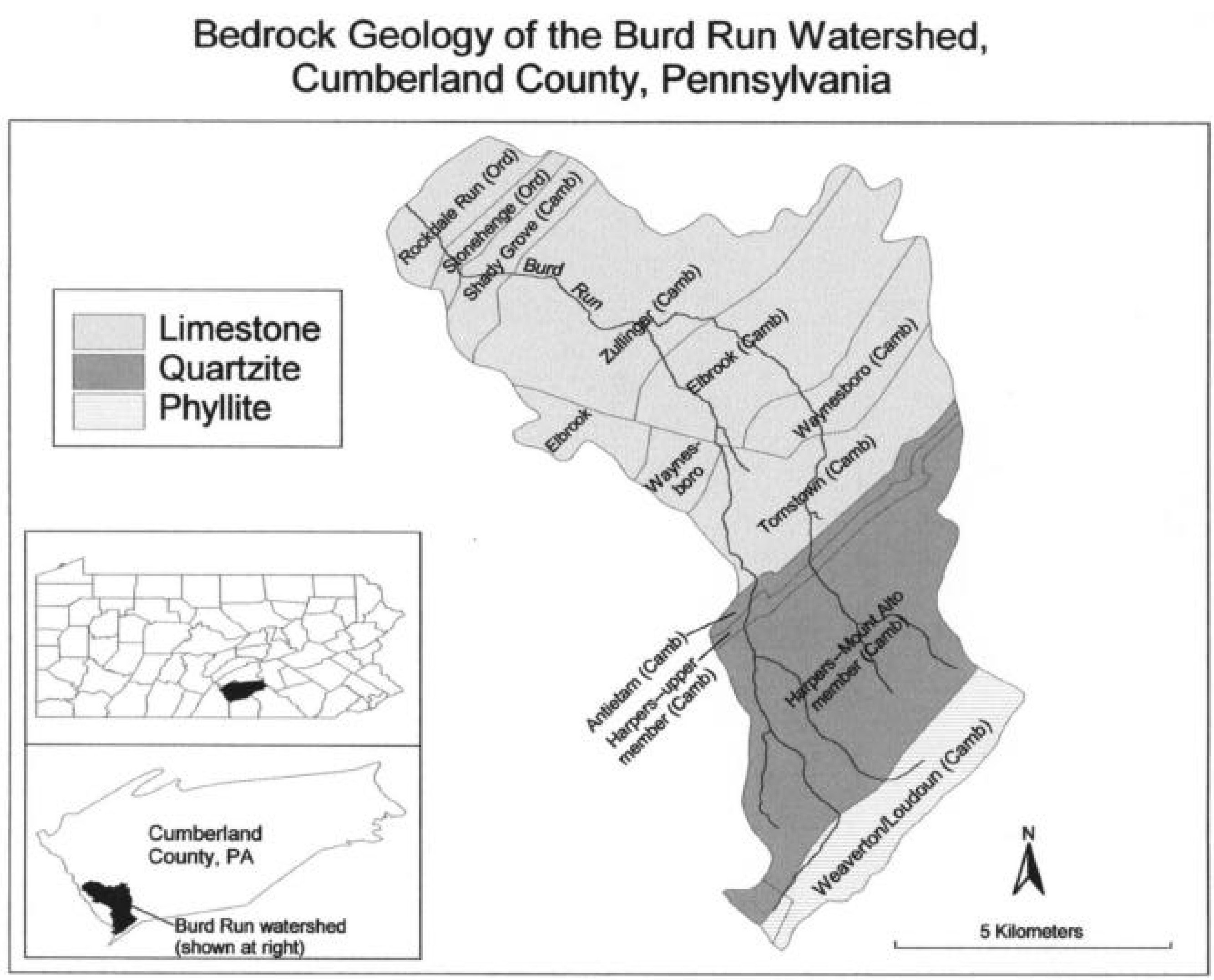

Figure 1. Bedrock geology of the Burd Run watershed. Insets show Cumberland County located in Pennsylvania and the Burd Run watershed located in Cumberland County.

(Watson, 1975; Meyers and Jones, 1993). Many single courses use watershed case studies, often incorporating team teaching to support interdisciplinary studies (e.g. Kirk et al,. 1997). The SU project was designed to go a step further, linking faculty and scientific perspectives across several courses in geography, earth science, biology, and education. Using this approach, important linkages among watershed characteristics, water quality, and aquatic ecology could be emphasized over several semesters, allowing students to build and integrate scientific skills throughout their education using the watershed as a common case study.

The concept of an interdisciplinary watershed study driven by multiple courses sharing a common research site and field data is not new. In 1993 a similar approach at Millersville University (a Pennsylvania State System of Higher Education sister institution), supported by a NSF award, established a GIS database to integrate analysis in hydrology and water resources courses. At Skidmore College the "sense of purpose and continuity [provided by a watershed case study] has proven to be an ideal method for teaching environmental science" (Kirk et al., 1997). Successful projects at Ohio State University (Mitsch 1998) and Iowa State University (Schultz et al., 1997) also provide useful models.

Courses using a watershed-based field approach emphasize concepts and problem-solving procedures, rather than "cookbook" methods (McKeachie, 1986). Small group assignments can be designed to foster positive interdependence and individual accountability, two basic tenets of effective teaching (Cooper and Mueck, 1990; Meyers and Jones, 1993). Once operational, watershed laboratories work to integrate faculty research, student research, and classroom instruction, providing benefits in terms of both student learning and faculty interest in student learning (Schratz, 1990).

DESIGN

The Burd Run watershed is an ideal setting for an environmental laboratory due to its manageable size (approximately 53 km^2); diverse physical, ecological, and land use characteristics; and proximity to the SU campus, with no part of the watershed more than 15 km from the university. Lindsey and Jewett (1997), in their description of the similarly sized Crooked Creek, Indiana watershed, suggest that medium-sized basins like Burd Run tend to make the most effective teaching laboratories. Smaller watersheds often lack physical and hydrological diversity, whereas larger watersheds are more difficult to integrate spatially and can overwhelm the student (and the faculty member) with data.

The headwaters of Burd Run are on top of South Mountain (the local name for the northern part of the Blue Ridge) at an elevation of 591m. Here, within Michaux State Forest, two mountain tributaries flow westward across sandy soils developed on Cambrian quartzite. These tributaries meet near the base of South Mountain where they flow across thick Pleistocene colluvial deposits that support mixed forestry and agriculture. As the colluvium thins with distance from the base of the mountain, several units of Ordovician and Cambrian limestone are exposed (Root, 1965), some of which include solution cavities and other karst features (Shirk, 1980). Agriculture is the primary land use on the silt loam and clay loam limestone soils until the stream reaches the Borough of Shippensburg. Here, urban land uses dominate the lower watershed, until the stream eventually reaches the SU campus at an elevation of 189 m. Throughout its course, Burd Run flows generally perpendicular to regional bedrock strike, maximizing variations in geology and soils (Figure 1).

Water quality varies considerably with geology and land use. For example, in the forest/quartzite environment, the stream is acidic (pH = 4.5), whereas within the limestone terrain of the Cumberland Valley, it is buffered (pH = 7.8). Temperature, dissolved oxygen, nutrient concentrations and other water quality parameters also vary considerably in the different watershed environments. This variability among topography, geology, land use, and water quality provides an excellent field laboratory for a wide range of course projects and investigations.

The project design involved three main components: 1) establishing spatial boundaries for the watershed laboratory, 2) specifying the equipment and activities necessary for data acquisition and field monitoring, and 3) determining the data files, software, and hardware needed for the web-based GIS. We designated the Burd Run Watershed Laboratory as that part of the basin upstream from the SU campus. This allowed us to establish an easily accessible hydrologic monitoring station on campus at the downstream end of the basin, where the risks of vandalism and flood damage are minimal. For security and accessibility, we restricted all permanent monitoring equipment to the university grounds. A section of the Burd Run floodplain adjoining campus was deemed the most appropriate site for training students in the use of portable stream monitoring and surveying equipment.

Field activities and equipment were determined in meetings of the 13 faculty members making up the Burd Run team. Team members from the Geography-Earth Science department provided GIS expertise. Each of these aspects of the watershed laboratory is described below.

IMPLEMENTATION

Funding - A project of this scope almost always requires extramural funding, as many teaching-oriented institutions do not have the necessary resources. Using similar projects at institutions across the country as our guide, we identified the Adaptation and Implementation track of NSF's CCLI program as the most appropriate source of funding. This program requires a 1-to-1 local match (cash or in-kind services) for all federal funding requested.

Because many teaching institutions lack suf- ficient matching funds, non-cash contributions can be an important part of grant development. In the Burd Run project, we were able to garner over $40,000 of in-kind services, including time donated by local consulting firms, industry donations of software, project use of University vans, and dedication of existing student assistantships to the project. NSF supported our project for two years beginning August 1999, funding equipment, supplies, faculty summer salaries, and drilling of observation wells.

Equipment - Project field and laboratory equipment (table 1) costs totaled $98,000 and included instruments for: (1) automated monitoring of stream discharge, water quality, and meteorology; (2) field studies in geomorphic mapping, surface and groundwater hydrology, wetlands, soils, aquatic biology, and land use; and (3) quantitative and spatial data analyses.

Data Collection - The watershed laboratory database is built around two central components: spatial data covering the entire drainage area and point data representing key locations within the watershed. All spatial data have been mapped using ArcView GIS. Some point data are collected continuously (e.g. water

PROJECT COMPONENT	EQUIPMENT	APPLICATION
Hydrology and water quality	Continuous monitoring probe	15-minute sampling of water level, conductivity, temperature, dissolved oxygen, and pH
	Stream current meter sets (2)	Field discharge measurement
	Portable spectrophotometers (2)	Field water quality testing
	Portable pH/ conductivity/ temperature meters (7)	Field water quality testing
	Portable turbidimeters (3)	Field water quality testing
Meteorology	Meteorologic instrument systems with datalogger (2)	Continuous sampling of radiation balance, temperature and relative humidity
Surveying / mapping	Total station	Detailed topographic surveying
	Hand levels (2)	Approximate surveying of stream channels and floodplains
	Clinometers (4)	Approximate slope measurements
	100 m fiberglass measuring tapes (3)	Field mapping
GPS	Trimble GeoExplorer 3 Educator 2-pack	Precise determination of location, approximate field mapping
Soils / sediment	AMS basic soil sampling kit	Soil sampling
	Eijkelkamp stony soil auger	
	33-inch soil probes (10)	
	Reciprocating shaker	Soil and sediment field/ laboratory analysis
	8-inch testing sieves (2 sets)	
	Munsell soil color charts (10)	
Hydrogeology	Drilled 50-foot observation wells (4)	Groundwater monitoring
	Slope Water Level Indicator	
Computing	Desktop computers (10)	Student access to watershed database
	Laptop computers (3)	Field data acquisition
	ArcView GIS software (25 licenses)	Watershed mapping and data analysis
Web site	Digital camera	Documenting field sites

Table 1. Equipment acquired to support the Burd Run Interdisciplinary Watershed Research Laboratory.

quality and meteorology on the SU campus) while other data are collected periodically.

The GIS database includes maps of topography, bedrock geology, surface geology, soils, surface hydrology, and land use. Existing data sources (e.g. USGS topographic maps, previous geologic studies) provided source information for much of the spatial data. Additional data came from a variety of student class projects during the first two years of the watershed laboratory that included: (1) the collection of land use data at the resolution of individual tax parcels, (2) construction of detailed topographic maps (1-foot contour interval) of selected critical floodplain areas, and (3) the production of an improved map of watershed colluvium thickness based on analysis of available well logs.

The continuously monitored point data include hydrologic and meteorologic measurements. In April 2000 we installed a water quality probe in Burd Run on the SU campus. This instrument records 15-minute samples of stream stage, water temperature, pH, specific conductivity, and dissolved oxygen. Stage data are converted to discharge via a rating curve established by repeated student sampling of stream flow using the wading discharge method. A meteorologic station was also established near Burd Run in June 2000. Continuously logged data include net total radiation, incoming and reflected shortwave radiation, relative humidity, air temperature, and wind speed and direction. In addition, daily meteorologic data (minimum and maximum temperature, rainfall and snowfall)

Level*	Course Name	Department	Use of Watershed Laboratory
100	Problems of the Environment	Biology	Collection and analysis of aquatic invertebrate data, use of laboratory maps to support basic watershed description
200	Atmospheric Studies	Geography- Earth Science	Collection and analysis of meteorologic data
200	Soils	Geography- Earth Science	Land use planning laboratory exercise based on watershed soils map and existing land use map
200	Hydrology	Geography- Earth Science	Analysis of previously collected water quality and stream discharge data
200	Land use	Geography- Earth Science	Mapping of current watershed land use, analysis of potential future land use change
200	Ecology	Biology	Collection and analysis of water quality and aquatic invertebrate data
300	Geomorphology	Geography- Earth Science	Individual student research projects using laboratory equipment and previously collected data.
400	Field Techniques	Geography- Earth Science	Collection and analysis of geologic, soils, meteorologic, hydrologic watershed data; surveying and mapping of specific sites.
400	Environmental Geology	Geography- Earth Science	Field description of watershed geologic units
400	Water Resources Management	Geography- Earth Science	Analysis of geologic and land use impacts on water quality
500	Geoenvironmental Hydrology	Geography- Earth Science	Analysis of fluvial geomorphology, computer-based rainfall-runoff modeling
500	Entomology	Biology	Environmental analysis of aquatic and upland collection sites
500	Ecosystems Ecology	Biology	Analysis of groundwater – surface water interaction using test wells
400/ 500	Independent Research	Geography- Earth Science / Biology	3 undergraduate and 9 graduate independent research projects completed to date

* 100 / 200-level courses are lower-level undergraduate, 300-level courses are upper-level undergraduate, 400-level courses are upper-level undergraduate/graduate, 500-level courses are graduate.

Table 2. Courses with substantial involvement in the Burd Run Interdisciplinary Watershed Research Laboratory.

are collected at an official National Weather Service station on the SU campus.

Periodically sampled point data include weekly water quality testing of significant springs throughout the watershed, discharge measurements along key losing or gaining stream reaches, storm total precipitation monitoring at 20 non-recording rain gauges throughout the watershed (April - October 2000), and seasonal sampling of aquatic macroinvertebrates at three sites. Each of these sampling efforts was led by students conducting research or completing course projects in the watershed. In the SU case, a total of five graduate students over three years have provided important quality assurance of student-collected data and management of the GIS database. At undergraduate institutions, these roles could be provided by select senior students, support staff, and/or faculty.

Data Dissemination - Project data are made available to campus and other users via an Internet site (www.ship.edu/~geog/burdrum). One graduate assistant, funded for two years under the project, provided assistance to a team of project faculty in the construction of the web site, which contains viewable and downloadable versions of GIS map layers, environmental data (hydrology, meteorology, aquatic

POSITION	EXPERTISE
Executive Vice President Skelly and Loy Environmental Consultants	Environmental monitoring
GIS Section Manager and Senior Associate Johnson, Mirmiran and Thompson	GIS and mapping
Wetland Scientist KCI Technologies, Inc.	Wetlands ecology
Earth Science Teacher Shippensburg (PA) Middle School	Environmental education
Vice President of Operations Valley Quarries, Inc.	Local geology
Senior Analyst Cumberland County (PA) GIS Department	GIS and mapping
GIS Specialist TASC, Inc.	GIS / Remote sensing
Director of Education Pennsylvania Audubon Society	Environmental education
Biologist Pennsylvania Game Commission	Ecological monitoring
Park Manager Pennsylvania Department of Conservation and Natural Resources	GIS and mapping
Environmental Education Program Specialist Pennsylvania Department of Conservation and Natural Resources	Environmental education
Assistant Director Stroud Water Research Center	Water quality monitoring
Geologist Delaware River Basin Commission	Hydrogeology
Professor, Department of Geography Colgate University	Meteorology and climatology
Professor, Department of Geography Michigan State University	Soils and geomorphology
Professor, Department of Geology and Geophysics University of Connecticut	Geology and field mapping
Professor, Department of Civil & Environmental Engineering University of Wisconsin	Surface water hydrology

Table 3. Advisory Board, Burd Run Interdisciplinary Watershed Research Laboratory.

1	Please examine the content of the project internet site (www.ship.edu/~geog/burdrun). What suggestions can you make to improve the web site? In particular, what additional information could be added to the site to make it more useful?
2	Please look over the attached list of equipment purchased for the laboratory. (This equipment complements pre-existing holdings at the University, such as a soils laboratory, computer laboratories, etc.) What additional equipment can you suggest that would be useful for student watershed studies and/or data collection to enhance the project?
3	Please look over the attached list of data collected at this point in the project. What additional data can you recommend that would enhance student field or classroom watershed studies?
4	Please review the attached list of curricular projects already implemented under the Burd Run Laboratory. We would appreciate any suggestions you can make for additional course projects, student research, or interdisciplinary linkages using existing (or suggested) project data and equipment.
5	Do you have any other suggestions for improvements to the Burd Run Interdisciplinary Watershed Research Laboratory?

Table 4. Burd Run Advisory Board Questionnaire (December, 2000).

biology) and curricular materials (data, lab exercises, presentation abstracts, published articles). The web site is inherently flexible and additional data are added continuously as they become available. In particular, the on-line curricular library is intended to expand as additional student projects are developed.

Curricular Projects - The Burd Run project is innovative in that it integrates learning across the science curriculum. We emphasize a systems approach that links disciplinary perspectives across courses in geography, earth science, biology, and teacher education. Repeated exposure to this common case study throughout students' undergraduate education facilitates learning of complex, interdependent environmental systems that are difficult to address within a single course. For example, ecology students can integrate water quality, geology, soils, and land use data to test hypotheses of aquatic invertebrate distributions. Geomorphology students are able to link research on floodplain development to upstream geology, soils, land use, and hydrology. Faculty research, student research, and classroom instruction have been integrated through field research projects, such as a comparison of radar-derived precipitation estimates and rain gauge measurements (Woltemade and Stanitski-Martin, 2002).

The watershed laboratory also facilitates improvements in individual courses (Table 2). For example, an undergraduate course in environmental land use planning conducted a semester-long field mapping exercise to develop the watershed land use map. Other curricular applications of laboratory data and equipment are focused on improving the teaching of individual concepts within a course. In hydrology and meteorology courses, data collected from a watershed network of 20 rain gauges are used to illustrate orographically enhanced precipitation.

The average student majoring in an environmental science field would likely take at least four courses that use the watershed laboratory. We have structured the course projects such that a specific sequencing of courses is not necessary. While GIS is essential to watershed data management and most students take an introductory GIS course early in their curriculum, GIS experience is not essential to most projects using the watershed laboratory. This has been accomplished by providing spatial data in both Arc View GIS and other more easily accessible graphic formats, such that more sophisticated analyses can be accomplished in GIS and simpler analysis can be conducted without GIS.

ASSESSMENT

Project review and improvement - A 17-member Laboratory Advisory Board provides annual project assessment and guidance. This board represents a wide variety of expertise and includes environmental science consultants, government agency personnel, faculty from other universities, and environmental education experts (Table 3). The advisory board is asked to critically review annual reports that describe ongoing watershed monitoring efforts, student field and laboratory projects, and course and curricular materials.

At the end of the project's first year, we sent an assessment survey to each advisory board member, asking for suggestions and improvements (Table 4). We designed the survey to require minimum effort while providing for both specific and open-ended input. Responses provided valuable insight for improvements to the project web site, future equipment acquisition, additional data collection needs, and curricular projects. Such an advisory board is easy to implement and provides an excellent way to provide the outside assessment required by many granting agencies. While the interdisciplinary nature of the Burd Run laboratory necessitated a diverse (and large) advisory board, a smaller board may be appropriate for many projects.

Keys to success - The Burd Run Interdisciplinary Watershed Research Laboratory provides an easily adaptable conceptual model for improving environmental science education at teaching-oriented institutions nationwide. Its success is largely attributable to three factors: (1) the project is stu- dent-centered and goal specific; (2) the selected watershed is accessible, diverse, and at a manageable scale; and (3) the use of an external advisory board provides for continuous revision, adaptation, and improvement.

Geographic information systems serve as the project's organizational focus, providing a powerful tool for data display, analysis and sharing. Most important, students receive extensive experience and training in GIS technologies, skills that are valuable in the job market and especially relevant to undergraduates.

Applicability to other institutions - This type of watershed-based interdisciplinary teaching and research project can be implemented at a range of educational institutions. In fact, the successes demonstrated by previous projects at similar institutions encouraged our own efforts and alerted us to the NSF Adaptation and Implementation funding track. The most important factors to consider in developing a similar project are: (1) an easily accessible watershed of appropriate size and environmental diversity, (2) cooperation among the various departments involved, (3) necessary institutional support, and (4) extramural funding. Although an equipment-intensive project like the Burd Run laboratory will almost always require grant funding, educationally valuable watershed projects could be gradually implemented based on a modest annual equipment budget.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. DUE-9950652.

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