ECOLOGY AND TECHNOLOGY

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Summary

The human race is now keenly aware that our activities can and do have local, regional, and even global impacts. Due to this, ecology and technology are often thought to be mutually exclusive. In fact they are not. Rather, a new set of constraints has become important to scientists and engineers as they pursue new technological achievements – ecological constraints. Multidisciplinary design teams with environmental scientists and

engineers working closely together must become the norm if humans hope to develop sustainable engineered systems. Progress in both engineering design and ecological understanding will be necessary for us to develop sustainable systems. Clearly, understanding how ecosystems function and how ecosystems respond to human intervention is a prerequisite for successful engineering designs.

1. Introduction

DDT, one of the most powerful pesticides the world has ever known, was formulated for the first time in the 1850s by a German doctoral student and was rediscovered by Paul Herman Müller and his team of Swiss chemists in the late 1930s. DDT appeared to be a miracle weapon against insect borne diseases like malaria and typhus. During the 1950s, DDT became the primary weapon of the World Health Organizations global anti-malaria program. For the next two decades, DDT saturation spraying resulted in a dramatic global reduction of malaria.

In 1962, Rachel Carson published *Silent Spring*, a seminal study demonstrating that DDT was a much greater threat to the global ecosystem than a panacea for insect borne diseases. Drawing on a wide range of scientific studies, Carson made the case that DDT not only affected the targeted insects, but the entire ecosystem. Unlike most pesticides, whose effectiveness is limited to destroying one or two types of insects, DDT was capable of killing hundreds of different species at once. Furthermore, because DDT deteriorated very slowly, the very quality that made it such an effective insecticide, it was spreading far up into the food chain with dire consequences for the species at the tip of the pyramid. By the time *Silent Spring* was published, the ecosystem effects of DDT were manifesting themselves on a grand scale and began to be noticed by the general public. In 1972, DDT was banned in the United States, although it continues to be used on a limited scale in many developing nations.

Thirty years after being published, *Silent Spring* was selected as the most influential book of the last fifty years by a panel of distinguished Americans. The meteoric rise and precipitous decline of DDT is at once an epic of human achievement in the war against insect borne diseases and a cautionary story about the unbridled enthusiasm for new technology. In his introduction to *Silent Spring*, U.S. Vice President Al Gore writes:

“Rachel Carson's influence reaches beyond the boundaries of her specific concerns in Silent Spring. She brought us back to a fundamental idea lost to an amazing degree in modern civilization: the interconnection of human beings and the natural environment. This book was a shaft of light that for the first time illuminated what is arguably the most important issue of our era.”

In 1948 Paul Herman Müller was awarded a Nobel Prize.

2. The Interconnection of Human Beings and the Natural Environment

Rachel Carson’s work challenged the accepted dogma that human beings were the masters of all things, and that scientific history was primarily the story of their domination. The very absurdity of that world view from todays perspective indicates how revolutionary Rachel Carson was. She single handedly thrust into our consciousness the interconnection between human beings and our ecosystem. The ecosystem is the basic functional unit of ecology and therefore its importance cannot be overemphasized. We are now keenly aware that our activities can and do have local, regional, and even global impacts.

While human-made systems are designed using the engineering sciences, the strength of ecosystems is their ability to self-organize or “self-design”. Natural environmental systems possess the characteristics of structure and function, terms that are applicable to human-made systems. Wetlands, forests, lakes, ponds, rivers, streams, grasslands, marine shores and deserts are just a few of the various types of ecosystems that have been naturally established. Ecosystem development, or ecological succession, is a process requiring long periods of time, sometimes geologic time, resulting in a diverse but well-structured organization. This self-organization serves critical, life-sustaining functions for society through its ability to dynamically cycle energy and matter. The system selects for the most efficient and available pathway for processing and assimilating inputs with associated outputs. Carbon, nitrogen, phosphorus are just a few of the elements cycled by aquatic and terrestrial ecosystems. While these elements are naturally occurring, anthropogenic inputs from such sources as agriculture and urban development now contribute heavily toward ecosystem loading. Although these systems can process a certain amount of anthropogenic loading, there is a threshold at which impairment or destruction occurs.

James Lovelock, a physical scientist, inventor and engineer, worked with Lynn Margulis to explain what they refer to as the Gaia Hypothesis. In this they explain the relationship between individual organisms and their physical environment. They point out that the chemistry of Earths atmosphere and its physical environment are completely different from other planets in our solar system and that Earths physical environment has a strong buffering capacity. The hypothesis contends that organisms have evolved with the physical environment to provide an intricate control system that keeps Earth’s conditions favorable for life. While it is clear that the physical environment affects biological life, what may not be as well known is that the converse is also true: organisms strongly influence the physical environment in which they live. With materials being constantly changed by organisms, new compounds are continually introduced. They conclude that Earths atmosphere, with its unique high oxygen-low carbon dioxide content and the moderate temperature and pH conditions of Earths surface, cannot be accounted for without the critical buffering activities of early life forms and the continued coordinated activity of plants and microbes that dampen fluctuations in physical factors that would occur in the absence of well-organized living systems.

3. Designing with Ecological Constraints

Ecology and technology are not mutually exclusive. Rather, a new set of constraints has become important to scientists and engineers as they pursue new technological achievements – ecological constraints. Scientists and engineers are accustomed to operating under design constraints ranging from the most rigid thermodynamic laws to budgetary constraints. Ecological constraints add one or more set of considerations to the list. Engineering designs are now expected to result in products or management plans whose use or implementation will not endanger important ecological conditions or processes.

Ecologists and other environmental scientists must collaborate with engineers to describe the requirements of important ecological conditions and processes in terms that can be incorporated into engineering design considerations and continue to work together to develop suitable engineering plans. Engineers and ecologists certainly cannot solve these problems alone, but they do have important responsibilities in efforts to keep human environmental impacts within acceptable bounds.

Multidisciplinary design teams with environmental scientists and engineers working closely together must become the norm if humans hope to develop sustainable engineered systems. Progress in both engineering design and ecological understanding will be necessary for us to develop sustainable systems. With the exception of selected sub-disciplines, there is so little dialog between engineers and ecologists that it is hard to know where to start. What would it mean to engineer within ecological constraints? What are the ecological constraints? Which constraints are most important? Can some be ignored? How would one distinguish satisfactory and unsatisfactory designs? What does it mean to keep human environmental impacts within "acceptable" limits?

In 1983, restoration biologist A. D. Bradshaw made the following statement which is as valid today as it was all those years ago: "The acid test of our understanding is not whether we can take ecosystems to bits on pieces of paper, however scientifically, but whether we can put them together in practice and make them work." Clearly, understanding how ecosystems function and how ecosystems respond to human intervention is a prerequisite for successful engineering designs. H.T. Odum, a leading ecologist, was among the first to identify the emerging discipline of ecological engineering as a key integrator for the design and development of sustainable ecosystems.

Before we can begin designing these ecosystems, we must be able to document the services provided by ecosystems in sufficiently explicit terms that society will not only protect and preserve those ecosystems still delivering such services, but design to whatever degree possible those ecosystems capable of delivering services at a sustainable level.

4. The Issue of Sustainability

Sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs. Therefore, stewardship of both natural and human resources is of prime importance. Stewardship of human resources includes consideration of social responsibilities such as working and living conditions of laborers, the needs of rural communities, and consumer health and safety, both in the present and the future. Stewardship of land and natural resources involves maintaining or enhancing this vital resource base for the long term.

The 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro focused on the sustainability of the worlds natural resources and highlighted the need to link and balance environmental stewardship, economic development, and community vitality. The Conference addressed the issue of sustainability by drawing attention to the common challenges of population growth, the need for strategies for sustaining food security and the need to conserve natural resources. Agenda 21, the blueprint for responsible action towards implementing sustainable development adopted at UNCED states:

“Major adjustments are needed in agricultural, environmental and macroeconomic policy, at both national and international levels, in developed as well as in developing countries, to create the conditions for sustainable agriculture and rural development. The major objective of sustainable agriculture and rural development is to increase food production in a sustainable way and to enhance food security. This will involve education initiatives, utilization of economic incentives and the development of appropriate and new technologies, thus ensuring stable supplies of nutritionally adequate food, access to those supplies by vulnerable groups, and production for markets; employment and income generation to alleviate poverty; and natural resource management and environmental protection.”

A systems perspective is essential to understanding sustainability. The system is envisioned in its broadest sense, from the individual farm, to the local ecosystem, and to communities affected by this farming system both locally and globally. An emphasis on the system allows a larger and more thorough view of the consequences of farming practices on both human communities and the environment. A systems approach gives us the tools to explore the interconnections between farming and other aspects of our environment.

4.1. Sustainable Agriculture

Agriculture has changed dramatically, especially since the end of World War II. Food and fiber productivity soared due to new technologies, mechanization, increased chemical use, specialization and government policies that favored maximizing production. Although these changes have had many positive effects and reduced many risks in farming, there have also been significant costs. Prominent among these are accelerated topsoil depletion, surface and ground water depletion and contamination from agrochemicals, the decline of family farms, continued neglect of the living and working conditions for farm laborers, increasing costs of production, and the disintegration of economic and social conditions in rural communities.

A growing movement emerged during the past two decades of the last century which has questioned the role of the agricultural establishment in promoting practices that contribute to these social problems. Today, in 2002, this movement for sustainable agriculture is garnering increasing support and acceptance within mainstream agriculture. Not only does sustainable agriculture address many environmental and social concerns, but it also offers innovative and economically viable opportunities for growers, laborers, consumers, policymakers and many others in the entire food system.

Sustainable agriculture integrates three main goals: environmental health, financial gain, and social and economic equity. A variety of philosophies, policies and practices have contributed to these goals. People in many different capacities, from farmers to consumers, have shared this vision and contributed to it. Despite the diversity of people and perspectives, the following themes commonly weave through definitions of sustainable agriculture:

4.1.1. Soil and Water Resources

When the production of food and fiber degrades the natural resource base, the ability of future generations to produce and flourish decreases. The decline of ancient civilizations in Mesopotamia, the Mediterranean region, pre-Columbian southwest U.S. and Central America is believed to have been strongly influenced by natural resource degradation from non-sustainable farming and forestry practices. Natural resources commonly associated with agricultural production include: water, soil, air, energy, and biodiversity.

Water is the principal resource that has helped agriculture and society to prosper, and it has been a major limiting factor when mismanaged. Several steps can be taken to develop water-efficient farming systems, including both policy and management actions:

- improving water conservation and storage measures;
- providing incentives for selection of drought-tolerant crop species;
- using reduced-volume irrigation systems;
- managing crops to reduce water loss; and
- selection of species and varieties that are well suited to the available soils.

Figure 1. Destruction of riparian vegetation results in loss of ecosystem services.

In addition to consumptive use through irrigation, water resources are also adversely affected by agricultural pollution. Translocation of soil and agrochemicals from agricultural production sites often results in non-point source pollution of water resources and subsequent reduction in water quality and biodiversity. Destruction of riparian (stream side) ecosystems within agricultural watersheds accelerates non-point source pollution, decreases wild habitat, and reduces fish and wildlife populations (Figure 1). The plant diversity in and around both riparian and agricultural areas should be maintained in order to support a diversity of wildlife. This diversity will enhance natural ecosystems and could aid in agricultural pest management.

Soil erosion continues to be a serious problem, both as a threat to our continued ability to produce adequate food and as the source sediment in receiving waters. Numerous practices have been developed to keep soil in place, which include reducing or eliminating tillage, managing irrigation to reduce runoff, and keeping the soil covered with plants or mulch.

Modern agriculture is heavily dependent on non-renewable energy sources, especially petroleum. The continued use of these energy sources cannot be sustained indefinitely, and yet to abruptly abandon our reliance on them would be economically catastrophic. In sustainable agricultural systems, there is a reduced reliance on non-renewable energy sources and a substitution of renewable sources or labor to the extent that is economically feasible.

Many agricultural activities affect air quality. These include smoke from agricultural burning; dust from tillage, traffic and harvest; pesticide drift from spraying; odors from concentrated animal feeding operations, and nitrous oxide emissions from the use of nitrogen fertilizer. Options to improve air quality include incorporating crop residue into the soil, using appropriate levels of tillage, and planting wind breaks, cover crops or buffer strips to reduce wind erosion.

4.1.2. Agronomic and Horticultural Production

Sustainable production practices involve a variety of approaches. Specific strategies must take into account topography, soil characteristics, climate, pests, local availability of inputs and the individual grower's goals. Despite the site-specific and individual nature of sustainable agriculture, several general principles can be applied to help growers select appropriate management practices:

- selection of species and varieties that are well suited to the site and to conditions on the farm;
- diversification of crops (including livestock) and cultural practices to enhance the biological and economic stability of the farm;
- management of soil to enhance and protect soil quality;
- efficient use of inputs; and
- consideration of farmers' goals and lifestyle choices.

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Bibliography

Bradshaw A.D. (1983). The reconstruction of ecosystems. *Journal of Applied Ecology* **20**, 1-17. [This article establishes some of the earliest principles of ecosystem restoration.]

Carson, R. (1962). *Silent Spring*, 368 pp. Houghton Mifflin Company, Boston, MA, USA. [A seminal study demonstrating that DDT was a much greater threat to the global ecosystem than a panacea for insect borne diseases.]

Constanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton and M. van den Belt. (1997). The value of the world's ecosystem services and natural capital. *Nature* **387**, 253-260. [Seminal article quantifying the economic value of ecosystem services.]

Haan, C.T., H.P. Johnson, and D.L. Brakensiek. (1982). *Hydrologic Modeling of Small Watersheds*, 533 pp. American Society of Agricultural Engineers, St. Joseph, MI, USA. [Provides a collection of contributions on modeling various aspects of the hydrologic cycle on small watersheds.]

Mitsch, W.J., and S.E. Jørgensen. (1989). *Ecological Engineering: An Introduction to Ecotechnology*, 472 pp. John Wiley & Sons, Inc., New York, NY, USA. [This book contains contributions by leaders in the emerging discipline of ecological engineering.]

Odum. E.P. (1993). *Ecology and Our Endangered Life-Support Systems*, 301 pp. Sinauer, Sunderland, MA, USA. [Description of important ecosystem services from the father of ecology.]

Schulze, P.C. (1996). *Engineering Within Ecological Constraints*, 213 pp. National Academy Press, Washington, DC, USA. [A product of the National Academy of Engineering that describes recent thinking on designing within ecological constraints.]

Stapelton D.H. (1999). The short-lived miracle of DDT. *Invention & Technology* **15**(3), 34-41. [This article describes the invention, use and discrediting of DDT as well as providing a perspective on enthusiasm for a new technology.]

Thayer, R.L. (1994). *Gray World, Green Heart: Technology, Nature, and the Sustainable Landscape*, 352 pp. John Wiley & Sons, Inc., New York, NY, USA. [Provides a summary of and examples of technologies that make unsustainable and sustainable landscapes.]

Zweers, W. and J.J. Boersema. (1994). *Ecology, Technology and Culture*, 310 pp. White Horse Press, Cambridge, United Kingdom. [Euro-centric collection of essays dealing with environmental issues debated in western societies.]

Biographical Sketches

George Vellidis is a Professor of Biological & Agricultural Engineering at the University of Georgia, Tifton, USA. He received his B.S. and M.S. degrees in Agricultural Engineering from Virginia Polytechnic Institute and State University (Virginia Tech), and his Ph.D. in Agricultural Engineering with a minor in Environmental Engineering from the University of Florida. His primary research interests are in measuring, modeling, and limiting environmental impacts of agricultural production systems. Dr. Vellidis leads a multidisciplinary, multi-institution project that is evaluating a landscape approach to protecting water quality in the southeastern coastal plain of the USA. This entails instrumenting three

400 km^2 watersheds for water quality parameter measurements, extensive GIS database creation, and field- and watershed-scale hydrologic modeling. Additional research involves evaluating the processing of pesticide and nutrient driven non-point source pollution by managed and restored riparian forests in the southeastern coastal plain. Dr. Vellidis has a secondary research interest in assessing and developing precision farming techniques for southeastern agricultural production. He is the project leader of a team developing yield monitoring technologies and techniques for peanuts, cotton, and specialty crops. His team holds the patent for the first peanut yield monitoring system.

David K. 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 worked as an Environmental/Sr. Environmental Engineer for Technology Applications, Inc./DynCorp conducting and supervising research in the transport, degradation and transformation of pesticides in aquatic systems. In this capacity, he also conducted research in methane consumption and production in soils and sediments. His current research and teaching is in water quality, watershed assessment, natural resource management, municipal solid waste management and GIS hydrologic modeling. Specifically, he is interested in linking ecological indicators with GIS-based water quality models and developing sustainable systems to improve watershed integrity and health.

Matt C. Smith is an Associate Professor in the Department of Biological and Agricultural Engineering at the University of Georgia, Athens, USA. He received his BSAE degree from the University of Georgia, his M.S. degree in Biological and Agricultural Engineering with a minor in Water Resources from North Carolina State University, Raleigh, and his Ph.D. in Agricultural Engineering with a minor in Environmental Engineering from the University of Florida, Gainesville. He conducts research on the fate and transport of chemicals and nutrients in surface waters, through soils, and in ground water. His main emphasis is the collection of field data at appropriate spatial and temporal scales to use in the development and validation of hydrologic/water quality models. He also conducts research in the areas of municipal solid waste management, phytoremediation, and the function of created wetlands for treatment of domestic sanitary wastewater.