Project Narrative

1) Statement of the work to be undertaken and expected significance

This project will bridge the gap between modern scientific research and science education by incorporating research modules with a computational emphasis into courses and by further developing our multidisciplinary summer research activity. Both course modules and summer research studies will focus on a problem of local concern: the transport, toxicity and fate of heavy metals within a local watershed. The modules will include laboratory, field, and computational modeling components. They will be integrated into existing courses, beginning with six introductory courses in the chemistry, biology, geosciences, mathematics, and computer science and in nine upper level courses in these disciplines as well as environmental programs (see Table I). Almost every one of Earlham's 1200 students will take at least one of these classes before graduation. Course modules augmented by summer research will contribute to the overall understanding of heavy metal biogeochemical cycling in the environment (*e.g.* development of new biotic ligand models). Additionally, our proposed research will contribute important location-specific information on heavy metals cycling that will benefit ongoing municipal, state and federal pollution studies.

Students will actively participate in collecting, analyzing and interpreting data that will be integrated into ecological and risk assessments at the contaminated site. By learning science while working in collaboration with a diverse array of peers, mentors and stakeholders, students will have tangible ownership of this project. We anticipate that this fresh approach will invigorate student interest and participation in science, even in introductory courses. By reformulating our model of science education to greatly expand active student participation in meaningful research, we expect a strong and positive impact on student learning.

For faculty, the outcome will be an enhanced perspective on the significance of one's own disciplinary contributions. Intentional removal of disciplinary barriers will stimulate faculty to ask and respond to research questions that they have not presently envisioned. The involvement of almost the entire science division in this endeavor is made possible by the long tradition of collaboration in the sciences at Earlham. Four aspects of our project work together to make it powerful: 1) our focus on local problems; 2) the combined use of field, laboratory, and computational methods; 3) the longitudinal involvement of students as they take introductory through upper-level science classes; and 4) the empowering of students to experience first-hand how modern science is multidisciplinary with teams of scientists who inform and illuminate the different disciplinary perspectives of a problem.

Our small size, our existing network of collaboration, and our interest and history in curriculum innovation make this proposal feasible at Earlham College. We believe that this effort will build the framework upon which future multidisciplinary environmental studies will be developed at Earlham College. Indeed, there are many potential avenues of scientific inquiry toward which our concept may grow. It is our desire that this integrated approach to undergraduate science education will also prove useful outside of Earlham College. Thus, as we continually adapt and refine our concept, we look forward to being able to compile and export our effort to other liberal arts institutions that may benefit from our innovations.

Table I. Courses to be impacted by the W. M. Keck project

Introductory Courses		*Students per year*	Advanced Courses		*Students per year*
CHEM 111	Principles of Chemistry	90	CHEM 331	Equilibrium and Analysis	25
			CHEM 371	Environmental Chemistry and Toxicology	10
BIO 111	Ecological Biology	100	BIO 341	Cell Physiology	60
GEOS 211	Physical Geology	75	BIO 346	Vertebrate Zoology	25
			GEOS 352	Geochemistry	10
CS 182	In Silico	10	GEOS 362	Hydrogeology	10
CS 290	Computational Science	10	CS 360	Parallel and Distributed Computing	10
MATH 120	Elementary Statistics	105	ENPR 242	Environmental Modeling	40
			MATH 300	Statistics	15

This will impact 385 students per year in the Introductory courses and 205 students per year in the Advanced courses. In addition, new introductory and advanced multidisciplinary seminars are planned as noted on p. 6

2) Objectives/goals for the proposed work.

The fundamental goal is the development of multidisciplinary curriculum modules and a related research program that incorporates computational methods to study an environmental problem of local significance. The project is designed to:

- bridge the gap for students between science education and scientific research by incorporating research modules into several lower and upper division courses
- increase student and faculty understanding of multidisciplinary use of field, laboratory, and computational methods to answer complex environmental problems
- investigate the biogeochemical cycling of metals within a small-scale local watershed
- develop a workshop to teach faculty at other liberal arts colleges how to incorporate multidisciplinary research modules into their science courses.

3) Project timeline keyed to the objectives/goals.

The implementation of this project begins with the development and refinement of the instrumentation and computer interfacing necessary to monitor field sites, and the development of the first sets of curriculum modules to be integrated into both lower and upper division science courses. It continues with the development and implementation of the remainder of the proposed curricular modules and the advanced research projects. The project will culminate with a faculty development workshop to disseminate the process and content of our model to similar institutions. A final task will involve assessing the completion of the goals and objectives and preparing an evaluation of the effectiveness of the effort.

Spring 2007 (January-April 2007)

- development of instrumentation and interfacing for field monitoring equipment
- development of CHEM 111 Principles of Chemistry module
- initiate design of assessment tools

Summer 2007 (May –August 2007)

- development of CHEM 331 Equilibrium and Analysis, GEOS 211 Physical Geology, BIO 341 Cell Physiology and BIO 111 Ecological Biology course modules
- deployment of field monitoring equipment
- development of the data model, data storage, and user interface for experimental data
- begin weekly summer student/faculty research seminars

Fall 2007 (September – December 2007)

- implementation of CHEM 111 Principles of Chemistry, BIO 111 Ecological Biology, BIO 341 Cell Physiology and GEOS 211 Physical Geology course modules
- development of modules for BIO 346 Vertebrate Zoology, CS 360 Parallel and Distributed Computing, MATH 120 Elementary Statistics and GEOS 362 Hydrogeology

Spring 2008 (January – April 2008)

- implementation of CHEM 331 Equilibrium and Analysis, BIO 346 Vertebrate Zoology, GEOS 362 Hydrogeology, MATH 120 Elementary Statistics, and CS 360 Parallel and Distributed Computing course modules
- development of course modules for ENPR 242 Environmental Modeling

Summer 2008 (May – August 2008)

- formative evaluation
- development of course modules for CHEM 371 Environmental Chemistry, GEOS 352 Geochemistry, CS 182 In Silico
- refinement of existing course modules
- multidisciplinary collaborative research on metals in the local environment

Fall 2008 (September – December 2008)

- implementation of CS 182 In Silico, ENPR 242 Environmental Modeling
- implementation of multidisciplinary colloquium

Spring 2009 (January – April 2009)

- implementation of CHEM 371 Environmental Chemistry and GEOS 352 Geochemistry course modules

Summer 2009 (May – August 2009)

- conduct National Institute for Technology and Liberal Education (NITLE) workshop on integrating computational methods into the undergraduate science curriculum
- preparation of papers and posters on the pedagogical aspects of this project
- development of MATH 300 Statistics course module
- continuing evaluation
- multidisciplinary collaborative research on metals in the local environment

Fall 2009 (September – December 2009)

- summative evaluation and preparation of the final report
- implementation of MATH 300 Statistics course module

4) Relation of the objectives to the present state of knowledge in the field, work in progress by the project personnel under other support, and work in progress at other institutions.

Inquiry-based, multidisciplinary science education that involves computational technology is transforming the landscape of undergraduate learning in the natural sciences. Courses that are shaped around the practice and process of science rather than the rote mastery of facts and theories have been shown to significantly enhance the learning of science in undergraduate courses (NRC, 1996; McConnaughay et al., 1999; Uno, 1999). Simply stated, most students learn science best when they *do* science. The importance of computational science in answering multidisciplinary research questions requires rethinking standard science curricula at the undergraduate level. Currently, several national mandates call for this type of curriculum restructuring (e.g. Bio 2010 from the NRC, 2003a; PITAC, 2005).

In a 2001 report entitled “Grand Challenges in Environmental Science” a National Research Council committee sought to highlight the most significant environmental problems facing humanity. The first grand challenge identified is the need to improve our understanding of biogeochemical cycles, particularly with respect to anthropogenic disturbance of natural balances. Because of the confluence of skill sets brought together in this proposal, we are uniquely situated to address this particular challenge by employing an active learning and exploration-based curriculum. Human societies place ever-increasing stresses upon the natural environment, with measurable destabilizing impacts upon complex ecosystems (NRC, 2003b). In light of the reality that ecosystem health has direct and tangible influence on the sustainability of human culture, a more thorough understanding of ecosystem functioning is needed, both under vanishing natural conditions and following anthropogenic changes.

There has been a long tradition of Earlham science faculty involvement in multi-disciplinary and computational student/faculty research. In the last 20 years, project faculty members in from the Biology, Geosciences and Chemistry departments have engaged in studies ranging from atmospheric measurements of mercury to aquatic ecosystem studies at the college’s Dewart Lake Biological Research Station to determination of metal contamination in lake sediments. Many of our research projects engage the student/faculty teams in multidisciplinary efforts. Currently, computer science faculty and students work with both biologists and chemists on computational projects, *e.g.* computational phylogenetic reconstruction and molecular dynamics simulations. For many years, key personnel in our Biology and Chemistry departments have collaborated on a variety of research and curriculum projects, *e.g.* determination of atrazine concentration from agricultural runoff in regional water sources and its effect on the physiological development of aquatic species.

One of the key faculty has conducted a study of metal content in sediments in an off-campus field site, Springwood Lake. Springwood Lake is a small lake (*ca*. 8 acres) located less than 2 miles from Earlham College. It was created in 1930 for swimming and water skiing by impounding a natural spring-fed wetland. Springwood Lake, presently owned by the City of Richmond, continues to be an important recreational destination for the Richmond and Wayne County community. The watershed area that drains into Springwood Lake is characterized by land-uses that are historically associated with environmental contamination, including large-scale industrial/manufacturing facilities and unregulated and regulated solid waste landfills. Ronald Parker and a student have measured a pronounced heavy metal concentration spike in lake-bottom sediments (Graham, 2003). Based on an average sedimentation rate derived from the 1930 flooding surface, the concentration spike occurs in sediments deposited between the mid

1960s to the late 1970s. As such, we believe this site is ideal to develop a continuous and comprehensive biogeochemical study.

Another key faculty member, Charles Peck, and his students, are developing curricula for computational science and parallel and distributed computing workshops under support from the National Computational Science Institute and the SuperComputing Education Program. These week-long workshops are designed to teach undergraduate science faculty from a range of disciplines how they can use computational methods in their research and teaching.

Many institutions have recognized the need for innovative approaches to science education at the undergraduate level. Carleton College has established an Interdisciplinary Science and Math Initiative (CISMI) aimed at integrating the physical sciences and mathematics in undergraduate courses and research projects. Additionally, Carleton College is currently working on ways to integrate computational modeling across their curriculum to enhance learning. Carleton is also emphasizing computational science at all levels of the curriculum, which is similar in scope to our proposed project. Trinity University (San Antonio, TX) is also focused on interdisciplinary faculty and student research as well as interdisciplinary curricular development with their recently funded Keck Center for Macromolecular Studies. Trinity's program, however, has a major focus on the integration of biology and chemistry, while our proposed program uses biology, chemistry, geosciences, mathematical, and computational science methods to explore environmental problems. Shippensburg University of Pennsylvania has implemented an Interdisciplinary Watershed Research Laboratory for field-based environmental laboratories. This project is similar in scope to our proposed project, but primarily integrates biology and geography/earth science, while we are proposing to involve more disciplinary perspectives as well as including computational modeling. Capital University (Columbus, OH) has done extensive work on developing an undergraduate curriculum and minor in computational science. With funding from the Keck Foundation they recently established the Keck Undergraduate Computational Science Education Consortium. While Earlham's focus is clearly different from theirs, they do offer a number of useful patterns and examples that we can learn from and build on when designing our own curriculum modules.

5) Concise description of methods and procedures for implementation and experimentation.

For our course modules and research, we have chosen to use three different approaches: laboratory-made samples, intense monitoring of an on-campus field site and a study of a small off-campus lake that links a local industrial watershed to the regional stream and river system. Samples prepared in the laboratory give the investigator maximum flexibility and control over the composition of the samples, facilitating the study of specific variables. The on-campus field site will be constructed on Earlham's 400-acre land on the back portion of the campus. The Soil Survey of Wayne County, Indiana (SCS, 1987) indicates that broad areas of the Earlham back-campus include a special class of soils of the Miami series that are noted as having a gravelly substratum. The site is characterized by at least 6 feet of soil over bedrock, granular soils with a suitable permeability, a depth to ground water of 2 to 5 feet and the absence of extensive human modification. The plot location will be finalized after the results of exploratory soil augering and backhoe test pits have verified the presence of suitable soil conditions. The plot will be rectangular and will be oriented with its long axis parallel to the probable ground water flow direction. Once a plot has been established, the subsurface conditions will be determined by soil borings. A test pit will be excavated in similar soils near the plot to permit visual inspection of soil horizons. This site will allow us to construct monitoring wells and install field-deployable remote monitoring systems (details are given later in the Hydrogeology course module). The off-campus site, Springwood Lake, is of local importance (as detailed in the previous section), and is an excellent site to study metals in the environment.

Curriculum modules will be incorporated into 6 introductory courses and 9 upper level courses in biology, chemistry, computer science, geosciences, mathematics and environmental science. In addition, we will offer two seminar courses open to all students who have taken at least one of these courses. One of these seminars will be appropriate for students who have introductory-level experience in science courses and one will be aimed at science majors who have participated in advanced course work in the sciences. The seminars will be facilitated on a rotating basis by the faculty involved in the course module development and implementation. The purpose of these seminars is to strengthen the multidisciplinary experience of our students. The introductory seminar will appeal to many of our undergraduates who arrive at Earlham with a strong interest in environmental science. We believe it will serve as an effective recruiting tool for all departments in the natural sciences division. The advanced seminar will require our upper-level students to think deeply and critically about environmental problems from different scientific perspectives, thus enhancing their experience in discipline-specific courses. At the end of these seminars, participating students will be required to present their class projects at a locally hosted poster session.

Students will also be involved in multidisciplinary collaborative projects during the summer months. The research component will involve developing and testing curriculum modules in each summer (4 in summer 2007, 3 in summer 2008 and 1 in summer 2009). In addition, particularly in summers 2008 and 2009, students will have the opportunity to conduct more advanced research related to metals in the environment including analyses of metals in a variety of environmental matrices, descriptions and quantifications of food chains and computational modeling of metal biomagnification rates, performance of whole-soil hydraulic conductivity tests and determination of soil mineral reactivities, and computer modeling of biochemical and ground water processes.

In biology, for example, some students involved in the curriculum modules will continue to work in summer research in 2008 and 2009. The biology coursework will characterize the populations and food-chains involved at Springwood Lake, while summer research will focus on the actual analysis of metals in representative organisms from the lake. In addition to the collected samples saved from the coursework discussed below, students will re-sample fish and turtles. Some fish will be sacrificed for analysis of metals in selected tissues, specifically gill, liver, kidney and gonad. Metal analyses will be performed by students and faculty in the Chemistry department. Bioaccumulation and biomagnification at higher trophic levels will be assessed. Tissues will also be processed for microscopy and examined for histopathologic evidence of metal intoxication using routine histologic techniques currently available at Earlham. We will also extend the Cell Physiology lab module into novel summer research designed to explore the correlation of the level of metallothionein expression in tissues with tissue metal levels and tissue histopathology. This work will involve Western blots and frozen tissue techniques, cryotomy and immunohistochemical techniques currently being done at Earlham and collaborating labs.

During each summer, approximately 6 faculty and 12 students will work on curriculum module development and advanced research. All students participating in summer research will have an opportunity each week to discuss the multidisciplinary perspectives related to their projects. Faculty from all departments will facilitate a weekly seminar where students will discuss their research projects.

CURRICULUM MODULES AND RESEARCH

Chemistry

The Chemistry department will develop and implement course modules in one introductory and two advanced courses. Because of the central nature of trace metal analysis in the biological and geological studies, chemistry faculty and students will collaborate on the preparation and analysis of biological, soil and sediment samples in summer research. During summer research we will also explore other aspects of metal research, such as the use of diffusive gradient in thin film (DGT) techniques for speciation in soils and sediments.

We propose to incorporate a new environmental chemistry module in our Principles of Chemistry class (CHEM 111, typical enrollment of 90). The module will be designed to:

- introduce basic spectroscopy concepts
- illustrate an application of equilibrium constants
- introduce students to spreadsheet modeling.

This unit will introduce students to fate and transport modeling by measuring the distribution coefficient, K_d, which is a common parameter used to estimate the concentration and movement of metal pollutants in ground water. K_d is a measure of the extent of interactions between a pollutant and the soil matrix and is one of the keys to the understanding of the mobility and persistence of metals in the environment. A distribution coefficient for copper has previously been measured in a standardized soil material (Dunnivant, 2002), and the procedure can be adapted to soils collected from our study sites.

The module will be conducted over two laboratory periods. The first week will consist of a spectroscopy lab, where the students will be introduced to atomic and molecular absorption spectroscopy for the determination of the metal concentration in water. In the second week, students will use atomic spectroscopy to determine K_d of a metal (copper in year 1, and additional metals in subsequent years) in both standard soils and soils collected from both our field and test sites.

The distribution coefficient for metal contaminants varies greatly with experimental conditions, both of the soil and the aqueous system (pH, ionic strength, concentrations of pollutants, etc.). This variability will be illustrated by looking at the effect of pH on K_d for the soils investigated. The results will be used to discuss such environmental issues as acid rain and metal mobilization. Using the K_d results obtained in the laboratory and some simple assumptions, students will calculate a retardation factor, R_f, for the movement of the metal through the soil/water system. The effects of the chemical changes on K_d and on R_f will be modeled using a spreadsheet based model. The soil K_d results will also be integrated in a database for use in transport modeling, and could be further studied in the student research projects in the Equilibrium and Analysis class (CHEM 331).

Equilibrium and Analysis is a sophomore level course with an approximate enrollment of 25 students per year. The module for this course will be conducted over a period of four lab meetings and will use diffusive gradients in thin films (DGT) to determine the speciation of metals (Cu, Ni and Zn) in both simulated laboratory solutions as well as water samples obtained both from the field site and the off-campus site. The speciation results of the DGT study will be compared to the results obtained with the speciation model Visual MINTEQ, a freeware version of the program released by the United States Environmental Protection Agency (USEPA).

This experiment will replace two of our current labs designed to expose students to atomic spectroscopy. It will accomplish the pedagogical goal of teaching students how to:

- prepare samples and standards for atomic analysis
- gain hands-on experience with the equipment necessary for spectroscopic analyses.
- understand the mechanisms of ion exchange
- understand metal speciation and the variables that affect it
- understand the environmental importance of bioavailability
- learn about the power of computational modeling.

In DGT, metals are accumulated on an ion exchange resin imbedded in a hydrogel and covered with a diffusion layer of a different hydrogel and a filter (Zhang and Davison, 1995). In this technique, the transport of metal ions to the resin occurs only by molecular diffusion, resulting in a direct linear relationship between the metal mass accumulated and the time of deployment (Zhang and Davison, 1995).

The advantages of DGT include its simplicity, relative independence from hydrodynamics of the system, multi-elemental capability and its inherent pre-concentration capabilities, which enables the measurement of even extremely small concentrations in solution. With this technique, only the labile forms of the metals in solution (i.e. the inorganic free metal forms and organic labile complexes) will be measured. In addition, since the labile inorganic and the labile organic complexes have different diffusion coefficients in the hydrogels, the concentration of each type of species can be determined by this method. Zhang and Davison (2000, 2001) have shown that by varying the properties of the diffusion hydrogel, both the organic and inorganic metal concentrations can be obtained. The authors also demonstrated that a single DGT device, with a very restrictive pore size, could measure the labile inorganic concentration with only a small correction factor. When using a single DGT device, the total concentration of a metal in the solution must be determined, and the difference between that total value and the DGT value will represent the organically bound metal. Because of their well-characterized nature, we will purchase the DGT device components from DGT Research Ltd during the first few years of implementation. As part of the summer research, we intend to characterize the diffusion coefficients of various metals and organic species (humic and fulvic acids) in polymers that we will synthesize. DGT devices will also be used to characterize mobilization and bioavailability of metals from soils and sediments from both the field and off-campus sites.

In practice, these devices are deployed into a well-stirred solution for times ranging from hours to days. After the designated duration, the device is disassembled and the metals are then eluted from the resin using a nitric acid solution and analyzed using either graphite furnace atomic absorption spectroscopy (GFAAS) or inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Three different systems will be tested using this method: a laboratory system with known parameters, a water sample from our field site, and a water sample from our remote site (Springwood Lake). These systems can be tested both for endogenous metals as well as the effect of adding spiked solutions. Additional parameters required for Visual MINTEQ modeling will be measured either by the teaching assistants, or derived from typical values obtained in the summer. Some will be obtained from the Environmental Chemistry and Toxicology (CHEM 371) class.

Previous literature indicates that DGT can accurately predict speciation under a variety of conditions for some metals if the water parameters are well characterized (Zhang and Davidson, 2000; Unsworth *et al*., 2006). In particular, it is important to know precisely not just the DOC (Dissolved Organic Carbon), but the percentage of DOC that is humic acid vs. fulvic acid. While both humic acid and fulvic acid complexes diffuse much more slowly than the inorganic form, humic acid complexes diffuse about twice as slowly as fulvic acid complexes. In addition, both acid concentrations have a large impact on the speciation model predictions (Zhang and Davison, 2000). We will explore the effect of varying these parameters on the fit of the model to the experimental data.

During the first of the four lab periods, the students will set up the water samples with the DGT devices and allow them to incubate until the following laboratory period (48 hours). They will also be introduced to the trace metal analysis equipment (GFAAS and ICP-AES) and will prepare and analyze standards and samples for major cations using ICP-AES. During the second lab period, students will elute the devices and analyze them using the appropriate method. During the third and fourth lab periods, the students will utilize the Visual MINTEQ program to calculate the speciation and then compare with the measured results. As part of the laboratory samples, students can explore the effects of pH, dissolved organic content and ionic strength on the DGT results and the agreement between the model calculations and the DGT measurement. Students will also be provided with data from the Principles of Chemistry class on K_d and its variation with the same parameters. The effects of transport and bioavailability on the ultimate toxicity of a given metal will be discussed.

In addition to this four lab module, students in this course will collaborate with students in the Geochemistry (GEOS 352) course on the analysis of heavy metals in sediment. This will be a part of the independent research projects, which occur during the last three weeks (6 lab periods) of the Equilibrium and Analysis course.

Environmental Chemistry and Toxicology (CHEM 371) is a new course that will be introduced in the spring of 2007. This will be an upper level chemistry course with a prerequisite of Equilibrium and Analysis. The expected enrollment will be 10-15 students. Two modules, conducted over 8 weeks of the laboratory, will be developed for this course. Learning outcomes for the students include:

- understanding the complexity of metal speciation in water
- proficiency in the operation of the many complex instruments needed (e.g. atomic methods, ion chromatography)
- understanding the basics of a toxicological study
- an appreciation for both the power but also the limitations of computational methods.

As an extension to the work performed in Equilibrium and Analysis, the first module will involve the *in situ* deployment of DGT devices at both our field site and our remote site. This module will take four weeks to complete. In the first three weeks, students will learn about water sampling and will deploy the DGT devices. Data on temperature, pH, redox potential, dissolved organic carbon, alkalinity, dissolved oxygen, as well as major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), iron and aluminum, major anions (SO_4^{2-} and Cl^-), and sulfide concentrations will be collected for both sites. In addition, further characterization of the dissolved organic content for each site will be performed in order to accurately quantify the amount of humic acid and fulvic acid present (these data will used in the Equilibrium and Analysis course). For this model, we will deploy several DGT devices, each of them corresponding to a different diffusion layer hydrogel. The data obtained will provide a direct measure of the metal speciation. During the fourth week, Visual MINTEQ will also be used to model each metal speciation.

A second module will involve the use of a model organism, *Daphnia magna*, to monitor toxicity of a metal in various water samples and the use of the biotic ligand model (BLM) to predict toxicity under the same conditions. This module will also encompass four weeks of lab. Toxicity testing with a specific organism is the most accurate method of determining the toxicity of a metal in the environment, but also the most time consuming. The biotic ligand model, which treats the organism of interest as a ligand which is competing for metal binding with the other ligands in the solution, is of great interest because of its ability to greatly simplify the measurement of potential toxicity.

Well-characterized water samples from our two test sites, as well as laboratory samples for various metals will be used in the study. *Daphnia magna* are crustaceans commonly used in environmental toxicity studies. These are easy to handle and grow, as well as inexpensive. Using these organisms, students will first construct toxicity curves for known metals (Cu, Cd, Zn) in synthetic water solutions with controlled parameters. These studies will then be repeated using water from the three systems described above. The results will then be compared to those predicted by the BLM (BLM, 2005) to demonstrate the usefulness of such a model as well as help students understand how they are constructed.

Biology

The ecological impact of heavy metal pollution in biota at Springwood Lake will be explored through modules within two field and one cellular biology classes and through summer research. We will develop a module for Ecological Biology (BIO 111). This is an introductory level course, with approximately 100 students annually. Non-science majors typically represent 50 - 65% of the class size. Students will help inventory the biota of the lake in a sampling lab, share data, interpret data, and be introduced to population modeling computation.
Learning outcomes include:

- gaining an appreciation for the interrelationships and natural history dynamics of ecological communities
- understanding the importance of quantitative techniques and reasoning in the description and study of complex ecosystems
- gaining the ability to critically evaluate sampling protocol efficacy and the quality of quantitative data.

In this module, each lab group will make a field trip to Springwood Lake and learn aquatic biota sampling techniques. Plants will be sampled manually; invertebrates by plankton tows, nets, and dredges; and vertebrates by seine or fyke nets. Students will work in groups of four or five and each group will gather species-specific data such as size and mass measurements, age estimations, population density and biomass calculations. Portions of samples will also be preserved for metal analysis by the Chemistry department during summer research. Groups will share data and an accurate biotic inventory of the lake will emerge.

This module will be introduced in the Fall of 2007 and will continue, allowing us to track changes in populations which will be vital information for assessing the significance of heavy metal pollution at the lake.

Biotic inventory work and food-chain construction will be continued in a module to be developed for Vertebrate Zoology (BIO 346). This is an upper-level course with a typical enrollment of 20-25 students.

Learning outcomes for this module include:

- learning the theoretical concepts as well as the field techniques of population ecology of vertebrates
- learning about vertebrates in aquatic ecosystems and aquatic toxicology and how geology and chemistry are vital to understanding these fields
- being exposed to the application of contemporary computational methods used in vertebrate population modeling.

In this module, students will use mark-recapture studies (using injection of passive integrated transponders [PIT tags]) to estimate population sizes and standing crop biomass of macrovertebrates (fish and turtles). Gut content analysis (by dissection for invertebrates, and non-destructive stomach flushing of vertebrates) will be used to determine food chains. Blood and/or tissue samples (non-destructive whenever possible) will be saved for analysis of metals during summer research, and these values will be related to the trophic ecology of individual species. We would also do sampling of tissues of these same organisms in other county lakes as reference values for this general region.

This module will be introduced in the Spring of 2008, and repeated annually, with special emphasis on following tagged animals and investigating evidence for bioaccumulation of metals in these animals.

A laboratory module will be developed for Cell Physiology (BIO 341). This is a sophomore level course, which typically has an enrollment of approximately 60 students. Over the course of the semester, students will investigate the effects of heavy metals on the expression of stress proteins in fish red blood cells and explore the roles of chemistry, geosciences, mathematics and computer sciences in toxicology.

Because they are nucleated and capable of transcription, translation, and protein synthesis, fish red blood cells are a valuable model for studying cellular responses to a variety of stresses, including heavy metal toxicity (Currie and Tufts, 1997). The heat shock proteins, HSPs, and metallothioneins, MTs, are two families of stress-induced proteins frequently studied in heavy metal toxicology. Fish red blood cells reliably respond to heavy metal stress by the expression of HSPs, and in some cases do so in a graded, dose-dependent manner, while the expression of MTs is more variable and less well studied (Fulladosa, et al, 2006). In this lab, fish red blood cells will be used to investigate the affect of metals on stress protein expression, and students will test hypotheses about what physical and chemical properties of aquatic environments affect bioavailability and bioabsorption of metals.

Learning outcomes will include:

- gaining an understanding of how cells and organisms respond to heavy metal intoxication
- understanding how bioavailability of heavy metals is a function of water characteristics and how chemistry and hydrogeology play important roles in toxicology
- gaining experience in experimental design, multivariate statistics, spectroscopy, protein quantification, and Western blot analysis
- being introduced to bioinformatics.

In weeks 1-3 of this lab module, students will use the science library and technology resources to explore primary and secondary literature on topics such as fish red blood cells, HSPs and MTs, aquatic toxicology, bioavailability, and heavy metal bioabsorption and toxic effects. After this introductory material, students will design their experiment protocols. They will choose what metals to use to challenge the cells. They will also choose what chemical or physical variables to add to the protocol to test hypotheses about what factors affect bioavailability/bioabsorption (see details below). Variables the students might explore include nitrates, sulfates, organic matter, anions, acid or alkaline conditions or variable temperature. During this period they will also construct standard curves for protein quantification on spectrophotometers with bovine serum albumin and the Bradford method.

In weeks 4-7, the wet lab will be conducted. We will purchase juvenile or adult rainbow trout, *Oncorhynchus mykiss*, from a regional supplier. Ideally, the trout will have previously been kept in Earlham aquaria for an acclimation period of one month. Trout will be anesthetized in buffered 3-aminobenzoic acid ethyl ester and blood will be drawn from the caudal vein. The red blood cells will be separated by centrifugation and then incubated in Hank's Balanced Salts Solution prepared with known amounts of $CdCl_2$, $PbCl_2$, or $K_2Cr_2O_7$, either alone or in combination with the chemical or physical variables chosen to assess bioavailability and bioabsorption. Cells will be incubated at 20 ^oC for 2 hours and samples prepared for protein analysis by lysis, centrifugation and supernatant collection. Total protein will be determined by the Bradford method, and gel electrophoresis and Western blot will be used to detect HSP70 using murine anti-HSP70 antibody. Students will be able to semi-quantitatively analyze changes in HSP70 expression among the various groups. MT expression will be detected by dot-blot analysis using murine anti-MT antibody. Groups will share their data with the entire class.

Weeks 8-12 will involve data interpretation and multivariate statistical analysis, as well as the bioinformatics portion of the module. A member of Earlham's Mathematics department will help with the instruction of the multivariate statistics. Biology students are first introduced to statistics in Ecological Biology and this represents an important step in the progression of their exposure to statistics.

The bioinformatics portion of this module will center around the metallothionein family of proteins. Like heat shock proteins, metallothioneins (MTs) are produced in response to metal intoxication in a number of organisms and models, including fish red blood cells (Bauman, et al, 1993). MTs are known to help protect cells against cadmium toxicity and they bind a variety of metals via abundant cysteine residues, which are highly conserved across phyla. Students will use Biology Workbench, SwissProt, and ClustalW to construct gene trees and phylogenies using the MT family of genes. They will also explore MT structure, folding, function and molecular evolution using PDB, Kegg and ConSurf. This introduction to bioinformatics is based on a curriculum module developed by the BioQUEST Curriculm Consortium based out of Beloit College, Beloit, Wisconsin.

This proposed module is a modification of the current Cell Physiology laboratory using very similar methods and equipment. In the current lab, students investigate the expression of HSP70 in hemolymph of the tobacco hornworn, *Manduca sexta*, as induced by a variety of stressors. This has been a very successful lab with good results. The initial literature search portion has also been an important component of Cell Physiology. Earlham has long-excelled in science library and science information technology pedagogy. This particular module will be developed in the summer of 2007 with summer research students performing all aspects of the lab, including preparation, writing a lab manual, and trouble-shooting. It will be the first time that multivariate statistics and bioinformatics will be taught in this course.

Geosciences

The Geosciences department will implement course modules in intro-level Physical Geology and upper-level Hydrogeology and Geochemistry courses. Additionally, the soils and sediment samples that will be analyzed during the Geochemistry module require extensive fractionation and treatment, and thus will be processed during the summer.

Physical Geology (GEOS 211) at Earlham is an introductory-level course that is taken by *ca.* 75 students annually, consisting of both science and non-science majors. Students in this course who are non-science majors generally lack confidence in their ability to *do* science and have had little or no exposure to an inquiry-based science classroom. In this course module, students will apply fundamental geologic methods of analysis to an environmental project. By the end of this module, students will be able to:

- use web-based geographic information system (GIS) to display and organize data relevant to the characterization of the project site
- use field and laboratory observations to describe the geology of the project site
- organize and analyze geochemical data to display the concentration distribution of heavy metals in lake bottom sediments at the project site
- establish a chronology of heavy metal loading to the project basin via interpretation of heavy metal stratigraphy
- create a scientific report synthesizing the results of the project and suggesting areas for further study.

This module will use the final four laboratory sessions in Physical Geology. Students will have a basic background in geology and will be able to apply that knowledge to the local area. Each laboratory section has a maximum of twenty-two students, with one professor and one upper-level undergraduate teaching assistant. In the first week of the course module, students will be assigned readings and worksheets that focus on the general problem of metals in the environment with emphasis on lake sediments as pollutant archives. Readings will be keyed to discussions of the hydrologic cycle with an emphasis placed on the connection between ground water flow and subsurface geology. Students will begin to learn how to use web-based GIS to create displays of the study area.

A field trip to the project site will occur in the second week of the project. Students will examine the geology and hydrology of the project site (Springwood Lake) and participate in a demonstration of sampling a sediment core from the lake. After students have seen the site locality and have done some initial reading, they will observe and describe a suite of sediment cores to determine terms of sediment composition, texture, color, sorting, fabric and sedimentological characteristics. Over the last two weeks, students will be given geochemical data keyed to the cores described in the previous week's lab. Geochemical data will initially be that collected by Graham (2003), and in later years, include data collected by upper-level geochemistry students or summer research students. Students will be required to plot and analyze this data and make interpretations about the concentrations of heavy metals in Springwood Lake over time as a result of their analysis. Students will then write a full scientific report and will share the results with other introductory-level science students working on different aspects of this project.

The course module will require some rearrangement of existing laboratory topics. The site field trip will replace an existing field trip that focuses on the Richmond, Indiana drinking water supply. An existing lab that is entirely devoted to sedimentary rock description will be modified and incorporated into another rock lab, with the sediment core studies replacing it. A current lab that introduces global positioning system (GPS) and GIS to students will be modified so that it becomes the laboratory session in which students read about the environmental problem and learn to use Web-based GIS. GPS techniques will be used in the field lab. A current lab offered in this course gives students experience with data analysis; however, the data used is related to plate motions over time and is part of a lab on global tectonics. The same techniques of analysis can be taught using the geochemical data related to Springwood Lake metals and will provide a real-life example of collecting and analyzing data related to an environmental problem.

Hydrogeology (GEOS 362) at Earlham emphasizes practical application of theoretical concepts. Hydrogeology course modules will be developed for each of the project sites. These course modules will enrich student comprehension of the significance of ground water/surface water interaction in the vicinity of the project sites and will develop student capabilities for collecting, analyzing, displaying and interpreting ground water data. In addition, students will interact with several types of ground water flow models. A detailed description and understanding of ground water flow is of obvious importance in understanding metal transport.

At the on-campus field site, students will be active participants in designing, installing and managing data collection from ground water monitoring devices. At Springwood Lake, students will use extant data derived from regulatory monitoring of surrounding contaminated sites. At the conclusion of these modules students will be able to:

- evaluate data collection requirements (number and spacing of piezometers, monitoring wells, etc.)
- prepare geologic and hydrostratigraphic unit cross-sections from well-boring data
- obtain laboratory measurements of whole soil porosity for each hydrostratigraphic layer at each of the project sites
- collect, tabulate and display ground water elevation data and prepare detailed maps of potentiometric surfaces
- determine horizontal hydraulic conductivity values for saturated media at each project area
- computationally analyze potentiometric and porosity data, slug test and constant-head discharge data to calculate rates of ground water flow, estimate hydraulic conductivity values, and determine time-drawdown and distance drawdown behavior as a means of establishing aquifer parameters transmissivity (T) and storativity (S).

The first module will teach students how to design and install ground water data collection devices within the on-campus research plot. Monitoring wells will be installed using a modification of the "casing drive and wash" technique common in the drilling industry. This method produces monitoring wells with slotted screens surrounded by filter sand pack. Wells are completed with a bentonite seal and a lockable steel protective casing. Multilevel piezometers will be installed using a modification of the hydraulic well-point technique. After installation, top of casing elevations will be surveyed with a transit and stadial rod to the nearest 0.01 foot. Students will collect ground water elevation data weekly using a Solinst Watermark Water Level Meter. Aquifer hydraulic conductivity will be determined via constant head slug tests (Domenico and Schwartz, 1998). Aquifer Transmissivity (T) and Storativity (S) will by acquired by means of a 24 hour constant-discharge pumping test. Data from the slug tests and the pump tests will be computationally evaluated using AQTESOLV, version 3.5 (5 licenses owned by the Geosciences department). After hydraulic testing, wells will be sampled for water quality. Ground water samples will be collected and analyzed for common anions and cations and EPA

Primary and Secondary Drinking Water constituents. These data will form the basis for student reports describing the quantity and quality of ground water flowing through the study plot.

The second module will challenge students to manage, organize, analyze and interpret extant ground water elevation data associated with the multiple ground water monitoring wells in the industrial areas surrounding Springwood Lake. These data are compiled by the Voluntary Remediation Program (VRP) at the Indiana Department of Environmental Management (IDEM) and are public records subject to open access. Students will be divided into small groups that will visit IDEM offices to obtain pertinent records. Students will then enter data into spreadsheets which will be imported into ArcGIS 9.1. These data will be be contoured and shaded to produced 3D maps of the water table surface at different times. Students will enter data into Visual MODFLOW to conduct forward modeling of ground water flow conditions. Each student will then be given a portion of the synoptic report to prepare. The collective report will describe the variation in the ground water system over time and will integrate subsurface data (soil stratigraphy from well logs, data from geophysical surveys, etc).

Geochemistry will participate in this multidisciplinary project in two ways: by summer research and by implementation of a course module. The target of both contributions will be to investigate the nature of the heavy metal association with soil and sediment solids by processing and analyzing material from the on-campus plot and Springwood Lake. The approach will be to fully characterize the mineralogy of sediments and soils to provide additional information for modeling sorptive behavior. This takes into account the different metal sequestration characteristics of fixed and variable charge humic substances, silica, aluminum and iron oxides and 1:1 and 2:1 phyllosilicates (Sposito, 1984; Sparks, 1995, Jenne, 1998).
At the conclusion of the geochemistry 2008 summer research, students will be able to:

- determine the bulk mineralogy of soil and sediment by powder X-Ray Diffraction
- remove binding and flocculating agents (carbonates, organic matter, iron oxides and multivalent cations) from dried soil and sediment samples by treatments with sodium acetate, hydrogen peroxide and sodium carbonate
- segregate different size fractions by sodium carbonate dispersion followed by specifically timed high-speed centrifugation
- evaluate mineral identities of sand and silt-sized fractions by use of the scanning electron microscope (SEM) and energy dispersive X-Ray (EDX) spectrometer
- identification of chemical bond configurations using Fourier-Transform Infrared spectroscopy (FTIR) in collaboration with chemistry faculty
- determine total iron content by dithionite-citrate-bicarbonate (DCB) digestion and measurement with the GFAAS or ICP-AES in collaboration with students and faculty in the Chemistry department
- determine the cation exchange capacity (CEC) of clay minerals by the degree of cation removal onto Na^+ saturated tetrahedral layer surfaces.

The methods for determining soil and sediment mineralogy involve a series of chemical treatments to isolate specific mineral fractions. The methods are described in detail in Dixon and White (1996) with thorough theoretical underpinning in Dixon and Weed (1989) and Sposito (1984, 1989). These preparations are too lengthy to be adapted to a 3 hour lab course. Hence, sample processing is best done during a summer session. Two or three students who have advanced training or experience will be invited to participate in the summer geochemistry research. Summer work will involve isolating individual soil minerals for chemical identification. Samples studied by the summer group will include freeze-dried lake bottom sediments collected in early 2003 from Springwood Lake and soils collected from the on-campus plot during the spring 2007 Hydrogeology module. Mineralogical processing requires an ordered sequence of steps to remove binding agents, dissolve iron, decompose organic matter, disperse fines, segregate particle sizes, strip interfering exchange ions, thermally decompose specific target minerals and completely dissolve residual silicates (Klute and Page, 1982; Sparks et al., 1996). As processing moves forward, mineralogical identification is accomplished by X-Ray Diffraction before and after thermal decomposition, saturation with a divalent cation (Mg^{2+}) and lattice expansion with a glycol. Identification continues with SEM-EDX, FTIR and ICP-AES (Hawthorne and Mineralogical Society of America., 1988; Hochella and White, 1990).

The Geochemistry (GEOS 352) course module will engage students in lake bottom sediment core collection, processing and analyses. At the conclusion of the Geochemistry course module students will be able to:

- collect a lake-bottom sediment core using a standard piston coring device
- process the sediment core into cm-scale increments to be weighed, frozen, freeze-dried, weighed again and pulverized
- quantify the heavy metal content of acid digests of the pulverized sediment via GFAAS or ICP-AES in collaboration with students and faculty in the Equilibrium and Analysis (CHEM 331) course
- determine a vertical concentration distribution in each core to expand the information on pollutant history initially observed by Graham (2003).

Students in the spring Geochemistry class will actively participate in collecting additional bottom sediment cores at Springwood Lake. Students will process each core by placing 1-2 cm thick layers of each core into weighed containers which will then be freeze dried. Water content will be determined by reweighing the containers. Organic matter and carbonate mineral content will be determined on the basis of Loss on Ignition (LOI) measurements following furnace treatment at 450 ^{o}C and 900 ^{o}C. Heavy metal concentrations will be determined for each 2 cm stratum of each core by microwave digestion in concentrated nitric acid followed by ICP-AES quantitation. Students will then prepare a report on the vertical stratigraphic variation in metals in lake sediments and will relate their findings to the pollutant loading history of Springwood Lake.

Computer Science

Working with scientists from other disciplines on computational methods has been a focus of our Computer Science department for some time now. We have experience with the pedagogical, research, and operational aspects of computational science and the high performance computing gear that support it. As an example, the Cluster Computing Group at Earlham has been working for several years in the area of molecular dynamics, specifically the modeling of protein folding, and we have done a significant amount of work with GROMACS, a popular open-source molecular dynamics package which is typically used with large bio-molecules such as proteins. We have participated in on-campus seminars with Biology and Chemistry on protein dynamics and on proteomics, and we are continuing to do collaborative work on protein folding with the Pande Lab at Stanford University (home of the Folding@Home project). Our presentations and papers cover a variety of topics in this area.

Computer Science will have four distinct roles in this W. M. Keck project. First, we will be designing and building field-deployable remote monitoring systems for the on-campus study plot. These will be small, solar powered, single-board computer based units with the capability to monitor, record, and up-load temperature, pH (digital), conductivity, redox potential, pressure, and nitrate levels. This will make current data available to any campus-linked computer system for classroom or laboratory use, for archiving and for model development and testing. These developments will build on existing work that the Hardware Interfacing Project, one of our student/faculty applied computer science groups, has done with field-deployable weather stations.

Second, we will be working with faculty in the Chemistry, Geosciences, Biology, and Mathematics departments to help them design and implement the computational components of their curriculum modules. For these disciplines, the challenges at hand are to teach their students a new framework for scientific inquiry, *i.e.* computational methods, and to show them how multi-disciplinary teams of scientists approach large, complex problems. Some of these developments will be initiated within computer science, but here the challenges are slightly different. While we share the need to show our students how multi-disciplinary teams of scientists work, we do not need to spend very much energy on computational methods. On the other hand we do need to show them how the tools of their trade are employed within chemistry, biology, etc. and give them first-hand experience doing experiments with both *in vitro* and *in silico* components. Our experience in developing curricula for the National Computational Science Institute and the SuperComputing Education Program will prove valuable here.

Validation ("Is it the correct model?") and verification ("Is the model implemented correctly?") are two critical topics to cover in the context of computational modeling, a central component of this project. Scientists of all disciplines must understand the limitations associated with simulating natural processes *in silico* and how to validate and verify the computational models they are working with. Our plan is to explicitly discuss these aspects in each course when a particular model is introduced in a curriculum module. For some topics, e.g. ground water flow modeling, we can perform experiments that give students first-hand experience with the verification process. In this case, we will use table-top ground water flow simulators which contain soil strata from our back-campus study plot. Working in a computer equipped soils lab students will be able to develop and refine a computational model of contaminant transport using the table-top simulator for verification. This will find obvious uses in particular courses in both Computer Science and Geosciences.

The third role of Computer Science is to design and implement a schema and user interface, based on a relational database management system, for the data generated by this project. This system will include both the field and experimental data and will be based on a web browser interface to maximize accessibility. The Green Science Group, another student/faculty applied science group, has developed schemas and user interfaces for energy and weather data, and we plan to work with them to develop the appropriate classroom and research interfaces for accessing and analyzing the extensive data that will be collected in all phases of this project.

Our fourth and final role will be the implementation of new computer science courses and new modules in our current courses that are more heavily based on laboratory and field science. As an example of the latter, we propose to develop a curriculum module for our upper-level Parallel and Distributed Computing (CS 360) class that will incorporate some of our experience with the GROMACS modeling package discussed above. This will give computer science students the opportunity to learn about the underlying science and to see how the simulation is developed from nature and how the *in silico* and *in vitro* experiments relate to and inform each other. Parallel and distributed programming techniques are at the heart of most of the scientific software kernels used for computational science and modeling. Problems in this domain tend to be computationally intensive, thereby requiring the use of clusters, grids, and other high performance computing platforms. The effective use of parallel and distributed algorithms, combined with high performance computing equipment, greatly accelerates the analysis process.

Computer science is developing two new courses germane to this proposal, Introduction to Computational Science (CS 290), and In Silico (CS 182). In Silico will be an introduction to simulating the natural world using spreadsheets and other relatively simple computational tools. This course will be designed for first-year students, both as an attractor to the sciences generally and as a foundation on which more sophisticated computational approaches can be developed later in the curriculum.

Introduction to Computational Science, developed and taught by Charles Peck, is also designed to be accessible to lower division students although here we expect to attract a high percentage of potential science majors from a variety of disciplines. The goals and objectives of this course are to:

- introduce the concepts of computational science, modeling, and simulation
- introduce and develop skills with the tools commonly employed within computational science, e.g. symbolic, numeric, and graphical computational packages
- facilitate collaborative learning through regular small group projects which have students from different majors working together.

The two new courses will be structured in a way that students taking either or both, and who go on to take any of the upper-level science courses with computational modules, will be well prepared to extend their learning in those areas.

Mathematics

Elementary Statistics (MATH 120) is a general education course taught twice a year, in which *ca.* 100 students are introduced to the key notions of statistics: descriptive statistics and inference testing. We will make use of the “metals in the environment” data sets in teaching students how to do typical tasks of descriptive statistics: measures of central tendency, measures of dispersion, and construction and interpretation of graphical displays of statistical information (univariate and bivariate data). Use of data sets from Springwood Lake and our back-campus field site will help students grasp the differences in origin and potential uses between observational and experimental data. Probably the greatest advantage of using this data is that it will be “real” to the students. They will know the sites (and potentially the historical context of those sites) where the data is collected, and the students involved in the experimental design and data collection.

Statistics (MATH 300) is a calculus-based introductory course that we teach every other fall semester. We would make similar use of the data sets as for MATH 120.

Environmental Models (ENPR 242) is taught each fall and is required for all students who are earning a major or a minor in either environmental science or environmental studies. This course is taught by a mathematics professor and includes application modules involving Biology, Chemistry, Computer Science, Geosciences, and Mathematics. The “metals in the environment” data will be used with the module on the chemistry of hazardous materials. The wells at the back-campus site will provide data that will be very useful for the module that introduces the organization, analysis and interpolation of scattered spatial data. The aquatic biota population data from Springwood Lake will be integrated into the population biology module. As with statistics courses, the use of Earlham-related data will motivate students in their use of linear algebra and geometry to model environmental situations.

6) Technical problems that may be encountered and how they will be addressed

There are several types of technical problems that could be encountered during this project. We are implementing many new methods, instrumentation and software as part of both course module development and our summer research projects. The methods will generally be adapted from the literature, but will require significant modification and testing to be suitable for use in an undergraduate course where students are still learning proper laboratory techniques.

While some of the instrumentation we will implement uses sensor technology which is new to us, the idea of field-deployable data collection and monitoring equipment is not new to Earlham. The Computer Science department, in the form of the Hardware Interfacing Project, has set up and maintains weather stations and other scientific equipment in field settings. Those experiences will help us overcome any obstacles the new devices may present.

For most of the modeling applications we will use open-source software packages. Many commissions and study panels have highlighted the value of open-source software in the context of scientific inquiry. One important attribute of open-source software is the ability to "open the hood," either to show students the core algorithms or to make adjustments to the code.

7) Roles of all key project personnel

Michael Deibel - As part of this project, Dr. M. Deibel will work with students to develop the course module for environmental chemistry . He will also collaborate with Dr. C. Deibel and students to develop modules for the Equilibrium and Analysis class. In addition, he will conduct research with students and other faculty to analyze water, soil and biological samples for various metals. As Project Leader, Dr. M. Deibel will help coordinate development and implementation of all modules and research and will be responsible for organizing the yearly and final reports.

Corinne Deibel - Dr. C. Deibel will participate in the development and implementation of the teaching modules in Principles of Chemistry and Equilibrium and Analysis. She will conduct research with students and other faculty to analyze water, soil and biological samples for various metals.

John Iverson - Dr. Iverson will develop and implement the module for Vertebrate Zoology. He will also collaborate with Dr. Matlack in training students in techniques to be used in summer research and in course modules, such as macrovertebrate sampling, tag and re-capture techniques, turtle handling, etc.

Michael Jackson - Dr. Jackson will develop and implement course modules for Elementary Statistics, Environmental Modeling, and Statistics. He will also work with other Earlham researchers to insure that data collection and organization enables the easy incorporation of data in classroom assignments.

David Matlack - Dr. Matlack will conduct summer biological research with students and develop and implement the module for Cell Physiology.

Ronald Parker - Mr. Parker will develop and implement course modules for Hydrogeology and Geochemistry.

Charles Peck - Mr. Peck will work with students to design, build, and deploy the field monitoring equipment to be used at the two study sites. Mr. Peck will work closely with the other faculty to develop the computational components for each of the course modules described in this proposal and to design and implement the data model, data storage, and user interface to the long-term environmental data to be collected and analyzed as part of this work. Working with colleagues in the Computer Science department, he will develop curriculum modules for In-Silico, Introduction to Computational Science, and Parallel and Distributed Computing.

Margaret Streepey - Dr. Streepey will develop and implement the course module for Physical Geology. She will also direct the management and coordination of the multidisciplinary student seminar programs.

Lori Watson - Dr. Watson will assist in the development and implementation of course modules for Principles of Chemistry. In addition, she will coordinate the program assessments during years 2 and 3 of the grant.

8) Organization chart of key project personnel

Earlham College
Organizational Chart
Computational and Multidisciplinary Curriculum and Research Initiative

President
Douglas Bennett

Provost
Len Clark

Project Leader
Michael Deibel

Key Personnel

Corinne Deibel (Chemistry)
John Iverson (Biology)
David Matlack (Biology)
Charlie Peck (Computer Science)
Lori Watson (Chemistry)
Michael Deibel (Chemistry)
Michael Jackson (Mathematics)
Ronald Parker (Geosciences)
Margaret Streepey (Geosciences)

9) Description of facilities, equipment and resources available for the project.

The science complex at Earlham consists of three interconnected buildings, Dennis Hall (Computer Science, Geosciences, Physics, and Mathematics), Noyes Hall (Science Library, large computer lab) and Stanley Hall (Biology and Chemistry) with a net square footage of 76,000.

The laboratory portion of the chemistry modules will use two laboratories (one for general chemistry/equilibrium and analysis and a separate lab for environmental chemistry). These labs have a total square footage of 2950 (1719 and 1230, respectively) and a combined total of 11 hoods. Each lab has bench space for approximately 20 students.

Analysis of metals will be conducted on two separate instruments: an inductively coupled atomic emission spectrometer (ICP-AES) and a combination flame/graphite furnace atomic absorption spectrometer (GFAAS). The ICP-AES (Perkin Elmer Optima 4100DV) is a dual view, multi-element analyzer capable of analyzing up to 50 elements in under a minute. We have also recently installed an ultrasonic nebulizer (CETAC U-5000-AT), which will increase our sensitivity by a factor of 10. The GFAAS (Perkin Elmer AAnalyst 800) is a state of the art transverse heated graphite tube system with Zeeman background correction. This instrument will be utilized in GFAAS mode to analyze metals when the detection limits of ICP-AES are insufficient for the levels present in our samples. It will be utilized in flame mode when analyzing major elements such as calcium or magnesium. Both instruments are fully automated (allowing the analysis to continue even after the 3 hour lab has ended) and utilize the same software platform (which will simplify student training).

Prior to analysis by the methods listed above, solid samples must be digested. Our current microwave digestion system (CEM MDS-2000) has pressure control and will be useful in method development for digestion protocols. It is, however, limited in sample throughput to 12 vessels.

Three different biology teaching laboratories will be used for the course modules. Each lab is approximately 1200 square feet, with bench space for 24 students. Equipment to be used includes dissecting microscopes, compound microscopes, spectrophotometers, UV spectrophotometers, mini-protein gel electrophoresis units, mini trans-blot cells, microcentrifuge, 6 computer stations for statistical analysis, E-gel units, refrigerators, ultra-low freezer, and environmental chambers. Summer research in biology will be conducted in the faculty research area, which is 1500 square feet. Additional equipment for this research will include microtome, a cryotome to be purchased with other funds in September 2006, two fluorescence microscopes, and a scanning electron microscope equipped with an energy dispersive X-ray detector.

The Geosciences department maintains a small Geochemistry laboratory that has two new hoods (2001), and wet chemistry equipment suitable for conducting soil mineral analyses and determinations including an IEC Centra 7 benchtop centrifuge and a Thermolyne 1400 Muffle Furnace. The department maintains a Rigaku MiniFlex X-Ray Diffractometer running Jade 6.1, Easy Quant, Peak Search and Match software running the Powder Diffraction File 2, Release 2001 (PDF-2) database. The department maintains equipment for collecting lake bottom sediment cores, processing them with a LABCONCO 2.5 L Lyophilization (Freeze Dry) unit. An OI Analytical Model 7295 Microwave Digestion System with two 12 vessel racks is used for concentrated nitric acid digestion of solids for chemical analysis. Geosciences maintains up-to-date ESRI ArcGIS capabilities running ArcView 9.1 and extensions (Spatial Analyst, 3D Analyst and Geostatistical Analyst).

The Computer Science department maintains file servers, computer servers, web servers, database servers, and three 16 node Beowulf clusters which are used for the development and testing of computational science curriculum modules, the teaching of parallel and distributed programming, and student/faculty research projects (see http://cluster.earlham.edu). This infrastructure is managed by a student/faculty applied computer science group, the System and Network Administrators (see http://cs.earlham.edu). The Hardware Interfacing Project, another student/faculty applied computer science group, has designed and developed a variety of field-deployable computing equipment. This includes stand-alone weather and energy monitoring systems. Computing Services at Earlham College maintains multiple Internet links for college-wide use.

10) Equipment requests

Large freeze dryer – There is currently one small freeze-dryer that would be available for this project. Given the large number of soil, plant, and biological samples that will be processed for this project, there is a need for a high capacity freeze dryer. The model we have requested will include bulk drying trays and a large capacity.

Acid digestion system - There is currently one microwave digestion system. Because of the large number of solid samples that must be processed, digestion will likely be one of the bottlenecks in the analysis of samples by our atomic spectroscopy equipment. The instrument that we propose to purchase will be a CEM MARSxpress system with a high throughput capacity (40 sample tray).

Atomic Absorption Spectrometer (AAnalyst 800) - We have recently purchased an AAnalyst 800 combination graphite furnace and flame atomic absorption spectrometer.

Semi-automated Total Organic Content Analyzer - For the more sophisticated models as well as the biotic ligand model, it is imperative to know the dissolved organic content. We do not currently have this capability.

Differential GPS - In order to resolve distribution trends of spatially heterogeneous data, it is crucial to be able to quickly and accurately locate all environmental sampling events from every type of media. The Geosciences department currently maintains one Trimble GeoExplorer III with post-processing Differential Global Positioning System (DGPS) capability. Our Trimble GeoExplorer III is 6 years old and is beginning to wear out. A new DGPS, dedicated to the project would accelerate data recovery and transfer.

Field monitoring equipment (temperature, pH, conductivity, redox potential, pressure transducer, nitrate selective probe, single board computer, packaging, and communications) - This equipment will be purchased, integrated and deployed at our field test site to provide a continuous monitoring of water quality parameters.

Field sampling equipment (Lake sediment cores to 2 m and Monitoring wells -one time install) - This equipment will be used for collecting lake bottom sediment cores and ground water samples and for construction of our on-campus field site.

Biology sampling gear: Nets and containers, Passive Integrated Transponder (PIT) tags and reader (InfoPet)- The Biology department has modest field sampling equipment but does not have the quantity nor quality of aquatic sampling gear needed as requested in this proposal. The equipment requested will only be used for sampling and re-sampling related to this proposal.

Spectroscopy supplies – We will need to purchase additional hollow cathode lamps and other supplies to utilize this instrument for the wide array of metals that we propose to analyze.

11) Plans for this project beyond the proposed time period, including financial support.

Because of the transformative nature of the course modules on our science curriculum, this project will have a lasting effect on our program. These modules will continue to be an integral part of our courses for many years to come. In addition, they will serve as templates for the development of additional environmental modules that may both expand the current studies on metals in the environment or expand it to other topics such as pesticides in the local watershed.

Earlham believes that the experience and knowledge we will gain by building and implementing the curriculum modules described in this proposal will be valuable to science faculty from other liberal arts institutions contemplating similar endeavors. As such we have arranged with the National Institute for Technology and Liberal Education (NITLE) to offer a workshop for our peers where we will describe what we have done and offer suggestions for how similar programs can be implemented at their institutions. The attached letter of support from NITLE provides background on Earlham's relationship with NITLE and details associated with this dissemination activity. We will hold the initial workshop for faculty at other liberal arts institutions during the grant period.

To continue the summer research program, we are embarking on a capital campaign that includes a goal of building a $3 million endowment for faculty/student research. The income from this endowment, along with operating funds, would provide research resources after the grant period ends. We also believe that a W. M. Keck Foundation investment will serve as a catalyst for major gifts from alumni, friends, corporations and other foundations as we continue and expand the program.

12) Describe how the success of the project will be evaluated in terms of the goals proposed. Include information regarding outside review committees, if appropriate.

We have identified several possible sources of both internal and external evaluation. Internal evaluations will be conducted by one or more members of the project and other faculty and staff within the science division who are not directly involved in developing or using these curricular modules. External evaluators will be drawn from program assessors who have worked previously with Earlham College and/or from organizations that provide consultancy services such as the Council on Undergraduate Research (CUR) or the W.M. Keck - Project Kaleidoscope Consultation Program (Keck-PKAL). CUR can provide program evaluation sensitive to issues at predominantly undergraduate institutions including evaluators with experience in evaluating interdisciplinary and interdepartmental programs. Keck-PKAL has strengths in program evaluation that focuses on creative approaches to the education of the STEM (Science Technology Engineering and Mathematics) student population.

Evaluation of the Keck program will occur both during (formative) and at the end (summative) of the grant period. The formative process evaluations conducted at various points throughout the grant period, particularly during year 2, and will assist the faculty and academic departments involved in this interdisciplinary project to refine the project goals and objectives and to make any ongoing modifications or revisions. They will identify what is working during the initial implementation and point to areas needing further development. The summative evaluation will take place at the end of the grant period and will provide a measure of how well the program goals were met as well as provide directions for future growth.

The key faculty members will meet with the evaluators to clarify, operationalize, and select and develop instruments that evaluate the stated and implicit goals of the project (above). The project evaluators will also help to conceptualize key issues or problems that would keep our program from meeting our stated objectives and specify particular criteria for success as well as identify particular data needed to determine how well the components of the program are meeting their objectives.

Delineating project goals will assist us in developing both qualitative and quantitative measures for determining how well our goals are being met during both the formative and summative evaluation phase. Qualitative evaluations will include:

- Open-ended surveys: The evaluator will collect answers without preset response categories to written questions. Surveys with an open-ended component would be given

to all students enrolled in courses where a research-based interdisciplinary module was used, faculty who developed and taught such courses, and participants in any workshops in which the faculty involved in the Keck program presented the pedagogy and organization of this project.
- Semi-structured interviews: The evaluator will conduct semi-structured interviews of key personnel and a representative sample of students to allow the evaluator some first hand experience with the evaluated activities and a chance for in-depth exploration of particular issues.
- Peer evaluation: Efforts at developing interdisciplinary course modules incorporating computational modeling will be described in peer-reviewed publications providing feedback from the reviewers as well as others who read the articles.

Quantitative evaluations will include:
- Quantitative surveys: Quantitative pre and post surveys of student or workshop participant attitudes toward and confidence in computational methodology, interdisciplinary collaboration, relevance of environmental studies in particular disciplines, and interest in science and society.
- Institutional data: Assessment of pre and post grant levels of student participation in undergraduate research, likelihood of taking a second science class, and number of science majors.
- Incorporation in curriculum: Measurement of the pre and post grant percentages of incorporation of computational modeling in primarily field or laboratory based courses and field or laboratory modeling in computational courses.
- Incorporation in co-curriculum: Comparison of the numbers pre and post grant interdisciplinary projects including collaborative research projects and grant writing efforts.

Final reports summarizing both the quantitative and qualitative data will be produced. They will assess which and to what degree goals have been met for affected students, faculty, and the institution as a whole as well as provide recommendations for further implantation and dissemination.

Dissemination activities will include:
- NITLE workshop on integrating multi-disciplinary computational methods into the undergraduate science curriculum.
- Earlham Science Poster Session (held each Fall)
- Student presentation of papers at regional and national scientific conferences (Butler Undergraduate Research Conference, Geological Society of America, American Chemical Society, etc).
- CUR publications and programs
- Student/Faculty papers in science pedagogy journals and basic science journals, as appropriate.