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Justification for Incorporating Ecological Sciences into a Natural Resources Engineering Degree Program With Areas of Emphasis in Environmental and Ecological Engineering

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Abstract

A Natural Resources Engineering degree program within the Department of Biological and Agricultural Engineering at the University of Georgia has been proposed and is currently under review. This initiative spawned from the realization by some engineering faculty, and other university scientists involved in the conservation and use of natural resources, that the interface between society and nature has become increasingly complex. These same engineering faculty members have concluded that the present natural resource area of emphasis in Agricultural Engineering and the environmental emphasis in Biological Engineering are too narrow in focus to prepare students to address this increasing complexity. A new degree program is proposed with areas of emphasis in environmental and ecological engineering focusing on point and non-point sources of pollution respectively. Within these two new areas will be the inclusion of mandatory and optional classes in ecology that will expand the engineering student's understanding into the present scientific view of environmental health and integrity. The objectives of this new degree program will focus on including ecological constraints when designing systems that will impact the tangible and intangible natural resources utilized explicitly and implicitly by society. Moreover, the conservation, management and protection of these resources will be emphasized. This paper presents a brief philosophical justification for the two areas based on the potential contributions of ecological science to the practice of engineering and on the commonality among engineering and ecology.

Introduction

Has the relationship between society and nature become so complex that traditional engineering education is not preparing its students to adequately understand the environment that they are expected to protect, conserve and manage? Over the past 30 plus years environmental disciplines have garnered much attention. As environmental awareness gained public momentum in the late sixties and early seventies environmental considerations were included in the design of societal systems. Much of what led to this resulted from the work of biologists and ecologists whose studies clearly demonstrated the need to protect natural resources for the sake of society. A major part of this was with regard to public health as well. Thus environmental protection was included in the engineering design process via federal and state regulations. In the realm of engineering education this has resulted in the incorporation of rigorous physical, biological and chemical principles in environmental engineering curricula.

Environmental problems associated with society have been addressed from as many perspectives as there are disciplines. Biologists, chemists, microbiologists, hydrologists, geologists, sociologists, ecologists, engineers, and others address environmental problems with oftentimes drastically different views and objectives. These differences have led to healthy and much needed debate regarding the protection, conservation and management of natural resources. Combined scientific and economic research has shown that the value of our natural resources is not limited to tangible products alone but includes services provided by nature as well[1]. Recognizing the need to associate nature with human value, others have developed coursework that links the science of ecology with engineering through the liberal arts[2]. Moreover, we have learned through decades of scientific research that the most serious threats from society are not point source discharges but rather the more complex non-point sources.

At the USDA CSREES Southern Region Research Project S-273 annual meeting held in Knoxville, Tennessee in October 1999[3], the consent was that the current geographic information system (GIS) approach to watershed modeling lacked the necessary biological and ecological input necessary to appropriately model watershed health and integrity. The incorporation of ecological criteria was included on the list of issues that must be addressed. While incorporating ecological inputs and outputs is no doubt a formidable and daunting task it is nonetheless a requisite for more realistic and representative watershed modeling.

The opening question, "Has the relationship between society and nature become so complex that traditional engineering education is not preparing its students to adequately understand the environment that they are expected to protect, conserve and manage", should then be debated vigorously to assess whether or not our approach to engineering education keeps our students current with scientific knowledge.

Objectives

The current structure of the University of Georgia's Biological and Agricultural Engineering Department has two areas of study with an environmental emphasis. The Agricultural Engineering degree program has an area of emphasis in Natural Resource Management while the Biological Engineering program has an area in Environmental Engineering. The Natural Resource Management area is a larger scale approach in that it addresses traditional Environmental Engineering practices of designing structured systems to process collected waste before it is re-introduced back into the environment. The Environmental emphasis under the Biological Engineering program is at a much smaller scale focusing more on biological processes and solutions. Traditional environmental engineering education has fulfilled a critical need over the past decades and it is not proposed in this paper that this tradition be abandoned nor is it proposed that the need for these engineers is on the decline. On the contrary, their contribution to developing solutions for environmental problems will continue. This paper does discuss the University of Georgia's efforts to broaden the base of knowledge in its existing environmental engineering curricula and perhaps introduce a more current perspective of environmental systems by incorporating coursework in ecological science. Moreover, it discusses a proposed area of emphasis in ecological engineering separate from the environmental emphasis.

Structure and Focus of the Program

At the 1999 ASEE conference, Tollner[4] submitted that the time had come for the establishment of Natural Resources Engineering as a distinct field of engineering. We embrace this submission and propose the field of study be subdivided into two areas of emphasis in environmental and ecological. The major requirements for the program of study are given in Table 1 and include both mandatory and optional coursework in ecology to be taught by Ecology faculty. The focus of the environmental emphasis will be traditional point source issues but enhanced by incorporating coursework in alternative engineering methods of natural treatment systems. The ecological area of emphasis will be directed more toward the larger scale problem of non-point source pollution and how to quantify and measure environmental quality/health/integrity at this scale. It will consist of much more ecology coursework than the environmental area of emphasis and the ecology courses will be taught by Ecology faculty rather than by engineering faculty serving as surrogate instructors in ecology. This will provide the students with the much needed ecological perspective.

Enhancing Traditional Environmental Engineering

Traditional environmental engineering education embodies, among other coursework, soil physics, chemistry, microbiology, hydrology, hydraulics, hazardous waste and environmental law into mechanical, electrical, structural and chemical engineering principles to prepare students to design systems that will collect, process and recycle or discharge societal waste at a level compliant with environmental regulations. These systems are essentially unit processes, with fairly well defined inputs and outputs, designed and constructed to protect the environment by meeting local, state and federal regulations. The primary focus is point source pollution with lesser emphasis on non-point source issues. As environmental problems become increasingly complex, the inherent limitations of these designs behoove us as engineering educators to re-examine the present course of study. While the traditional course of study is not in need of an overhaul, its scope could be augmented by including coursework wherein the structure and function of ecological systems is presented and considered in the solution of problems. This new degree program fills this void through a capstone design course featuring an interdisciplinary team project where team members attempt to solve a traditional environmental problem with non-traditional natural treatment methods. Moreover, the faculty directing the course will also be interdisciplinary.

Ecological Engineering as a Separate Area of Emphasis

The recognition of ecological engineering as a bonafide engineering discipline is debatable. What is less debatable though is the contribution of over 100 years of ecological research to our present understanding of the environment. We have progressed from a compartmentalized view of biological life to the current perspective that nature consists of biotic compartments interacting with their surrounding abiotic compartments. These interacting compartments comprise the basic functional unit of ecology referred to as an ecosystem. During the past two decades ecology has grown so rapidly that it has become the source of many of the environmental regulations in force today.

When a scientific basis becomes sufficiently established, the science is applied through an engineering discipline. Such has been the case with the basic sciences of physics, chemistry and biology. Even more specific branches of these basic sciences such as genetics, microbiology and electromagnetism have found their way into people's lives by way of engineering application. Inherent to many of these applications has been the harvesting of natural resources and the subsequent discharge of by-products back to the environment. This cycling of natural resources resulted in the need for technology that would sustain the resources upon which society depends. The science of ecology has branched off from biology and is now an established field of its own with the ecosystem as its basic functional unit. While the physical, chemical and biological sciences have found their place in engineering design, ecology has yet to be embraced in such a manner.

One basic principle of ecosystem function is their ability to self-design. With a myriad of biotic and abiotic compartments, nutrient and energy flows through an ecosystem may follow various pathways depending on current conditions. As conditions change these flows will select for the most optimal available pathway. Such diversity leads some to conclude that ecology is not a hard quantifiable science, lacking the necessary governing equations to be incorporated into engineering design. At the organismal level governing equations can be developed based on kinetic principles to predict enzymatic reactions, metabolism, growth rates, degradation rates, etc. Such biological principles have been incorporated into engineering practice and contributed much toward developing solutions for environmental problems. However, at larger scales of environmental concern, such as the watershed-scale, where the interaction of society with nature are most telling, the complexity has increased tremendously. At this scale, where ecosystems are the basic functional unit, we should take advantage of (not exploit) the ability to self-design since perturbations at this level are so dynamic.

The concept of ecological engineering is not new. Among the first to define it was the noted ecologist H. T. Odum in 1962 and 1963, whose concept was "environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources". Odum (1971) added later, "the management of nature is ecological engineering, an endeavor with singular aspects supplementary to those of traditional engineering. A partnership with nature is a better term". We are proposing in this new degree program that incorporating ecological science into engineering practice is a necessary step to be taken toward addressing the complex issues related to non-point source problems at the larger watershed scales where environmental problems must be addressed.

The following lemma is submitted:

For a new engineering discipline to be practicable there should be,

- a need that is presently not being met
- a scientific basis, novel to present engineering practice, upon which to base the technology to meet this need

1. The need
   - majority of societal waste is spatially distributed, non-point source
   - majority of societal waste cannot be treated by conventional environmental engineering practices based on unit processes
   - the basic functional units of biology, chemistry and physics are not sufficient to address complex environmental issues at the watershed scale

2. Ecological science basis to meet this need
   - nature is comprised of ecosystems, the basic functional unit of ecology
   - ecosystems are very complex and follow the principle of self-design
     - negative --- difficult to quantify with same precision reached at lower scales
     - positive --- resilient
   - ecosystems have structure
     - feedback and control mechanisms
     - inputs (forcing functions) and outputs
     - carrying capacities, thresholds, tolerances
   - ecosystems perform inherent functions and processes that are vital to society
     - nutrient cycling
     - climate regulation
     - waste treatment
     - disturbance regulation (buffers)
     - raw materials production
     - food production
     - recreational and aesthetic value
       In a 1997 *Nature* paper, Constanza, et al.[1] estimated the value of these functions and processes to be $33 trillion annually -- the total global gross national product is about $19 trillion annually
   - societal input to these systems can alter and/or negatively impact these functions
   - ecosystems do not have definite boundaries, they are a continuum
   - environmental health is best indicated by how well ecosystems function
   - diversity of species within an ecosystem increases it's efficiency and resilience .

The Role of Engineering Education

Engineering students are being prepared to design, construct and operate systems that perform specific functions. Each design consists of subsystems such as mechanical, electrical, structural, chemical or biological that are engineered to fit together. In learning the concurrent engineering design process, engineering students are motivated to cycle through ideation, refinement and implementation until it is evident that all components of the design are compatible. As rigorous ecological studies over the past century have led us to understand nature as a continuum of systems rather than isolated components, engineering educators should apply the same element of compatibility to natural systems as is applied to societal systems. Concepts such as tolerance, capacity, fit, threshold, efficiency, design and compatibility are common to both ecologists and engineers. Nature provides not only tangible natural resources, but also associated processes that are life sustaining for mankind. Since nature is comprised of systems performing functions that are economically staggering, engineering educators should extend the engineering concepts of capacity, limits, fit, tolerance, compatibility, etc to environmental systems. Major vectors for transport of environmental contaminants are within the hydrologic cycle. Engineers can couple the principles of hydrology, fluid mechanics, soil physics, open channel flow and mass transport with the principles of limnology, systems ecology, microbial biogeochemistry, microbial ecology and physiological ecology to assess and monitor the compatibility of a societal system with a natural system.

Conclusions

Environmental problems are becoming increasingly complex and at larger scales. The traditional unit process approach has its limitations and engineering students should be aware of these limitations. They should be given the background to understand that the environment they are being prepared to protect is comprised of ecosystems that perform functions vital to society and that these functions are impacted at a systems level. This proposed program of study moves the University of Georgia's existing engineering program in the direction of incorporating ecological principles that must considered in the design of societal systems which impact the environment on a large scale.

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Biographical Information

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David Gattie is an Assistant Professor of Biological and Agricultural Engineering at the University of Georgia. He received his BSAE from the University of Georgia in 1983 and his Ph.D. in Ecology in 1993. For 10 years he

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Matt Smith is currently and Associate Professor of Biological and Agricultural Engineering at the University of Georgia. He received his BSAE from the University of Georgia in 1980, his MS in Biological and Agricultural Engineering from North Carolina State University in 1983 and his Ph.D. in Agricultural Engineering from the University of Florida in 1988. His research and teaching is in water quality, soil and water resource management, watershed assessment, and hydrologic and chemical transport modeling. He is a Registered Professional Engineer.

Table 1

Proposed Natural Resources Engineering Major Requirements

Environmental Emphasis				Ecological Emphasis		
ENGR	2110	Decision Making		ENGR	2110	Decision Making
ENGR	2120	Statics		ENGR	2120	Statics
ENGR	2150	Fluid Mechanics		ENGR	2150	Fluid Mechanics
ENGR	2170	Electric Circuits		ENGR	2170	Electric Circuits
ENGR	3150	Heat Transfer		ENGR	3150	Heat Transfer
ENGR	3410	Nat. Res. Mgmt.		ENGR	3410	Nat. Res. Mgmt.
ENGR	3440	Water Mgmt.		ENGR	3440	Water Mgmt.
ENGR	3520	Mass/Rate Transfer		ENGR	3520	Mass/Rate Transfer
ENGR	1120	Engr. Graphics		ENGR	1120	Engr. Graphics
ENGR	1920	Intro. Engr. Design		ENGR	1920	Intro. Engr. Design
BIOL	1108	Princ. Biology II		BIOL	1108	Princ. Biology II
BTNY	1220	Organismal Plant Biol.		BTNY	1220	Organismal Plant Biol.
CHEM	2211	Mod. Organic Chem.		CHEM	2211	Mod. Organic Chem.
CRSS	3060	Soils and Hydrology		CRSS	3060	Soils and Hydrology
ENGR	4460	Natural Treat. Systems*****		ENGR	4460	Natural Treat. Systems*****
MIBO	3000	Intro. Appl. Microb.		MIBO	3000	Intro. Appl. Microb.
MATH	2200	Calculus		MATH	2200	Calculus
MATH	2210	Integral Calculus		MATH	2210	Integral Calculus
ENGR	3140	Thermodynamics		ECOL	3500	Ecology
ENGR	4440	Env. Engr. I		ECOL	4000	Org., Pop. & Comm. Ecology
ENGR	4450	Env. Engr. II	or	ECOL	4010	Ecosys. Ecol.
ENGR	4480	Instr. Env. Quality		ECOL	4020	Field Systems Ecology
CRSS	4600	Soil Physics	or	ECOL	4240	Physiological Ecology
			or	ECOL	4310	Limnology
				ENGR	34xy	Ecological Engineering
				MARS	4620	Microbial Ecology

Electives

EHSC	4350	Env. Chem.	BTNY	4240	Plant Geography
EHSC	4080	Env. Air Quality	BTNY	4340	Ecological Biogeography
EHSC	4150	Solid & Haz. Wst. Mgmt.	ENGR	4430	Hydrologic Modeling
EHSC	4590	Water & Wastewater	ENGR	4440	Env. Engr. I
ENGR	4420	Industr. Vent & Control	ENGR	4450	Env. Engr. II
ENGR	4430	Hydrologic Modeling	ENGR	4480	Instr. Env. Qual.
ENGR	44xx	Solid Waste Processing	ENGR	44xx	Solid Waste Processing
ENGR	44xy	Aquatic Chemistry	ENGR	44xy	Aquatic Chemistry
FORS	4110	Forest Hydrology	MARS	4810	Microbial Biogeochemistry

***Capstone Design Course**