Ecosystem Services Discussion Paper

CSREES Ecosystem Services Working Group (ESWG)
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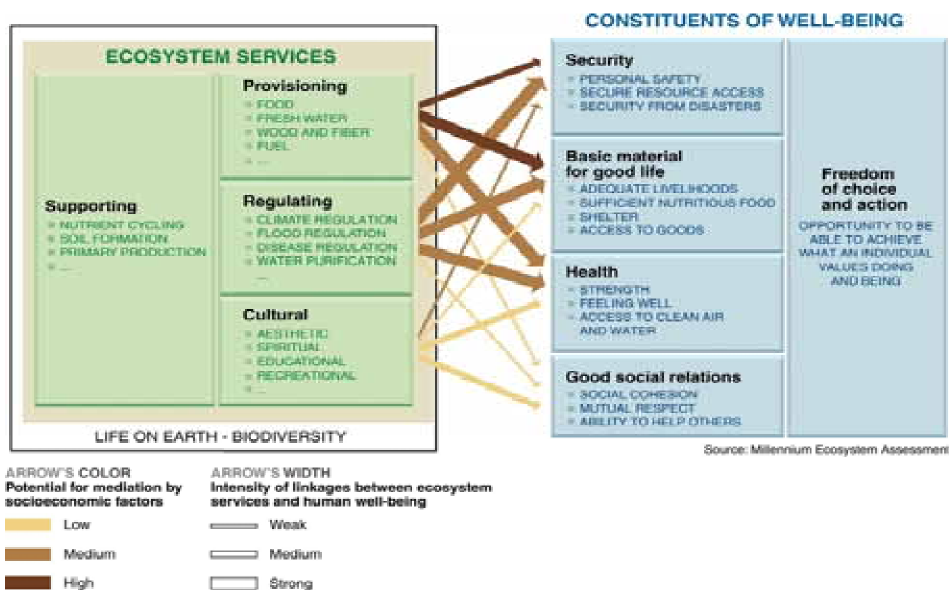
Introduction

The purpose of this paper is to outline the background and interest of the Cooperative State Research, Education, and Extension Service (CSREES) in the area of ecosystem services and to provide information about future activities on this topic.

An ecosystem is a dynamic complex of plant, animal, microorganism, and the nonliving environment interacting as a functional unit. **Ecosystem services (ES) are the benefits that people obtain from nature.** The Millennium Ecosystem Assessment (MA, 2005), sponsored by the United Nations to assess the conditions and trends of the global ecosystems, divides ecosystem services into four categories and linked ecosystem services to human well-being. These include provisioning services, such as food, water, timber, fuel and fiber, genetic resources; regulating services that affect climate, floods, drought, disease, waste, land degradation, and maintenance of air and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services, such as soil formation, photosynthesis, biodiversity, and nutrient cycling.

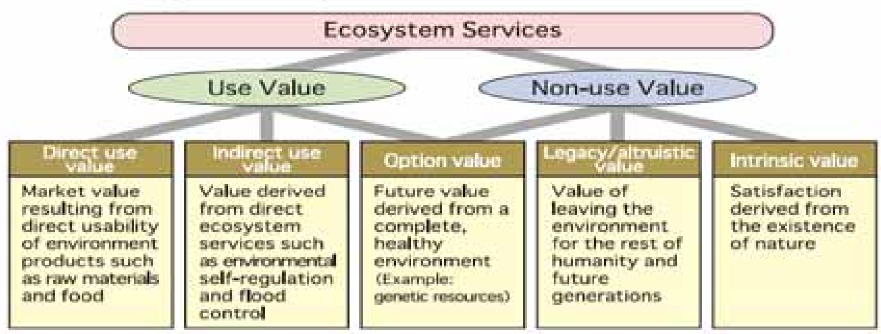
Consequences of Ecosystem Change for Human Well-being



Over the last 50 years, humans have changed agricultural and natural ecosystems more rapidly and extensively than in any comparable period of time in human history. The MA reported that 15 of the world's 24 ecosystem services are in decline. The declining ability of the Earth's systems to meet the needs of a growing population and sustain the life support systems of the planet is a very urgent and serious issue. How can society and nature interact in a way that will integrate the Earth system, social development, and be sustainable?

Ecosystem services directly and indirectly provide products for human consumption and maintain healthy living environments. 'All human activity, including the global economy, is made possible through the diversity of ecosystem services nature provides.' Ecosystem services may have monetary or intrinsic values based on consumer perception (Research on the Scientific Basis for Sustainability (RSBS), 2006). It is difficult to quantify the value of ecosystem services (see Appendix 1). They are valuable to different people in different ways. How ecosystem services are managed also depends upon the goals of those who manage them.

Figure 1: Ecosystem Services Value Classification



Adapted from *Science on Sustainability: Summary Report 2006*
Research on the Scientific Basis for Sustainability (RSBS)

Agricultural Ecosystem Services

Agricultural lands, encompassing over 940 million acres of working ranch and farm lands, or approximately half the U.S. landmass, have had major impacts on the function, production, and economics of ecosystem services. Agricultural production is dependent on many ecosystem services, such as nutrient cycling, pest control, and pollination. Management of agroecosystems can enhance or degrade the ability of these systems to provide ecosystem services, such as clean water and air, habitat and food sources for biodiversity, soil conservation, carbon sequestration, disease and invasive species suppression, and climate regulation.

The grand challenge for agriculture is how to reconcile agricultural productivity and environmental and social integrity (Robertson, 2005). Thus, the future viability and long-term sustainability of agriculture depends on how effectively we understand and manage the social, economic, ecological, and policy elements of agricultural ecosystems (Tilman et al., 2002; CSREES Social Science white paper, 2006; CSREES Environment and Natural Resources discussion paper, 2007; CSREES Long-Term Integrated Program–Agroecosystem Report, 2007; CSREES Specialty Crops white paper, 2007).

Implementing an Ecosystem Services Portfolio

Why focus on agricultural ecosystem services? Human well-being is inextricably linked to the optimal use and management of agroecosystems. The future of agriculture is dependent on acquiring a more balanced approach to the management of these systems, one that optimizes the production of agricultural goods and services. Fundamental questions need to consider human design and engineering of ecological processes in whole ecosystems, emergent behavior, and the dynamics on interacting agricultural, natural, and socioeconomic systems. For example, we know that increasing the production of agricultural goods (food, fuel, and fiber) tends to result in the decline or degradation of other ecosystem services. Management of agricultural systems for a full complement of goods and services, especially stacked or bundled services (e.g., food production, energy production, and biodiversity), is an emerging scientific field. Full economic valuation of all services provided by agricultural systems can also enhance declining producer profitability by providing multiple streams of revenue for management and marketing of multiple ecosystem services. Finally, informing and addressing societal values on market and non-market valued services, can potentially change the land-use and policy decisions for future generations.

Agricultural ecosystem services provide for a vast array of goods and services in a multitude of agricultural ecosystems. Even though ES relates to all USDA and CSREES strategic goals, an ES portfolio would focus on Goals 3, “Supporting Increased Economic Opportunities and Improved Quality of Like in Rural America,” and Goal 6, “Protect and Enhance the Nation’s Natural Resource Base and Environment” (see Appendix 3). More internal to the agency, a portfolio focusing on ES provides a focused and organized approach in developing basic research and integrated programs to deliver scientifically based information for advising and guiding agricultural management, social, and policy decisions. An ES portfolio could thematically link to other agency initiatives, such as the Environmental and Natural Resources (ENR) Enterprise, the Biofuels Initiative, the Specialty Crops Initiative, integrated pest management (IPM) programs, and other system levels programs.

An ES portfolio approach would allow for collaborative management of ecosystem services topics at multiple levels—from specific services (e.g., clean water, species habitat, and nutrient flows) to complex multiple service systems. A hierarchically structured portfolio would allow for single-service programmatic activities (air quality), multi-service system thematic programs (energy flows, land use changes, climate change, environmental health, human health), and cross-unit linked programs (research, extension, higher education, multi-state projects).

A focus on the systems approach would be novel to CSREES, since other agencies generally do not focus on the multiple ecosystem services interactions and attributes. A systems approach could also lead to complementary inter-agency collaborations (see Appendix 2). The importance of educational components, for both basic scientific literacy (i.e., what are ecosystem services and why are they important) and an understanding of human rights to ecosystem services (as these rights are developed) would be unique to CSREES education and social science units. The scientific basis for understanding environmental and economic consequences in managing for multiple services ("Multifunctional Agriculture"), especially over the long term, is in its infancy (Boody et al., 2005). Examples of these efforts have been described under such terms as "Doubly Green Revolution" and "Ecoagriculture" (Conway, 2007; McNeely and Scherr, 2003). Multi-state endeavors, such as the "Improving the Sustainability of Livestock and Poultry Production in the US project," are being reorganized to consider these complex systems (MS-1000/Applegate, 2007) (Boody et al., 2005). The current structure of disciplinary or single ES evaluation only provides for a glimpse of the interactions and synergistic effects occurring in an agroecosystem. As more services become monetized, the issues of scale become increasingly important. One service should not be provided at the expense of other services and the long-term productivity of the system. Validation and quantification of the levels and number of services provided for will become necessary to maximize production efficiencies.

Portfolio Recommendations

Portfolio Structure

CSREES currently funds through competitive, formula funds, and special grants for a diverse range of projects that relate to ecosystem services (see Appendix 4). However, there is no formal structure or organization to link these projects. There is no commonality that helps to identify the goals of these projects that will enhance our understanding and managements of agricultural ecosystems for ecosystem services.

Based on input and recommendations from CSREES staff and external stakeholders, the CSREES ESWG recommends an integrated multi-level and multi-topic approach for research, extension, and educational activities. A portfolio of programs and activities includes four high-priority thematic topic areas.

Portfolio program levels: (See Diagram 1)

- Ecosystem Service Programs (ESP) area—Identify current programs that support activities related to a specific ecosystem service (e.g., Water and Watersheds, Air Quality, Soil Processes, Markets and Trade, Integrated Water). Establish terminology to monitor funding for these components and ecosystem services. Develop a multi-unit team to coordinate program foci and include support for research, extension, and educational needs.
- Ecosystem Services Systems Programs (ESSP) area—Identify integrated ES systems programs which would provide better information about the interrelationships of environmental/health, social, economic, and legal/policy implications (see Appendix 6). These programs should emphasize performance-based solutions to assure accountability. These programs could be local, regional, or national in scope; future-oriented and anticipatory of emerging challenges; multidisciplinary; and include agricultural universities, medical schools, and public and private partnerships (Abdalla and Lawton, 2006).

  The ESSP area would include:
  1. Existing systems programs (i.e., Managed Ecosystems, Agricultural Prosperity for Small and Mid-sized Farms, Biology of Weedy and Invasive Species in Agroecosystems, Integrated Pest Management (IPM), Integrate Organic, Risk Avoidance And Mitigation Program (RAMP), Crops at Risk (CAR), and the proposed Long-Term Integrated Program- (LTIP) Agroecosystems)
  2. Development of Integrated Ecosystem Service (IES) programs that employ an interdisciplinary multiple ecosystem services approach. The programs would be managed by a multi-disciplinary program leader team incorporating biological, economic, social, research, educational, and extension expertise. Such high-impact topics as health, environmental quality, rural poverty, and energy production could be focus examples for these programs.
- Multi-state ES Programs (MSP)—Support current and emerging multi-state projects on ecosystem services topics that would include Ecosystem Services Districts analysis (See Appendix 5).

- Non-Competitive Programs (NCP)—Establish tracking procedures and information exchange team for non-competitive funded projects related to ecosystem services.

Ecosystem Services Integrated Issues to be Addressed by an ES Portfolio Approach

A systems approach, with a focus on advancing understanding of coupled human-environment systems, is needed applying research, extension, and educational skills to solve complex issues of connected ecosystem services and impacts on biotic and abiotic components within ecosystems. Research needs to be translational to provide knowledge to users through extension and educational activities for implementation of strategies to support multi-ecosystem services. A program should consider two scales for ecosystem services: (1) geographic scale, ranging from crop and field, to watershed and landscape level, to regional level and service level scale; and (2) service scale, from a single ecosystem service to managing multiple services.

The emerging field of ES effectively spans almost all disciplines relating to production agriculture, land, use, socioeconomics, and natural resources management. One challenge of engineering programs on ES is to maintain the breadth of the topic while at the same time narrow the focus so that program goals and parameters can be defined and evaluated. Based on the agency's mission, the emphasis on integrating research, education, and extension, and the potential to move the ES field forward, the ESWG considered four programmatic foci.

Issue: Human and Environmental Health
Problem Question: What is the relationship between agriculture production, ecosystem services, environmental quality, human health, and quality of life?
Focus Areas:

- Identify major linked services that have a direct impact on environmental quality and human health.
- Quantify changes in environmental quality that impact human health.
- Mitigate the human health impact of pollution and environmentally mediated diseases, pathogens, and pests.
- Identify major linked services that have direct impacts on quality of life.
- Link valuation of ES to human health or well-being.

Issue: Environmental Security
Problem Question: What is the potential for unanticipated consequences due to long-term demand for multiple ecosystem services?
Focus Areas:

- Determine the appropriate balance between extractability of services and renewability of the environment.
- Determine how and where to intensify agricultural production and integrate with other ES—e.g., agricultural production and biodiversity conservation at different spatial scales for multiples benefits (economic, production, conservation).
- Determine the consequences of natural resource degradation temporally and spatially due to lack of nutrient recycling.

- Develop a systems approach to develop tools and approaches for improved management of diverse landscapes for multiple purposes (e.g., agricultural, water provision, carbon sequestration, and industrial use).
- Understand that trade-offs will be necessary to support goods and services (i.e., food and water security, energy production will require broader studies to include multiple ecosystem services in the same system and provide a common currency (economic value) for comparison).
- Develop models for ecosystem management that will improve degraded environments and maintain/achieve sustainable development.
- Develop new models that will better explain and value management of ecosystem services at different scales over time for services that vary over time.
- Identify models and management systems for stacked ecosystem services (e.g., air and water quality, soil restoration/conservation, and wildlife habitat).
- Develop guides for allocation decisions if stacking or bundling services is not possible or limited.
- Estimate how stacked, bundled, or regulated services can be unstacked or deregulated in a timely fashion in an event of world food shortage or other disaster.
- Evaluate and measure the real and potential loss of diversified production systems and changes in land use.
- Develop institutional innovations that foster cooperation between agricultural and other resource users.
- Assess and monitor to quantify the quality and quantity of ecosystem services produced.
- Identify differences in change in ecosystem service levels at different scales—farm level vs. landscape level.
- Monitor trends in detection and verification of ecosystem services.
- Train producers about the value of management for ecosystems services.
- Distribute technical guides about watershed level services and links to aggregated trading.
- Assess new market opportunities from U.S. Environmental Protection Agency (EPA) environmental credit trading and U.S. Department of Transportation (DOT) and other agency wildlife habitat offsets.

Issue: Policy Impacts on Providing Ecosystem Services
Problem Question: How can we evaluate the impacts of policy on sustaining ecosystem services?
Focus Areas:

- Identify the role of public and private payments to producers (e.g., conservation payments, green box payments, etc., and sequestration and offset contracts, etc.).
- Develop a common currency (valuation) for market and non-market services.
- Develop tools and methods for ecosystem services evaluation.
- Develop models to determine the appropriate land use diversity to provide for optimum ecosystem services.
- Understand land ownership and property rights implications (legal implications of ES on private landownership, liabilities, legal duties, and indices of property ownership).
- Determine how land use changes impact the ability to provide ecosystem services.

- Determine what are the legal rights and responsibilities that are conveyed or implied through the buying or selling of pollution, emissions, or sequestration credits or contracts. What statutes, agencies, etc., have regulatory or oversight authority?
- Create protocols to resolve legal, ownership, and fraud conflicts.

Issue: Valuing Ecosystem Services
Problem Question: How can we develop a bioeconomy that will valuate market and non-market ecosystem services and develop processes and procedures for economic compensation?
Focus Areas:

- Model economic impacts/benefits of ES on private and public interests.
- Combine ecological and economic models to value individual and collective ES.
- Apply economic methods to assess the changes in quality of life due to availability of ES.
- Determine the role of markets and/or regulations in defining priorities for specific ES.
- Develop methods to valuate ES, and develop aggregators to provide trading and setting of trading ratios.
- Establish baselines and monitor changes in levels of services, develop fate, and transport models.
- Develop methods for ES compensation—green payments, conservation payments/easements/offsets, land use planning, and institutional innovations.
- Understand land ownership and property rights implications of governing policies.
- Reduce rural poverty from ES payments.
- Develop an extension base to fully inform landowners about markets, trading, and regulations.
- Develop and standardize valuation techniques for non-market benefits from ES to allow comparison between and among systems.
- Scale and aggregate ES to obtain the net values of services to appropriately inform policy decisions.
- Develop an ecosystem valuation reference inventory.

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Appendix 1. Regulatory Background

Theoretical and Regulatory Brief for Ecosystem Services

The ability to provide ecosystem services for public and private benefits is being increasingly regulated through legislation, policy, and market economics. The goal of this section is to outline the policy theory and historical regulatory trends governing the treatment of environmental issues and the valuation of ecosystem services. Further, it establishes a preliminary conceptual framework for discussions of the underlying issues that need to be addressed more carefully.

Historically, policies and regulations that govern the solution of environmental challenges have moved from a legalistic approach that emphasizes the legal rights of stakeholders, to one that attempts to account for the incentives of those involved. In addition, they explicitly discuss efficiency and distributional concerns and formalize analysis of trade-offs. This means that in more, but not all, cases the underlying efficiency and distributional issues are more likely to be addressed with the application of methods that account for quantified cost and benefits. Thus, this increasing acceptance and explicit recognition of costs and benefits has provided the very foundation for valuing ecosystem services. However, adoption of this approach is not universal and tensions continue to exist between perspectives that consider the rights involved intrinsic[1] and those that seek to resolve environmental conflicts through some measurement of the worth of the environmental assets in conflict.

Four fundamental policy theoretical approaches are currently discernable. These are:

- The Legal Approach;
- The Marginal Tax/subsidy Approach;
- The Market-based Approach with explicit assignment of rights; and;
- The Ecosystem Service Valuation Approach.

The evolution of these approaches is not strictly linear because this set of policy instruments may be applied singly or collectively. Also, the later approaches are not necessarily considered more sophisticated than the earlier ones. However, this list represents the chronological order of their development and illustrates increased sophistication in tackling environmental issues.

Another key point is that in spite of an emphasis on the assignment of legal rights in the Market-based Approach, this approach encourages the quantification of costs and benefits. Thus, the ideological fault lines are typically greatest between the application of a pure legalistic approach that may eschew measurement and strictly rely on appeals to principles, and the latter three approaches.

[1] The term “intrinsic” has a very specific meaning in the context of valuation. An asset’s intrinsic worth is considered deontological (founded on a duty) and thus includes both the value to humans and any value that is non-anthropocentric, in contrast with “existence” values that only include anthropocentric values.

The Legal Approach

The Legal Approach is the oldest, and when early legal suits about environmental concerns were tried, arguments often relied on intrinsic rights that were presumed to be immeasurable. For instance, when the Supreme Court relied upon the initial Endangered Species Act of 1973 to make its judgment in the famous "Snail Darter" case (U.S. Supreme Court 1978 Tennessee Valley Authority v. Hill et al.), it found that the Act failed to provide authority for courts to apply any form of cost benefit analysis. Therefore, it ruled as if the species had intrinsic rights in which value of its loss was "incalculable." Congress remedied this by amending the Act in 1978 to permit the use of cost-benefit and other quantitative analysis in the resolution of these disputes. In spite of greater quantification of impacts in environmental decisions, direct appeals are still often made to the "priceless" value of natural assets. In some cases, these are based on purely on the grounds of ideals/values and in some cases on more pragmatic grounds, such as a claimed failure of market-based approaches (*Nature* 2006, vol 443, p. 27). Clearly, these differences in perspectives may continue into the future as they can rest on deeply held values. Conversely, the second, third and fourth policy approaches are significantly different because they all rest on a premise that some form of quantification of relevant costs and benefits can improve judgments and decisions regarding natural assets with public good characteristics.

It is also important to note that the legal approach can prevail in situations that have been well considered and are relatively definable but still involve environmental objects that affect many parties. For instance, Ohio relies on three legal doctrines to resolve disputes over a surface issue such as drainage water, The Common Enemy Doctrine, The Civil Law Doctrine, and The Doctrine of Reasonable Use[2]. The later doctrine is a more recent development that is part of a larger trend by the courts and states limiting some uses of personnel property. Legal approaches evolve with science over time.

The Marginal Tax/Subsidy Approach

The Marginal Tax/Subsidy Approach relies on the "polluter pays" principle as well as economic theory that distinguishes between social and private costs and benefits and demonstrates there is optimal resource efficiency when the marginal total social benefits and marginal total social costs are equalized. In this approach, an entity flushing effluent into the air or water resulting from the production of an otherwise beneficial product adds to society's costs in addition to its

[2] The Common Enemy Doctrine, which usually applies in urban areas, allows landowners to dispose of drainage water as they see fit since it is a common enemy of the people, so water can be disposed of without regard to the consequences to adjoining landowners. The Civil Law Doctrine historically applied to rural areas. The doctrine requires the lower landowner to accept the natural water flow, but prohibits the upper landowner from changing the natural drainage, thereby increasing the burden on the lower landowner. The Reasonable Use Doctrine evolved to provide flexibility and practicality to application of Ohio's drainage laws. It essentially provides that an acceleration or an obstruction of surface water flow should be examined to determine whether or not the change is "reasonable" in the particular case. The Ohio high court, in a 1980 case, defined the rights of landowners as follows: "A landowner is not unqualifiedly privileged to deal with surface water as he/she sees fit, nor is he/she absolutely prohibited from interfering with the natural flow of surface waters to the detriment of others. A possessor of land is legally privileged to make a reasonable use of his/her land even though the flow of water is altered, thereby causing harm to others."

own private costs of production. If these social costs are uncompensated, then there is market failure with the polluting entity causing a "negative externality." This understanding led policy makers to correct market disequilibria by measuring and applying a proper penalty on the polluter (a tax[3]) in such a way that the equilibrium between total social costs and total social benefits would be restored and internalize the negative externality. In other words, it applies this rate to the producer in a way that may still permit it to continue to pollute, but at least compensate for the social costs imposed on those harmed by this pollution. Furthermore, a per-unit tax creates an incentive for the producer to find effective ways to reduce its pollution.

A very important conclusion from this theoretical discussion is that although the total social benefit will increase with the tax, if the marginal social benefit from a producer's production is downward sloping—the demand for its product is somewhat elastic—there will be a negative effect on the entity's output with the tax. From a regulator's perspective, this is an acceptable result. In practice, this likely reduction in output can imply considerable resistance from the producer's stakeholders.

Market-based Approach

The Market-based Approach is based on the same theories as the Marginal Tax/Subsidy Approach, but goes beyond just the recognition of negative externalities and equilibriums in social costs and benefits. It treats these situations as market failures that can be remedied by the creation of an appropriate market. The most prevalent style of this market development is "Cap & Trade" programs. The production of a public "bad" is capped at a desired level by a public regulator and the rights to produce this "bad" are distributed to the producer/polluter. Producers can buy and sell the rights in a way that equalize their marginal costs and so can minimize the production losses in the most cost effective manner. Producers that incur high costs of change can purchase permits and produce more of the bad than other producers and so transition their production to minimize the "bads" in a manner of their own choosing at the same time as the regulators meet their total emissions quotas ("bad" production limits).

There are two sets of requirements to a "Cap & Trade" program that must be met for it to succeed. The first involves the definition, clarification, and assignment of rights of the goods, services, or things affected by negative externalities. As the Coase Theorem[4] suggests, this assignment of rights has a tremendous potential to affect the equity of a conflict, but it will nevertheless lead to an efficient outcome. However, if this assignment is well considered along equity lines it can also contribute to the success of the second set if requirements, which is the creation of a market that will fill the failure. Optimally the market remedy will lead to the pure competitive equilibrium of neoclassical economic theory and its optimal allocation of resources.

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[3] If they were trying to encourage a positive incentive, they would have provided a subsidy.

[4] The "Coase Theorem" is based on a blend of law and economics (Coase 1960) and suggests that as long as there are no legal, strategic, or informational barriers to bargaining, the assignment of rights to 'goods' or 'bads' involved is all that is required for the parties themselves to negotiate an efficient outcome. Note that when Coase means efficient, he is simply saying that the optimal total net social benefit will result. He also carefully notes the distribution of these benefits can and will change, depending on what party possesses the assigned rights. Understanding this distributional aspect can be crucial to understanding the feasibility of implementing various remedies.

The features needed for this are: (a) perfect information, i.e., the buyer and the seller do have not information that the other party does not also have; (b) neither the buyer nor seller has substantial control over the price; and (c) the product is nearly identical. Given the success of these two steps, allocative efficiency is most readily achievable.

Although these two aspects are all that is necessary for a "Cap & Trade" approach to succeed as a practical matter, eco-systems services transactions seldom are in situations where all these features exist. In particular, it may be difficult to create a situation where a continual set of exchanges or transactions of right can be made and provide a liquid market. If it cannot, and the transactions involved are few, the allocational and distributional questions may have to be addressed differently. The situation belongs to a class of exchange problems known as "small numbers" bargaining. This situation usually does not have the ideal properties the neoclassical pure competitive equilibrium does. Nevertheless, it can possess some of them and so it is often the second-best remedy. However, the bargaining power of each trader/player will be more likely to come into play as will the probability that the valuation of the ecological asset or service will be made outside the confines of a market.

Ecosystem Service Valuation

Given the prerequisites discussed above are met, Eco-Service Valuation can be applied to augment the Marginal Tax/Subsidy or Market-based Approaches that address on-going pollution issues, such a water and air pollution. However, it can also be a stand-alone application for individual policy problems, such as a local government deciding how much effort to invest in a natural resource to improve local tourism. Moreover, it is well-suited to situations where there is a "Tragedy of the Commons" (Hardin 1968) or a public good subject to degradation rather than the curtailment of a 'bad,' such as point-source pollution (e.g., the eco-services of clean air and water; biodiversity; and ocean fisheries). These public goods and services are often non-rivalrous[5] in consumption or non-excludable[6]. The distinction between these two aspects of a public good is important because policymakers have an easier time assigning rights to things that can be made excludable. We are now recognizing that even watersheds, fisheries, and other natural goods that were once considered infinitely vast, are now scarce or congestible. Their use by one consumer may reduce the utility or benefit to another consumer. Therefore, many experts recommend transforming previously public goods into private, congestible, or club goods through the assignment of rights, and eco-system service valuation is a means of determining how they will be allocated.

This approach encompasses both economic (monetary) and nonmarket valuation methodologies. The goal, of course, is properly assessing the worth of an environmental asset or service. The benefit-cost estimates usually applied above are considered to rest on utilitarian constructs. However, these methods can include more broadly construed concepts of instrumental, intrinsic, anthropocentric, biocentric, ecocentric, and deontological values. The use of these different standards can also imply that individuals will hold multiple values regarding different aspects of an ecosystem and these values are additive or "stackable."

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[5] Non-rivalrous means that the use of a unit of a good, does not lead to a degradation in the utility to another consumer using the same unit, for example, the enjoyment of a sunset.
[6] Non-excludable means that non-payers cannot be easily prevented from using a particular good or service.

These methods recognize that when an individual considers the value an ecosystem service their task is complex. If asked directly what they thought, as they would be with a "Stated Preference" valuation approach, they still might not be able to produce a very reliable answer. These complexities include the uncertainty in assessing an environmental benefit, ecosystems with non-linear or threshold response dynamics, temporal effects from discounting the expected future benefits to the present, and determining values beyond a personal lifetime, among other issues. Even when performing a less-esoteric economic valuation, another significant measurement issue may arise. Potential users of the service may not have the proper incentive to reveal their true preferences for the service if they think they will be asked to pay for part of it. There are a number of ways to handle this issue. One method has been to ask a potential user the same question in two ways. The first attempts to assess a user's willingness to pay (WTP) for an eco-system service. The second attempts to find their willingness to accept compensation (WTA) if the same service is taken away[7]. These values can bracket the true preference, since a WTP for an improvement is likely to be less than a willingness to accept compensation when the service is taken away. When these values are close together, there is greater confidence in the estimates. Both these techniques are "Stated Preference Approaches," as is Conjoint Analysis. However, methods exist that attempt to capture users preferences without directly asking them. These "Revealed Preference Methods" observe behavior and then infer the agent's preferences. The methods include direct methods that examine competitive or simulated market prices; and indirect methods that can rely on Household production function models, Hedonic methods, and Referendum votes. These indirect methods are usually based on the recognition that people behave as though they value collections of characteristics about a single ecosystem service or environmental quality and so do not make decisions based solely on one feature of a good. This set of characteristics most directly affects their price (value).

Another important valuation criterion with direct repercussions for the contentiousness of valuation conclusions regards valuing non-market characteristics or features and recognizing intrinsic or non-anthropocentric values. One method, the Total Economic Valuation (TEV) approach relies on stackable values and attempts to bridge the divide between the accounting of economic and non-economic values. It has consumers of a service consciously distinguish between use and non-use values of a service. In other words, the consumer estimates how much they value a service in terms of what they feel they gain by simply knowing it exists.

Conclusions

What does all this mean for ecosystem services? First of all, the debate raised by the article in *Nature* (September 2006) hinged on the premises behind the effectiveness of two of the regulatory approaches outlined above, the Legal Approach and the Market-based Approach. Second, the issues discussed highlight the importance of the fundamental characteristics of environmental goods, because these will determine the ease with which assigning rights can take place and so lead to the creation of a successful and sustainable market. It also raises the possibility that the characteristics will not allow for this rights assignment in an enforceable way,

[7] These are consistent with the compensating variation and equivalent variation more often found in economic theory.

or in a way that can lead to a liquid market. Other modes of regulation, although not perfect, may be more effective in specific cases.

Regulatory Approach	**Punitive**	**Distributional Equity**	**Allocative Efficiency**	**Enforceability**	**Ease of Implementa-tion**
Legal	Yes	Criminal – Can be Civil – Yes	Seldom	Not uniform	Easiest
Tax/Subsidy	No	Can be	Yes	Easy	Harder
Market-based (Cap & Trade)	No	Less likely than tax/subsidy	Yes	Easy	Easier

Appendix 2. External Agencies and Organizations Ecosystem Services Activities

Ecosystem Services:

USDA seeks to broaden the use of private-sector markets for environmental goods and services through emerging voluntary market mechanisms. Former USDA Secretary Mike Johanns announced in August 2005 that USDA is seeking to expand its use of new market incentives that will encourage landowners to invest in the maintenance, creation, and restoration of healthy ecosystems. Market-based environmental stewardship approaches tend to be more cost effective in achieving conservation and environmental goals. Market-based approaches include many environmental factors, including greenhouse gases, water, air, wetlands, and wildlife habitat. Mechanisms include credit trading, insurance, mitigation banking, competitive offer-based auctioning, and eco-labeling. USDA believes market-based environmental stewardship can encourage competition, spur innovation, and achieve environmental benefits, while helping USDA constituents comply with environmental regulations.

A Market-based Environmental Stewardship Coordination Council was created to ensure development of a sound market-based approach to quantifying conservation practices. Mark Rey, Under Secretary for the Natural Resources and Environment and Chair of the USDA Market-based Environmental Stewardship Coordination Council, has recommended cooperation with other agencies and partners to expand the use of private-sector markets for environmental goods and services. To be successful, the council stressed establishing more effective policies and programs; improving accounting methods for quantifying environmental goods and services; testing innovative tools and practices; and conducting education, technology transfer, and partnership building activities. The following is a brief review of activities within USDA, other federal agencies, land-grant universities (LGU), and other stakeholders involved in ecosystem services.

Agriculture Research Service

USDA's Agriculture Research Service (ARS) is involved in research on carbon sequestration, water quality, and air quality that will help provide the scientific background needed to make environmental credit trading decisions. ARS activities fall into four categories:

- Developing measurement techniques for carbon sequestration and contaminants in water and air;
- Developing management practices and technologies for improving carbon sequestration, air quality, and water quality;
- Documenting environmental benefits of the management practices and technologies; and
- Developing and improving decision tools to predict environmental benefits of management practices and systems across a range of conditions.

Two large projects currently undertaken by ARS and partners are the Conservation Effects Assessment Project (CEAP) and GRACEnet. CEAP measures and predicts the water and soil quality benefits of management practices and systems at the watershed scale. Twelve ARS watersheds are included in the CEAP program. The GRACEnet program measures carbon sequestration and greenhouse gas emissions under different cropping systems and practices at 30 locations around the country. GRACENET is a long-term project.

Economic Research Service

The Economic Research Service (ERS) recently completed a paper entitled "Agricultural Resources and Environmental Indicators," edited by Keith Wiebe and Noel Gollehon. This publication describes trends in resources used in and affected by agricultural production, as well as the economic conditions and policies that influence agricultural resource use and its environmental impacts. ERS is part of a USDA Steering Group on "Market-based Incentives." The focus for ERS is in the environmental services as it pertains to residential and rural economics.

Forest Service

The Forest Service (FS) has established a Carbon Market Team to develop principles for a carbon trading program that builds on ongoing efforts but are specific to forestry. FS established an Ecosystem Services Coordinator position as a focal point for agency actions on ES and market-based environmental stewardship. FS also established an ES Group to provide support and advice to agency executives in developing an overall strategy on ES. FS has convened several stakeholder meetings to solicit input on the FS role in ES. FS has also set up a blog for ES and established a listserv providing updates on FS activities on a monthly/bimonthly basis. With regards to trading, FS' initial focus is on private land. FS is working on the World Summit on Sustainable Development (WSSD) partnerships–Conservation Agriculture.

NRCS

The Natural Resources Conservation Service (NRCS) uses a Market-based Approach with ES. The goal is to broaden the use of markets for environmental and ecosystem services through voluntary market mechanisms. NRCS believes that market-based environmental stewardship can encourage competition, spur innovation, and achieve environmental benefits, while helping landowners comply with environmental regulations. The idea is to help bring producers and consumers together and to develop innovative tools to quantify environmental impacts.

NRCS has a new strategic plan that includes a Market-based pproach to conservation. It has a very broad role for market-related incentives and seeks new ways to expand market-based options for conservation. Some of the incentives involve agreements and payments—such as credit trading. Others may be options driven by market conditions or opportunities that farmers and ranchers have to increase productivity and improve environmental stewardship. NRCS is looking to expand its understanding of incentives that encourage conservation and that are voluntary. NRCS is developing fact sheets and a handbook that focus on environmental credit training. They are strengthening their Performance Results System, which is a database used to report results of conservation practices installed under conservation programs.   It is anticipated that a new title in the Farm Bill will address market based approaches. It will ensure that farmers can access other market payments for ecosystem services along with government payments.

NRCS is also participating in CEAP to identify the specific benefits of conservation practices, such as conservation buffers, erosion control, wetlands conservation, restoration, etc. NRCS also manages the Conservation Innovation Grants program, which is involved with trading.

Environmental Protection Agency

The EPA is planning an ES workshop in 2007. There will be new grants on ecological evaluations of ES. EPA has released an Ecological Benefits Assessment Strategic Plan. EPA has been focusing on Environmental Management Systems. The Office of Research and Development (ORD) has an Eco Research program and OPPI working on new research areas. EPA and USDA recently signed a joint water quality trading agreement for trading pollutants. EPA also has the its Environmental Stewardship-Everyday Choices: Opportunities for Environmental Stewardship. EPA, along with NRCS and FS, has shared pilot projects in application research. EPA has funded competitive STAR grants that document aquatic ecosystem thresholds to maintain function.

Land-Grant Universities

LGUs are actively conducting research in various areas of ecosystems services. Projects are wide-ranging in scope—from quantifying the value of specific ecosystem services from agriculture in Michigan based on their cost of production, to analyzing the benefits and costs of natural resource policies affecting public and private lands in West Virginia and Washington, to measuring wildlife and ecosystem services on the Delmarva Peninsula. There are currently 83 active ecosystem services-related projects underway across the country. Of those, CSREES is funding 55 projects through Mcintire-Stennis, Hatch, and other special funding. Other USDA participation includes the Forest Service funding 10 projects, ARS funding 6 projects, and State Agricultural Experiment Stations (SAES) funding 8 projects. Other cooperating institutions are funding four projects.

Regionally, there are 17 ecosystems services projects in the Northeastern region, 14 in the Southern region, 26 in the North Central region, and 26 in the Western Region. Universities are researching other areas within ecosystem services. There are four universities conducting research in Green Payments, all funded by CSREES. Of the eight ongoing projects in Carbon Trading, four of these are with CSREES, three with ARS, and one with the State Agricultural Experiment Station. Research in Carbon Sequestration is receiving the most activity, with a total of 264 ongoing projects. Approximately 152 of these projects receive funding through CSREES, 71 with ARS, 18 with FS, 5 with other cooperating institutions, and 18 with SAES.

The livestock and poultry industry practices have an effect on air, soil, or water quality, but presently there are few ES projects in this area but that will probably increase. An example of how ES are being used in agriculture is the Market based Approach for preventing greenhouse gases. Producers can install digesters that convert manure into methane and carbon dioxide. Methane has 23 times more greenhouse gas effect than carbon dioxide. Producers can sell the credits to convert the methane to carbon dioxide thru the Chicago Climate Exchange (CCX) in Chicago, IL.

Environmental Trading Network

The Environmental Trading Network (ETN) began in 1998 to support the Kalamazoo River (MI) Water Quality Trading Demonstration Project. In the past 5 years, the Network has grown to include international representation. The ETN is an organization dedicated solely to the development and implementation of successful water quality trading programs and other market-based strategies for achieving healthy sustainable ecosystems. It is the only national clearinghouse for key policy and regulatory issues, and transferable water quality trading program design elements. The goals of the ETN are to obtain, generate, evaluate, and disseminate information on trading programs, support regional and watershed-based trading initiatives, increase public awareness and support for trading, and facilitate implementation of programs established by state and federal environmental regulations.

Forest Trends

Forest Trends is a Washington, DC,-based non-profit organization created in 1999 by leaders from conservation organizations, forest product firms, research groups, multilateral development banks, private investment funds, and foundations. Forest Trends is an international organization that works to expand the value of forests to society and promote sustainable forest management and conservation by creating and capturing market values for ecosystem services. Their goal is to help accelerate the development of markets for forest ecosystem services and expand markets and investments that encourage improved forest management.

Katoomba Group

The Katoomba Group is an international working group composed of leading experts from forest and energy industries, research institutions, the financial world, and environmental nongovernmental organizations dedicated to advancing markets for some of the ecosystem services provided by forests. The Katoomba Group seeks to address key challenges for developing markets for ecosystem services and builds upon the knowledge and experience of network members. The group met for the first time in Katoomba, Australia, in 1999. The group recently launched a new initiative**,** *Ecosystem Marketplace,* where providers and beneficiaries of ecosystem services get together to capture the value associated with ecosystem services. They provide a coordinated, informative platform for users and providers of ecosystem services to meet and communicate. *Ecosystem Marketplace* also helps to improve the quality and value of ecosystem transactions by providing up-to-date information, news, and expertise. Their Web page, www.ecosystemmarketplace.com, can be used to track global market prices on ES.

The Katoomba Group engages in market education and advocacy to enable the legislation and institutions needed for payment schemes to work appropriately. One initiative, the *Forest Climate Alliance*, has brought environmental and rural development leaders together to promote the development of forest carbon markets that conserve biodiversity and mitigate climate change while improving the livelihoods of poor communities. *Climate Alliance* seeks to explore how forest carbon can be a strategic interface between the Rio Convention's (the 1992 Rio de Janeiro Convention on biological diversity) and the Millennium Development Goals.

Appendix 3. CSREES Matrix Analysis

CSREES funds about 2,000 competitive research grants yearly. Approximately the same number of formula-funded (Smith-Lever, McIntire Stennis, Evans-Allen, etc.) research project proposals are approved, and Congress earmarks funding for special research grants and cooperative agreements. Most agency-funded or oversight activities have a duration of 3–5 years, resulting in a portfolio of over 25,000 active projects.

Elsewhere in this document, the term *ecosystem services* was defined as the benefits from the natural systems that support human life, such as soil, water, and climate. Over 24 ecosystem services are generally related to agricultural activities. Seven specific components of these services have been chosen to help categorize the research that CSREES funds under this topic:

- Clean air;
- Clean, abundant water;
- Carbon sequestration;
- Soil conservation and quality;
- Biodiversity, forests, and rangelands;
- Nutrient cycling; and
- Aesthetics and recreation.

The comprehensive nature of ecosystem services makes it difficult to confine this work to a particular goal or objective, or to specific areas of science. For example, natural systems that enhance water, air, and soil quality clearly benefit production agriculture (Goal 2), improve quality of life (Goal 3), and enhance the natural resource base (Goal 6). As a contemporary issue and focus of science, ecosystem services transcend the normal classification codes used to report agency-sponsored research. For example, Knowledge Areas relating to water defined in the *Manual of Classification for Agricultural and Forestry Research, Education, and Extension* (http://cris.csrees.usda.gov/manualvii.pdf) capture some, but not all, of the environmental services that result in clean and abundant water, but other natural and human-introduced activities also contribute, including forestry practices, low-disturbance tillage systems, waste disposal, and a host of others. Finally, the current research taxonomy lags the emerging topic. What is referred to here as ecosystem services might also be described as "environmental services" or "positive externalities." The term "ecosystem services" has not yet been standardized either for classification or for measurement[8]. An ES organizational matrix was designed to shown the relationship between selected ES and their impacts on natural and human functions.

[8] See, for example, Boyd and Banzhaf, What Are Ecosystem Services? The Need for Standardized Environmental Accounting Units; *Resources for the Future*, RFF DP 06-02, January 2006.

Links between Ecosystem Services and Biological and Human functions

Environmental Service ↓	Environmental Governance The policy, social, or economic conditions that influence, motivate, or constrain change.	Service Measures Proxy units of measurement that help to quantify the perceived net value of a public good or service, the distribution of its benefits, and the burden of its costs.	Biophysical Repsonses Biological adjustments to exogenous change	Interactions The physical, biological, or social intersections of systems activities.
Clean Air KA 141 Air Resource Protection & Management KA 124 Urban Forestry SOI 0410 Air	Economic well-being; Property rights; Capital mobility	Valuation; Policy impacts	Natural or human-caused disturbances; Variability & dispersal; Composition; Threshold determination	Biosocioeconomic; Urban forest
Clean and Abundant Water KA 111 Conservation & Efficient Use of Water KA 112 Watershed Protection & Management KA 605 Natural Resource & Environmental Economics	Motivations & economic incentives; Market-based responses; Alternative private responses; Management decisions	Valuation; Policy impacts; Policy transactions costs	Natural or human-caused disturbances; Variability & dispersal; Composition; Threshold determination, Biological competition & resource sharing; Metapopulation responses; Restoration & remediation consequences; Spatial & temporal	Stream-riparian; Forest-prairie; Riverine forest
Carbon Sequestration KA 125 Agroforestry Rangeland Ecology Policy Soil Management	Environmental goals; Economic well-being; Risk management; Motivations & economic incentives; Market-based responses; Management decisions; Coordination among independent parties	Valuation; Policy impacts; Policy transactions costs; Quantification of cycles; Distribution of benefits		Biosocioeconomic; Pasture-cropland
Soil Conservation and Quality KA 103 Management of Saline & Sodic Soils & Salinity KA 104 Protect Soil from Harmful Effects of Natural Elements SOI 0110 Soil SOI 0120 Land	Economic well-being; Motivations & incentives; Management decisions	Valueation; Willingness to pay	Natural or human caused disturbances; Variability & dispersal; Composition; Restoration & remediation consequences; Spatial & temporal	Biosocioeconomic; Farmland-habitat

SOI 0199 Soil & land,				
Biodiversity, Forests, and Rangelands 121. Management of Range Resources 122. Management and Control of Forest and Range Fires 123. Management and Sustainability of Forest Resources 124. Urban Forestry 125. Agroforestry	Economic well-being; Management decisions; Coordination among independent parties	Valuation; Policy impacts; Policy transactions costs; Non-market value; Distribution of benefits	Natural or human-caused disturbances; Variability & dispersal; Composition & density; Restoration & remediation consequences; Spatial & temporal	Biosocioeconomic; Forest-field; Wetland-range; Field-grassland; Embedded wetland
Nutrient Cycling KA 102 Soil, Plant, Water & Nutrient Relationships KA 206 Basic Plant Biology	Environmental goals; Management decisions	Quantification of cycles	Natural or human-caused disturbances; Biocompetition & resource sharing; Metapopulation responses; Restoration & remediation consequences	Biosocioeconomic; Wetland-range; Agroforest; Forest-prairie; Marine ecosystem
Aesthetics And Recreation KA 134 Outdoor Recreation KA 605 Natural Resource & Environmental Economics SOI 0510 Wilderness SOI 0520 Campgrounds & picnic areas SOI 0530 Parks & urban green space SOI 0599 Recreational resources, general/other	Environmental goals; Economic well-being; Risk management; Motivations & economic incentives; Management decisions; Coordination among independent parties	Valuation; Policy impacts; Policy transactions costs; Non-market value; Distribution of benefits; Willingness to pay	Natural or human caused disturbances; Threshold determination; Restoration & remediation consequences; Spatial & temporal	Biosocioeconomic; Marine ecosystem; Forest watershed; Open space

Appendix 4. CSREES Ecosystem Services Assessment

CRIS searches were conducted in 2006 and 2007 for all active projects in the database that included following key words. the searches resulted in the following projects:

	2006	2007
Ecosystem services	98	228
Environmental services	55	0
Carbon trading	12	43
Green payments	7	17
Market-based environmental	4	681
Green labeling	1	0
Environmental credits	0	92
Environmental credit trading	0	0
Market-based environ. services	0	0

Example of funded projects:

CEAP funded 12 watersheds under the Section 406 National Integrated Water Quality Program to measure environmental outcomes of specific conservation practices, and to determine optimum placement in the landscape. It also included social and economic factors to prioritize which practices that producers were most likely to install and maintain. Additional watershed studies were funded by ARS and NRCS. NRCS has funded an additional wildlife and wetland measurement study. USDA's Farm Service Agency has also funded studies of Conservation Reserve Program lands to measure ecosystem services provided.

NRCS has funded a curriculum handbook with Iowa State University to train producers on concepts of ES. Additional curricula needs at different academic levels could be funded through the higher education division. Extension programs will be needed to explain new conservation provisions and economic opportunities that are proposed in the farm bill.

Program area example—Livestock and Poultry Ecosystem Services activities:

Over 300 million ha of public and private rangelands in the United States are characterized by low and variable precipitation, nutrient-poor soils, and high spatial and temporal variability in plant production. This land type has provided a variety of goods and services, with the provisioning of food and fiber dominating through much of the 20th century. More recently, food production from a rangeland-based livestock industry is often pressured for a variety of reasons, including poor economic returns, increased regulations, an aging rural population, residential development, and increasingly diverse interests of land owners. A shift to other provisioning, regulating, cultural, and supporting services is occurring with important implications for carbon sequestration, biodiversity, and conservation incentives. There are numerous goods and services possible, from rangelands that can supply such societal demands as clean water and a safe food supply. The use of ecologically-based principles of land management remains at the core of the ability of private land owners and public land managers to provide these existing and emerging services (Kris Havstad, ARS, 2006) (Society for Range Management Meeting Abstracts).

Expansion of livestock production around the world has often led to overgrazing and dryland degradation, rangeland fragmentation, loss of wildlife habitat, dust formation, bush encroachment, deforestation, nutrient overload through disposal of manure, and greenhouse gas emissions (R6-ES). There appears to be few directed programs/activities using ecosystem services/(environmental credit trading) for the livestock and poultry industry in the United States. Livestock and poultry industry practices may affect air, soil, or water quality, but presently ES are not likely to direct their support or compensation to those producers. It is much more likely that ES will direct their support to "practices" whether it is the livestock or the row crop or the forestry operator (carbon sequestration, soil erosion, water quality, etc). A CRIS search showed that there are very few "hits" for the term "ecosystem services, livestock," in contrast with just a search for "ecosystem services." A listing is shown below.

Livestock and poultry-related environmental credits:
- 14, ecosystem services, livestock
- 1, green payments, livestock
- 0, green payments, animal agriculture
- 0, environmental services, animal agriculture
- 5, environmental services, livestock

After further review of each of the 14 'ecosystem services' projects, it appeared that only one project had used ecosystem services (as described in this document) directly applied to a livestock system.

The main premise of an environmental credit trading effort for agriculture is to reduce the effects of pollution on our environment. To do this, practices (purchase or installation of actual structures or equipment) will be put in place to prevent, reduce, or eliminate pollution. The farmer, municipality, or industry will be able to buy credits from another provider if it is less expensive than investing in their own facilities to meet some water quality criteria. Likewise, if the farmer, municipality, or industry has water treatment capacity that more than exceeds the discharge water quality criteria he/she can sell environmental credits to another operator. On a global scale, some livestock producers have covered manure storage to reduce methane and other greenhouse gases and traded these credits.

There is no difference between cropping systems and livestock and poultry systems regarding environmental credit trading as both are trying to achieve the same goal, “pollution prevention.” Each system will have several practices that can be installed to prevent pollution. Some examples of practices that can be installed for livestock and poultry operations include fencing livestock from streams; buffer strips down slope from land application areas; soil injection manure applicators; manure spreaders; manure irrigation systems; manure storage structures; lagoons; aerators for lagoons; liquid-solid separators; composting facilities; and methane digesters.

The NRCS EQIP (Environmental Quality Incentive Program) program is required by law to dedicate 60 percent of funds of their approximately $1 billion per year for improvements and installation of practices at livestock and poultry operations, including grazing systems, to protect the environment. This is a cost share program with each state prioritizing the proposals that were submitted by livestock and poultry producers.

Appendix 5: Example of Multi-state Project Using a Systems Approach, Including Multiple Ecosystem Services:
Balancing production vs. environment vs. energy in developing strategies for the livestock and poultry industry.

Request for Replacement Multi-state Research Project
Project Title: Improving the Sustainability of Livestock and Poultry Production in the United States
Requested Duration: October 1, 2007,–September 30, 2012

Statement of the Issues and Justification:

The Need for a Systems Orientation. The federal and state governments in the major livestock- and poultry-producing regions of the United States have committed significant resources over the past 10+ years to the development, evaluation, and adoption of best management practices (BMP), advanced technologies, and other science-based tools to reduce or prevent environmental pollution from concentrated animal production systems. Many of those tools have been validated at the laboratory, pilot, and/or field scales in tightly controlled experiments, but their overall, dynamic impact at the ecological scale is not well understood. Even so, these technologies and practices, as well as policies and incentive structures conceived around them, are being routinely recommended and adopted.

Without a comprehensive, general understanding of the systems interactions that govern the overall effectiveness of a technology, a practice, an incentive structure or a policy, the American livestock and poultry industries and state and federal governments will continue to expend huge sums of public and private revenue on implementation of those tools without reasonable expectation of a particular cost/benefit threshold for any of them. It is one thing, for example, to show that a particular tactic is capable of reducing nitrogen requirements in feed without sacrificing mean animal performance (e.g., milk production, lean meat deposition). It is another thing to show that a suite of nitrogen-reduction tactics implemented together on a model farm will reduce net ammonia emissions to the atmosphere. But it is quite another thing entirely to illustrate that the overall impact of a proposed strategy on North American ecosystems (including energy and water resources, wildlife, water and air quality, human health and economic sustainability) will be a net positive—and even more elusive is knowledge of what the true cost of that benefit is likely to be on the economic, political, and social structures in which Animal Feeding Operations operate and on which they are dynamically interdependent[9].

[9] To illustrate, what if the technologies are far more energy intensive than the status quo? Does an air-quality benefit in one livestock-intensive airshed simply export air pollution to another airshed in the form of increased demand for electrical power? How might widespread adoption of process-level tactics affect, and be affected by, market distortions resulting dynamically from those tactics or from externalities?

Figure 1 (adapted from Sweeten, 1999) provides a useful context for these systems considerations. This diagram is a model of the environmentally significant stocks, flows, and transformations of matter in the North American beef-production system. Of course, any one of the elements in the diagram may be encircled and called an "open system" by itself, and that is indeed what has been happening over the past several decades as we have developed individual technologies and refined existing processes to increase the efficiency of those individual elements. It is becoming clear, however, that increasing efficiency at the process level does not necessarily reduce ecological stress overall[10]. Because real ecological systems are characterized by feedback, human choice, and other nonlinearities, changes in one element of the system may propagate through the entire system in an unpredictable or even counterintuitive way.

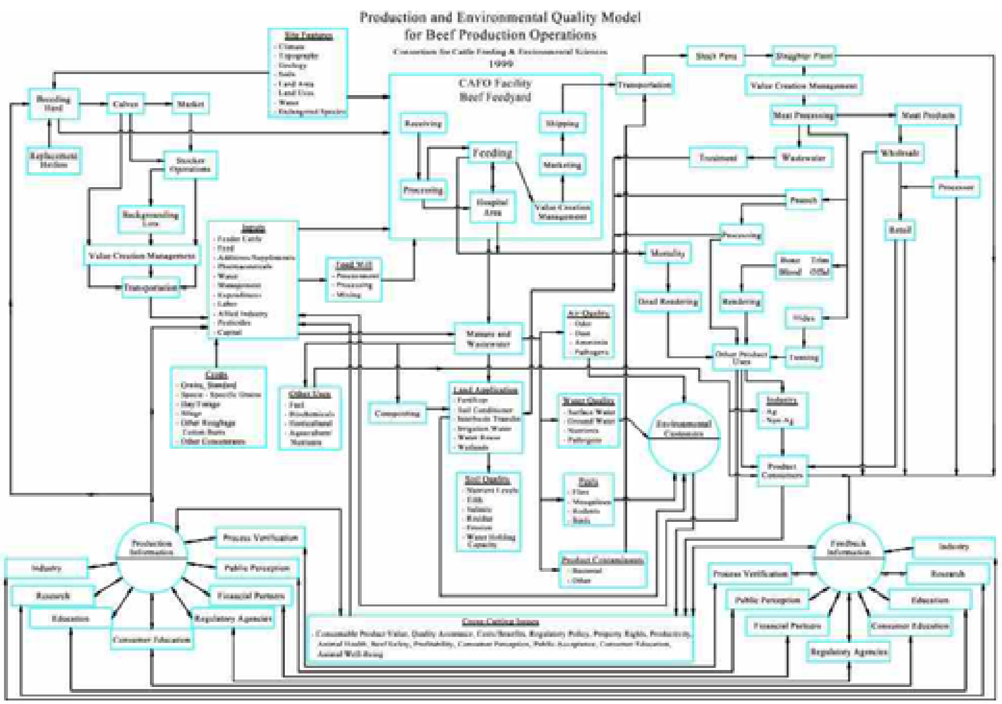

Figure 1. Schematic diagram of an environmental quality model of beef production in the United States, adapted from Sweeten (1999).

[10] The accelerating depletion of the Ogallala Aquifer, which results in large measure from improved irrigation efficiency, is an important illustration of the sometimes perverse effect of technological advance (Marek, 2005; Allen, 2006). In that case, improved irrigation technologies are bringing dryland acreage back into irrigated production, increasing irrigated acreage, and net aquifer withdrawals. This phenomenon is sometimes referred to as the "rebound effect."

Another critical characteristic of ecological systems is that they provide very real, very important services that sustain life on the planet. The fact that these services do not have a cash value complicates the accounting and makes their inclusion in economic analyses difficult. But because of the complex nonlinear interactions described above, as well as the global nature of today's human economic activity, including agriculture and the energy that supports it, the true value of ecological services must be included in future analyses. Researchers have developed several analytical tools and disciplinary paradigms to account for these services and the impact of human activity, including ecological footprint analysis (EFA), embedded energy ("emergy") accounting, exergy, life-cycle analysis (LCA), ecological efficiency, and industrial ecology.

Related, Current, and Previous Work:

The central motivation for EFA, emergy accounting, and other analytical frameworks is that when we focus our attention only on open systems (systems that exchange matter and energy with their surroundings), we implicitly assume that the sources of matter and energy flowing into the system are infinite—or, more damning, we choose to ignore the reality that those sources are finite. Wackernagel and Rees (1996) framed the issue in geopolitical terms by drawing system boundaries coincident with national boundaries, then demonstrating that when the ecological footprint of a highly advanced, energy-intensive nation exceeds its "ecologically productive" land and sea area, that nation necessarily appropriates ecologically productive areas from other nations via commerce. Because the Earth's ecologically productive resources are finite, trading for other nations' surplus ecological resources artificially perpetuates the illusion that a highly sophisticated, energy-intensive society is sustainable merely through further technological advancement and free trade. Technology and free trade may, in fact, be central to ensuring sustainability, but they may not be sufficient to do so by themselves as the global economy nears its biophysical limits of energy available to do work.

In a similar vein, Manning (2004) chose to draw the system boundary around the Earth and the Sun, recognizing that all of the significant energy reserves potentially available on the Earth derive from a finite combination of (a) net current solar energy flux, (b) net solar energy sequestered in the earth since its formation, and (c) the initial energy (kinetic, enthalpic, chemical, and nuclear) sequestered in the Earth at its formation. So-called "renewable" energy sources, such as solar, wind, tidal, biomass, and hydroelectric power, derive principally from the interaction of global circulation and the net current solar energy flux, which drives climate, short-term weather phenomena, and the hydrologic cycle. So-called "non-renewable" energy sources (e.g., fossil fuels and fissile materials) derive principally from historical solar energy fluxes and the energy originally stored in the Earth. Ultimately, however, those sources are limited, and harvesting them requires ever-increasing expenditures of the available energy already at our disposal (Hubbert, 1949). Underscoring the point, Hubbert (1982) responded to a colleague with these observations:

If oil had the price of pharmaceuticals and could be sold in unlimited quantity, we probably would get it all out except the smell. However there is a different and more fundamental cost that is independent of the monetary price. That is the energy cost of exploration and production. So long as oil is used as a source of energy, when the energy cost of recovering a barrel of oil becomes greater than the energy content of the oil, production will cease no matter what the monetary price may be. During the last decade we have very large increases in the monetary price of oil. This has stimulated an accelerated program of exploratory drilling and a slightly increased rate of discovery, but the discoveries per foot of exploratory drilling have continuously declined from an initial rate of about 200 barrels per foot to a present rate of only 8 barrels per foot.

In summary, the long-term sustainability of agriculture will ultimately be governed by the sustainability of solar energy to the planet. If sequestered energy reserves (e.g., nuclear and fossil fuels) accessible to mankind exceed the balance of energy obtainable from the Sun, we must simply make our sequestered reserves last as long as possible, preferably until the Sun itself expires. But, if the Sun's remaining energy exceeds our sequestered energy reserves, long-term sustainability demands that (a) we pursue a course in which our total energy use is less than that we can practically harvest from the Sun, or (b) we content ourselves with the prospect of a declining quality of life (or an equivalent decline in population for a given quality of life) as our sequestered sources are depleted. Solution (b) is achievable by default, by simply continuing on our present trajectory of total energy consumption. Solution (a), by contrast, requires a coherent, scientific framework for estimating, and then reducing if necessary, the net consumption of those ecological resources that are ultimately powered by the Sun.

We propose to develop computer-based mathematical descriptions of the animal production industries using measures of sustainability and environmental impacts that will help us describe and define that scientific framework. Although all aspects of animal production must be included, we propose to put special emphasis on evaluating manure management and utilization BMPs and their impact on sustainability and environmental impacts beyond the farm and field scale. A number of interesting and useful analytical paradigms already exist for describing and modeling the sustainability of arbitrarily defined systems, and we do not intend to suggest that one of them is necessarily superior to the others in every conceivable use or context. Each of them has strengths and shortcomings that depend on the way in which it is used. For example, EFA is strongly intuitive and visual, lending itself well to technology transfer to non-technical or even non-specialist audiences. Emergy accounting, in contrast, is rooted in 2nd-law thermodynamics considerations (i.e., not all forms of energy have the same ability to do work) but is not easily translated into useful public language. Because EFA and emergy accounting can be configured with solar energy as their common referent[11], however, it is

[11] Indeed, it is tempting to suggest that because a finite area of "ecologically productive land and ocean" is capable of harvesting a finite proportion of the Earth's incoming solar radiation, there is a conceptual nexus at which, properly defined and comprehensively rendered, EFA and emergy accounting are but alternative expressions of the same fundamental ideas. We have not proved that conjecture, obviously, but it is a provocative, potentially satisfying property to be explored in our proposed work.

conceivable that the scientifically rigorous analysis of animal-feeding systems could be conducted in emergy terms and then translated into eco-footprint language for public consumption. Similar observations could be made concerning LCA, eco-efficiency and other analytical paradigms. Consequently, we have framed our methods using the lexicon of EFA as shorthand for what we intend to be a fuller, more rigorous, multifaceted approach using all of the tools these emerging disciplines have to offer.

Ecological Footprint Analysis of AFO Systems. The concept of ecological footprint analysis, as applied to human populations, has been defined succinctly by Rees (1997) as estimating "the total area of productive land and water required to produce on a continuous basis all the resources consumed and to assimilate all the wastes produced by [a] population, wherever on Earth the land may be located." Among the key principles underlying EFA are that (a) all stocks of material resources, including water, air, nutrients, and energy, are finite; (b) where a local deficiency in any of those stocks is overcome by commerce, the transaction merely displaces the ecological stress associated with harvesting and using that stock but does not eliminate it; and (c) humans are integral rather than external to the ecosystems in which they operate. EFA purports to be a means by which "to monitor progress toward sustainability; to compare the ecological impacts of cities, life-styles, or technologies; or to weigh aggregate human demand against available supply" (Rees, 1997). It is precisely that suite of promises that the committee intends to explore and (if possible) exploit in the context of concentrated animal production.

Rees' approach to EFA, described and exemplified in Rees (1997), essentially reduces all of the ecological costs being considered to a single unit of currency: (ecologically productive) land area *per capita*. If sustainability is viewed primarily in terms of long-term, global, net energy flow, a single land-area currency may be fully satisfactory. But, we must also grapple with nearer-term sustainability issues at the regional and national levels that can help us describe the contours of a transition from today's livestock production systems to tomorrow's systems. To accomplish that, we will need to consider other ecological values (e.g., water and air quality, ground water quantity) that shape public discourse and policy. In regional application, the ecological footprint concept may be multi-dimensional.

The aim in this 5-year research effort is to begin applying EFA in a detailed fashion to the livestock sectors, extending its scope to include considerations of water, energy, and nutrient stocks and flows, as well as air and water quality. This system-oriented approach will not require abandoning process-oriented, reductionist research. Rather, we will attempt to synthesize it with, and integrate it into, broader considerations of the ecosphere and the development of new ecological "currencies" that could be used to mediate allocation of ecological goods and services within the livestock sector of the regional economy.

A comprehensive approach to ecological footprint modeling of concentrated livestock production would require, at a minimum:

1. Procedures for estimating the stress imposed by livestock production on the following, dynamic components of an ecosystem:

a. Quality of environmental media (air, surface water, ground water, soil)
b. Natural resources (populations, reservoirs, and flows)
   i. Recoverable, conserved resources (e.g., energy, water, nutrients)
   ii. Non-conserved resources (e.g., species)
c. Climate
d. Markets for livestock products and by-products
e. Quality of life; and

2. A rational means of normalizing and integrating those model components to express the net change in cumulative ecological stress that would be expected as a result of implementing policy, technology, or other measures in the concentrated livestock sector.

A CRIS search revealed five regional projects closely related to the proposed replacement project: WERA-103, Nutrient Management and Water Quality, whose objectives are more related to optimizing and minimizing crop nutrient application; S-1025 Systems for controlling air pollutant emissions and indoor environments of poultry, swine, and dairy facilities; SDC-321, Environmental issues affecting poultry production; NE-132, Environmental and Economic Impacts of Nutrient Management on Dairy Forage Systems, whose objectives are to study dairy forage systems primarily in the northern states; and NC-119, Management systems to improve the economic and environmental sustainability of dairy enterprises. These projects are largely focused either on specific regions, species, or environmental media and therefore would be largely complementary and do not represent duplication to the proposed project. One of the strengths of the terminating project, S-1000, for which this proposed project is a replacement is that it has established a track record of a multi-disciplinary, integrated project.

Objectives:

1. Develop preliminary models of each animal industry that describe its cumulative ecological risk, emergy flows, or ecological footprint as a dynamic, nonlinear function of the stocks, flows, and transformations of matter and energy comprising confined animal feeding operation (CAFO) systems.
2. Continue the development and performance evaluation of process-level strategies and tactics to reduce environmental pollution at the process level from CAFOs. This work will include 1) management tools, strategies, and systems for land application of animal manures and effluents that optimize efficient, environmentally friendly utilization of nutrients and are compatible with sustained land and water quality; 2) physical, chemical, and biological treatment processes in engineered and natural systems for management of manures and other wastes; 3) methodology, technology, and management practices to reduce odors, gases,

airborne microflora, particulate matter, and other airborne emissions from animal production systems; and 4) feeding systems for their potential to alter the excretion of environmentally-sensitive nutrients by livestock.

Linkages, Cooperation, and Collaborators

The following experiment stations will be participants in this project: Alabama, Arkansas, California, Colorado, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, North Carolina, Ohio, Oregon, South Carolina, Tennessee, Texas, Virginia, and Wisconsin. In addition, scientists from ARS and CSREES will also participate.

For a complete description of the project contact:
Chair, Todd Applegate, Purdue University.
Chair-Elect, John Classen, North Carolina State University.
Secretary, Ted Funk, University of Illinois.

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Appendix 6: Matrix of Issue Topics Related to Ecosystem Services

Environmental Service	Issue: Human & Environmental Health	Environmental Security	Policy Impacts	Valuation
Food Production	Food Security Public Health	Stackability Competition	Commodity Programs Conservation Programs Biofuels	Food Expenditures Insurance Costs Subsidization Costs
Water Quality & Quantity	Public Health Food Security	Wildlife Habitat Water Security Stackability Competition Spatial Optimization Pollution Dispersion Mitigation Banking	Voluntary Registration Conservation Programs Regulation Market Incentives	Water Quality Markets Pollution Markets Property Rights Subsidization Costs Liability
Carbon Sequestration	Public Health Food Security	Temporal Optimization Competition	Voluntary Registration Conservation Programs Regulation Market Incentives	Carbon Markets Property Rights Taxation Liability
Nutrient Cycling	Public Health	Temporal Optimization Competition	Voluntary Registration Regulation Market Incentives	Nutrient Markets Property Rights Taxation Liability
Air Quality	Public Health	Spatial Optimization Pollution Dispersion	Voluntary Registration Conservation Programs Regulation Market Incentives	Emissions Markets Property Rights Taxation Liability

Biodiversity	Food Security Public Well Being Stackability	Spatial Optimization Temporal Optimization Wildlife Habitat	Conservation Programs	Property Rights Willingness to Pay
Recreation & Aesthetics	Public Well Being Community Well Being	Wildlife Habitat Stackability Competition	Commodity Programs Conservation Programs	Willingness to Pay Property Rights/Access Liability
Pollination	Food Security	Wildlife Habitat Competition	Commodity Programs Conservation Programs	Subsidization Costs
Fuels Production	Energy Security	Competition Water Security	Biofuels Regulation Market Incentives Commodity Programs Conservation Programs	Fuel Expenditures Subsidization Costs
Pest, Pathogen, Disease Control	Public Health Food Security	Wildlife Habitat Water Security	Regulation	Liability Mitigation Cost
Temperature Modulation	Public Health Food Security	Water Security Wildlife Habitat	Voluntary Registration Regulation Market Incentives	Markets Property Rights Taxation Liability
Flood Control	Public Health Food Security Community Well Being	Water Security Stackability Spatial Optimization	Conservation Programs	Subsidization Insurance Costs
Erosion Control	Food Security Community Well Being	Water Security Stackability Spatial Optimization	Conservation Programs	Property Rights Liability

Appendix 7. Ecosystem Services Logic Model

Ecosystem Services Integrated Portfolio

<table>
<tr><td colspan="2">Priorities</td><td>Over the last 50 years, humans have changed agricultural and natural ecosystems more rapidly and extensively than in any comparable period of time in human history. Ecosystem Services are the benefits that people obtain from Nature; from both natural and human-modified ecosystems. These declining trends in ecosystem services challenge our ability to sustain the capacity of society to meet the needs of a growing population and sustain the life support systems of the planet.</td></tr>
<tr><td colspan="2">Inputs</td><td>CSREES ESWG and ENR group; CPs and non-CP related to ES; Multi-state projects</td></tr>
<tr><td colspan="2">Activities</td><td>An integrated multi-level and multi-topic portfolio for research, extension, and educational activities..Develop an integrated systems program, which would increase information about the interrelationships of environmental/health, social, economic, and legal/policy implications related to ecosystem services. Cross link single ES programs and multi ES systems programs.</td></tr>
<tr><td colspan="2">Outputs</td><td>Decision and evaluation tools for whole system management
Market and non-market valuation of ecosystem services
Tools and methods to restore and enhance ecosystem functions and services
Catalyze innovations with new systems information through extension and education activities</td></tr>
<tr><td rowspan="3">Outcomes</td><td>Knowledge</td><td>Occurs when there is a change in knowledge or the participants actually learn:
Improve the environment as ecosystem services are increased and maintained</td></tr>
<tr><td>Actions</td><td>Occurs when there is a change in knowledge or the participants actually learn
Improve the health and resilience of rural communities</td></tr>
<tr><td>Conditions</td><td>Occur when a societal condition is improved due to a participant's action taken in the previous column.
Increase prosperity while improving the environment; Improve economic conditions for producers from multiple markets</td></tr>
</table>

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