Natural Resource, Agriculture, and Engineering Service NRAES–130

# Managing Nutrients and Pathogens from Animal Agriculture

Proceedings from
"Managing Nutrients and Pathogens from Animal Agriculture"
A Conference for Nutrient Management Consultants,
Extension Educators, and Producer Advisors

Radisson Penn Harris Hotel and Convention Center
Camp Hill, Pennsylvania
March 28–30, 2000

University of Connecticut • University of Delaware • University of the District of Columbia
University of Maine • University of Maryland • University of Massachusetts • University of New Hampshire
Rutgers University • Cornell University • The Pennsylvania State University • University of Rhode Island
University of Vermont • Virginia Polytechnic Institute and State University • West Virginia University

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- United States Environmental Protection Agency
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## Planning Committee

The planning committee for this conference included (in alphabetical order)

- Douglas Beegle, Department of Agronomy, The Pennsylvania State University
- Sharon Buck, US EPA
- Eldridge Collins, Biological Systems Engineering, Virginia Polytechnic Institute and State University
- Robert Graves, Agricultural and Biological Engineering, The Pennsylvania State University
- Richard Kohn, Animal and Avian Science, University of Maryland
- J. J. Meisinger, USDA-ARS
- Roberta Parry, US EPA
- Marty Sailus; Natural Resource, Agriculture, and Engineering Service
- Andrew Sharpley, USDA-ARS
- Peter Wright, Cornell Cooperative Extension

## Thanks to Speakers

The planning committee would like to thank the speakers for their diligence in submitting their papers early enough so that these proceedings could be distributed at the conference.


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## Session 1

# Nutrients and Water Quality

# Nutrients and Water Quality

Hank Zygmunt
United States Environmental Protection Agency

This conference sponsored by the Natural Resource, Agriculture, and Engineering Service with its fourteen cooperative extension agencies from many excellent land grant universities provides an excellent forum to continue to discuss and learn more about the continued challenge of improving the nation's water quality and public health. Local, state, and federal governments, academic educators, the agricultural community, environmental organizations, corporate leaders, and in particular the youth of tomorrow are all dedicated to becoming better educated to make needed improvements in our environment as we immerse ourselves in the next decade of the new millennium.

The nation has made great strides in dramatically improving the health of rivers, lakes, and coastal waters. By implementing the Clean Water Act, it has prevented billions of pounds of pollution from adversely impacting waterways throughout the nation and in so doing has doubled the number of waterways to be safe for fishing and swimming. Also, as many rivers, lakes, and coasts being part of the traditional natural heritage have been restored these improvements have helped the economic viability for healthy communities of tomorrow.

Despite the tremendous progress that has been achieved in reducing water pollution, almost 40 % of the Nation's waters that have been assessed by States do not meet water quality goals. Based upon water quality monitoring information submitted to EPA by State Water Quality Agencies, about 15,000 waterbodies are impacted by siltation, nutrient, bacteria, oxygen-depleting substances, metals, habitat alteration, pesticides, and organic toxic chemicals. With much of the pollution associated from factories and sewage treatment plants being dramatically reduced, polluted runoff from city streets, rural areas, and other sources continue to degrade the environment and place drinking water at risk. As many of you have know, EPA's Water Quality Inventory report, based upon data furnished by States, have reported that agriculture is the leading source of impairment in the Nation's rivers and lakes, and a major source of impairment in estuaries. The impairment comes from nutrients associated with agricultural operations. These farming activities are not the only source of nutrient pollution. Other loadings come from wastewater treatment plants, industrial plants, and septic tanks. Atmospheric deposition of pollutants is yet another source of nitrogen, an area of research receiving much needed attention. Amongst all of these sources of pollution it should be recognized that investments of responsibilities have been and will continue to be made by the conservation movement with commensurate levels of support from state and federal governments for both technical and financial resources. In consideration of the conservation ethic and land stewardship that the agricultural community has and will continue to demonstrate one of the critical components of future success is the development and implementation of comprehensive nutrient management plans (CNMPs). These CNMPs represent the cornerstone of both voluntary and regulatory activites and as such will manage nutrients and quantities of manure on our nation's animal feeding operations resulting in improvements to water quality and protection of public health. It is clear that as the agricultural community is led by the farm community, their conservation efforts should directly correlate to improvements in the environment. Without clean water and air that makes up a part of their environment, continued reliance upon these precious natural resources could provide situations that are difficult to support sustainability and impact future generations.

## NITROGEN AND PHOSPHORUS

EPA in 1988 reported that nitrogen and phosphorus from agriculture accelerate production in receiving waters resulting in a variety of problems including clogged pipelines, fish kills, and reduced recreational opportunities. Nitrate is also a potential human health threat.

The Economic Research Service describes the existence of regional problems based upon a variety of pollutants impacting water quality in the Great Lakes, the Chesapeake Bay, and the Gulf of Mexico. In the Great Lakes most of the shoreline is polluted from toxic chemicals, primarily polychlorinated biphenyls, mercury, pesticides, and dioxins found in fish samples. Atmospheric deposition of toxics, point sources, and contaminated sediment are the leading sources of water quality impairment.

The Chesapeake Bay has been impacted primarily for elevated concentrations of nitrogen and phosphorus leaving the Bay overenriched. Much progress has been made in implementing both voluntary and regulatory programs yet additional reductions in nutrients that promote algae growth and have led to poor water quality which has dramatically reduced shellfish harvest needs to occur.

The Gulf of Mexico has experienced a doubling in the size of an oxygen-deficient "dead" zone to a 7,000 square mile area. The primary cause is believed to be increased levels of nitrates carried to the Gulf by the Mississippi and Atchafalaya Rivers. A major source of nitrates is fertilizers from the Upper Mississippi Basin.

## GROUND WATER

Unlike the nations comprehensive surface water quality program, a comprehensive groundwater program presently does not exist. However due to the concerns about the impacts on surface waters and the relationship between both surface and ground waters, State agencies do report on the quality of ground water resources in State Water Quality reports under Section 305(b) of the Clean Water Act. Generally, States report that sources of ground water contamination is localized with over 45 States reporting that pesticides and fertilizer applications were sources of contamination. Other indications of ground water quality are derived from EPA's National Survey of Pesticide in Drinking Water Wells. This survey provided the first national estimate of the frequency and concentration of nitrates and pesticides in community water system wells and rural domestic drinking water wells.

## HUMAN HEALTH CONCERNS

Based upon a report completed in December,1997 by the United States Senate Committee on Agriculture, Nutrition, and Forestry, the report indicates that much attention is focused on the direct impact of animal waste on the aquatic environment but there are human health concerns associated with animal waste pollution that need to be further studied.

Animal manure contain pathogens that can be harmful to humans. Some of these include Salmonella, Cryptosporidium, and Giardia which have polluted drinking water supplies and adversely impacting the health of humans. Microorganisms in livestock can cause several diseases through direct contact with contaminated water, consumption of contaminated drinking water or consumption of contaminated shellfish. Fortunately proper animal management practices and water treatment can minimize the risk to human health posed by these pathogens.

## THE USDA/EPA UNIFIED ANIMAL FEEDING OPERATION STRATEGY

Nutrients from manure is an increasing concern given the recent trend toward larger, more specialized beef, swine, and poultry operations. As many of you know the nature of the animal feeding industry has changed dramatically over the past decades. Advances in technologies for raising and feeding animals, decreases in transportation costs, and organizational changes in agricultural businesses and corporations have transformed the industry. The data overwhelmingly shows a shift in the industry from smaller to much larger operations. The total number of feeding operations has declined in every livestock sector. Yet over the last several years the total number of animals in each livestock group has increased.

As a result of the nation's increasing awareness of waterbodies being adversely impacted by polluted runoff and in part the recognition of the number of animal feeding operations and the trends in agriculture towards greater consolidation of these operations, EPA and the U.S. Department of Agriculture developed the Unified Strategy for Animal Feeding Operations announced on March 9, 1999. The Strategy outlines a flexible, common-sense approach to minimize the water quality and public health impacts of animal feeding operations while ensuring the long term sustainability of livestock production in the nation.

Farmers were among the first stewards of our nation's natural resources and farmers have consistently recognize the value of protecting water quality and the environment. Conservation translates to improving water and air quality and enhancing our natural resources. In consideration of the Strategy a national performance expectation has been established that all AFO owners and operators should develop and implement technically sound, economically feasible, and site specific comprehensive nutrient management plans for properly managing the animal wastes produced at their facilities.

While the vast majority of the estimated 450,000 AFOs nationwide are encouraged to develop CNMPs on a voluntary basis, between 15,000-20,000 large AFOs, generally those with 1,000 Animal Units or more, will be required to implement CNMPs as part of their NPDES discharge permit, under the authority of the Clean Water Act. Currently, EPA estimates that several thousand CAFOs now have NPDES permits under the Clean Water Act.

## FUTURE EFFORTS

As we prepare for the next ten years, EPA will continue to implement the provisions of the AFO Strategy which call for a number of innovative opportunities to be developed in continuing to address water quality and public health impacts from animal feeding operations.

Seven major strategic issues are included in the AFO Strategy. They are:

1. Building Capacity for CNMP Development and Implementation;

2.Accelerating Voluntary, Incentive-Based Programs;

3. Implementing and Improving the Existing Regulatory Program;

4. Coordinated Research, Technical Innovation, Compliance Assistance, and Technology Transfer;

5. Encouraging Industry Leadership;

6. Data Coordination; and

7. Performance Measures and Accountability.

Also described in the Strategy is a two phased regulatory approach that will improve upon the existing Clean Water Act's permit program as the National Pollutant Discharge Elimination System is administered by State Water Quality Agencies and EPA.

Throughout 2000 EPA and States will issue permits to CAFOs under the existing CWA regulations. To further explain how the EPA NPDES program for CAFOs needs to be implemented, a Guidance document is planned to be released by EPA this March. This document has been developed based upon extensive public comment review and should reflect a well balanced approach of applying a common sense approach to permitting CAFOs.

In December of 2000, EPA is planning on releasing draft CAFO regulations that will represent an update to existing regulations based upon revised effluent guidelines for the livestock industry. These draft regulations will convey to the general public the most up to date cost effective technology based pollution control abatement efforts that will protect water quality and public health. Final regulations, based upon completing the effluent guideline process, is planned to go into effect in 2005.

Throughout the development of both the voluntary program and regulatory program for animal feeding operations the technical underpinning for success is associated with the fundamental design and implementation of the comprehensive nutrient management plan. It is clear as both USDA and EPA continue to implement the key actions of the AFO Strategy that many professionals both within the public and private sectors will need to play a vital role in developing levels of expertise as CNMPs are developed for certification purposes. Some of these levels of expertise will be associated with technical advancements in the area of phosphorus as a limiting nutrient that will need to be incorporated into the development of CNMPs and the resulting potential need for using quantities of manure in alternative ways.

MANAGING NUTRIENTS

USDA's Natural Resources Conservation Service has adopted a new policy for nutrient management. Fundamental to the new policy and the Nutrient Management Conservation Practice Standard (#590) released in May 1999 are both the production and environmental protection considerations of nutrient management.

Presently, State NRCS offices are developing state specific nutrient management programs in response to the 590 Standard which are due to be completed in the Summer of 2001. One of the basic requirements of the new policy is the development of nutrient management plans that will include: Field and Soil Maps, Crop Sequence, Realistic Yields, Soil Test and Other Analysis, Sources of Nutrients, Nutrient Budget, Rates, Methods and Timing of Nutrient Application, Identification of Sensitive Areas, and Guidance for Implementation, Operation and Maintenance for Recordkeeping. Of particular importance as the nation manages the application to land of both commercial fertilizers and animal manures will be the heightened awareness of certified specialists, both public and private, in determining the appropriate application rates of nutrients, both nitrogen, phosphorus, and potassium in producing crop yields as well as for protecting the environment.

## PHOSPHORUS

The role of phosphorus in agriculture and water quality is receiving significant attention form agricultural organizations, environmental groups, government , and the news media. Since phosphorus can contribute to water quality impairment, there is a growing awareness that effective management of phosphorus in traditional conservation approaches is undergoing a national review. In particular, as animal manure continues to be widely used as an excellent source of plant nutrients, typical application rates determined based upon the nitrogen requirement of the crop produce an increase in the amount of phosphorus in the soil. Over time the accumulation of phosphorus in the soil can become significant and overall contribute to eutrophication in many impaired waterbodies throughout the nation. The fundamental goal to reduce phosphorus losses from agriculture should be to balance off-farm inputs of it in feed and fertilizer with outputs in product, and to manage soils in ways that retain crop nutrients resources and do not result in excessive accumulations in the soils. As we continue to further understand how best to manage phosphorus as comprehensive nutrient management plans are developed and implemented, it will be of utmost importance to minimize soil phosphorus buildup in excess of crop requirements, reduce surface runoff and erosion and improve our capability to identify fields that are major sources of phosphorus loss to waterways.

## FUTURE MARKETS

The agricultural community is recognizing that in certain on farm situations there are opportunities for third parties to use value added manure for a variety of uses that not only benefit both the farmer and the third party but potentially the environment. As phosphorus considerations become incorporated into nutrient management plans where appropriate and as called for by conservation offices and are also required by law, we will see a call on the part of not only the farm community but a variety of entrepreneurs who claim to have the " silver bullet" to help solve the nations "excess" manure situation. We have already established third parties who are benefitting from the use of value added manure products but we are only in the early stage of development. As state conservation offices finalize their responses to NRCS #590 nutrient standard by the summer of 2000, progressive communities and counties will plan accordingly to fully utilize quantities of manure generated from livestock operations for resource generating opportunities that benefit those involved in the production, marketing and use sector. The opening of value driven, environmental markets are being evaluated today by a number of companies that understand that changes are potentially being discussed particularly in geographic areas throughout the nation that are generating more manure than the adjacent land areas can absorb in any environmentally sound manner. The role of the agricultural community in this developing science driven equation is to understand the basis for the concern and the relevant opportunities that will present itself to essentially transport organic materials away from generation areas to benefit other agricultural or other uses.

## FEDERAL PROGRAMS THAT ADDRESS AGRICULTURAL NONPOINT SOURCE POLLUTION

The United States Environmental Protection Agency is primarily responsible for policies and programs that address water quality under the authority of the Clean Water Act. In mentioning a few of these national programs the National Pollutant Discharge Elimination System (NPDES) establishes limits on individual point source discharges is the program that will be continued to be used to permit Concentrated Animal Feeding Operations (CAFOs) as the National USDA/EPA Animal Feeding Operation Strategy is implemented for those facilities that require a discharge permit. As mentioned above the design of a comprehensive nutrient management plan is the technical underpinning of the permit.

When technology based controls are not sufficient for waters to meet State established water quality standards, Section 303(d) of the Clean Water Act requires States to identify those waters and to develop total maximum daily loads. The TMDL process is flexible and is a locally driven process although both EPA and State Water Quality Agencies are involved in the approval process.

Overall management of nonpoint sources primarily is associated with Section 319, the Nonpoint Source Program, Section 314, the Clean Lakes Program , and the National Estuary Program under Section 320. Section 319 currently is providing $200 million in grants to States to promote the implementation of NPS management programs. Section 319 funds also are available to assist reduce nonpoint source pollution for the nation's Clean Lakes program. The National Estuary Program assist States develop and implement comprehensive basin wide programs to conserve and manage precious estuary resources.

The Safe Drinking Water Act (SDWA) requires EPA to establish standards for drinking water quality and requirements for water treatment by public water systems. The SDWA authorized the Wellhead Protection Program to protect supplies of ground water used as public drinking water from contamination by chemicals, pesticides, nutrients, and other agricultural chemicals.

USDA also administer a number of excellent programs that assist the agricultural community better manage nutrients and thus help protect both surface and ground water. These programs rely upon providing technical assistance, education, research, and financial assistance to help achieve water quality and other environmental objectives. These programs include: the Environmental Quality Incentives Program, the Water Quality Program, Conservation Technical Assistance, Conservation Compliance, Conservation Reserve, the Wetlands Reserve Program, and the Small Watersheds Program.

## CONCLUSION

Much of the progress in reducing water pollution has been associated with implementing controls as part of effective national programs over discharges from sewage and industrial wastes. As we continue to address these significant pollution sources, a major water pollution challenge associated with nonpoint source runoff pollution from our urban areas, construction sites, forest harvesting operations and agricultural activities is taking center stage.

As the nation directs needed attention to a variety of sources of pollution that stem from nonpoint source runoff, a greater level of responsibility of those that are part of the rural and urban areas need to continue to further understand how their operations are impacting the environment and to further understand the solutions that are being offered from a voluntary incentive based approaches or common sense regulatory programs. In consideration of the amount of land that is private in our nation, approximately 70 percent, national attention for those that own these valuable lands in the future will become an increasing national priority. Priorities should be based in part upon the strong reliance upon smart conservation that translates into environmental benefits in achieving clean air and water. Other approaches that are regulatory in nature will draw upon common sense values that provide a flexible system for local governments to best address solutions. Innovative and creative approaches are needed as the nation makes significant strides in reducing pollution abatement from all sources of pollution.

This conference does provide a superb gathering of important and relevant topics and professional speakers that can deliver a strong a precise message. The Planning group is to be strongly commended and the Natural Resource, Agriculture, and Engineering Service with its fourteen universities equally commended for having such a timely, thought provoking, science based conference.

# Sources of Nutrients in the Nation's Watersheds

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Biographies for most speakers are in alphabetical order after the last paper.

### *Introduction*

Animal agriculture is a common source of nutrients in watersheds, but it is never the only source. Indeed, the diverse and ubiquitous nature of nitrogen and phosphorus forms in the environment introduces significant complexity to the increasingly important task of managing nutrients in watersheds. Thus, it is appropriate near the outset of this conference to attempt a systematic quantification of nutrient sources in surface waters as a means of exploring the relative importance of animal agriculture's influence on the nutrient balance in aquatic ecosystems under different conditions.

In this paper, we present estimates of the percentage contribution of five categories of nutrient sources to the total nitrogen and total phosphorus flux from watersheds in the major water resources regions of the conterminous United States. It is noteworthy that our estimates pertain to "in-stream" conditions rather than "input-level" contributions from each of the source categories. The latter represent a simpler way to quantify nutrient source contributions (see for example Puckett, 1995; Jaworski *et al.* 1992) but do not account for the effects of landscape and stream processing of nutrient material, and thus may give a very different picture of the importance of a particular source on water quality conditions. For example, agricultural fertilizer inputs to watersheds may be estimated from state- or county-level sales data or from estimated usage rates and cropland acreage. But fertilizer inputs generally exceed stream nutrient yields (mass per area per time) by a factor of two or more (Howarth *et al.* 1996; Carpenter *et al.* 1998) due to crop uptake and removal. In input terms, therefore, agricultural fertilizers appear to be a larger contributor to watershed nutrients than when they are expressed in in-stream terms.

Our estimates of in-stream source contributions are obtained through application of SPARROW (SPAtially Referenced Regressions On Watersheds; Smith, *et al*, 1997), a recently developed technique for interpreting water quality monitoring data in relation to watershed sources and characteristics. We begin with a brief discussion of methods for relating in-stream nutrient flux to source inputs and develop the rationale for spatial referencing of model terms. Next we provide a brief overview of the SPARROW model followed by a description of the data sources used here. The results pertaining to nutrient sources in general are presented in Tables 1 and 2. The results for animal agriculture are presented in map form in Figure 1. A brief discussion of the results and conclusions completes the report.

### *Quantifying watershed nutrient contributions by source category*

A variety of deterministic and statistical methods have been used to develop estimates of nutrient contributions to watersheds from human and natural sources. The simplest deterministic approaches consist of a simple accounting of the inputs and outputs of nutrients. A mass balance is achieved by comparing major source inputs (*e.g.*, fertilizer application, livestock waste, atmospheric deposition, and point sources) with outputs (*e.g.*, river export, crop removal) and by assuming that total losses to volatilization, soil adsorption, sedimentation, groundwater storage and denitrification equal the difference between the total inputs and outputs. Such simple models must assume that loss processes operate equally on all sources and that the relative contributions of sources to watershed export are proportional to the inputs. More complex deterministic models of nutrients in watersheds describe transport and loss processes in more detail and incorporate terms for spatial and temporal variations in sources and sinks. A major limitation on the applicability of such models at the regional or national scale is the problem of obtaining the necessary data for process description, especially if processes are treated dynamically.

Statistical approaches to modeling nutrients in watersheds have their origins in simple correlations of stream nutrient measurements with watershed sources and landscape properties. Recent examples include regressions of coastal total nitrogen flux on population density, net anthropogenic sources, and atmospheric deposition (Caraco and Cole, 1999; Howarth *et al,* 1996). A noteworthy advantage of the statistical approach is the ability to quantify errors in model parameters and predictions. Simple correlative models consider sources and sinks to be homogeneously distributed in space, do not separate terrestrial from in-stream loss processes, and rarely account for the interactions between sources and watershed processes. By contrast, more complex empirical approaches (Smith *et al.* 1997; Preston and Brakebill, 1999; Alexander *et al.* 2000; Alexander *et al. in press*; Johnes, 1996; Johnes and Heathwaite, 1997) indicate that knowledge of spatial variations in watershed properties that influence nutrient attenuation can significantly improve the accuracy of estimates of export and source contributions at larger watershed and regional scales.

SPARROW (Smith *et al.* 1997), a hybrid statistical/deterministic approach, expands on previous methods by using a mechanistic regression equation to correlate measured stream nutrient flux with spatial data on sources, landscape characteristics (*e.g.*, soil permeability, temperature), and stream properties (*e.g.*, flow, water time of travel). The model separately estimates the quantities of nutrients delivered to streams and the outlets of watersheds from point and diffuse sources. Spatial referencing of land-based and water-based variables is accomplished via superposition of a set of contiguous land-surface polygons on a digitized network of stream reaches that define surface-water flow paths for the region of interest. Water-quality measurements are available from monitoring stations located in a subset of the stream reaches. Water-quality predictors in the model are developed as functions of both reach and land-surface attributes and include quantities describing nutrient sources (point and nonpoint) as well as factors associated with rates of material transport through the watershed (such as soil permeability and stream velocity). Predictor formulae describe the land-to-water transport of nutrient mass from specific sources in the watershed surrounding each reach, and in-stream transport from reach to reach in downstream order. Loss of nutrient mass occurs during both land-to-water and in-stream transport. In calibrating the model, measured rates of contaminant transport are regressed on the set of predictor formulae evaluated at the locations of the monitoring stations, giving rise to a set of estimated linear and nonlinear coefficients from the predictor formulae. Once calibrated, the model can be used to estimate contaminant transport (and concentration) in all stream reaches. In addition, because the nutrient contribution from each source is tracked separately in the model, the percent contribution from each source category (*e.g.*, fertilizer, animal agriculture, etc) can also be computed for each reach. A study of model reliability is given in Alexander *et al.* (*in press*).

SPARROW has been applied nationally in the United States (Smith *et al.* 1997) with separate studies of nitrogen flux in the Chesapeake Bay watershed (Preston and Brakebill, 1999), the Mississippi River and its tributaries (Alexander *et al.* 2000), the watersheds of major U.S. estuaries (Alexander *et al. in press*), and watersheds of New Zealand (Alexander, R.B., U.S. Geological Survey, written comm., 1999).

### *Data sources and methods*

Detailed descriptions of the data sources and calibration results for the SPARROW total nitrogen (TN) and total phosphorus (TP) models used in this study are given in Smith *et al.* (1997). Observations of in-stream nutrient transport (i.e., the dependent variables in model calibrations) were based on U.S. Geological Survey (USGS) long-term stream monitoring records of TN and TP for the period 1974 to 1989 for 414 (TN) and 381 (TP) sites in the conterminous United States. Data for nutrient sources were developed for five major source categories: 1) municipal and industrial point sources, 2) commercial fertilizer, 3) animal agriculture, 4) nonagricultural runoff, and 5) atmospheric deposition (TN model only). Watershed inputs of nutrients for the source category fertilizer are based on fertilizer sales data. Nitrogen contributions from leguminous crop fixation are assumed to be reflected in the estimated coefficient for the fertilizer source category. Nutrient inputs for the source category animal agriculture are based on federal surveys of animal populations and literature data on animal waste production and the nutrient content of animal wastes. Atmospheric deposition sources are based on measured inputs of wet nitrate deposition, which are scaled by the model to reflect additional atmospheric contributions from such sources as wet deposition of ammonium and organic nitrogen and dry deposition of inorganic nitrogen. The source category nonagricultural runoff is scaled according to nonagricultural land area, and includes remaining nutrient sources unaccounted for by the other categories. This source may include surface and subsurface runoff from wetlands and urban, forested, and barren lands.

Data on the source inputs and terrestrial characteristics, available for nearly 20,000 land-surface polygons, were referenced to approximately 60,000 stream reaches in a digital stream network using conventional spatial disaggregating methods in a geographic information system [see Smith *et al.* 1997]. The surface water flow paths, defined according to a 1:500,000 scale digital network of rivers for the conterminous United States, cover nearly one million kilometers of channel, and are obtained from the U.S. Environmental Protection Agency River Reach File 1 (RF1). The river reach network provides the spatial framework in the model for relating in-stream measurements of flux at monitoring stations to landscape and stream channel properties in the watersheds above these stations. The median watershed size of the reaches is 82 $km^2$ with an interquartile range from 40 to 150 $km^2$. Stream attributes of the digital network include estimates of mean streamflow and velocity from which water time of travel is computed as the quotient of stream length and mean water velocity.

Model predictions of nutrient export were summarized for the 2,057 nontidal watersheds (hydrologic cataloging units; see Seaber *et al.* 1987) comprising the major water-resources regions of the conterminous United States (see Smith *et al.* 1997; model output is available at http://water.usgs.gov/nawqa/sparrow/wrr97/results.html). These watersheds are a logical choice for national level water-quality characterization because they represent a systematically developed and widely recognized delineation of U.S. watersheds, and provide a spatially representative view of water-quality conditions (Smith *et al.* 1997; Seaber *et al.* 1987).

### *Results and discussion*

A statistical summary of TN and TP export from the watersheds of the major water resources regions of the conterminous United States is given in Tables 1 and 2. The tables give median total export and the median and quartile percent contributions to export from each of the five source categories. According to Table 1, for example, the estimated median TN export from the watersheds in the Mid Atlantic region is 9.0 kg $ha^{-1}$ $yr^{-1}$ . The median contribution to TN export from animal agriculture in the same region is 15.5 percent with quartile (i.e., 25$^{th}$ and 75$^{th}$ percentile) values of 8.2 and 23.0 percent.

Median export of TN and TP varies among the regions by more than an order of magnitude, with the highest rates for both elements occurring in the Upper Mississippi and Ohio regions and the lowest occurring in the Great Basin and Rio Grande regions. Recognizing that these figures refer to the median rate in each region, it is clear that the total range of variation in nutrient export rates among all watersheds is much larger.

From Tables 1 and 2, it is also clear that the relative importance of the different categories of nutrient sources in watersheds vary greatly from one region to another. Not surprisingly, point sources, which generally represent the smallest contributors to nitrogen and phosphorus export from watersheds, are seen to reach their highest importance in the densely populated Northeast, Mid Atlantic, and Great Lakes regions. In the Northeast region, in fact, point sources contribute more than half of the total phosphorus export in at least twenty-five percent (i.e., upper quartile) of the watersheds. Fertilizer is a large contributor to nutrient loads in the high-export Upper Mississippi and Ohio regions, but makes its highest contribution in percentage terms (median TN=75 percent; median TP=64 percent) in the Red-Rainy basin in the northern plains where total export is low. In the southwestern regions, where total export is also low, nonagricultural runoff from forest, barren, and range lands contributes the largest percentage to watershed export of nutrients. Atmospheric nitrogen contributes more than a quarter of the total nitrogen export in a majority of watersheds in the northeastern quadrant of the United States, and is the dominant source in the Great Lakes and Mid-Atlantic water-resource regions.

The importance of animal agriculture as a nutrient source in watersheds is presented in the regional summaries in Tables 1 and 2 and also in map form in Figures 1a and 1b, which show the percentage contribution to TN and TP export from each of the 2,057 hydrologic units. For total nitrogen, the median contributions of animal agriculture in the

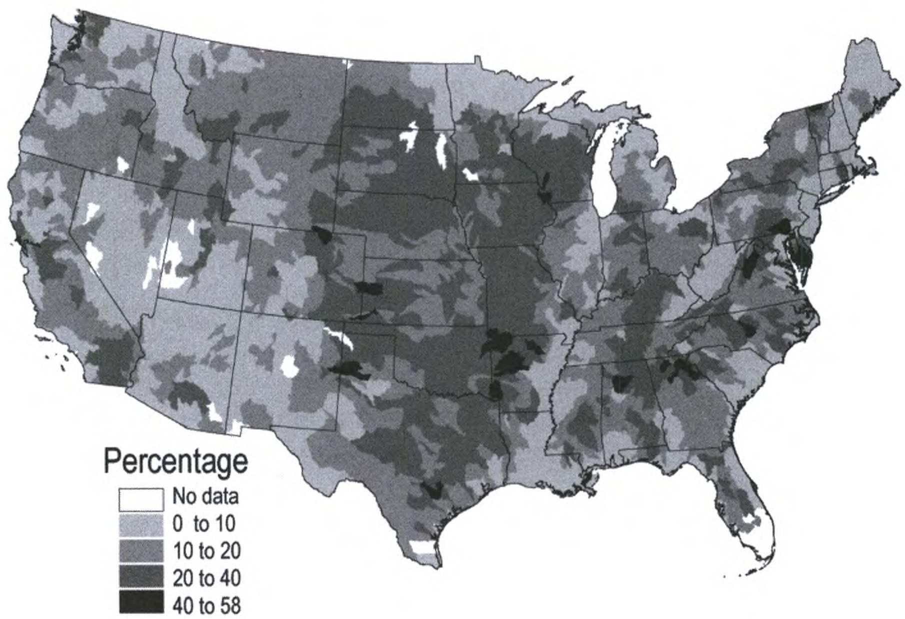
**Table 1.** Point- and nonpoint-source contributions to total nitrogen export from watersheds in major water-resource regions of the conterminous United States. Total export is the median export from hydrologic cataloging units in each region. The median and quartile values for the source contributions within each region are expressed as a percentage of the total export.

| Region | Total Export ($kg\ ha^{-1}\ yr^{-1}$) | Percentage of Total Export | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Point Sources | | Fertilizer | | Animal Agriculture | | Atmosphere | | Nonagricultural Runoff | |
| | | Median | Quartiles | Median | Quartiles | Median | Quartiles | Median | Quartiles | Median | Quartiles |
| Northeast | 6.7 | 4.3 | 1.2 – 19 | 6.2 | 3.6 – 13 | 5.8 | 2.8 – 9.3 | 30 | 25 – 38 | 38 | 27 – 52 |
| Mid Atlantic | 9.0 | 4.1 | 1.6 – 20 | 14 | 10 – 22 | 16 | 8.2 – 23 | 32 | 20 – 40 | 22 | 14 – 28 |
| Southeast Atlantic-Gulf | 5.9 | 2.7 | 1.1 – 8.2 | 26 | 17 – 38 | 14 | 8.8 – 21 | 21 | 15 – 28 | 26 | 19 – 34 |
| Great Lakes | 8.0 | 4.3 | 1.3 – 12 | 22 | 7.8 – 41 | 10 | 4.6 – 17 | 25 | 16. 34 | 17 | 6.5 – 40 |
| Ohio | 11 | 1.8 | 0.7 – 7.0 | 30 | 9.2 – 58 | 14 | 9.2 – 20 | 25 | 15 – 42 | 13 | 6.4 – 23 |
| Tennessee | 8.3 | 2.7 | 0.6 – 7.2 | 22 | 16 – 29 | 19 | 15 – 25 | 26 | 21 – 33 | 24 | 18 – 28 |
| Upper Miss. | 13 | 0.8 | 0.5 – 1.6 | 55 | 40 – 66 | 21 | 15 – 27 | 13 | 11 – 17 | 3.6 | 2.1 – 10 |
| Lower Miss. | 7.6 | 2.3 | 1.0 – 11 | 40 | 14 – 64 | 6.3 | 3.2 – 10 | 22 | 14 – 28 | 18 | 8.0 – 28 |
| Red Rainy | 3.5 | 0.3 | 0.1 – 0.6 | 75 | 57 – 81 | 5.2 | 2.8 – 9.0 | 9.3 | 7.4 – 14 | 7.2 | 3.4 – 20 |
| Missouri | 2.1 | <0.1 | <0.1 - <0.1 | 30 | 8.8 – 51 | 20 | 15 – 25 | 16 | 12 – 20 | 29 | 9.5 – 55 |
| Ark-Red | 3.9 | 0.8 | 0.2 – 1.9 | 29 | 20 – 46 | 23 | 17 – 29 | 18 | 14 – 23 | 20 | 12 – 28 |
| Texas-Gulf | 3.7 | 0.9 | 0.1 – 5.3 | 30 | 18 – 41 | 19 | 14 – 26 | 18 | 14 – 21 | 23 | 13 – 37 |
| Rio Grande | 1.0 | <0.1 | <0.1 - < 0.1 | 1.7 | 0.6 – 5.1 | 11 | 6.2 – 14 | 13 | 8.9 – 16 | 71 | 63 – 80 |
| Upper Colorado. | 1.9 | 0.1 | <0.1 – 0.4 | 2.0 | 1.1 – 4.5 | 8.7 | 5.3 – 12 | 17 | 14 – 20 | 72 | 64 – 76 |
| Lower Colorado | 0.7 | <0.1 | <0.1 – 0.4 | 1.6 | 0.7 – 16 | 6.6 | 2.9 – 10 | 8.6 | 5.0 – 9.9 | 78 | 65 – 84 |
| Great Basin | 0.9 | <0.1 | <0.1 - <0.1 | 3.6 | 0.9 – 9.2 | 9.3 | 5.6 – 15 | 6.4 | 5.4 – 8.1 | 78 | 61 – 86 |
| Pacific NW | 4.2 | <0.1 | <0.1 - <0.1 | 12 | 5.5 – 30 | 11 | 7.3 – 14 | 13 | 8.0 – 16 | 57 | 34 – 69 |
| California | 4.8 | 1.2 | 0.3 – 6.7 | 21 | 8.9 – 52 | 12 | 7.6 – 17 | 8.7 | 5.5 – 13 | 35 | 16 – 62 |
| United States | 4.7 | 0.8 | 0.5 – 3.4 | 22 | 7.5 – 45 | 14 | 8.2 – 21 | 16 | 11 – 23 | 28 | 13 – 56 |

**Table 2.** Point- and nonpoint-source contributions to total phosphorus export from watersheds in major water-resource regions of the conterminous United States. Total export is the median export from hydrologic cataloging units in each region. The median and quartile values for the source contributions within each region are expressed as a percentage of the total export.

| Region | Total Export ($kg\ ha^{-1}\ yr^{-1}$) | Percentage of Total Export: Point Sources Median | Point Sources Quartiles | Fertilizer Median | Fertilizer Quartiles | Animal Agriculture Median | Animal Agriculture Quartiles | Nonagricultural Runoff Median | Nonagricultural Runoff Quartiles |
|---|---|---|---|---|---|---|---|---|---|
| Northeast | 0.41 | 18 | 7.1 – 55 | 7.7 | 4.1 – 13 | 6.8 | 3.1 – 14 | 54 | 28 – 68 |
| Mid Atlantic | 0.68 | 14 | 5.6 – 45 | 19 | 14 – 26 | 25 | 13 – 38 | 22 | 12 – 37 |
| Southeast Atlantic-Gulf | 0.54 | 7.9 | 3.4 – 22 | 23 | 11 – 32 | 30 | 20 – 40 | 29 | 18 – 40 |
| Great Lakes | 0.49 | 13 | 4.7 – 24 | 26 | 12 – 41 | 18 | 8.0 – 29 | 22 | 6.6 – 59 |
| Ohio | 0.93 | 7.3 | 2.6 – 21 | 30 | 15 – 45 | 30 | 20 – 41 | 14 | 6.2 – 33 |
| Tennessee | 0.67 | 7.2 | 2.3 – 16 | 24 | 18 – 30 | 33 | 26 – 43 | 23 | 16 – 34 |
| Upper Miss. | 1.1 | 3.6 | 1.7 – 6.8 | 37 | 30 – 44 | 47 | 35 – 55 | 3.6 | 2.1 – 10 |
| Lower Miss. | 0.53 | 9.6 | 4.7 – 27 | 29 | 6.7 – 58 | 15 | 8.9 – 25 | 27 | 13 – 39 |
| Red Rainy | 0.22 | 1.7 | 0.9 – 3.6 | 64 | 45 – 77 | 12 | 7.8 – 22 | 11 | 5.1 – 23 |
| Missouri | 0.19 | 1.0 | 0.3 – 2.4 | 20 | 6.8 – 30 | 42 | 28 – 55 | 29 | 14 – 60 |
| Ark-Red | 0.36 | 2.7 | 1.0 – 5.4 | 18 | 10 – 29 | 48 | 38 – 56 | 24 | 13 – 33 |
| Texas-Gulf | 0.38 | 2.7 | 0.5 – 14 | 18 | 8.6 – 25 | 39 | 29 – 49 | 29 | 16 – 46 |
| Rio Grande | 0.12 | <0.1 | <0.1 - < 0.1 | 0.9 | 0.3 – 2.7 | 16 | 11 – 20 | 81 | 73 – 87 |
| Upper Colorado | 0.14 | 0.4 | <0.1 – 1.8 | 1.1 | 0.6 – 2.6 | 16 | 10 – 21 | 81 | 75 – 88 |
| Lower Colorado | 0.10 | 0.3 | <0.1 – 1.3 | 1.0 | 0.4 – 7.7 | 12 | 4.9 – 18 | 83 | 69 – 91 |
| Great Basin | 0.09 | 0.2 | <0.1 – 2.1 | 3.5 | 1.7 – 8.1 | 14 | 8.4 – 20 | 79 | 65 – 88 |
| Pacific NW | 0.30 | 1.5 | 0.2 – 8.9 | 7.1 | 2.9 – 18 | 19 | 12 – 25 | 65 | 43 – 78 |
| California | 0.41 | 4.0 | 1.1 – 19 | 9.5 | 3.7 – 30 | 19 | 12 – 29 | 40 | 20 – 71 |
| United States | 0.37 | 3.0 | 0.7 – 11 | 17 | 5.5 – 31 | 26 | 15 – 42 | 33 | 15 – 65 |

## a Total Nitrogen




## b Total Phosphorus

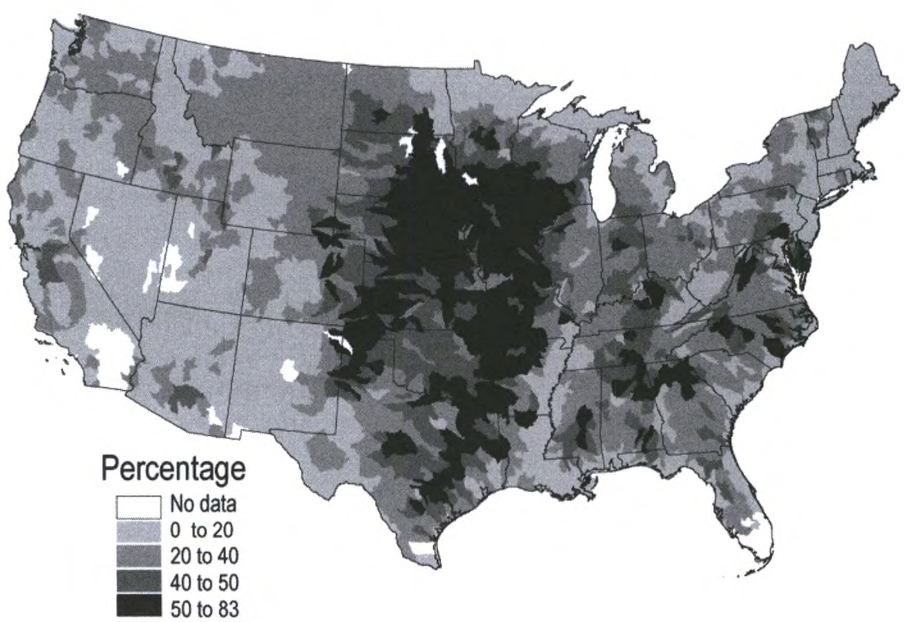



**Figure 1.** Contributions (percentage) of animal agriculture to nutrient export from hydrologic cataloging units in the conterminous United States.

water resource regions range from about 5 to 23 percent (Table 1). The highest contributions (median=18 to 23 percent) are found in the Tennessee, Upper Mississippi, Missouri, Arkansas-Red, and Texas-Gulf regions. Figure 1a indicates that in many watersheds in the states of Wisconsin, Iowa, Missouri, Oklahoma, and Texas, animal agriculture contributes from 20 to 58 percent of TN export. Although animal agriculture in the Mid-Atlantic and Southeast regions contributes a median of only about 8 percent to export (Table 1), farm animals contribute more than 20 percent of the exported nitrogen from many watersheds within these regions (Figure 1a). The lowest contributions of animal agriculture (i.e., less than 10 percent) are found in the Northeast, Great Lakes, and many western water-resources regions.

For total phosphorus, the median percentage contributions of animal agriculture in the major water-resource regions range from about 7 to 48 percent (Table 1) or approximately twice the contributions estimated for total nitrogen. The highest contributions occur in the Upper Mississippi, Arkansas-Red, Missouri, and Texas-Gulf regions, including watersheds in the states of Wisconsin, Iowa, Nebraska, Missouri, Kansas, Arkansas, Oklahoma, and Texas (Figure 1b). The water-resource regions with the lowest contributions of animal agriculture to stream phosphorus (i.e., less than 20 percent) are similar to those found for total nitrogen, and include the Northeast, Great Lakes, and many western regions.

### *Summary and Conclusions*

Estimating the importance of animal agriculture as a source of nutrients in watersheds is made difficult by the diverse and ubiquitous nature of nitrogen and phosphorus forms in the environment. The relative importance of nutrient sources is most meaningfully expressed in "in-stream" terms rather than as raw inputs. However, the contribution of individual nutrient sources to in-stream water quality is not directly measurable in large watersheds, and must therefore be estimated using a watershed model. The results of recent research indicate that spatial referencing of variables improves the accuracy of watershed nutrient models. SPARROW models of TN and TP have been calibrated with stream monitoring records from more than 370 locations across the conterminous United States. These models were used here to estimate nutrient contributions from five source categories for the 2,057 cataloging unit watersheds comprising the major water-resources regions.

The relative importance of the different categories of nutrient sources in watersheds vary greatly from one region to another reflecting differences in human activities. Point sources generally contribute little to nutrient export from most of the nation's watersheds, but contribute a majority of the total phosphorus export from many watersheds in the densely populated northeastern United States. Atmospheric deposition is the largest contributor to stream export of nitrogen in more than half of the watersheds in the northeastern United States. In the southwestern United States, nonagricultural runoff is the predominant source of both nitrogen and phosphorus in watershed export. Fertilizer is an important contributor to nutrient export in many watersheds throughout the central United States, and is the largest contributor in most watersheds in the Ohio Valley and Midwestern states. Animal agriculture is also an important contributor of both nitrogen and phosphorus in watersheds in the same regions, but animal wastes constitute a much larger fraction of phosphorus export than nitrogen export in these areas.

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## Session 2

# Animal Agriculture and Nutrients

# A Changing Animal Agriculture: Implications for Economies and Communities in the Northeast and Middle Atlantic States

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**Introduction**

The structure of animal agriculture in the US is rapidly changing. These structural changes include the number and size of farms, marketing arrangements for coordinating the vertically linked food system, and the location of animal agriculture (Martin and Norris, 1998). The changes are occurring as part of an industrial transformation involving technological change, specialization and changing organizational arrangements that has been underway in agriculture for more than four decades, but that has recently accelerated (Abdalla, Lanyon, and Hallberg, 1995). A number of authors have written on the reasons behind these changes and their consequences for agriculture (Barkema and Cook, 1993; Pagano and Abdalla, 1994; Lanyon and Thompson, 1996; Drabenstott, 1998). To set the stage for discussions about nutrient loadings from animal agriculture, this paper describes the changes occurring in the structure of animal agriculture in the Northeast and Middle Atlantic States. Emphasis is placed upon the economic role of animal agriculture within states in this region and highlighting trends and regional patterns of change. This description is followed by a discussion of several important issues for communities and economies.

**A Changing Animal Agriculture: The Northeast and Middle Atlantic Regions**

For the purpose of helping to set the stage for discussions at the conference, a profile of the animal agriculture sectors in the Northeast and selected states in the Middle Atlantic region was assembled. These 14 states included: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Vermont, Virginia and West Virginia. Information was obtained primarily from the US Agricultural Censuses and supplemented with other sources (see references).

## Human Population

Since some environmental issues and many nuisance and related issues have to do with the proximity of people and animals, information on human population patterns and trends is important. Table 1 presents information on states' population in the region and its growth from the 1970s to the present. The most populated states are New York, Pennsylvania, New Jersey, North Carolina, Massachusetts, Virginia, and Maryland. The fastest growing states over the 1970 - 1990 period (North Carolina, Virginia, Delaware) were in the southern part of the region with the exception of New Hampshire. The population in the two most populated states, New York and Pennsylvania, remained almost unchanged over this period.

**Table 1 - Human Population by state**

| State | Year 1970 | 1980 | 1990 | 1999 |
|---|---|---|---|---|
| Maine | 993,722 | 1,125,043 | 1,227,928 | 1,253,040 |
| New Hampshire | 737,681 | 920,610 | 1,109,252 | 1,201,134 |
| Massachusetts | 5,689,170 | 5,737,093 | 6,016,425 | 6,175,169 |
| Rhode Island | 949,723 | 947,154 | 1,003,464 | 990,819 |
| Connecticut | 3,032,217 | 3,107,564 | 3,287,116 | 3,282,031 |
| New York | 18,241,391 | 17,558,165 | 17,990,455 | 18,196,601 |
| Vermont | 444,732 | 511,456 | 562,758 | 593,740 |
| New Jersey | 7,171,112 | 7,365,011 | 7,730,188 | 8,143,412 |
| Pennsylvania | 11,800,766 | 11,864,720 | 11,881,643 | 11,994,016 |
| Delaware | 548,104 | 594,338 | 666,168 | 753,538 |
| Maryland | 3,923,897 | 4,216,933 | 4,781,468 | 5,171,634 |
| West Virginia | 1,744,237 | 1,950,186 | 1,793,477 | 1,806,928 |
| Virginia | 4,651,448 | 5,346,797 | 6,187,358 | 6,872,912 |
| North Carolina | 5,084,411 | 5,880,095 | 6,628,637 | 7,650,789 |

## General Agricultural Economy

To illustrate the size of each state's agricultural economy, states' total annual agricultural receipts are presented in Table 2. In 1974, the top ranking states were North Carolina, New York, Pennsylvania, Virginia and Maryland. In 1997, North Carolina remained number one - with over $8.2 billion in total receipts - but Pennsylvania - with about $4.1 billion annually overtook New York for the number two spot.

**Table 2 - State Total Cash Farm Receipts ($1000)**

| State | Year 1974 | 1987 | 1997 |
|---|---|---|---|
| Maine | 418,397 | 408,549 | 489,376 |
| New Hampshire | 70,384 | 136,023 | 152,531 |
| Massachusetts | 187,463 | 385,333 | 531,136 |
| Rhode Island | 22,994 | 75,631 | 63,104 |
| Connecticut | 202,585 | 364,424 | 501,087 |
| New York | 1,505,428 | 2,620,935 | 2,835,548 |
| Vermont | 221,403 | 434,316 | 499,632 |
| New Jersey | 343,140 | 628,114 | 794,263 |
| Pennsylvania | 1,504,894 | 3,236,697 | 4,131,936 |
| Delaware | 271,991 | 486,912 | 754,239 |
| Maryland | 632,553 | 1,128,957 | 1,534,792 |
| West Virginia | 142,044 | 267,699 | 396,840 |
| Virginia | 958,086 | 1,738,242 | 2,406,046 |
| North Carolina | 2,582,471 | 3,767,443 | 8,230,000 |

Farm-related Employment. One measure of the economic importance of the agricultural economy is the number of farm and farm-related jobs. This measure was obtained for 1996 only (US Bureau of Labor) and ranged from 11 percent to 19 percent. The state with the most farm-related employment were North Carolina (19.1), Vermont (16.8) and Maine (16.7). Those states with the least included Connecticut(11.0), New Jersey (11.9), New York (12.1) and Massachusetts (12.3).

## Animal Agriculture's Role in States' Agricultural Economies

Several states in the region have significant animal agriculture sectors. One way to obtain a better picture of animal agriculture's role is examine revenues from crop and livestock receipts separately. Since the 1970s, North Carolina has been the leading state in terms of crop cash receipts. In 1974, Virginia was second followed by New York, Pennsylvania and Maryland. By 1987, Pennsylvania overtook New York and Virginia fell to fourth place, followed by Maryland. The relative rankings were the same in 1997 with the exception of New Jersey replacing Maryland at fifth place.

The relative size of state animal agriculture sectors has also changed significantly over the past 25 years. In 1974, Pennsylvania ranked first followed by New York, North Carolina, Virginia, and Maryland. By 1987, North Carolina had overtaken New York and by 1997, this state surpassed Pennsylvania to become the leading livestock state in the region.

The size and emphasis of a state's agricultural economy toward animal agriculture can be represented by the ratio of a state's livestock receipts to its total farm receipts. Table 3 gives this ratio for the 14 states in the region for three periods: 1974, 1987 and 1997. Alternately, this measure represents the degree of diversification of a state's agricultural economy.

| Table 3 - Percent of Total Cash Farm Receipts from Livestock | | | |
|---|---|---|---|
| | | Year | |
| State | 1974 | 1987 | 1997 |
| Maine | 54.6% | 54.5% | 56.5% |
| New Hampshire | 72.5% | 51.0% | 44.8% |
| Massachusetts | 52.9% | 31.2% | 21.5% |
| Rhode Island | 50.6% | 16.8% | 13.8% |
| Connecticut | 58.4% | 52.2% | 44.5% |
| New York | 68.5% | 68.4% | 64.5% |
| Vermont | 92.1% | 87.1% | 82.9% |
| New Jersey | 33.1% | 31.0% | 21.1% |
| Pennsylvania | 69.3% | 72.0% | 67.9% |
| Delaware | 58.6% | 76.1% | 76.7% |
| Maryland | 58.1% | 65.0% | 60.5% |
| West Virginia | 71.0% | 77.7% | 82.5% |
| Virginia | 47.8% | 72.0% | 64.1% |
| North Carolina | 35.6% | 56.1% | 57.4% |

In both 1974 and 1997, Vermont, New Hampshire, West Virginia, Pennsylvania, and New York were among that states with agricultural economies that were heavily reliant (i.e. a ration of greater than .75) on animal agricultural receipts. In 1997, Delaware, Virginia and North Carolina also appeared in this group.

Several trends are evident from the data. In several New England states (New Hampshire, Massachusetts, and Rhode Island) the ratio declined dramatically over this period. It also fell in Vermont and New Jersey by 10 percent. The ratio remained fairly steady in three states in the central part of the region, New York, Pennsylvania, and Maryland. Growth in the relative proportion of animal receipts in total revenues was most pronounced in the southern part of the region, particularly in Delaware, Virginia and North Carolina. Most increases in livestock dependence for these three states occurred from 1974 to 1987. The ratio increased steadily over the period only for West Virginia, a state which started the reference period as a very livestock dependent state.

## Farmland Loss and Farm Exits

Farms. In 1974, total number of farms in the Northeast and Middle Atlantic Region was about 307,000. By 1997, the number of farms had decreased significantly (by almost one-quarter) to about 234,000 farms. At the same time the amount of land acreage in farms declined from about 51 million acres in 1974 to 42.5 million acres in 1997, a loss of about 16 percent. A large proportion of the total quantity of land that went out of agriculture in this period was located in four principal states: New York, Pennsylvania, Virginia and North Carolina. Other states with significant amounts of land transitioning out of agricultural use included Maine, New Hampshire, Massachusetts, Connecticut, Vermont, New Jersey, and Maryland. West Virginia was the only state in the region that reported relatively little loss of their agricultural land base over this time period.

Farm Exits. The change in farm numbers was most dramatic in North Carolina, with a loss of more than 40,000 farms (Table 4). In addition, significant proportions of farms went out of business in Delaware, New York, Virginia, Maryland, Pennsylvania and Maine. Several states with small or medium sized agricultural economies, including Connecticut, New Hampshire, New Jersey, Massachusetts, Rhode Island and West Virginia, actually increased their farm numbers over time. (For many of these states, the increase in number of farms may not reflect the number of "working" farms since in many cases, hobby farms or farmettes are included in these figures.) Moreover, states with the largest agricultural economies tended to be the same states with largest number of farm losses, suggesting a industrial transformation in these economies to a more consolidated agriculture based on smaller number of larger farming units was underway.

**Table 4 - Number of Farms by State**

| State | Year 1974 | 1987 | 1997 |
|---|---|---|---|
| Maine | 6,436 | 6,269 | 5,810 |
| New Hampshire | 2,412 | 2,515 | 2,937 |
| Massachusetts | 4,497 | 6,216 | 5,574 |
| Rhode Island | 597 | 701 | 735 |
| Connecticut | 3,421 | 3,580 | 3,687 |
| New York | 43,682 | 37,743 | 31,757 |
| Vermont | 5,906 | 5,877 | 5,828 |
| New Jersey | 7,409 | 9,032 | 9,101 |
| Pennsylvania | 53,171 | 51,549 | 45,457 |
| Delaware | 3,400 | 2,966 | 2,460 |
| Maryland | 15,163 | 14,776 | 12,084 |
| West Virginia | 16,909 | 17,237 | 17,772 |
| Virginia | 52,699 | 44,799 | 41,095 |
| North Carolina | 91,280 | 59,284 | 49,406 |

## Livestock Farms

The number of farms producing animals or animal products, such as eggs, in the Northeast and Middle Atlantic Region has declined significantly. This trend can be seen by looking at number of farms reporting livestock inventories in each state (calculated by adding together the number of farms with livestock inventories of major livestock categories in three years). Using this as indicator of animal production operations, the following six states lost more than 50 percent of livestock farms: North Carolina, Delaware, Maryland, New York, and Virginia (Table 5). Other states with significant losses of such farms included Pennsylvania, Maine, Vermont, and West Virginia.

## Animal Production

From the standpoint of environmental and nuisance issues the number of animals is important. Information was collected on the annual inventories of milk cows, swine (hogs and pigs), and poultry (layers/pullets and broilers/meat chickens) for several time periods. An overview of trends for these animal species emphasizing the dominant production states and any relative changes over the 1974-1997 period is presented on the next page.

**Table 5 - Number of Livestock Enterprises by State 1/**

| State | Year 1974 | 1987 | 1997 |
|---|---|---|---|
| Maine | 4,813 | 3,654 | 2,615 |
| New Hampshire | 2,276 | 1,773 | 1,523 |
| Massachusetts | 3,021 | 3,198 | 2,175 |
| Rhode Island | 394 | 381 | 327 |
| Connecticut | 2,495 | 2,214 | 1,688 |
| New York | 39,339 | 26,518 | 18,309 |
| Vermont | 6,591 | 5,045 | 3,748 |
| New Jersey | 3,574 | 3,390 | 2,593 |
| Pennsylvania | 55,965 | 41,471 | 28,872 |
| Delaware | 1,509 | 861 | 575 |
| Maryland | 11,388 | 7,538 | 5,038 |
| West Virginia | 22,423 | 15,419 | 12,810 |
| Virginia | 56,047 | 32,505 | 26,182 |
| North Carolina | 69,374 | 33,217 | 25,420 |

1/ Calculated by adding the number of farms reporting inventories of beef, milk cows, hog & pig inventory, and layer & pullets. Due to multiple enterprise, the figures do not reflect the actual number of livestock farms in each state.

Dairy. Milk production is significant for several states in the Northeast and Middle Atlantic Region. The major production states (in order of their milk cow numbers) are New York and Pennsylvania, followed by Vermont, Virginia and Maryland. The relative rank was unchanged from 1974 to 1997 (Table 6). The number of dairy farms declined very significantly in all states. While the number of cows also declined over time, milk production generally expanded due to adoption of productivity enhancing technologies on most remaining farms.

**Table 6 - State Ranking for Number of Milk Cows**

| Ranking | Year 1974 | 1987 | 1997 |
|---|---|---|---|
| #1 | New York | New York | New York |
| #2 | Pennsylvania | Pennsylvania | Pennsylvania |
| #3 | Vermont | Vermont | Vermont |
| #4 | Virginia | Virginia | Virginia |
| #5 | Maryland | Maryland | Maryland |

Poultry. Poultry production is very significant in the Northeast and Middle Atlantic region. The dominant states for egg production are Pennsylvania and North Carolina with Maine, Virginia, Maryland and New York also having significant production. Table 7 shows the relative shares of production increasing for Pennsylvania and Maine and decreasing for New York and Virginia. With the exception of Maine, production generally declined in the New England states. Several states, including West Virginia, Maryland, Pennsylvania and Delaware, rapidly expanded their inventories of layers and pullets over this time period. Over the region as a whole, the number of egg producing farms declined significantly.

**Table 7 - State Ranking for Layers and Pullets Inventory**

| Ranking | 1974 | Year 1987 | 1997 |
|---|---|---|---|
| #1 | North Carolina | Pennsylvania | Pennsylvania |
| #2 | Pennsylvania | North Carolina | North Carolina |
| #3 | New York | Maine | Maine |
| #4 | Maine | Virginia | Virginia |
| #5 | Virginia | New York | Maryland |

The portion of the poultry industry raising chickens for meat is very significant in the region. A measure of this growth is the number of broiler and meat chickens sold annually. The leading state in both 1974 and 1997 was North Carolina (Table 8). Other current major states include Virginia, Maryland, Delaware, and Pennsylvania. Virginia has increased its relative position since 1974, with Maryland and Delaware declining slightly in their relative shares. The shifts in broiler production within states in the region are noteworthy. For example, Maine was fifth in sales in 1974 and now has very little production. Pennsylvania more than doubled its sales over the past 25 years and now is fifth in the share of sales. Production in several New England states and New York and New Jersey declined over the period. West Virginia is a state that steadily expanded its production and sales. Farm numbers expanded only in the major production state of Virginia and in a few states with much smaller production levels (e.g. New Hampshire, New Jersey and Vermont).

**Table 8 - State Ranking for Broilers/Meat Chickens Sold**

| Ranking | 1974 | Year 1987 | 1997 |
|---|---|---|---|
| #1 | North Carolina | North Carolina | North Carolina |
| #2 | Maryland | Maryland | Virginia |
| #3 | Delaware | Delaware | Maryland |
| #4 | Virginia | Virginia | Delaware |
| #5 | Maine | Pennsylvania | Pennsylvania |

<u>Hogs and Pigs</u>. The region contains North Carolina, where many innovations in hog production systems occurred in the last decade and where significant rapid expansion has happened. In 1997, North Carolina's production was almost 10 times the magnitude of the next largest production state, Pennsylvania, in terms of inventories. Pennsylvania's swine production has been increasing and in 1987 it replaced Virginia as the second leading state in the region. Relatively smaller amounts of production occur in New York and Maryland. Both states exhibit a long-term trend of declining hog and pig inventories and sales.

The rapid decline in hog farm numbers illustrates the impact of technological and market change on farm structure. In the leading state of North Carolina, 20,000 of the approximate 23,000 swine farms exited from 1974 to 1997. In Pennsylvania, about 7,700 of the more than roughly 11,000 hog farms went out of business over this time period.

**Table 9 - State Ranking for Hog and Pig Inventory**

| Ranking | Year 1974 | 1987 | 1997 |
|---|---|---|---|
| #1 | North Carolina | North Carolina | North Carolina |
| #2 | Virginia | Pennsylvania | Pennsylvania |
| #3 | Pennsylvania | Virginia | Virginia |
| #4 | Maryland | Maryland | Maryland |
| #5 | New York | New York | New York |

## Discussion

Based on the information provided in the previous section, three important questions for discussion can be identified.

1.) Given the trends and patterns of the past three decades within the region, what will the future structure of animal agriculture look like? What expansion and/or regional shifts in location of animal agriculture are likely within or outside of the region? Also, what will be the environmental and other costs of such future growth?

2) What are the economic benefits of the emerging animal agriculture to communities and economies? Given the potential negative environmental from loadings of nutrients from animal agriculture, communities are increasingly asking what do they get out of animal facilities. The nature of this tradeoff will affect communities' and perhaps states' willingness to host additional animal facilities and/or allow expansion.

3) What public policy innovations could be developed to allow the beneficiaries of animal agriculture to compensate those potentially harmed so that orderly and appropriate development of animal agriculture might be possible?

## Emerging Patterns of Animal Production

As described earlier, there are clearly important changes occurring in patterns of animal production. In general, animal agriculture has become relatively less economically important in the northern parts of the region and become relatively more important in the southern part of the region. Several states, most notably Pennsylvania and New York, are holding their own or expanding slowly.

The process of structural change is a complex one. USDA researchers (Reimund et al 1981) identified three sets of external forces-new mechanical, biological or organizational technology; shifting market forces and demand; and new government policies and programs-that initiate the structural change process. Technological factors that were changing in the broiler industry in the 1950s and 1960s included mechanical and engineering advances in bird housing, materials handling, and processing, and adaptable organizational technology such as contracting and vertical integration. Important market-related factors were the existence of alternative production areas eager to accept new enterprises, potential for expanded consumption, high product market risks with respect to both price and access, high input risk in the form of difficulty in accessing capital, and ease of entry into production. Policy factors conditioning these market shifts included reduced feed grain costs due to the USDA commodity programs, federal tax provisions favorable to agriculture, and antitrust rules that were not prohibitive of industry activities. The researchers concluded that structural change is catalyzed by one or more external factors prompting an adjustment process that occurs in four stages: (1) *technological change*-innovators adopt new technology; (2) *locational shifts*-production of the commodity moves to areas more amenable to changed methods than to traditional ones; (3) *growth and development*-output rises as a result of new efficiencies; and (4) *adjustment to risks*-new institutions for coordination emerge and relationships within the sector evolve to manage new risks. The shift of the poultry industry out of New England and to the Delmarva Peninsula and other areas of the country can be explained by this progression.

Another concept that is helpful to explaining animal industry development and location is agglomeration economies or clustering (Pagano and Abdalla, 1994). The need to achieve economies of scale in processing appears to have been the factor that has driven vertical integration in the swine and poultry industries. For example, in Delaware, Maryland, and Virginia, eight firms with annual production of approximately contract over 500 million chickens in about 6,000 production units operate within a 16,000 square kilometer region Normally, poultry contract producers are located within 25 miles of the vertical integrator's processing facilities in the Delmarva peninsula (Narrod et al., 1994). Following a pattern similar to the poultry cluster to the north, North Carolina increased its hog processing capacity and used its new coordination arrangements to rapidly expand the size of production units and overall production volume in the first half of the 1990s.

More recently, a new factor - ecological concern - appears to be acting as a constraint to future expansion of existing animal agriculture clusters or possibly to development of new ones. Due to a major swine manure spill in North Carolina in June 1995, the state legislature enacted tougher water quality protection rules and a multi-year moratorium on certain-sized hog facilities. These public policy developments, as well as evidence about risks of locating large animal facilities in the flood plain revealed by Hurricane Floyd in September 1999, has caused some observers to predict that hog production may shift to areas with fewer environmental rules such as the Great Plains or southwest US (Drabbenstott, 1998; Bernick, 2000). However, the little systematic research conducted on this issue to date shows that economic, business climate and natural endowment factors are more important than environmental rules in determining growth and expansion in swine production among the leading states. The fish kills and related concerns about pfiesteria in the Pocomoke river in Maryland in summer 1997 and the subsequent enactment of a phosphorus-based state nutrient management law may also be a bellwether of stronger state or federal environmental rules for the Middle Atlantic Region. Such change will inevitably cause the environmental costs of animal agriculture to be factored into firms' decision-making, possibly affecting future expansion or location decisions.

**Economic Benefits of Animal Agriculture to Communities**

As noted earlier, animal agriculture provides significant benefits to economies in states in the Northeast and Middle Atlantic region in terms of income and jobs. An important question is: as animal agriculture becomes more industrialized, what is the distribution of those benefits to individuals and communities? And are those benefits large enough to offset potential or actual environmental costs from excessive nutrient loadings or other costs that are incurred by communities that host large-scale facilities?

Due to its need for feeds and other inputs, traditional animal agriculture was closely linked local on-farm enterprises or to other farmers and economic agents. As such it benefitted from and provided benefits to the local or regional agricultural economy. With industrialization, animal agriculture has been transformed into a specialized and generally larger capital-intensive activity that is linked to economic agents far from the local community or region. Since larger-scale vertically integrated farms are more closely linked to companies further from the local area, a logical hypothesis is that industrialized agricultural provides less local economic benefits that traditional agricultural production systems.

Little empirical work has been completed to shed light upon this question. One important study is by Chism (1993) who examined the spending patterns among a sample of smaller and larger crop and livestock farmers in southwest Minnesota. When farms were divided by operation type, crop-intensive farms showed a very weak relationship between farm size and local expenditures. This suggested larger crop farms replicate the expenditure patterns of the smaller farms they replace. However, livestock-intensive farms showed a different expenditure pattern with local spending on a percentage basis rapidly declining with size. However, local spending per-acre changed relatively little with the livestock-intensive farm size. For livestock operations, a certain base amount of spending occurs locally. Increases in spending after a certain point due to size seem to occur outside the local area. The differences between crop and livestock operations was also clear in input purchase patterns. The major crop inputs (crop chemicals, fertilizer, fuel and seed) were from local sources at least 85 percent of the time. Major livestock inputs, livestock purchases and feed, were from local sources 11 and 59 percent of the time. Part of livestock-intensive farming spending patterns may be due to the specialized technology used in larger operations. Local suppliers rarely can supply all the specialized equipment and construction techniques used in modern large scale livestock operations. Local suppliers may also be unable to provide the consistent quality and high volume of inputs needed in a large scale livestock operation. Specialists in breeding, along with discounted medicines and feeds are more likely to be found in distant markets. While a limited sample, these findings suggest that as livestock farms increase in size more economic benefits accrue beyond the local community's boundaries. More research is needed to validate these findings and to determine if they are applicable to other areas.

**Public Policy Innovations**

In some communities and states, expansion of animal agriculture has been blocked as a result of local community concern about the potential adverse environmental, health or nuisance effects. One approach to such opposition has been that of education and community relations. However, if the risks or economic damages (e.g., property value declines) to the community are real, it is unlikely that education and or promises of good behavior will be sufficient to resolve a stalemate. There appears to be a need for public policy innovations that permit the beneficiaries of changes in agriculture to compensate those potentially harmed. Thus far, there does not appear to be either a formal or informal institutional arrangement that can facilitate this negotiated transaction or exchange. One potential difficulty is that the environmental, and especially the nuisance, effects of animal operations are relatively focused upon neighbors or local community members while the economic benefits are more diffuse and broadly enjoyed by a region or state, or more generally, by consumers. Another challenge is that many of these costs are not reflected in markets and thus we have few available indicators of their magnitude. New and creative public policies that reconcile these disparate patterns of costs and benefits resulting from industrialized animal production will be needed for a more orderly transition of the agricultural economy and appropriate development of rural areas.

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# Farm Management and Nutrient Concentration in Animal Agriculture

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Biographies for most speakers are in alphabetical order after the last paper.

**Introduction**

Animal agriculture has been implicated as a source of nutrients that are degrading groundwater and surface water and increasing atmospheric nutrient levels. Classification of animal agriculture operations as CAFOs and AFOs and national strategies for change are attracting a lot of attention. Many suggestions have been made and a wide range of regulations have been adopted to change farm management in response to concerns about nutrient losses to water and air. These suggestions and regulations usually rely heavily on the voluntary adoption of farm practices or development of nutrient management plans by farmers that include explicit criteria for environmental protection. Locally-led conservation efforts by agency staff and educators are viewed as the delivery mechanism for the information about the improved practices or the enhanced plans. Can these actions based on the assumptions of voluntary action meet the challenges faced by an animal agriculture that attempts to balance production with environmental protection? Do the approaches to nutrient management that are being promoted match the scope of the farm management change required? How will these issues influence the success of nutrient management consultants, extension educators, and producer advisors?

## Current Status of Nutrient Management

Definitions of nutrient management vary widely in their scope and detail. Nutrient balance in field applications of nutrients from all sources with the nutrient requirements of the planned crops is generally part of most definitions. This criterion of nutrient balance is assumed to prevent the application of nutrients at rates that will exceed the capacity of the soil and planned crops to assimilate nutrients and prevent pollution (USDA/USEPA, 1999). Nutrient management is often described as sustaining an increase in agricultural production while protecting the environment (Hrubovcak et al., 1999). Under these circumstances, promoting changes in farm management is considered to be a transfer of technology problem — what is needed is known and it is in the best interests of potential adopters to accept it.

Farm structure, natural resource variability, and the economic risk of new practices, along with potential profitability, are often described as barriers to the adoption of "green" technologies such as nutrient management (Hrubovcak et al., 1999). Farm structural barriers include farm size and the availability of capable management and adequate labor. Diverse soil resources can increase the effort required to implement new practices by increasing the information required and the factors to be considered as well as the success of implementing selected practices that depend on soil characteristics. Because nutrients are required for crop growth, farmers who are not comfortable with risk may be slow to reduce the nutrient supply they provide and to depend on other sources. Typical incentives for farmers to overcome these barriers are economic incentives such as cost-sharing and regulations requiring their use. Has a comprehensive perspective of the situation been developed that will be the basis for effectively overcoming the barriers?

## Why Do Nutrients Concentrate in Animal Agriculture?

Biologically, animals rely on the energy captured by plants through photosynthesis. Every plant contains minerals and other nutrients required by animals in addition to fixed, high-energy carbon. Animals burn the energy of plants to grow and maintain themselves. They excrete unavailable, unused, or "used" minerals that were part of their bodies, but replaced in the process of maintaining themselves. Plants must reuse these excreted minerals as they fix more energy that will be used by animals. Mineral excretion in nature is critical to the process of energy capture by plants and animal growth. Domesticated animals also depend primarily on the high-energy carbon of plants and they excrete minerals in the same ways. Wherever animals are concentrated and supported by concentrated feed supplies, nutrients will tend to accumulate also.

Socially, a set of technologies were developed and policies implemented, especially since the end of WW II, to deliver feed that was not produced on the farm where the animals are located to animals. Obviously, transportation technologies are essential to the movement of bulky animal feeds from where they are produced to where they will be consumed. Perhaps more importantly, is the technology to manufacture fertilizers that can replace the minerals harvested in the crops and exported from the crop production areas. Without fertilizers, the farms producing the crops would be mined of their reserves and ultimately not be able to supply the feed chain. This depletion of farm nutrient supplies was a serious concern in many countries during the 19th century and the early part of the 20th century. Fertilizers are currently substituting for the cycling of nutrients that normally occurs in nature and offsetting the exporting of nutrients from crop producing farms. Animals can now be far removed from the cropland that produced their feed and concentrated in numbers that exceed the crop production capacity of the available land where they are located. (Lanyon, 1995).

Additional sets of technologies and policies contributed to the reorganization of agriculture and the development of specialized production locations (Lanyon, 1994). Breaking the bonds of nutrient deficiency was essential and the ability to transport feeds was critical, but policies that encouraged the growth of specific crops for animal feed through farm programs or investment policies that made gave preferential treatment to capital investments in animal facilities also contributed to the concentration of animals. With the concentration of animals in specialized production locations came the concentration of nutrients in those same places (Lanyon, 2000).

In addition to technologies and policies promoting specialization in agriculture, several complementary farm management pathways to concentrated animal production exist. For instance, some agricultural areas have been faced with declining prosperity as competition for their traditional commodities developed from new production regions. Opportunities for businesses to create integrated animal production arrangements meant these regions could develop replacement or complementary agricultural enterprises to stabilize their agricultural economy (Hart, 1991). Some regions settled by farmers with a cultural heritage that favors establishing the next generation on a farm have intensified animal production based on the wide range of external factors that made investments in animal agriculture feasible and attractive. This intensification was often facilitated by the local agribusiness infrastructure that was prepared to provide the necessary inputs and the product marketing. Finally, another set of "producers" with financial capital to invest has been taking advantage of the opportunities to consolidate animal production in new production locations. This has been the case in the concentration of the historically dispersed hog production on many fewer units with capital intensive facilities from breeding to finishing and processing.

**The Importance of Different Levels of Management**

The concentration of nutrients in animal agriculture seems to have less to do with the "need" of local crops for nutrients than with the consequences of animal biology and the technical and policy factors that made a new pattern of organization for agriculture possible. The current focus of nutrient management in animal agriculture on the use of nutrients in crop production is not consistent with the reasons behind the concentration of animal agriculture (and nutrients) that resulted from the variety of external factors.

One way to better understand the current situation is to compare proposals for nutrient management with the different levels of management that are at work. Operational management deals with the day-to-day activities of how things are done. Tactical management emphasizes short-term planning and allocation of internal resources to the activities of the organization. Strategic management is externally oriented. It attempts to determine what the organization should be doing and what external resources should be acquired in order for the organization to survive over the long-term. (Lanyon and Beegle, 1993).

Many nutrient management efforts have focused on operational management (soil testing, manure testing, spreader calibration, keeping records, etc.). New efforts aimed at reducing the levels of nutrients in animal feeds are also in this category. Nutrient management planning has typically been a form of tactical management with its emphasis on the distribution of manure according to potential crop requirements and the supplementation of manure and other biologically based nutrients with fertilizer. The Phosphorus Index is a tactical tool to incorporate landscape and hydrologic features into the development of these plans. Few approaches to strategic management that determines farm characteristics, how farms are organized, and how farms function have been developed or implemented.

Instead of applying nutrients "better" (operational) or planning the allocation of internal farm resources (manure and land) according to new criteria (tactical), strategic management — reconciling the external requirements of successful competition in the business of agriculture with the protection of environmental resources — seems to be a critical management level. Approaching the challenges of dealing with nutrients in excess of crop requirements within a farm relying heavily on animal production at the strategic level would be consistent with reasons behind the specialization of the farm. Attempting to impose constraints at the operational or tactical level of management that are inconsistent with the strategies of farmers will limit the voluntary adoption of the practices and will perhaps increase the need for enforcement action for compliance with regulations. Furthermore, these constraints will become part of the set of external factors influencing the future direction of each farm. Operational and tactical constraints imposed that add to the costs of farming may actually accelerate the concentration of animals as farmers attempt to cover the sunk costs associated with compliance. Nutrient management consultants, extension educators, and producer advisors are likely to find themselves amidst the dilemmas created by the inconsistencies of programs that address only part of the range in management that has contributed to concentrated animal agriculture.

**Contrasting Worldviews**

The apparent contradiction between the strategic reasons for increasing concentration of animal production and the adoption of practices to limit the impacts of animal manure on local water resources reflects basic differences in the ways different people, groups, or organizations view the world (Jacobs, 1994). Some, the guardians, are inclined, or explicitly charged, to consider the consequences of all actions for the conditions of a specific place or territory. Impacts of nutrients from animal agriculture on groundwater or surface water in a particular location are examples of guardian concerns. Others with a commercial view focus on the transactions of business and the functioning of interconnected nodes of production activity. How activity at the nodes is conducted or the consequences of their integration into a coordinated network often is influenced little by the consequences for specific locations or territory (Friedman and Weaver, 1979). Farming tends to be at the intersection of these worldviews with a connection to the land, but a need to succeed in the marketplace. As agriculture specializes, the tendency is for the commercial view to dominate over the guardian perspective. As the scope of farming widens to include so many off-farm activities associated with specialized agriculture, resolution of the tension between the guardian and commercial views will affect agribusinesses in addition to farmers. Taking actions to reduce the impacts of the nutrients in an area that are in excess of potential crop utilization will affect the viability of agribusinesses in the targeted areas.

**Dealing with Change**

Current expectations for nutrient management in animal agriculture will actually require farmers, and the associated agribusinesses, to manage for two bottomlines - one commercial and the other guardian. This expanded perspective on farm performance that includes the social concerns of territory, such as nutrient management for environmental protection, will be compatible with management criteria for preserving the ecological integrity of a specific location. It may be less effective in maintaining a vibrant, vigorous farm-based economy if the commercial bottomline is compromised in order to achieve the guardian demands. The key to successful change will be the ability of farmers and agribusinesses to deal effectively, according to both sets of criteria, with the nutrients in animal manure that are in excess of the potential crop utilization on their farms or in the region where they do business.

Excess nutrients on a farm can be reduced by decreasing the imports of nutrients in excess of the potential crop utilization in the area. This can be done by limiting the nutrients in animal diets or by limiting the number of animals that are supported by external inputs so that nutrient balance goals for land application of manure are achieved. This approach can affect the competitiveness of individual farms by limiting their potential income (Westphal et al., 1989; Pease et al., 1998) and may make it difficult for agribusnesses to survive. Excess nutrients can be reduced by relocating some of the animal production away from an area. This approach can be good for the producers who move with the production to other locations, but it can have unfavorable consequences for the businesses, community, and other producers left behind. (Clouser et al., 1994). Internalizing the costs of dealing with excess nutrients on individual farms can increase the costs of production for those operations compared to other producers who are not required to have those costs. This may mean that some producers will actually intensify their operations even more in order to reduce the costs of compliance for each unit of production and/or some producers will not be able to cover the additional expenses and will cease production. Another alternative that has not been extensively developed is the "marketing" of environmental performance.

Environmental management systems (EMS) are becoming a part of industry management programs in fields outside of production agriculture in response to the interests of customers and suppliers, regulators, communities, special interest groups, and investors. An EMS involves setting targets for environmental performance and then developing specific actions that will contribute to meeting those targets. It will typically involve an environmental policy, planning and implementation, monitoring and corrective action, and management review (Nadler, 1997). The idea is to create a mechanism for pollution prevention as an integral part of management. The challenge is to cover the costs of the system. In some cases this can be done with internal cost savings. However, there are other situations in which economies of efficiency are not sufficient. In these situations the role of those parties interested in the environmental impacts of businesses may develop reward systems for those that meet the additional expectations of pollution prevention. Because the EMS movement has been generated in response to these same outside groups, this may be an opportunity for external, strategic forces to exert a positive influence on the production process through novel, perhaps even market-based, approaches. These incentives will recognize performance and outcomes. They will not be tied to transfer and adoption of specific technology. They will search out and reward the businesses doing the best job in both production and protection. They will not approach each and every situation as a problem to be fixed with a known answer. They will meet the interests of both commerce and guardians.

## Conclusion

Nutrients accumulate in locations where animals are concentrated because of the biology of animals, the technological accomplishments that created abundant nutrient supplies, and the favorable policies promoting specialization in agriculture. The environmental consequences of this pattern of agricultural organization are now generating conflicts between those who view the world as guardians and those in farming and agriculture who must survive in the world of commerce. The challenge for nutrient management consultants, extension educators, and producer advisors is to work with clients to develop fully integrated business management systems that will support environmental protection goals. As new perspectives on the concentration of nutrients in animal agriculture emerge, these systems can contribute to value-added agricultural activity by providing pollution prevention. Under these new circumstances the systems will be consistent with and can be included in the strategic goals of all who participate in agriculture. Nutrient management consultants, extension educators, and producer advisors will participate in management and provide essential assurance to farmers, agribusinesses, and other stakeholders about management outcomes.

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# Advances in Animal Waste Management for Water Quality Protection: Case Study of the Delmarva Peninsula

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## The Delmarva Peninsula[1]

The Delmarva Peninsula is a lowland coastal area in the Mid-Atlantic region of the eastern coast of the United States (Figure 1). Delmarva includes all of Delaware and parts of Maryland and Virginia and is bordered on the west by the Chesapeake Bay and on the east by the Delaware Bay and the Atlantic Ocean. The peninsula is mainly located within the Atlantic Coastal Plain physiographic region and is dominated by flat to gently rolling topography. Altitudes on the peninsula range from sea level to a maximum of ~30 m. The northernmost portion of Delmarva is within the Piedmont physiographic province. Upland areas of the peninsula are bordered by low plains that slope toward coastal areas which contain tidal rivers, wetlands, and marshes. There are also many freshwater wetlands in upland forests and riparian wetlands in stream valleys. Rainfall is plentiful (115 cm/yr) and rather constant, averaging 7.5 to10 cm/month in the winter and spring and 10 to 12.5 cm/month in the late summer. Soils on Delmarva range from well-drained, highly productive silt loams in the Piedmont to well- and excessively well-drained sandy loams and loamy sands in the coastal plain. Significant areas of poorly drained soils are also present, particularly in southeastern Delaware.

Delmarva is fairly rural in character, with no large metropolitan areas and a total population of about 750,000. The two largest cities are in Delaware (Wilmington and Dover, populations of 72,000 and 30,000). However, urbanization of the peninsula is proceeding rapidly, particularly in northern Delaware and the coastal areas of Delmarva. In addition to permanent population growth, coastal areas annually experience large influxes of tourists; about five million tourists per year visit the Delaware beaches which have a resident population of < 25,000.

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[1]Information on the Delmarva peninsula obtained from Shedlock et al., 1999.

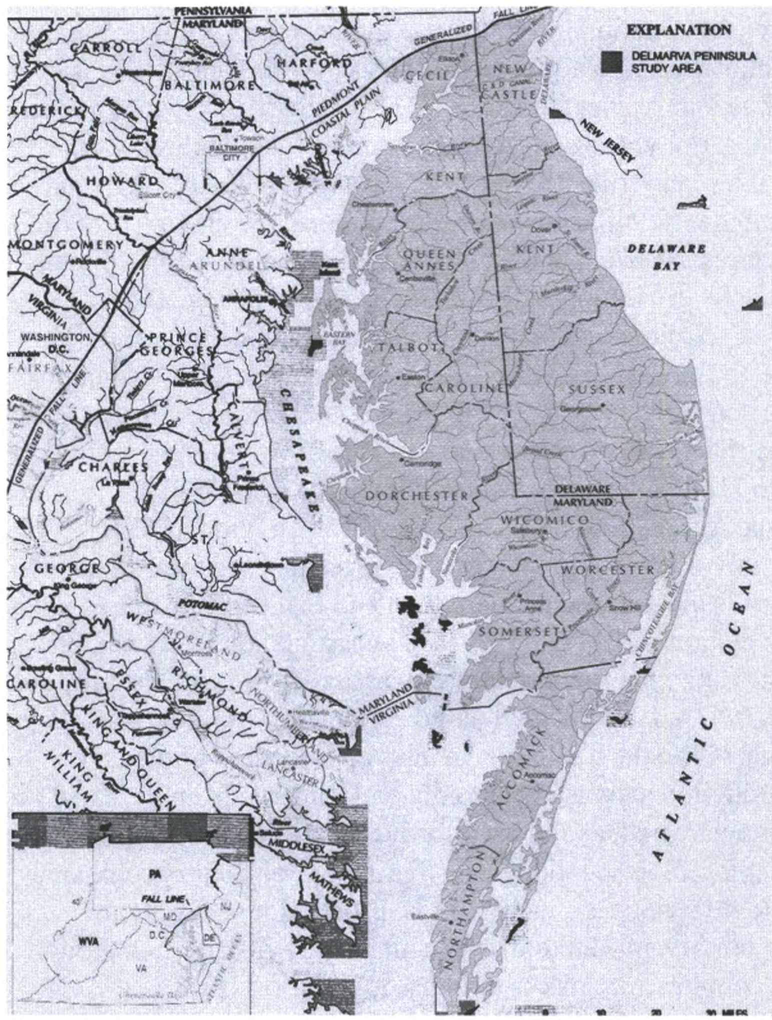


Figure 1. The Delmarva Peninsula (from Shedlock et al., 1999).

The hydrology of the Delmarva peninsula has been studied extensively and is well characterized. Most of the peninsula (~70%) drains westward to the Chesapeake Bay; the remaining lands either drain into the Delaware Bay or the Atlantic Ocean. Drainage from the central upland of the peninsula begins with many small streams that eventually enter tidal rivers and marshes. A notable characteristic of Delmarva is the absence of large watersheds; most drainage basins are < 25 $km^2$ in area. A rather extensive network of drainage ditches has been constructed throughout the peninsula to lower the water table and discharge surface runoff, especially in the poorly drained areas, such as southeastern Delaware. Groundwater on Delmarva is found in nine major confined sand aquifers. In much of Delmarva the confined aquifers are overlain by a surficial, water-table aquifer. The surficial aquifer serves as a source of water supply to most land uses and as a recharge source to underlying aquifers. Most of the rural population obtains its drinking water from domestic wells drilled into the surficial aquifer. Annual recharge to the surficial aquifer is about 40 cm/yr. Water-table depths in this aquifer range from near land surface to about 7 m in most areas but can be as deep as 10 m in well-drained areas.

## Overview of Agriculture on the Delmarva Peninsula

Agriculture is the predominant land use on Delmarva. Of the15,500 km$^2$ total land area, on the peninsula about 48% is in agriculture, 31% is in woodlands, 13% is in wetlands (fresh and tidal), 7% is in urban and residential use, and1% is in barrier beaches and islands. Major crops grown on Delmarva are soybeans, corn, small grains (wheat/barley), grain sorghum, hay/alfalfa, commercial vegetables, and fruits (Table 1). The "green industry" (greenhouses, and nurseries, landscaping) contributes significantly to the agricultural income in parts of Delmarva (e.g., for Delaware, cash receipts of ~$30 million, compared to $40 million for soybeans, the highest valued agronomic crop) and is growing rapidly especially in urbanizing areas

Delmarva's agriculture is dominated by a large and geographically concentrated poultry industry that is vital to the economy of the region. Approximately 600 million broiler chickens are produced each year on Delmarva, mainly in eight counties located in the southern portion of the peninsula (Table 1; DPI, 1999). Note that estimates by the poultry industry of the number of broilers produced on Delmarva each year (602 million; DPI, 1999) are substantially greater than those by the National Agricultural Statistics Service (502 million; NASS, 1997). The cause of this discrepancy is unknown. The poultry industry reported that the total value of broilers "processed and delivered" from Delmarva was $1.63 billion and that the industry as a whole had an annual payroll of > $350 million (DPI, 1999). In Delaware alone, $560 million in agricultural cash receipts (72% of the state total for agriculture) was associated with the production and marketing of broiler chickens (DDA,1998). Only limited production of other animals (beef, dairy, swine) occurs on Delmarva, hence the discussion in this paper focuses primarily on the poultry industry.

Poultry production increased markedly on Delmarva from the 1960's to early 1990's but has stabilized in recent years (see Figure 2 for Delaware). Today on Delmarva, there are about 2,700 contract poultry growers working with five integrated poultry companies. On average, each grower has 2.1 poultry houses, each with a production capacity of ~23,000 broilers. As mentioned above, poultry production is not uniformly distributed around Delmarva, but is localized in eight counties in close proximity to each other (Sussex, DE; Caroline, Talbot, Dorchester, Somerset, Wicomico, and Worcester, MD; and Accomack, VA). Seven of the eight counties have < 40,000 ha of cropland; Sussex County, DE has the largest agricultural land base (~100,000 ha) and the largest annual production of broilers by far (190 million per year based on NASS, 1997; local estimates are higher, in the range of 220 million per year). Animal densities, in livestock units/ha (LU/ha; all species, but predominantly poultry) on the peninsula range from < 0.2 to 1.65 LU/ha (Table 1; Sims et al., 2000). By way of comparison animal densities in the 12 countries of the European Union, where concerns about environmental pollution from confined animal production are long-standing, range from 0.5 LU/ha in Spain to 4.0 LU/ha in the Netherlands and average 0.9 LU/ha. The Delmarva poultry industry imports large quantities of corn and soybeans from other regions for use in feed. Approximately 69 million bushels of corn and 35 million bushels of soybeans are used by the industry each year. Based on recent (1993-1998) average yields for corn and soybeans grown in Delaware (115 and 30 bu/acre, respectively; DDA, 1998) and cropland data for Delmarva as a whole (Table 1), about 20 million bushels of corn and 15 million bushels of soybeans must be imported to meet the nutritional requirements of Delmarva's poultry industry. These feed imports, which also represent nutrient imports, have major implications for regional nutrient management and water quality issues, as discussed below.

Table 1 Overview of agriculture on the Delmarva Peninsula (NASS, 1997).

| County | Cropland[†] | Corn | Soybeans | Small Grains | Hay | Vegetables | Broilers | Animal Density[‡] |
|---|---|---|---|---|---|---|---|---|
| | ---ha--- | | | | | | --# sold x $10^6$-- | ---LU/ha--- |
| *Delaware* | | | | | | | | |
| New Castle | 27,000 | 9,900 | 11,100 | 5,700 | 1,600 | 400 | <1[¶] | 0.08[¶] |
| Kent | 68,000 | 17,300 | 32,400 | 17,400 | 2,800 | 6.700 | 34[¶] | 0.34[¶] |
| Sussex | 100,000 | 36,400 | 46,800 | 20,600 | 2,000 | 11,300 | 190 | 1.22 |
| *Maryland* | | | | | | | | |
| Caroline | 38,300 | 8,300 | 20,100 | 12,100 | 900 | 2,700 | 35 | 0.50 |
| Cecil | 25,600 | 7,900 | 5,800 | 3,400 | 3,400 | 40 | n/a | 0.34 |
| Kent | 39,600 | 15,900 | 14,300 | 7,100 | 1,700 | 10 | 4 | 0.16 |
| Queen Anne's | 58,900 | 20,600 | 28,200 | 14,900 | 1,200 | 1,000 | 10 | 0.15 |
| Talbot | 37,600 | 13,600 | 19,500 | 9,600 | 500 | 500 | 12 | 0.16 |
| Dorchester | 40,200 | 7,700 | 23,400 | 9,600 | 150 | 3,300 | 20 | 0.30 |
| Somerset | 16,100 | 4,900 | 9,000 | 2,900 | 60 | 300 | 42 | 1.65 |
| Wicomico | 28,700 | 8,900 | 14,000 | 4,900 | 900 | 900 | 76 | 1.38 |
| Worcester | 35,600 | 14,700 | 16,300 | 4,400 | 400 | 100 | 57 | 0.99 |
| *Virginia* | | | | | | | | |
| Accomack | 30,300 | 5,500 | 17,500 | 10,000 | 150 | < 10 | 22 | n/a |
| Northampton | 20,200 | 1,100 | 10,000 | 7,900 | 30 | < 10 | 0 | n/a |
| Delmarva | 566,100 | 172,700 | 268,400 | 130,500 | 15,790 | 27,250 | 502 | n/a |

[†]Total cropland area. Values for crops are hectares harvested in 1997. [‡]LU/ha=livestock units/ha, based on all animal types produced in each county (poultry, dairy, beef, swine). From Sims et al. (2000); [¶]Estimated from local data as information was not available in NASS 1997 statistics due to confidentiality requirements. n/a=not available.

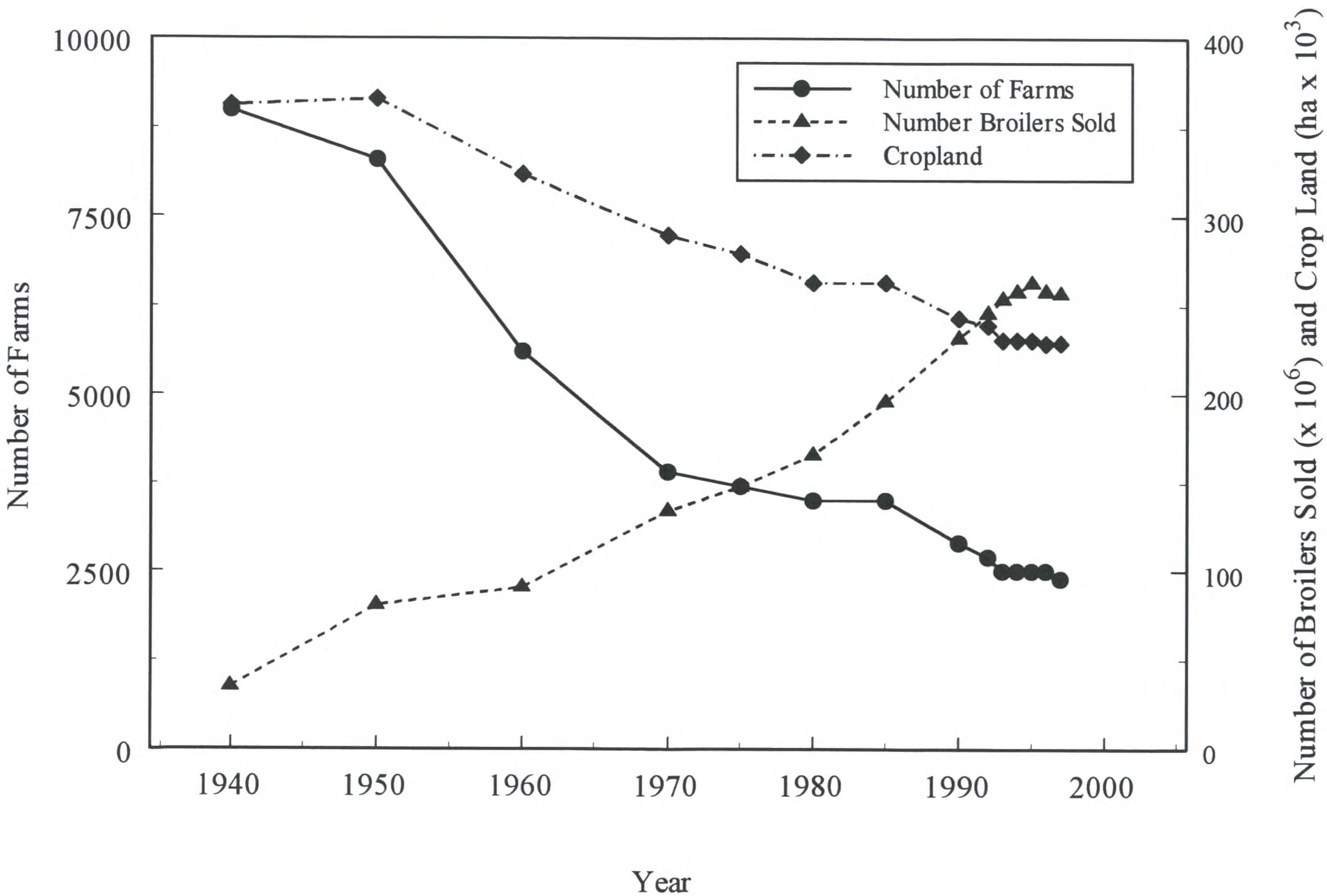


Figure 2. Poultry production trends for Delaware (1940 - 1998).

**Environmental Issues Facing Agriculture on the Delmarva Peninsula**

There are a number of significant environmental problems related to water quality on Delmarva. For example, a recent report by the Delaware Water Resources Center identified the following priority areas for water quality research and education programs:

- point and non-point source pollution of ground and surface waters and coastal estuaries by nutrients, sediments, pathogens, organics and trace metals, etc. -- of increasing importance as total maximum daily loads (TMDLs) are now being established in Delaware for many surface waters as a result of court-ordered state efforts to protect and improve these waters as required by the Clean Water Act.

- urban stormwater runoff and sediment delivery to surface waters, increasing in importance because of the rapid urbanization of the state

- impacts of septic systems and wastewater irrigation systems on ground water quality

- degradation of habitats, especially stream habitats

- an improved understanding of the responses of aquatic ecosystems to pollutant inputs

- identification and protection of recharge areas for ground water aquifers

- restoration and protection of wetlands

- leaking underground storage tanks, landfills, and chemical spills (past and present)

While agriculture may have some degree of involvement in many of these issues (e.g., wetlands, stream habitats, wastewater irrigation), the most pressing water quality problem faced by agriculture in the past, and still today, is its role in the nonpoint source pollution of ground and surface waters by nutrients, particularly nitrogen (N) and phosphorus (P). Federal and state environmental agencies and environmental advocacy groups have long been concerned about nitrate-N contamination of drinking water supplies and the potential role of N and P in agricultural runoff and groundwater discharge in surface water eutrophication. These concerns have been driven by documented instances of ground water pollution and degradation of surface water quality (Hamilton and Shedlock, 1992) and years of research that have shown the potential for N and P from agriculture to contribute to water quality degradation.

In particular, there has been serious concern that the geographic intensification of the poultry industry, which has resulted in farm, county, state, and regional nutrient surpluses, such as those calculated for Sussex County, Delaware, one of the nation's most concentrated poultry producing areas (Table 2; Cabrera and Sims, 2000), has created an agricultural setting that is prone to non-point source pollution. Simply put, the agricultural land base on Delmarva is not adequate to support the environmentally efficient use of the by-products of the poultry industry (manures, litters, composts). There are several reasons for this. Nutrient surpluses on farms (or at larger scales) primarily result from the fact that nutrient inputs in feed and fertilizers exceed outputs in

Table 2. Simplified annual mass balance for N and P in Sussex County, Delaware (Adapted from Cabrera and Sims, 2000).

| Nutrient Input or Output | Nitrogen | Phosphorus |
|---|---|---|
| | ---------------------------Mg/County------------------- | |
| *Nutrient Inputs:* | | |
| Animals | 330 | 45 |
| Feed | 37240 | 7510 |
| Fertilizer | 8050 | 1230 |
| Nitrogen fixation | 3700 | n/a |
| Total nutrient inputs | 49320 | 8740 |
| *Nutrient Outputs* | | |
| Animals | 16680 | 2090 |
| Harvested crops | 12870 | 1730 |
| Total nutrient outputs | 29550 | 3820 |
| Nutrient surplus (Mg/county/yr) | 19770 | 4920 |
| Nutrient surplus (kg/ha/yr) | 198 | 49 |
| % of nutrients that are "surplus" | 40 | 56 |

*Assumptions:*

1. There are 220,000,000 broiler chickens produced per year in Sussex County.

2. The county has 100,000 ha of cropland used to produce full-season soybeans (34,000 ha), corn (36,000 ha), wheat (20,000 ha), and double-cropped soybeans (12,000 ha). Average yields for corn are 7.8 Mg/ha, for full-season soybeans are 2.7 Mg/ha, for wheat are 4.0 Mg/ha, and for double-cropped soybeans are 1.7 Mg/ha.

3. Fertilizer inputs are based on statewide averages for N and P use (DDA.1998).

4. Nutrient inputs and outputs for animals were calculated using standard poultry feeding programs and animal composition data (Sims and Vadas, 1997).

animal products and crops. Note that these surpluses do not result from animal agriculture alone; commercial fertilizer use is a significant cause of the nutrient surpluses shown in Table 2. The surplus nutrients from feed are concentrated in animal manures which are heterogeneous in composition and have somewhat unpredictable rates of release once incorporated into soils. Poultry manures also have an unfavorable N:P ratio relative to most grain crops, resulting in over-application of P when manures are applied to meet crop N requirements, the long-standing agronomic practice in this region. Many soils in the poultry producing region of Delmarva are now considered "excessive" in P (Figure 3; Sims et al., 2000) relative to crop P needs and are sufficiently saturated with P to be of concern for soluble P losses in leaching and runoff (Pautler and Sims, 2000). Manures and other animal wastes (e.g. composts) are also difficult to store properly and apply uniformly in a timely manner that is well-synchronized with plant uptake patterns. This combination of nutrient surpluses and logistical constraints to efficient use of manure nutrients has created a situation where nonpoint source pollution is prone to occur. The likelihood of ground and surface water pollution by agricultural nutrients is further enhanced by the nature of the topography, soils, hydrology, and climate on Delmarva. Abundant rainfall, easily leached or ditch-drained soils, and shallow aquifers that are interconnected with surface waters (streams, rivers, and estuaries) form a setting that facilitates nutrient transport from land to water.

In summary, agriculture on Delmarva, and especially animal agriculture faces serious environmental challenges today. Public concerns about nonpoint source pollution of ground and surface waters has resulted in recent nutrient management legislation in all three states (discussed below) that will significantly impact agriculture by regulating nutrient use. At the same time efforts are underway in all three states, and regionally, to develop new and more efficient approaches to nutrient management and confined animal production. The remainder of this paper focuses primarily on the research and education programs now being considered, or implemented, to sustain agriculture and protect Delmarva's environment.

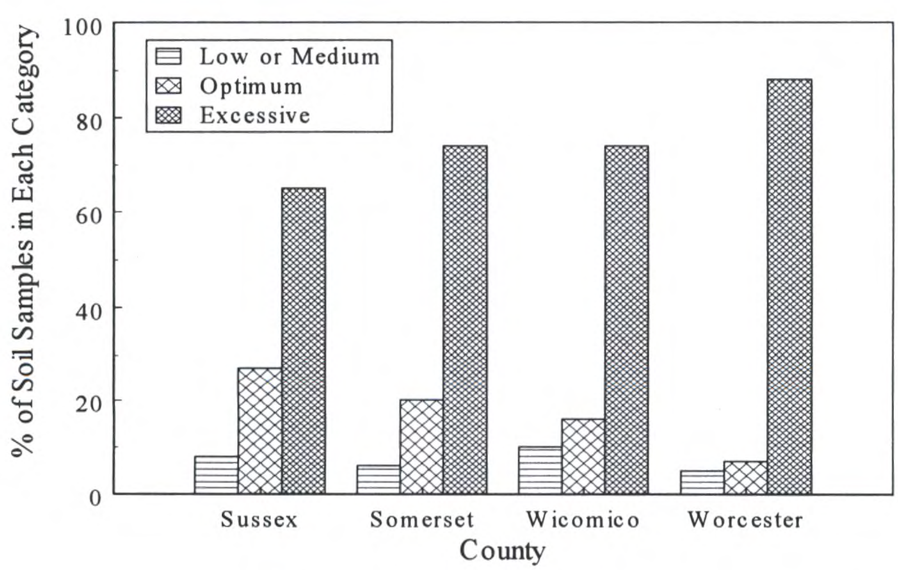


Figure 3. Soil test P status in Delmarva counties where poultry production is concentrated.

## Recent Environmental Legislation and Policy on the Delmarva Peninsula

In the past three years a series of events have led to the passage of nutrient management laws in Delaware, Maryland, and Virginia and to increased federal involvement in the regulation of confined animal agriculture in the region. The approximate chronology of these actions is as follows; some specific details on each state's action are provided in Table 3.

The first significant step of relevance to Delmarva was a lawsuit filed in1996 by a consortium of environmental groups that sued the U.S. Environmental Protection Agency (USEPA) for "failure to perform its mandatory duties under the Clean Water Act to identify and then improve water quality" in Delaware. In 1997 the state of Delaware, through the Department of Natural Resources and Environmental Control (DNREC), negotiated a Total Maximum Daily Load (TMDL) agreement with USEPA. This agreement established a 10-year schedule to develop TMDLs for affected waterbodies and to then promulgate "pollution control strategies" to ensure that pollutant loadings are below TMDL values. Virginia entered into a TMDL agreement with USEPA in 1998, adopting a 12-year schedule to set TMDLs and, subsequent to this, to implement plans to reduce pollutant inputs to levels needed to meet the desired water quality. Maryland does not have a TMDL agreement but a lawsuit has been filed to compel USEPA to establish TMDLs for impaired water bodies in that state.

The first state water quality legislation that impacted Delmarva was Maryland's Water Quality Improvement Act of 1998. Passage of this act was stimulated by public concerns over fish kills in the summer of 1997 that were reportedly caused by *Pfiesteria spp.* a toxic dinoflagellate that had been implicated in earlier, massive fish kills in North Carolina and also in human health problems. Detailed information on the events that led to Maryland's law are provided by Simpson (1998). However, it is fair to say that the Maryland law, which passed in a politically-charged atmosphere, stimulated similar efforts in Virginia and Delaware, under pressure from the USEPA, to move away from the voluntary nutrient management practices advocated in the past and in the direction of regulated programs, especially for large confined animal feeding operations (CAFOs, usually those operations with >1000 animal units). The states of Delaware and Virginia worked throughout 1998 and into 1999 to draft legislation addressing nutrient management and water quality. Virginia was the next state to pass legislation, in the form of a poultry waste management bill approved in January of 1999 (see Table 3 for details). In Delaware the Governor appointed an Agricultural Industry Advisory Committee on Nutrient Management, consisting of ten farmers, to develop recommendations for state actions. The efforts of this committee led to the passage in June of 1999 of Delaware's state nutrient management act. Subsequent to the passage of these state laws, committees or commission were appointed to draft the regulations required by each state's legislation. For example, in Delaware a Nutrient Management Commission (DNMC) has been established to develop and implement a state nutrient management program that will protect and improve water quality. Specific information on Delaware's act and the responsibilities of the DNMC is provided by Sims (1999).

National policy initiatives are also underway that impact animal agriculture on Delmarva. By far the most significant is the USEPA-USDA Unified National Strategy for Animal Feeding Operations (AFOs), adopted in March of 1999 after lengthy discussion and public review. This document contains nine "guiding principles" for the joint effort between the nation's lead regulatory agency (USEPA) and its lead technical agency for agriculture (USDA) to "..address the water quality and public health impacts associated with AFOs" (USDA&USEPA, 1999):

*Guiding Principles in the USDA-USEPA Unified National Strategy for AFO's*

1) Minimize water quality and public health impacts from AFOs.

2) Focus on AFOs that represent the greatest risk to the environment and public health.

3) Ensure that measures to protect the environment and public health complement the long-term sustainability of livestock production in the U.S.

4) Establish a national goal and performance expectations for AFOs.

5) Promote, support, and provide incentives for the use of sustainable practices and systems.

6) Build on strengths of federal agencies and their state/local partners and make appropriate use of diverse tools including voluntary, regulatory, and incentive-based approaches.

7) Foster public confidence that AFOs meet performance expectations and that federal and state/local governments are ensuring the protection of water quality and public health.

8) Coordinate activities among USDA, USEPA, and state agencies and other organizations that affect or influence the management and operation of AFOs.

9) Focus technical and financial assistance to support AFOs in meeting national goal and performance expectations established in the Unified National Strategy.

Following up on this strategy, in the summer of 1999 the USDA Natural Resources Conservation Service released a "national nutrient policy" which will require more comprehensive nutrient management planning and implementation of plans for farmers receiving technical assistance and cost-sharing funds. In September of 1999 the USEPA released for public comment the "Guidance Manual and Example NPDES Permit for Concentrated Animal Feeding Operations" and in December of 1999 the USDA-NRCS released for public comment the "Technical Guidance for Developing Comprehensive Nutrient Management Plans (CNMPs)"[2]. As described in the USDA-NRCS guidance, the objective of a CNMP is "..to combine management activities and conservation practices into a system that, when implemented, will minimize the adverse impacts of animal feeding operations on water quality". Six elements are proposed to be considered in a CNMP: (1) Animal outputs - manure and waastewater collection, handling, storage, treatment, and transfer; (2) Evaluation and treatment of sites proposed for land application; (3) Land application; (4) Records of CNMP implementation; (5) Inputs to animals; and (6) Other utilization activities (e.g., power generation, composting, pelletization).

State agencies, farm organizations, universities, and environmental advocacy groups are now working to understand and then to integrate federal guidance and regulations with that mandated by new state laws. Most anticipate that this process will take from five to ten years.

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[2] Information on the USDA and USEPA documents described in this paper is available on the web sites of the two agencies (USDA: http://www.nhq/nrcs/usda/gov; USEPA: http://www.epa.gov/owm).

Table 3. Summary of nutrient management legislation in Delaware, Maryland, and Virginia (from Sims, 1999 and Simpson, 1998).

| State | Overview of Key Components of the Legislation |
|---|---|
| *Delaware*<br><br>(Nutrient Management Act of 1999) | • Establishes a 15-member, politically appointed Delaware Nutrient Management Commission (DNMC) to develop and implement a state nutrient management program. Anyone with > 8 animal units or who applies nutrients to > 4 ha of land must have and implement a nutrient management plan. Plans will be reviewed beginning in 2003 and the state nutrient management program must be implemented by 2007. For agronomic plans N applications will be limited to that required for a "realistic yield" (defined as best 4 yields from the past 7 years); application of P to "high P" soils (remains to be defined by the DNMC) shall not exceed a 3 year crop removal rate. The act also proposes that the state's NPDES program for CAFOs be delegated to the Department of Agriculture who will rely on the act to the greatest extent practical in the development of CNMPs for CAFOs. Municipalities applying biosolids to cropland are exempt from the act (except for reporting) because they are already permitted by the state through other programs. Financial penalties are included for those who do not comply with the act.<br><br>• The DNMC will also: (i) consider the establishment of critical areas for targeting voluntary and regulatory programs; (ii) establish BMPs to reduce nutrient losses to the environment; (iii) develop educational and awareness programs; (iv) consider the need for a transportation and alternative use incentive program to move nutrients from areas of overabundance to areas where they are needed; (v) establish a state certification program for four classes of nutrient users and a method to evaluate an applicant's suitability for certification; (vi) cooperate with state agencies to provide cost-share funds for NMP development and BMP implementation; (vii) work with "commercial processors" (e.g. poultry integrating companies) to provided technical assistance and educational programs for contract growers to improve the storage and management of animal wastes; and (viii) keep records and provide annual reports to the legislature on the progress of the DNMC in implementing the requirements of the act. The DNMC is now developing the regulations required by the act. |

Table 3 (cont). Summary of nutrient management legislation in Delaware, Maryland, and Virginia (from Sims, 1999, Simpson, 1998).

| | |
|---|---|
| *Maryland*<br><br>(Water Quality Improvement Act of 1998) | • Requires that any agricultural operation with > $2500 in gross annual income or > 8 animal units must develop and implement a NMP. The law clearly includes municipal biosolids application to cropland and impacts non-agricultural nutrient users (e.g. commercial lawn care, nurseries, turf grass producers) who apply nutrients to more than 1.25 ha of land. The WQIA requires that anyone who only uses commercial fertilizer must "develop and implement a N and P based plan by 12/31/02; those using biosolids or animal manures must comply by 12/31/05. The act includes financial penalties for those who do not comply. The addition of restrictions on the amount of P that can be applied is a major change from nutrient management planning efforts in Maryland.<br><br>• All NMPs must be developed and approved through the Maryland Department of Agriculture; cost-sharing is provided for plan development. A state Nutrient Management Advisory Committee with wide-ranging representation developed and recently released (December, 1999) the proposed regulations that will implement this act. These proposed regulations are now under review and may be subject to additional public hearings. |
| *Virginia*<br><br>(Poultry Waste Management Bill of 1999) | • Requires the development and implementation of nutrient management plans for "any person owning or operating a confined poultry feeding operation". These NMPs will govern the storage, treatment, and management of poultry waste. Also provides for poultry waste "tracking and accounting".<br><br>• States that N application rates in mandated NMPs shall not exceed crop nutrient needs as determined by the Virginia Department of Conservation and Recreation (DCR). Poultry wastes shall also "be managed to minimize runoff, leaching, and volatilization losses and reduce adverse water quality impacts from nitrogen".<br><br>• After 10/1/01 P application rates in mandated NMPs shall not exceed the greater of crop nutrient needs or crop nutrient removal as determined by DCR. Poultry wastes shall "be managed to minimize runoff and leaching and reduce adverse water quality impacts from P". Prior to 10/1/01 comprehensive soil conservation plans consistent with USDA-NRCS guidelines will be required for soils with a soil test P (Mehlich 1) value > 55 mg/kg (ppm) |

**Advances in Animal Waste Management to Protect and Improve Water Quality on the Delmarva Peninsula**

Clearly in the past three years dramatic changes have occurred in the approach that will be used in the future for agricultural nutrient management on the Delmarva peninsula. These changes will impact many nutrient generators and users, but will have the greatest effect on animal agriculture. Most changes are still in progress, or are still being hotly debated, and will likely not be finalized for several years. Given this, it is somewhat difficult to predict, or describe, what the future holds for nutrient management and water quality on Delmarva. Some things seem certain to occur, while others that seem necessary or promising today may be abandoned after further research and economic, or political, evaluation. Two major changes, however, are likely to occur that will permanently alter the way agriculture is practiced on Delmarva:

<u>Nutrient Management Planning</u>

Nutrient management planning is not a new agricultural activity; farmers and their advisors have developed and implemented plans for the profitable use of nutrients for decades. Environmental considerations, such as preventing soil erosion and reducing nitrate leaching have always played a role in these voluntary plans. It seems apparent, however, that NMPs developed in the future on Delmarva will be more formal, even regulatory, in nature. The passage of the three state laws described in Table 3 and the development of regulations to implement these laws will require most nutrient users (agricultural and non-agricultural) to develop and implement NMPs for their operations. Record-keeping will be required and penalties can be assessed for failure to comply with state and federal requirements. What can be expected as a result of these state and federal actions? Several changes seem likely:

- Expansions in funding and activities of government, university, and private sector advisors involved in educational efforts on NMPs, the design and implementation of NMPs and associated BMPs, and cost-sharing to facilitate NMP implementation can be expected in the future. This should result in the more efficient use of nutrients by agriculture which should in turn contribute to the long-term improvements in water quality hoped for by those that passed the legislation in these three states.

- Perhaps the most significant specific change that will occur will be the re-design of NMPs to include P management practices that are protective of the environment. A regional effort is now underway to develop a holistic approach to P management that integrates site properties related to P transport, water-body sensitivity to P, soil P status, and P management of fertilizers and manures into a field-scale risk assessment tool (the *Phosphorus Site Index;* Leytem et al., 2000). Once a reliable P Site Index has been developed areas requiring more intensive management to prevent P losses in runoff can be prioritized and BMPs implemented most effectively.

- Wide-scale development of NMPs will likely confirm the exact magnitude and specific geographic locations of nutrient surpluses on Delmarva. This is critical because farm-scale NMPs are designed to use the optimum amount of nutrients needed to achieve realistic yields; not to economically dispose of surplus nutrients that are not needed on the farm. Individual farmers do not have the economic wherewithal to design and construct the infrastructure needed to economically use nutrient surpluses of the magnitude estimated to be present on Delmarva. State or regional efforts, involving private industry, as described below, will be required for long-term resolution of the nutrient imbalance problems facing Delmarva agriculture today.

Alternative Uses for Animal Wastes

For the past two years a concerted effort has been underway in this region to critically analyze alternative uses for animal wastes based on the premise that application to agricultural cropland cannot remain the sole end use for the by-products of animal production. Most recently a task force was established by the Chesapeake Bay Executive Council with the charge to "..recommend appropriate procedures pertaining to the interstate distribution of animal wastes". This task force conducted a thorough review of all proposed alternatives to land application of animal wastes and made the following recommendations (Chesapeake Bay Program, 1999):

1) A memorandum of understanding should be signed by the six states in the Chesapeake Bay watershed (DE, MD, PA, NY, VA,WV) that will formalize a long-term commitment to ensure the proper land application of animal wastes regardless of their final destination.

2) The six states should adopt technical guidelines addressing animal waste transport procedures, NMPs, storage of wastes, biosecurity, and monitoring/tracking of animal waste transfers.

3) Potentially feasible alternatives to land application of animal wastes include expanded land application, composting, pelletization or granulation for fertilizers, use in animal feeds, and energy generation. The task force provided detailed analyses of each option and stated:

   - The most appropriate mix of alternative uses and incentive solutions will vary by area. Areas with slight oversupply should expand the use of more distant land application of animal wastes and secondary uses such as composting for the landscape industry. Areas with significant oversupply should pursue waste reuse options such as pelletization and shipment to nutrient deficit areas, energy generation, and minor use options.

   - Nutrient reduction through more effective feeding strategies should be encouraged for liquid wastes which are more difficult to transport for alternative uses.

   - Incentive programs should be developed to promote alternative uses, with preferences given to recurring incentives; incentives with a phase-out period; start-up incentives such as grants and low-interest loans; and insurance mechanisms to reduce the risk of adopting a new practice. Market-based solutions and additional research on alternative uses should be encouraged.

   - Long-term success will require good faith cooperation, funding, risk assumption, and personnel resources from integrating animal production companies, livestock growers, manure brokers, state and federal agencies, utilities involved in energy generation from wastes, and groups such as the Chesapeake Bay Program.

## Future Challenges and Directions for Delmarva's Animal Agriculture

Agriculture on the Delmarva peninsula is at a crossroads of sorts. Fundamental questions are being asked about the sustainability of the animal agriculture that dominates the economy of this region. The voluntary approaches to nutrient management used in the past are being replaced by regulatory programs that will require farmers, and other nutrient users, to follow more intensive, and thus costly, approaches to nutrient management planning. Many in agriculture question the need and scientific validity of these changes. Others ask for delays in their implementation to allow for more research to justify the actions required in state laws and more time for an economic evaluation of their impact on agricultural profitability. At the same time, federal agencies, environmental advocacy groups, and the media are pressing states to move forward more rapidly to protect and improve water quality.

Given the rather contentious nature of this issue, what steps should be taken today to address the need to sustain agriculture and protect environmental quality on Delmarva? First, there is a need for all parties involved to recognize that the issue of nutrient management on water quality requires serious attention, in the short and long-term. Sufficient information is available from research on Delmarva and in other states of countries to justify the immediate need for improved nutrient management practices, particularly for animal agriculture. Consequently, there is a need for reasoned public debate on the issue to identify the most appropriate changes that should be required to reduce agriculture's impact on water quality. Second, some changes should occur now, specifically concerted efforts to implement nutrient management practices that are accepted by agriculture, but not widely used due to economic constraints. Examples include the use of diagnostic nitrogen tests to increase fertilizer use efficiency, more extensive efforts to identify soils that are "high" enough in P to be of environmental concern, use of modified animal diets and manure treatment technologies to reduce the potential for nutrient losses, wider implementation of soil conservation practices (e.g. buffer strips), and avoiding poorly timed or badly located applications of animal wastes. Finally, most scientists agree that more information is needed on nutrient cycling and management, particularly for phosphorus. A significant research effort is underway today and all indications are that support for nutrient management research (basic and applied) will continue to be strong for the next decade. This argues for patience and flexibility in the implementation of regulations until the research is completed and clearly understood by all interested individuals.

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# Session 3

# EPA and NRCS Goals in Nutrient Management

# EPA Programs for Attaining Water Quality Goals from Nonpoint Sources

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Biographies for most speakers are in alphabetical order after the last paper.

**Introduction**

Agricultural sources of pollution–cropland, animal feedlots, livestock grazing–are the primary sources of pollution to lakes and rivers nationwide. (U.S. EPA, 1998a) Under the Clean Water Act, one agricultural activity, confined animal feeding operations, is defined as a point source of pollution. Discharges to waters of the United States from any point source are regulated under the U.S. Environmental Protection Agency's (EPA) water permit program. All other sources of agricultural pollution are considered nonpoint sources. EPA has several plans and on-going programs to help control pollution from agriculture and other nonpoint sources of pollution.

**Clean Water Action Plan**

The Clean Water Action Plan is a blueprint for restoring and protecting the nation's waters. It contains many actions for water quality programs in EPA and other federal agencies which strengthen on-going efforts. However, the focus of the plan is on four key tools to achieve clean water goals: 1) a watershed approach; 2) water quality standards; 3) natural resource stewardship; and 4) improved public information.

1) The watershed approach encompasses a collaborative effort by federal, state, tribal, and local governments; the public; and the private sector to restore polluted watersheds and sustain healthy conditions in other watersheds. This approach helps to ensure that strategies to control pollution are more site-specific and cost-effective. It is based on an assessment of

the condition of the watersheds, restoration strategies, and pollution prevention efforts.

2) Strong federal and state water quality standards are needed to protect public health, prevent polluted runoff, and ensure accountability. The key actions include ensuring safe shellfish and beaches, better control of storm water runoff, enforceable authorities for polluted runoff, reduced pollution from animal feeding operations, and the establishment of quantitative nutrient water quality criteria.

3) Federal agencies will enhance natural resources for the protection of water quality and the health of aquatic systems on federal lands and for federal resource management. To meet this goal, federal land managers will improve water quality protection for over 2,000 miles of roads and trails each year through 2005 and decommission 5,000 miles each year by 2002. Federal land managers will also accelerate the cleanup rate of watersheds affected by abandoned mines and will implement an accelerated riparian stewardship program to improve or restore 25,000 miles of stream corridors by 2005. In addition, federal agencies will work with private land owners to protect and restore wetlands and coastal waters and create two million miles of conservation buffers by 2002. New incentives for private land conservation will be explored.

4) Effective management of water resources requires reliable water quality data. The data must be communicated with the public in a meaningful way. The U.S. Geologic Survey will lead an effort improve monitoring and assessment, focusing on nutrients and related pollutants and communicate the information to the public.

In June 1999, the Wyoming Association of Conservation Districts (WACD) filed a lawsuit against EPA and the other federal agencies involved in the development of the Clean Water Action Plan. WACD alleges that the Clean Water Action Plan should have been subjected to a formal public review and comment process since it is a major federal action. The U.S. Department of Justice has filed a motion to dismiss the lawsuit arguing that the plan is not a final federal action and is therefore not subject to review by the courts. Individual regulations called for in the plan will be subject to the rulemaking process.

**Nutrient Water Quality Criteria**

Water quality standards are a basic building block of the Clean Water Act. States are required to set water quality standards as a tool to evaluate the condition of their water bodies. Water quality standards identify the uses for each waterbody, for example, drinking water supply, swimming, and fishing, and the scientific criteria to support that use.

Nutrients are the major pollutants in lakes and estuaries and the second leading source of pollution in rivers (U.S. EPA, 1998a). However, states often use subjective water quality criteria to assess the seriousness and extent of the nutrient problem. This lack of quantitative criteria can result in widely varying assessments. 17 states have no water quality criteria for nitrogen and 21 states have no water quality criteria for phosphorus (U.S. EPA, 1998b). Many of the other states only use a narrative criteria for nutrients. It is difficult to use these criteria to determine when a water body is clean or polluted. Research to improve the basis for understanding and assessing nutrient over-enrichment problems is critical to better control of nutrient levels in waters and to meet the nation's clean water goals.

In order to provide a scientific basis for quantitative water quality criteria, EPA has developed a national nutrient strategy (U.S. EPA, 1998b). This strategy requires states and tribes to adopt numerical nutrient criteria into their water quality standards by the end of 2003. The strategy identifies 14 eco-regions and 4 waterbody types (lakes, rivers, estuaries, and wetlands) that will require different criteria. The criteria will be based on the technical guidance that EPA will finalize in early 2000 (U.S. EPA, 1999a, 1999b). The draft technical guidance focuses on assessing total phosphorus, total nitrogen, algal biomass, and turbidity to establish nutrient criteria. States and tribes will also be responsible for monitoring and evaluating the effectiveness of programs to control nutrients as they are implemented.

**Nonpoint Source Program–Section 319**

Under Section 319 of the Clean Water Act, EPA provides grants to the states to carry out regulatory and nonregulatory programs to control nonpoint sources of pollution. Nonpoint sources include any activity that is not defined as a point source under the Clean Water Act. Nonpoint sources include most agriculture operations (except concentrated animal feeding operations), forestry, and urban runoff. The EPA grant money may be used for a variety of projects: enforcement, technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring. The government has allocated over one billion dollars for the nonpoint source program since its inception. 200 million dollars have been allocated for the program in both fiscal years 1999 and 2000. President Clinton's fiscal year 2001 budget calls for a $50 million increase to $250 million.

In fiscal year 2000, $100 million of the allocation was given to states to support implementation of their nonpoint source programs. The other half of the allocation will be distributed to states based on the extent to which they have incorporated nine key elements into their programs. The elements include:
1. explicit short- and long-term goals, objectives and strategies;
2. strengthened partnerships with appropriate government entities (including conservation districts), private sector groups, and citizens groups;
3. emphasis on both state-wide programs and management of individual watersheds;
4. abatement of known water quality impairments and prevention significant threats to water quality from present and future activities;
5. identification of impaired waters and important threatened waters and a process to implement watershed plans;
6. review, upgrade, and implementation of all components required by Section 319 and establishment of flexible, targeted, and iterative approaches to expeditiously achieve and maintain beneficial uses of water;
7. identification of federal lands and activities which are not managed consistently with state nonpoint source program objectives;
8. efficient and effective management and implementation of the program; and

9. periodic review, evaluation, and revision of the program

The success of the nonpoint source grants in protecting water quality has been difficult to evaluate from a national perspective because of the wide variety in individual state programs. These key elements will help to make the state programs more consistent. In addition, EPA established the Section 319 National Monitoring Program to provide credible documentation of the feasibility of controlling nonpoint sources, to improve the technical understanding of nonpoint source pollution, and to evaluate the effectiveness of nonpoint source control technology and approaches. 20 of the 23 monitoring projects focus on agricultural sources.

**Coastal Zone Act Reauthorization Amendments of 1990**

The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) are an additional federal tool to address nonpoint sources of pollution in the coastal zone. CZARA requires coastal states to develop coastal nonpoint source pollution control programs that include technology-based management measures to control nonpoint pollution in accordance with EPA's guidance (U.S. EPA, 1993a and 1993b). The state CZARA program must implement the management measures in their coastal zones in six categories: agriculture; forestry; urban; marinas and recreational boating; hydromodification; and wetlands, riparian areas, and vegetated treatment systems. It must contain enforceable policies and mechanisms to ensure implementation of the management measures. CZARA required EPA and the National Oceanic and Atmospheric Administration (NOAA) to approve state programs. If the state programs did not meet the standards, both agencies were required to withhold a percentage of grant money. The NOAA and EPA guidance required state programs to be implemented by January 1999.

No state submitted a fully approvable program by the deadline. NOAA and EPA conditionally approved state programs with no penalties for up to five years. The three most common reasons that NOAA and EPA delayed the full approval of state programs were that: individual management measures were not in place, enforceable policies and mechanisms were not in place, and coastal zone boundaries excluded areas with significant impact on coastal waters. Currently, of the 34 states and territories in the coastal zone program, only Maryland has a fully approved CZARA program. 28 states have conditional approval and two states submissions are currently under review

**Total Maximum Daily Loads**

Where water quality standards are not being met, even after the implementation of programs to control point and nonpoint sources, the Clean Water Act requires states to develop a total maximum daily load (TMDL) to determine the assimilative capacity of a water body and develop a plan to bring the water body into compliance with the standards. The importance of this program is emphasized by the fact that 218 million Americans live within 10 miles of a polluted waterbody. 300,000 river and shore miles and 5 million lake acres are not meeting water quality standards. Waste water treatment plants and industry are the sole cause of pollution in only about ten percent of impaired waters.

The focus on TMDLs has increased dramatically within the past few years as a result of about 45 lawsuits filed against states and EPA for not appropriately implementing this portion of the Clean Water Act. (EPA is responsible for developing TMDLs where states fail to act.) Almost half of these lawsuits have been settled, setting deadlines to implement TMDLs for impaired water bodies. Over 2000 TMDLs are currently under development.

In response to these lawsuits and the findings of an advisory committee, EPA has proposed revisions to the TMDL regulations. The proposed regulations set a more definitive structure for state TMDL programs. The proposal would give states flexibility in priority setting, although high priority waters would include public drinking water supplies and water that supports endangered or threatened species. The states would have 15 years to establish their TMDLs. The TMDL must include an implementation plan and provide reasonable assurance that the pollution sources will attain the specified reductions. The reasonable assurance requirement can be filled by voluntary programs for nonpoint sources as long as adequate funding, staffing, and technical assistance are available for implementation. The final TMDL regulations are scheduled to be released in the summer of 2000.

**Safe Drinking Water Act**

Historically the Safe Drinking Water Act (SDWA) has focused on treatment requirements for public drinking water supplies. Pollution prevention efforts in the watershed were not the domain of this Act. Two new provisions in the 1996 amendments to the Act have shifted the focus somewhat--the Ground Water Rule and Source Water Assessments.

The Ground Water Rule, when it is proposed in the spring of 2000, will require the control of contamination of groundwater public water supplies from microbial sources. Studies of the occurrence of bacterial and viral pathogens or fecal contamination indicators in ground water indicate that the number of ground water sources with fecal contamination is significant. The proposed regulation will specify the appropriate use of disinfection and encourage the use of alternative approaches, including best management practices and control of contamination at the source

SDWA requires states to develop and implement Source Water Assessment Programs (SWAP) to analyze existing and potential threats to the quality of the public drinking water throughout the state. Every state is required to submit a program to the EPA by February 1999 and to complete all the assessments in the state by May 2003. A state SWAP includes:

- delineating the source water protection area,
- conducting a contaminant source inventory,
- determining the susceptibility of the public water supply to contamination from the inventoried sources, and
- releasing the results of the assessments to the public

While the new amendments do not give states any new regulatory or enforcement authorities for drinking water source protection, many of the provisions are intended to encourage states and localities to go beyond source water assessments and implement efforts to manage identified sources of contamination in a manner that will protect drinking water supplies.

**Websites**

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Coastal Zone Program http://www.epa.gov/OWOW/NPS/czmact.html

Drinking Water http://www.epa.gov/safewater/protect.html

Nonpoint Source Program http://www.epa.gov/owow/nps/Section319/fy2000.html

Nutrient Water Quality Criteria http://www.epa.gov/ost/standards/nutrient.html

Section 319 Monitoring Program http://h2osparc.wq.ncsu.edu/99rept319/

Total Maximum Daily Loads http://www.epa.gov/owow/tmdl/index.html

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# Water Quality Goals for Agriculture

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Biographies for most speakers are in alphabetical order after the last paper.

The Federal Government has ranked agriculture as the principal contributor to Water Quality Impairment in Lakes and Rivers. To address this problem, particularly the contribution made from confined livestock production, USDA and EPA jointly issued the Unified National Strategy for Animal Feeding Operations (AFO Strategy) in March 1999. The AFO Strategy describes the activities that the two Federal Departments plan to take to address water quality and public health impacts associated with Animal Feeding Operations or AFOs. The AFO Strategy also sets forth the goal of minimizing water pollution from the confinement area and land application of manure.

The AFO Strategy envisions about five percent of the AFOs nationwide falling into the Federal regulatory program and the strategy intends that the remainder of the AFOs will voluntarily improve their animal waste disposal practices, assisted by a variety of financial and technical programs. The AFO Strategy's national performance expectation is that all AFOs should develop and implement Comprehensive Nutrient Management Plans (CNMPs) through either the voluntary assistance offered by USDA or through the regulatory program and the issuance of an National Pollutant Discharge Elimination System (NPDES) permit.

EPA is responsible for revising the existing regulations to which as many as five percent of AFOs will be subject. This group of AFOs are defined as Concentrated Animal Feeding Operations (CAFOs). CAFOs are currently defined as those operations with more than 1000 Animal Units (AUs) or smaller operations that meet certain conditions and are subject to NPDES permit requirements to control wastewater discharges.

The regulations that define the term CAFO are found at Title 40 Code of Federal Regulations Part 122.23. These regulations were issued 20 years ago. EPA is currently revising these regulations. The revisions being considered include expanding the definition of CAFO to include land application areas owned or operated by the CAFO to which manure is applied. EPA is also evaluating options for the definition of CAFO for medium sized operations. Currently an AFO can be designated as a CAFO contributing pollution to surface waters on a case-by-case basis if: 1) it houses more than 1000 AUs, or 2) if it houses between 300 AUs and 1000 AUs and also has a manmade conveyance, or 3) has water that originates outside of the AFO and run through or pass over the AFO, or 4) if animals come in direct contact with these waters. In addition to these criteria EPA is considering other criteria that could reflect the potential of medium-sized AFOs to discharge waste and wastewater to Waters of the U.S. EPA is also considering clarifying the definition of CAFO to specifically include poultry operations with dry manure systems.

EPA issued technology based performance standards or effluent limitations guidelines regulations for the feedlots point source category in 1974. These regulations are found at Title 40 Code of Federal Regulations Part 412 and apply to large CAFOs or feedlots with greater than 1000 AUs. The regulations established zero discharge except when chronic or catastrophic rainfall events cause an overflow from a facility which has been designed, operated and maintained to contain all waste and wastewater and the runoff volume associated with a 25 year, 24 hour storm.

EPA is revising the Effluent Guidelines Regulations. Some of the revisions being considered include establishing management practices or requirements to control manure or wastewater application to crop or pasture land. In addition, EPA is considering establishing monitoring and recordkeeping requirements, such as collection of soil and manure samples and recording manure applications, crop yields and other factors related to land application of manure. EPA is also considering requiring practices and inspections that help to ensure the manure storage structures are being adequately maintained. Dry poultry requirements are being considered as part of this rulemaking effort, consistent with the inclusion of dry poultry operations under the definition of CAFO. EPA is also considering establishing effluent guidelines requirements for facilities below the 1000 AU threshold.

The revised regulations are scheduled to be proposed late in 2000 and finalized by 2002. In the interim EPA is developing a permit guidance manual intended to provide guidance for permit writers who will issue NPDES permits to CAFOs. This permit guidance will describe the types of requirements that should be included in NPDES permits issued to CAFOs. Included in these requirements will be the development of a CNMP. The permit guidance will describe what should be included in a CNMP. The CNMP will include activities necessary to ensure that manure storage and animal housing structures are adequately maintained to ensure structural integrity and are operated in such a way as to avoid a discharge. The application of manure and wastewater to crop or pasture land should also be performed in an appropriate fashion. The CNMP should account for the nutrient needs of the crop, the nutrient levels in the soil, the timing of application, the hydraulic loading of the soil and proximity to surface waters.

EPA is working with states that have authorized NPDES programs to issue permits to CAFOs. The AFO Strategy and permit guidance describe two types of permits that can be issued to CAFOs. Most CAFOs are expected to be subject to general permits. A general permit is written to cover a category of point sources with similar characteristics for a defined geographic area (e.g., all CAFOs in a State). General permits offer a cost-effective approach for NPDES permitting authorities because of the large number of facilities that can be covered under a single permit. At the same time, the general permit also provides flexibility for the permittee to develop and implement pollution control measures that are tailored to the site-specific situation of the permittee. To receive coverage by a general permit, facilities submit a notice of intent (NOI), which would include descriptive information about the facility including legal name and address of owner or operator, facility name and address and contact person, physical location type, and number of animals, and receiving stream information. EPA has stated that all CAFOs should develop Comprehensive Nutrient Management Plans as a requirement of their NPDES permits which would address the site-specific features of each CAFO.

The other type of permit would be an individual permit which is developed especially for the affected facility and is written specifically for the conditions at the facility. EPA is considering requiring individual permits for facilities when they meet the following criteria:

- exceptionally large operations;
- operations undergoing significant expansion;
- operations that have historical compliance problems;
- operations that have significant environmental concerns; and
- new CAFOs.

# Comprehensive Nutrient Management Plan from a USDA Perspective

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**Abstract**

Livestock manure has emerged over the past few years as a major political, as well as an environmental issue. As the Congressional Research Service described the situation in a May 1998 report: "Social and political pressure to address the environmental impacts of livestock production has grown to the point that many policy-makers today are asking what to do, not whether to do something." It added: "The bulk of current policy debate on animal waste issues, both legislative and regulatory, is occurring in states, and that activity is vigorous and multi-faceted. Federal attention followed more recently."

National policy attention had reached a peak over the last few years, as symbolized by the issuance of the USDA/EPA Unified National Strategy on Animal Feeding Operations. Below the national level, no less than 34 states have passed, voted on, or at least debated policies in the last five years that would directly or indirectly affect control of livestock manure. Numerous counties have passed their own ordinances relative to the matter. Finally, in the non-governmental realm, some of the national livestock producer groups have undertaken their own initiatives during the past two years to curb manure runoff and related environmental problems.

Market forces, technological changes, state and local regulations, and industry adaptations have produced unprecedented increases, concentrations, and geographic shifts in confined livestock production in the United States. Public perception of the impacts that this concentration of livestock may have on the environment is based on the Pfiesteria outbreaks along the mid-atlantic; urban water supplies contaminated by Giardia, Cryptosporidium parvum, and nutrients; and increased in-stream nutrient, pathogen, and organic loading correlated with livestock numbers. Two issues of growing concern are: 1) non-point source pollution of the Nation's water from AFOs, and 2) the inadequacy of traditional land-based manure nutrient management strategies as livestock operations surpass the carrying capacity of the land in some geographic areas.

## Introduction

"Technical Guidance for Developing Comprehensive Nutrient Plans" is a document intended for use by the Natural Resources Conservation Service (NRCS) and conservation partner state and local field staffs, private consultants, landowners/operators, and others that will be developing or assisting in the development of the comprehensive nutrient plans (CNMPs). This technical guidance is not intended as a sole source of reference for developing CNMPs. Rather, it is to be used as a tool in the process of providing technical assistance in identifying the conservation practices and management activities that will be included in a CNMP.

A Comprehensive Nutrient Management Plan (CNMP) is a component of a conservation plan that is unique to animal feeding operations. A CNMP is a grouping of conservation practices and management activities which, when combined into a system, will help to ensure that both production and natural resource goals are achieved. It incorporates practices to fully utilize animal manure and organic by-products as a beneficial resource. A CNMP addresses natural resource concerns dealing with nutrient and organic by-products and their adverse impacts on water quality. A CNMP needs to be in compliance with all applicable local, tribal, State, and Federal regulations. For certain unique, impacted watersheds or water bodies, special management activities or conservation practices may be incorporated to meet specific local, tribal, State, or Federal regulations.

The conservation practices and management activities in a CNMP for which NRCS maintains technical standards are to meet these standards. Components of a CNMP for which NRCS does not currently maintain standards are to meet criteria established by local, tribal, State, Federal government or others recognized by NRCS. Ultimately, it is the producer's responsibility as the decision-maker to select the system of conservation practices and management activities that best meet their needs from the alternatives available.

The goal of a CNMP as described in the Unified National Strategy for animal feeding operations (AFOs) is to minimize the adverse impacts of (AFOs) on water quality and public health. To accomplish this goal will require a significant increase in the intensity and comprehensiveness of technical assistance provided to producers.

## Potential Workload

The work load analysis (WLA) conducted by Natural Resources Conservation Service and the conservation partnership shows that there are about 1.4 million animal feeding operations with 0.1 of an animal unit or greater base on the 1997 Census of Agriculture. Of this universe of 1.4 million, it is estimated that 298,500 would need technical assistance to develop CNMPs. There are slightly more than 500,000 operations with goats, horses, sheep, mules and rabbits included in the 1.4 million universe.

A CNMP is to be developed by the client for the client's use to record decisions for production, natural resource protection, conservation, and enhancement.

Decision and resource information needed during implementation and maintenance of the plan are recorded. The narrative and supporting documents provide guidance for implementation and may serve as a basis for compliance with state, tribal, and federal regulations.

A CNMP is to include all land units, on which manure and organic by-products will be generated, handled, or applied, that the client either owns or has decision-making authority over.

## ELEMENTS TO CONSIDER WHEN DEVELOPING A COMPREHENSIVE NUTIRENT MANAGEMENT PLAN -

### 1. Animal Outputs - Manure and Wastewater Collection, Handling, Storage, and Treatment, and Transfer

A manure and wastewater management system for a given animal feeding operation (AFO) should include all the components and management activities necessary to minimize degradation of water quality. A system may consist of a single component or as many components as necessary to meet the objectives of the owner/operator while minimizing the environmental impacts. An on-site visit is required to identify existing and potential resource concerns, problems, and opportunities in the siting of manure and wastewater management system components. It is also important during this site visit to document the existing in-place infrastructure, equipment available, and transfer processes being used.

### 2. Evaluation and Treatment of Sites Proposed for Land Application

An on-site visit is required to identify existing and potential resource concerns, problems, and opportunities for the conservation management unit (CMU). This process will be used to identify and assess operations and activities needed to address existing and potential natural resource problems.

### 3. Land Application

The potential long and short–term impacts of planned land application of all nutrients and organic by-products (e.g., animal manure, waste water, commercial fertilizers, crop residues, legume credits, irrigation water, etc.) must be evaluated and documented for each Conservation Management Unit (CMU).

### 4. Record of CNMP Implementation

If the landowner/operator is to adequately apply and assess their CNMP, it is critical that they maintain a record of their activities and the functionality of the system. A record keeping plan should be developed that addresses key elements of the CNMP to aid in the application and assessment documentation.

### 5. Inputs to Animals – Feed Management

Feed management activities may be used to reduce the nutrient content of manure making it easier to manage in a land application scenario. These activities may include phase feeding, amino acid supplemented low crude protein diets, and the use of low phosphorus grain and enzymes such as phytase or other additives. When used, feed management activities shall be in accordance with recommendations by Land Grant Universities, Industry, and others recognized by NRCS.

### 6. Other Utilization Activities

Using manure and organic by-products to provide for alternative, environmentally safe, uses and solutions should be an integral part of the overall CNMP. This is especially true where past land application of manure and organic by-products are a problem because of residual soil nutrient content, and future land application will make conditions worse.

## Summary

In 1998, NRCS conducted a study titled "Nutrients Available from Livestock Manure Relative to Crop Growth Requirements". Using farm-level data from the 1992 Agriculture Census, the authors presented county estimates of pounds of manure nitrogen and phosphorus potentially generated from confined livestock, and compared these estimates to the potential for nitrogen and phosphorus uptake/removal by crops and application on pasture land. This study indicated that the number of counties where manure nutrients exceed potential plant uptake and removal, including pasture land applications, has increased dramatically since 1949. For instance, the number of counties with excess manure production that have the potential to cause water quality problems (nitrogen and phosphorus) more than doubled between 1982 and 1997.

Also, the aggregate effect of odors and gaseous emissions from land application of manure, manure handling, decomposition of dead animals, and, to some extent, from wet feed pose nuisance and public health problems. Current science and technology offer approaches to minimize the problems, but not to entirely eliminate them.

Most of the efforts by USDA and EPA regarding CNMP development have been on land application of manure and organic by-products. To effectively address the manure management concerns, especially in highly concentrated animal areas, other utilization options, such as converting to high-value products need to be a part of the overall management and utilization process.

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# Environmental Water Quality Regulations Applied to Animal Production Activities

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## Introduction

When designing the Clean Water Act's regulatory structure in the 1970's, Congress chose the law's objective to be the restoration and maintenance of the chemical, physical, and biological integrity of the Nation's waters[1]. In selecting regulatory tools to achieve this goal, Congress introduced several key concepts that have evolved over time to become central issues in today's debate about the future of federal and state water quality regulation affecting agriculture, particularly animal production. Two of these key concepts which are discussed in this paper are the distinction between point and nonpoint sources of pollution[2] and water quality standards for regulation of pollution sources.[3]

Discharge of pollutants into waters of the United States from a point source must meet the fundamental regulatory requirement of complying with Clean Water Act requirements before the pollution occurs.[4] Within the definition of a point source are other key concepts such as that of a discernible, confined and discrete conveyance from which pollutants are or may be discharged. At the time it was adopted, the Act put in place these statutory provisions that were the subject of agency interpretation or later explained in regulations. In most cases

[1] 33 U.S.C. section 1251 (West, 1998).
[2] Id. Section 1362 (14) defines a "point" source. Whatever does not meet the definition of a "point" source is considered a "nonpoint" source of pollution.
[3] Id. Section 1313 (d).
[4] Id. Section 1311 (a) establishes the central regulatory requirement of the Act, "Except as in compliance with this section and [other] sections of this title, the discharge of any pollutant by any person shall be unlawful. In this context, "discharge" is defined to include the addition of any pollutant from a point source into waters of the United States, section 1362 (12).

these regulations have existed unchanged for a considerable period. The contextual basis upon which these statutory and regulatory provisions were built has changed considerably over that period. How should change that has taken place be reflected in applying existing provisions to changed situations?

In regard to water quality standards, the Clean Water Act mandates that states identify those waters within the state's boundaries for which effluent based limitations are not stringent enough to implement any water quality standard for such water.[5] States are further mandated to establish a priority ranking for restoration of identified impaired waters based on the severity of the pollution identified and the uses to which the waters are put. States quantify the Total Maximum Daily Allowable Loads for pollutants in each listed water body and to allocate the maximum loads among the contributing sources, whether they be classified as point or nonpoint in origin. Determining Total Maximum Daily Loads establishes the maximum amount of pollutants that a water body can receive. However, despite such mandates, states have been slow to move forward with programs to accomplish these goals. Litigation to force states to move forward has been the result of the inaction.

In the nearly thirty years since major federal water quality legislation was passed, considerable progress has been made toward achieving the law's stated purpose. However, the job is far from finished. As noted in the 1995 General Accounting Office Report to the Senate Committee on Agriculture, Nutrition, and Forestry, significant portions of America's surface waters are impaired as a result of agricultural activities.[6] This report, which was based on data taken from state water quality assessments, led GAO to conclude that agriculture is the main source of groundwater pollution in the United States. As to surface water pollution the report noted that soil and nutrient run off, as well as animal waste run off from animal feeding operations, contributes greatly to the impairment of streams and lakes through introduction of excess nutrients, organic matter and pathogens. Excess nutrient loadings stimulate algae development which when decomposed robs water of oxygen needed by fish and aquatic animals for their own survival.[7] Pathogenic contamination can impact on water quality for personal use, recreation and wholesomeness of fish and shellfish obtained from the water source. In watershed areas studied by the U.S. Geological Survey's National Water Quality Assessment, increases of stream loadings of nitrogen and phosphorous have a strong statistical correlation, in part, to increases in the concentration of livestock in the watershed area.[8] The study noted this statistical correlation exists despite the fact that most nutrients applied to land do not end up in lakes, rivers and streams as they are taken up by plants in the watershed or returned to the atmosphere as gas.

While all of this was taking place on the regulatory front, substantial changes were taking place in the agricultural sector of the economy. Several prominent commentators describe this change as the application of a manufacturing mentality to traditional agricultural

[5] Id. Section 1313 (d).

[6] See GAO Report, "Animal Agriculture, Information on Waste Management and Water Quality Issues" (GAO/RCED-95-200BR), at p.9. (Hereafter, GAO Report).

[7] Id., p. 11.

[8] Id., p. 13.

production practices.[9] No longer do agricultural producers ask the question whether consumers will buy what they produce. Producers now actively seek to determine what consumers want to buy and then design production practices and structures that deliver to consumers precisely what consumers want. Traditional production practices are also modified through increased use of production contracting arrangements for livestock production, greater integration of production, processing and distribution channels, increased investment in assets devoted to production and movement away from the so called "traditional' farm. By the end of the 1990's, an increasing share of total agricultural production was being generated by a relatively small, but growing, number of large-scale producers. A description of the modern agricultural sector would include a fairly small number of very large producers; a significant number of small-scale producers; and a like number of mid-sized producers. It is the mid-sized producers who wrestle with the question of whether the producer can afford to continue to operate at present levels, or must a choice be made between opposite ends of the spectrum just described[10].

Despite the fact that the small number of large producers generate a large part of the total output of the sector, small producers who face the competitive pressures posed by large-scale producers have not accepted their lot in life without objection. In several parts of the country, active opposition to proposals for placement of large animal production facilities is being mounted on grounds that allowing such facilities in rural areas adversely affects "family farmers", the group which Jefferson considered to be the very basis of a democratic society. Of important significance from a political and economic policy perspective is that the agricultural community now appears fragmented into groups that favor or oppose expansion of production facilities.

While these changes in the agricultural economy continue to evolve, the Courts also have a role in shaping the debate. The Second Circuit's 1994 decision in *Concerned Area Residents for the Environment v. Southview Farms, Inc.*[11] examined the question of when a given set of production practices or management approaches could be viewed as subject to mainstream environmental regulation. In many ways the Southview Farms case presents a number of key issues to address. First, as Southview Farms can be described as a model of what large animal production facilities ought to be (in that case a dairy farm), is the decision an indictment of the manufacturing mentality applied to new types of production facilities? How much weight did the Court's decision put on the factual record of poor manure management practices by Southview employees? Are those factual elements crucial to evaluating the impact that the decision could have? Why didn't the court simply rely on the numbers animals alone to determine that Southview met the definition of a CAFO and, therefore, needed a permit that it failed to have at the time the discharge occurred?

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[9] See Michael Beohlje, *Industrialization of Agriculture: What are the Policy Implications?* Contained in *Increasing Understanding of Public Problems and Policies,* edited by Steve A. Holbrook and Carrol E. Myers, The Farm Foundation, Oak Brook, Illinois, 1996.

[10] Milton C. Hallberg and Dennis R. Henderson, Structure *of Food and Agricultural Sector,* contained in *Food, Agriculture, and Rural Policy into the Twenty-First Century, Issues and Trade-Offs,* edited by Milton C. Hallberg, Robert G.F. Spitze, and Darryl E. Ray, Westview Press, Boulder Colorado, 1994, at p. 58,59.

[11] 34 F.3d 114 (2nd Cir., 1994).

In this article we explain the principal water quality oriented provisions of federal environmental law that directly apply to animal agricultural production practices and facilities. Included in this discussion is the recently developed joint USDA/EPA National Strategy for dealing with pollution threats posed by large-scale animal production facilities. Concerns about pollution from such sources are not merely idle speculation. Over the past five years events across the country, and particularly in North Carolina[12], Maryland and Virginia have made these environmental consequences the subject of headline news at the national level.

## 1. The Federal Water Pollution Control Act

The *Federal Water Pollution Control Act* of 1972 was meant to restore the integrity of the nation's navigable water to fishable and swim-able quality by 1983, with a total elimination of pollutant discharges by 1985. Although this goal was never realized, the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act, has done much in terms of cleaning up the nations rivers and streams.[13] The Clean Water Act's primary tool in regulating the discharge of pollutants into the nation's navigable water is the National Pollutant Discharge Elimination System (NPDES) found in Title IV of the Clean Water Act. Under the Act water pollution sources are classified as either *point sources* or *nonpoint* sources of pollution. The primary regulatory focus of the NPDES is controlling the discharge of pollutants from point sources.[14] Under the Act a point source is defined as:

> Any discernable confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.[15]

In order to discharge any pollutant from a point source, a permit is required under the NPDES. A discharge of a point source pollutant without a permit is illegal under the Clean Water Act. To be granted a permit under this section of the Clean Water Act, a point source polluter must conform to a certain set of technology based standards that are tied to the pollutant source and the nature of the pollutant being discharged. In addition to meeting technology-based effluent limits, point sources of pollution may also be subject to regulation based on water quality standards. Under the Act, states are directed to identify those waters within their boundaries for which the technology based effluent limitations required under the NPDES are not stringent enough to implement a water quality standard that is applicable

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[12] Reference here is made to a release of raw swine manure from a treatment lagoon located next to the Neuse River in North Carolina and the recent fish kills along the Pocomoke River in Maryland and Virginia that is attributed to the microbe, *Pfiesteria piscicida*.

[13] U.S. Department of Agriculture and Environmental Protection Agency Draft Unified National Strategy for Animal Feeding Operations, 63 Fed. Reg. 50192, 50195 (1998). (Hereinafter, Unified Strategy).

[14] Under 33 U.S.C. section 1311, except as in compliance with the Clean Water Act, the discharge of a pollutant is unlawful. "Discharge of a pollutant" is defined in section 1362 (12) as the addition of any pollutant to navigable waters from a point source.

[15] Id., section 1362(14).

to that water.[16] It is through this section of the act that the quality of the receiving waters is taken into consideration. For waters that are identified by the states, a total maximum daily load (TMDL) for specific pollutants is identified for each body of navigable water, or a designated segment of the water course. The TMDL is set at the level necessary to implement the applicable water quality standard. In this way, the TMDL acts as a restriction on all sources of pollution that discharge into the body of water.

In contrast to the detailed definition of a point source, nonpoint sources are largely undefined. A good universal definition of a nonpoint source is anything that is not covered under the point source category. Despite the advances made to regulate point source pollution, nonpoint source pollution has been blamed for a significant portion of the nation's current water pollution problems.[17] Nonpoint sources come from a variety of activities, including storm water runoff, forestry, mining and farming.

Under the Act's original approach, states were directed to develop area-wide waste treatment management plans to identify those areas which have substantial water quality control problems and design and implement plans to address them. In addition, these plans were directed to include a process by which the state could identify agricultural and silvicultural related nonpoint sources of pollution, including runoff from manure disposal areas and from land used for livestock and crop production. In addition such plans were to set forth procedures and methods to control these sources.[18] To carry out these control measures, the Secretary of Agriculture was authorized to enter into contracts with land owners and farm operators who controlled rural land for the purpose of installing and maintaining best management practices to control nonpoint sources of pollution as part of these approved plans.[19]

**2. Point Source Discharge Prior to Legislation**

The EPA originally held a very broad view of the definition of a point source. Many agricultural activities that generated pollutants could be included in that broad definition. For example, irrigation return flows and rainfall runoff were considered to be point sources if the water was channeled or collected by any man-made activity.[20]

Under this broad view of a point source, many agricultural activities were required to obtain permits under the NPDES program. The EPA estimated the number of silviculture point sources to be over 300,000 and approximately 100,000 separate storm water discharge point sources.[21] Each individual point source would need a permit under the NPDES requirement. This proved to be a heavy administrative burden on the EPA. For this reason, the EPA

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[16] Id., section 1313(d).
[17] GAO Report, p. 6.
[18] 33 U.S.C. section 1288(b)(1)(A); (2)(F).
[19] Id., section 1288 (j)(1).
[20] Drew L. Kershen, "Agricultural Water Pollution: From Point to Nonpoint and Beyond", Natural Resources and the Environment, Winter, 1995, 3.
[21] NRDC v. Costle, 568 F.2d 1369 (D.C. Cir. 1977), Costle II.

exempted agricultural activities from the NPDES requirement.[22] The EPA justified their exemption of all agricultural activities under section 402 of the Clean Water Act.

In the early 1970's, the Natural Resources Defense Council filed suit against the EPA and asked the Court to order EPA to enforce the NPDES requirement for all point sources, including those originating from agricultural sources. In *NRDC v. Costle*[23], the court ruled against EPA's decision to exempt all agricultural activities. The court held that EPA could not exempt a wide class of point source polluters merely because of administrative burdens. NPDES requirements applied to all discharges of pollutants without exception. Section 402 of the Act directed EPA to issue permits for point source polluters.

As a result of the *Costle* decision, all agricultural and silvicultural activities that discharged pollutants from point sources were expected to meet NPDES requirements. This meant that irrigation return flows and storm water run discharges collected and distributed by man made activities were required to have a permit. Activities of this nature were considered to be nonpoint sources at the time of this decision. This is an example of where the point source regulatory requirements were seen to be moving into the field of regulating nonpoint sources.

### 3. Later Amendments and Definition Following Litigation

After the *Costle* decision, many agricultural related activities were required to comply with the Act and obtain a permit under the NPDES. In response to it, Congress amended the Clean Water Act in 1977 and redefined the term "point source" to exclude "return flows from irrigated agriculture."[24] As a result of this amended definition, irrigation return flows were now included in the nonpoint source category.[25]

In 1987, Congress amended the Act with the passage of the Water Quality Control Act of 1987. Included in this Act's provisions was a renewed effort to deal with pollution from nonpoint sources through adoption of nonpoint source management programs. Under the amended provisions, the Governors of the states were directed to prepare and submit to the Administrator for approval reports that identified navigable waters within the state's borders which, without additional action to control nonpoint sources of pollution, could not reasonably be expected to attain or maintain applicable water quality standards or meet the goals of the Act.[26] In this report the states were also to identify those state and local programs which would control pollution from nonpoint sources. Principal reliance under such plans would be placed on best management practices and measures designed to reduce pollutant loadings from particular nonpoint sources. To assist in designing these plans, the Administrator was directed to make grants to the States to assist in carrying out the needed groundwater quality protection activities that are part of the State's comprehensive nonpoint source pollution control program.[27]

[22] Kershen, infra note 20, p. 4.
[23] NRDC v. Costle, 568 F.2d 1369 (D.C. Cir. 1977), Costle II.
[24] 33 U.S.C. section 1362 (14).
[25] Drew L. Kershen, infra note 20, p.4.
[26] 33 U.S.C. section 1329 (a).
[27] Id., section 1329(I)(1).

The 1987 amendments also adopted a similar exemption from NPDES permit requirements for storm water discharges as those created for irrigation return flows in the 1977 Clean Water amendments. As a result of both the 1977 and 1987 acts, the EPA's position in *NRDC v. Costle* was that such activities, although arguably meeting the definition of a point source, should not be regulated as such was incorporated into the Act. This lifted a serious obligation from the shoulders of agricultural producers.

Not all agricultural activities, however, were intended to be exempted from Clean Water Act regulations. The point source definition, originally enacted and as it stands today, specifically includes *concentrated animal feeding operations* (CAFOs) within the meaning of the term point source.

### 4. Animal Feeding Operations and Concentrated Animal Feeding Operations

An example of an agricultural activity that has significant potential for detrimental effect upon the nation's navigable waters is an *animal feeding operation* (AFO). For Clean Water Act purposes, an AFO is a facility in which animals are confined and fed for a total of no less than 45 days in a 12-month period;[28] and no crops or vegetation grown or sustained over any part of the facility during the normal growing season.[29] AFOs pose a number of risks to water quality and public health because of the amount of animal manure and wastewater they generate.[30] Manure and wastewater from AFOs have the potential to contribute pollutants such as nutrients (i.e. nitrogen or phosphorous), sediment, pathogens, heavy metals, hormones, antibiotics, and ammonia to the environment. Excess nutrients in water can result in or contribute to eutrophication, anoxia, and, in combination with other circumstances, have been associated with outbreaks of microbes such as *Pfiesteria piscicida*.

There are an estimated 450,000 animal feeding operations within the United States.[31] Approximately 85% of the AFOs are run by small farm operations with fewer than 250 animals. As will be seen in subsequent discussion, a large majority of AFOs is not subject to the NPDES permit requirement. In the classic distinction between point sources and nonpoint sources, those which did not meet the regulatory definition of a point source were regulated under Clean Water Act programs such as the section 208 and 319 programs described above. However, the Clean Water Act definition of point source has always included *concentrated animal feeding operations* (CAFOs) as point sources of water pollution.

A concentrated animal feeding operation (CAFO) first and foremost is an AFO that meets further regulatory requirements that focus on the size of the operation or the manner in which the facility has operated. Under the NPDES program, an AFO is a CAFO if more than 1000

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[28] 40 CFR 122,23 (b)(1).
[29] Id.
[30] Unified Strategy, 50195.
[31] Office of Wastewater Management, Animal Feeding Operations, January 18, 2000, <wysiwyg://35/http://www/epa.gov/owm/afo.htm>.

animal units are confined at the facility. For Clean Water Act purposes, an "animal unit" is a means of comparing the diverse types of animals raised under confined conditions. The animal unit concept was developed by EPA to make comparisons between species possible. Rather than relying solely on the aggregate number of animals as the determining factor, each livestock type, with the exception of poultry, is assigned a multiplication factor to determine the total number of animal units , or AUs, at a given facility.[32] The number of actual animals located at the facility is multiplied by the appropriate factor for that species to determine the number of animal units at the facility.

Large facilities having more than 1000 animal units are considered to pose a threat to water quality and public health because they produce manure in such volume that the risks are considered to exist whether or not the facilities are well managed.[33] The amount of manure stored at such facilities, if spilled while handling or during a breach of a storage system, can release large amounts of manure and wastewater to the environment with potentially catastrophic results. In addition, land application of large volumes of waste requires careful planning to avoid adverse impacts to the environment.

If a facility has between 301 and 1000 animal units located on the facility, the facility can be considered a CAFO if it meets one of the following specific criteria: (1) Pollutants are discharged into waters of the United States by means of a ditch, flushing system, pipe or other man made device; or (2) pollutants are discharged directly into waters of the United States which originate outside of and pass over, across, or through the facility or some other direct contact with animals confined on the feedlot[34].

Under either of these two CAFO definitions is an exemption from the classification of CAFO if the facility can establish that it would discharge pollution only in the event of a 25 year, 24 hour, or larger, storm event.[35] It is EPA's position that to be eligible for this exemption, the facility owner or operator must demonstrate to the permitting authority that the facility has not had a discharge.[36]

Generally, AFOs that have up to 300 animal units are not considered to be CAFOs. However, EPA can also designate an AFO as a CAFO on a case by case basis if the AFO is determined to be a significant source of pollution.[37] These determinations are made on the basis of a visual observation and results of water quality monitoring.

**5. Litigating the Definitions**

Many AFOs operated under the notion that they did not meet the CAFO definition and therefore were not subject to NDPES requirements. In *Concerned Area Residents for the*

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[32] 40 CFR Part 122 Appendix B.
[33] Unified Strategy, page 50200.
[34] 40 C.F.R. Section 122 app. B.
[35] Id., app. B(a).
[36] EPA Guidance manual and Example NPDES Permit for Concentrated Animal Feeding Operations, Review Draft, August, 1999., page 2-9.
[37] 40 C.F.R. part 122.23(c).

*Environment v. Southview Farms*, the U.S. Court of Appeals for the Second Circuit ruled against a large dairy operation and designated it as a CAFO.[38] This case is one of the most influential court decisions in terms of agricultural regulation under the Clean Water Act.

In *Southview Farms*, the plaintiffs were a group of landowners who lived near the defendant, Southview Farms, a large dairy operation. Southview Farms' methods of raising dairy cattle were unlike traditional means. Dairy cattle were kept in a confined area and not allowed to graze in a pasture.[39] The handling of manure was unlike other dairy operations as well. Through the use of man made devices, the manure was separated into liquids and solids.[40] The liquid manure was pumped into one of five various lagoons located upon the farm. At that point, the manure was dispersed upon the fields by means of a complex irrigation system, which included a piping system and liquid manure spreading vehicles. The whole manure irrigation process at Southview Farms managed millions of gallons of liquid manure.[41] In testimony provided by Southview's neighbors was evidence indicating that on several occasions Southview employees spread liquid manure from vehicles onto the same field. Subsequent to these applications, liquid manure was seen trickling off the field, crossing under a fence by means of a pipe and into a ditch that led to a creek, that ran into a nearby river.[42]

There are important points to be made concerning the Southview decision holding it to be a CAFO that has important ramifications to all livestock producers. First, Southview Farms was found to be a CAFO despite the fact that over 1,100 acres was dedicated to crop production and may have been more than enough land to properly disperse the manure generated by the farm's dairy herd. Under NPDES regulations, a major criteria of AFO designation is that there are no crops or vegetation grown or sustained over any part of the facility where the animals are confined.[43] The court, in determining that Southview was a CAFO, did not look to the farm unit as a whole, but looked specifically to the facility where the animals were confined. Southview Farms' practice of confining its dairy cattle, unlike traditional dairy cattle practices, is a key factor in concluding that the facility is a CAFO that is subject to NPDES regulation.

The second aspect of the Southview Farms decision addressed the fact that the facility was considered a CAFO despite the fact that the discharge occurred during rainfall. As mentioned above, for AFOs with more than 300 animal units, the designation of CAFO will not apply if the facility owner or operator can establish that it has not discharged and has the additional capacity to effectively manage the manure despite a 25 year, 24 hour storm event."[44] In the Southview Farms case, the mere fact that the discharge occurred while it was raining was not enough to trigger application of the storm discharge exemption.

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[38] Concerned Area Residents for the Environment v. Southview Farm, 34 F3d 114 (1994).
[39] Id., at 116.
[40] Id., at 116.
[41] Id., at 116.
[42] Id., at 118.
[43] 40 CFR 122,23(b)(1).
[44] Id., section 122 app. B(a).

Third, a production facility owner or operator has a continuing responsibility to manage employees to assure that they recognize the importance of performing their job properly. Southview Farms had a considerable sized workforce to manage its operation, but the sloppy performance of some of its employees is a central factor in the dispute and the Court's rationale for imposing liability on the Farm.

With the changing nature of livestock production practices, the designation of CAFO status on Southview farms is very significant. With the declining number of privately owned "family" farms, and a growing number of "industrial" / "corporate" agricultural entities, more agricultural activities employ large-scale methods of animal production that utilize non-traditional production methods to generate desired economic rewards from the intensified management. Those smaller "family" farms find themselves increasingly confronted by the question whether the scale of their production facility will enable them to compete in the market. If the intensified production processes are more widely adopted, more and more farms may meet the CAFO designation and ultimately be subject to regulation as a point source.

**6. The Clean Water Action Plan**

In February 1998, President Clinton released the Clean Water Action Plan (CWAP), which provided a roadmap to restoring and preserving the Nation's navigable waters. One of the main areas of concern in the plan was the discharge of manure runoff from AFOs. The CWAP called for cooperation between the USDA and EPA in creating the Unified National Strategy to minimize the water quality and public health impacts of AFOs.

The USDA and EPA announced the release of the Unified National Strategy on September 16, 1998. The major goal of the Unified Strategy was for AFOs to minimize water pollution from their confinement facilities and land application of manure.[45] In order to meet its goal, all AFOs are encouraged to develop "technically sound and economically feasible" Comprehensive Nutrient Management Plans (CNMPs).[46]

The general purpose of CNMPs is to outline a plan for disposing of manure from AFOs. The Unified Strategy expects each CNMP to address, at a minimum, feed management, manure handling and storage, and land application of manure. The CNMPs should be tailored to address the individual needs and practices of each individual AFO. CNMPs that are developed to meet the requirements of the NPDES are to be developed by a person who is certified to develop them, by a State agency or by the Natural Resource Conservation Service. In addition, private individuals or nonprofit groups may also be approved to develop such plans.

While CNMPs are voluntary for most AFOs, the implementations of CNMPs are mandatory for facilities that require NPDES permits. All CAFOs, which require a point source discharge permit, must also have a CNMP. As of 1998, approximately 2000 facilities have

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[45] Unified Strategy, p. 50195 (1998).

[46] Id.

been issued NPDES permits under section 402 of the Clean Water Act. Smaller CAFOs that are required to have NPDES permits, such as those with between 301 and 1000 animal units, can opt to exit the CNMP requirement at the end of the five year permit term by demonstrating the facility has successfully addressed the initial condition which caused it to be designated as a CAFO and it is in full compliance with the plan and other permit requirements.[47]

While the Unified Strategy is aggressive in its goals, the CNMP program is only voluntary for most AFOs. Strongly encouraged, CNMPs are considered the best way to improve the cleaning and preservation of the Nation's navigable waters. Three types of a voluntary programs to help AFOs implement the CNMPs are available: 1) Locally Led Conservation; 2) Environmental Education; and 3) Technical and Financial Assistance Programs. Once approval is granted by the appropriate agency, the AFOs must agree to implement the CNMPs through the voluntary programs before any financial assistance becomes available.

Whether or not the Unified Strategy will be successful in its goals of further cleaning and preserving the Nation's navigable water supply has yet to be seen. While the development of CNMPs are mandatory for a small number of AFOs designated as CAFOs, it is still largely a voluntary program. The Unified Strategy implements no new mandatory regulations, but uses existing regulations in a different way. It is primarily up to each and every individual AFO owner to decide what to do to promote water quality.

### 7. Regulations of Wetlands

Section 404[48] of the Clean Water Act provides the principal federal authority to regulate wetlands use. Both the Environmental Protection Agency (EPA) and the Army Corps of Engineers use the same definition to describe "waters of the United States." Under their definition traditionally navigable waters are included, as well as all interstate waters, including commerce, impoundments, tributaries, territorial seas and wetlands adjacent to waters other than wetlands. Artificially created wetlands are also generally recognized as being subject to regulation under the Clean Water Act.

The Environmental Protection Agency and the Department of Justice are the principle federal agencies involved with the development of regulations and other enforcement action regarding its provisions. Under section 404, landowners and developers must obtain permits from the Army Corps of Engineers in order to carry out dredge and fill activities in navigable waters, which include adjacent wetlands. The authority of the Army Corp of Engineers to be in such matters is one of historical significance dating back to 1890 and the adoption of the Rivers and Harbors Act.[49]

The Clean Water Act specifically exempts certain activities, including normal agriculture, forestry, and ranching, provided they do not convert areas of U.S. waters to uses which they

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[47] Id.

[48] 33 U.S.C. section 1344.

[49] Id. section 403.

were not previously subject and do not impair the flow or circulation of such waters or reduce their reach[50]. Of particular interest to agricultural producers are exemptions for normal farming, forestry, or ranching activities, maintenance of dikes, dams, and levees, construction or maintenance of farm ponds or irrigation or drainage ditches. If performance of any of the discharge activities change the use of the waters, impair its flow or circulation or reduces its reach, such an activity may be recaptured and therefore regulated under section 404 of the Act. Therefore, primarily routine activities which have relatively minor impact on waters are considered to be exempt activities. Activities that convert large areas of water into dry land or impede circulation or size of the body of water are outside of the exemptions. In regard to the drain clearing exemption, several issues have arisen in cases where prior drainage ditches, once abandoned, are then re-opened. In such cases, the property owner who desires to re-open the drain must seek a permit to do so.

### 8. The Food Security Act of 1985

By most estimates, section 404 regulates only about 20 percent of the activities that destroy wetlands. Activities not regulated under section 404 include drainage, ditching, and channelization for agricultural production, which are major causes of past wetland losses. To fill this gap in coverage, the Food Security Act of 1985 – also referred to as the 1995 Farm Bill – included two major wetlands-related provisions, Swampbuster and the Conservation Reserve Program (CRP). Both of these programs involve the U.S. Department of Agriculture in the development of regulations and other enforcement action. The Food, Agriculture, Conservation and Trade Act of 1990 – referred to as the 1990 Farm Bill – amended Swampbuster and CRP. Further amendments were then made again with the Federal Agriculture Improvement and Reform Act of 1996 – also referred to as the 1996 Farm Bill.

### 9. Swampbuster

Prior to the enactment of the Food Security Act of 1985, federal agricultural policies indirectly encouraged farmers to convert wetlands to farmland by providing credit and commodity price supports. The Swampbuster provision of the Food Security Act of 1985 denied federal farm program benefits to producers who planted an agricultural commodity (defined as an annually tilled crop or sugarcane) on wetlands that were converted after December 23, 1985. Swampbuster violations result in farmers losing eligibility for commodity program benefits, crop insurance, disaster payments, and other federal benefits.

The Food, Agriculture, Conservation and Trade Act of 1990 strengthened Swampbuster by stipulating that a person who drains or otherwise manipulates wetlands for the purpose, or to have the effect, of making the production of an agricultural commodity possible on such converted wetlands (actual planting is not required), is ineligible for farm program benefits for that year and all subsequent years. The act also created a system of graduated sanctions for inadvertent violations and provided that farmers can regain lost federal benefits if they restore converted wetlands.

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[50] Id. section 1344(f).

Under the Federal Agriculture Improvement and Reform Act of 1996, the reach of Swampbuster was scaled back. Under previous incarnations, farmers were subject to the Swampbuster provisions despite the fact that they had obtained a permit under the Clean Water Act to convert wetlands. Now, a farmer is exempt from the Swampbuster provision provided that a Clean Water Act permit is obtained and measures are taken to mitigate the damages concerning the converted wetlands.[51]

[51] Bradley C. Karkkainen, *Biodiversity and Land*, 83 Cornell L. Rev. 1, 67.

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# Session 4

# Waterborne Pathogens

# Ag-Related Waterborne Pathogens

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**Introduction**

The focus on livestock farms as potential sources of waterborne pathogens in watershed systems is the result of several converging trends. Media and consumer awareness of foodborne and waterborne illnesses is high. Public health officials have identified livestock manure as a potential source of enteric (intestinal) bacterial and protozoan agents[1, 2]. While manure has the potential to harbor a large number of different animal and human pathogens [3, 4], relatively few microbial agents cause the majority of human waterborne disease outbreaks (see Table 1) [5-7].

This paper will provide an overview of the major pathogens that have been associated with waterborne disease outbreaks in humans and discuss the potential role of livestock or livestock manure as one source of these pathogens in watersheds. Pathogens are defined as any microbial agent such as a virus, bacterium, fungus, or parasite (worms or protozoa) capable of causing infection or disease. Zoonotic pathogens (pathogens transmitted among animals and humans) of concern in watersheds will be emphasized in this paper.

Most pathogens are shed in feces from hosts with active infection. The majority of organisms present in manure and feces are part of the normal microflora of the intestinal tract which includes fecal coliforms including *E. coli*, fecal streptococci and other organisms. The potential for fecal material from a given source to cause infection or disease depends on the types and number of pathogenic organisms present, ability of the pathogen to survive or multiply outside of a host, and the potential for contact with a susceptible host. Strains within a given species of organism can vary in their ability to infect a host. For example, several different strains of *C. parvum* have been identified with different host ranges and different infectious doses for each host [8, 9]. Host susceptibility varies with immune status. The very young, the elderly and individuals with compromised immune system are at greatest risk of infection by most enteric pathogens. *C. parvum* [10] infection in previously infected adults resulted in less severe illness and less shedding of organism. Therefore, the ability of a "pathogen" to cause disease depends on a number of different host, pathogen and environmental variables.

**Microbial Agents of Concern in Waterborne Disease Outbreaks**

Microbial agents associated with waterborne disease outbreaks (WBDOs) can be divided into three categories: (1) Those associated with intestinal infection and feces from multiple species including humans such as *Cryptosporidium parvum*, *Giardia species (sp.)*, *Escherichia coli* O157:H7, *Campylobacter jejuni*, and *Salmonella sp.*; (2) those associated with human intestinal infection and feces such as *Shigella sp.*, *Salmonella typhi* and human intestinal viruses; and (3) those which live in the environment such as *Pseudomonas* and *Legionella* that are associated with a variety of human illnesses including skin infections (dermatitis), and Legionaire's disease. Intestinal infections are the most common type of waterborne infection and affect the most number of people.

A collaborative surveillance system for reporting waterborne-disease outbreaks in humans has been maintained by The Centers for Disease Control (CDC) and the US Environmental Protection Agency (USEPA) since 1971. The results are used to assess water systems, the type of agents associated with waterborne disease outbreaks (WBDO) and to improve water quality regulations. The pathogens causing gastrointestinal illness and type of water exposure have been summarized from CDC/EPA reports published in the last decade in Table 1[5-7, 11].

Protozoal infections caused by *Giardia sp.* and *Cryptosporidium parvum* were the leading cause of infectious WBDOs for which an agent was identified both in total cases and in number of outbreaks. Most bacterial WBDOs are caused by *Shigella sp.* which are bacteria associated specifically with human feces. *Escherichia coli 0157:H7* (*E. coli* O157) is emerging as the second most important cause of bacterial waterborne disease.

Most drinking water outbreaks have been associated with sewage contamination, drinking water treatment failures, or biofilms in post-treatment distribution systems. Untreated ground water is emerging as an important source of drinking water contamination. Recreational water exposure is also emerging as an important source of waterborne gastrointestinal illness. *C. parvum* outbreaks are increasingly associated with treated (pool) recreational water exposure indicating the need to educate users about the hazards of fecal accidents especially in pools used by diaper-aged children. Untreated recreational water was the most common source of exposure for *Shigella sp.* and *E. coli* O157. The presence of

*Shigella sp.* indicates human fecal contamination emphasizing the need for education of users.

Information extrapolated from voluntary surveillance systems has limitations [5, 12]. There may be under reporting of the true incidence of water borne disease outbreaks (WBDO) and inaccurate reporting of the relative frequency of disease caused by particular agents. Viral waterborne disease is probably under reported because of difficulties in routine diagnosis of enteric viral infections. Community outbreaks may be investigated more commonly than individual infections which tend to be under reported.

**Table 1. Etiology of Waterborne Disease Outbreaks Causing Gastroenteritis 1989-1996**

| Type of Organism | Etiologic Agent | Number of Outbreaks | Outbreaks associated with Drinking Water | | Outbreaks Associated with Recreational Water | |
|---|---|---|---|---|---|---|
| | | | Surface | Ground | Natural | Pool/ Park |
| Protozoa | *Giardia sp* | 27 | 12 | 6 | 4 | 5 |
| | *Cryptosporidium parvum* | 21 | 4 | 4 | 2 | 11 |
| Bacteria with Potential for infecting multiple species | *Escherichia coli O157:H7* | 11 | | 3 | 7 | 1 |
| | *Campylobacter jejuni* | 3 | 3 | | | |
| | *Salmonella typhimurium* | 1 | | 1 | | |
| | *Salmonella java* | 1 | | | | 1 |
| | *Leptospira grippotyphosa* | 1 | | | 1 | |
| Bacterial infections associated with humans | *Shigella sonnei* | 17 | | 7 | 10 | |
| | *Shigella flexneri* | 2 | | 1 | 1 | |
| Human Viruses | Hepatitis A | 3 | | | | 3 |
| | Norwalk virus | 1 | | 1 | | |
| | Norwalk like virus | 1 | | | | 1 |
| | Small Round Structured Virus | 1 | 1 | | | |
| Acute Gastro-enteritis | Unidentified Etiology – many are consistent with viral epidemiology | 60 | 8 | 44 | 7 | 1 |
| Other | Cyanobacteria like bodies | 1 | 1 | | | |

Many of the agents discussed can also be transmitted by direct contact and foodborne exposure [1, 2]. Implication of water as the true source of infection requires timely epidemiological and laboratory investigations. Information presented in the surveillance summaries is used to guide regulatory programs so the key agents (*C. parvum*, *Giardia sp.*) identified by this surveillance system will be the focus of the rest of this paper. Information about and *E. coli O157* will be provided because of a recent large waterborne and foodborne outbreak implicating cattle as one potential source of infection [13].

**Characteristics of Waterborne Pathogens**

*Protozoa: Cryptosporidium parvum and Giardia sp.*

Protozoan parasites such as *Cryptosporidium parvum* and *Giardia sp*. are important causes of waterborne infection that are also potentially present in animal and human manure and feces. *C. parvum* and *Giardia species* are commonly spread by fecal contaminated water or by direct contact [14, 15]. Foodborne transmission is possible but contributes to a smaller percentage of infections [16].

The factors which contribute to their importance as waterborne disease agents include: their relative resistance chlorine water treatment [14], their ability to survive in water for a month or more [14, 17, 18], the wide host range which includes wild mammals, companion animals, livestock and humans [19, 20]; and the relatively low dose required to cause infection [2, 8, 14]. Infection in humans and animals leads to fecal shedding of numbers of cysts (*Giardia*) and oocysts (*Cryptosporidium*) for 1-2 weeks or longer. Infection can be present with or without signs of intestinal illness which include diarrhea. While both infections are generally self limiting, infection can be more severe and life threatening and result in higher rates of fecal shedding in immune compromised individuals.

In a survey of surface water for protozoal contaminants, *Cryptosporidium sp.* and *Giardia* were identified in 87% and 81% of 66 surface water sites tested [21]. Because protozoa do not multiply outside of the host, wildlife, companion animals, humans and livestock serve as the potential sources of contamination to each other and to watersheds. There are additional species of *Cryptosporidium* carried by birds, reptiles and fish, and cattle and mice (*C. muris*). *C. muris* can infect older cattle [22]; however, only *C. parvum* appears to be infective to humans. Differentiation of *Cryptosporidium* sp. requires examination by special tests or by an experienced diagnostician. Determining viability of oocysts requires use of special dyes. Both issues present challenges in assessing environmental contamination with for *C. parvum*. As mentioned above, genetic differences exist within the *C. parvum* species [9, 23]. Current studies suggest that cattle and human strains exist an may be associated with different cattle to human and human to human cycles of waterborne infection [24-26] .

Genetic differences also exist within the *Giardia.* Human isolates can infect animals but the potential for *Giardia* from different animals to cause human infection has not been well defined [19].

*Bacteria: Escherichia coli O157:H7*

Bacteria such as *Escherichia coli* O157:H7 and to a lesser degree, *Salmonella sp.* , *Campylobacter jejuni*, and *Leptospira sp.* are also found in livestock manure and have been associated with waterborne disease. Most human infections caused by enteric bacterial pathogens are spread by foodborne or by direct contact [1, 27]. Hazard analysis critical control point (HACCP) programs have been developed to reduce contamination of meat products and vegetable crops by pathogens potentially present in livestock manure. Although less frequently transmitted by water than by food, *E. coli* O157 is emerging as an important cause of bacterial waterborne infection in untreated and recreational water.

Cattle were originally thought to be the main reservoir of infection but *E. coli* O157 has been isolated from humans, a dog, horse, sheep, goats, deer, and flies [28-33]. Infection can be life threatening especially in the young children and elderly patients. Illness caused by *E. coli* O157 is rare in hosts other than humans. *E. coli* O157 has been identified in a viable but non-culturable state in numerous surface water sources tested in Japan [34, 35]. Unlike protozoa, growth may occur outside of a host in water under certain conditions [28, 36, 37]. Agricultural water sources have been implicated as an important source of infection to cattle [28, 30, 38-40]. It's ability to survive for months in water [36, 37, 41-43] and feces [44, 45] and low infectious dose [46-48] contribute to its infectiousness and potential for waterborne transfer.

Intestinal viruses, which have been strongly implicated in a number of waterborne disease outbreaks (WBDO) are considered to be host specific and farms are not considered to be a source of infection for humans unless human septic sludge is present.

In summary, to cause waterborne disease, microbes suspended in feces and manure need to survive environmental conditions long enough and at high enough doses to infect a host. Dilution and loss of viability occur when pathogen laden feces is mixed with normal feces, transported across landscapes and mixed in water. Waterborne pathogens of greatest concern have the following characteristics:

- the organisms are either shed into the environment in fairly high numbers, or are highly infectious to humans or animals at low doses (*E. coli O157:H7*, *Cryptosporidium parvum*, *Shigella spp*.);
- the organisms have the ability to survive and remain infectious in the environment for long periods of time ( *C. parvum, Giardia, E. coli O157*) or are highly resistant to water treatment (*C. parvum*); or
- The organisms can potentially multiply in the environment under appropriate conditions (*E. coli O157:H7*).

**The Role of Livestock Agriculture as a Source of Pathogens to Watersheds**

The role of livestock farms as the source of WBDOs has been documented in a limited number of cases. Two outbreaks of *C. parvum* were traced to contamination of drinking water by cow manure in England [49] . One outbreak of *E. coli O157* in a farm family from well water was reported from Canada [50]. The well was located in area subject to runoff by manure contaminated surface water and *E. coli* O157 was cultured from a large number of the cows in the herd. Most waterborne disease outbreaks that affect more than the individual farmer have not been directly linked with agriculture. However, it is important to identify and control the potential contaminants from agricultural sources to address perceptions of a public health risk to water quality from farms.

Livestock (especially ruminant) manure has been identified as potential source of *C. parvum, Giardia sp.* and *E. coli O157.* Most livestock prevalence surveys have been done on cattle farms. In a national survey in the USA, the presence of *Cryptosporidium* sp. was identified on 59% of farms tested and in 22.4% of calves [51]. Increased risk of calf infection correlated with increased herd size. Close to 50% of calves shed oocysts between 1-3 weeks of age. The infection rate declined to 22% in 3-5 week old calves and to < 15% in 5 week and older calves. However, the diagnostic method used did not differentiate *C. parvum* from *C. muris*. C. muris is found in older calves and adults and is not infective to humans [22, 52, 53].

*C. parvum* is typically shed by calves between 4 and 30 days of age Most calves stop shedding within 2 weeks of being infected [54]. Oocyst shedding by adult dairy cattle has not been reported in North American studies [53, 55]. Oocyst shedding in beef calves [56, 57] and lambs [58, 59] tends to be seasonal and peaks with presence of youngstock in the herd. Adult sheep shed oocysts around the time of lambing and are believed to be a source of infection to lambs [58, 59]. Preweaned foals have been found to shed oocysts for up to 19 weeks of age [60]. Infection and shedding in foals appears to be less sporadic across farms [61]. Infection in swine has been reported in nursing and weanling groups [62].

While no large prevalence studies have been reported, *Giardia* infections appear to be widespread in livestock [52-54, 63-65]. Most shedding occurs in calves less than 6 months of age but all ages of cattle can shed *Giardia sp.*[52-54]. Compared to *C. parvum* shedding, calves begin to shed Giardia at older ages (average 31 days) and can shed for up to several months [52-54, 66]. Giardia shedding by pigs, sheep and horses appears to occur more frequently in youngstock but adults can present a risk of infection [60, 62, 67].

*E. coli* O157 farm surveys have been reported in dairy [28, 30, 38, 40, 68-73] and beef cattle [74-76]. Surveys done at one point in time did not accurately assess the prevalence of infection. *E. coli* O157 was found on the majority of farms tested if testing was repeated over time. Fecal shedding was strongly seasonal and peaked during summer months on most premises. Typically 1- 5 % of cattle shed *E. coli* O157 in their feces. The maximum shedding was detected in heifers after weaning. Less than 1% of adults typically shed organisms. Fecal shedding lasted < 1 month in most cattle and usually was not detected beyond 3 months [73, 77]. Numbers shed by heifers were relatively low ($10^2$ - $10^4$/ gram of feces) [40]. Detection and accurate diagnosis of *E. coli* O157 can be diagnostically challenging [78, 79].

In summary, animal manure from young stock represents the highest potential risk to the environment for these selected pathogens. However, *C. parvum* (in sheep only), *Giardia sp.*, and *E. coli O157* can be shed by adults to a lesser degree. Fecal contamination can be seasonal. This is especially true for *E. coli* O157, and *C. parvum* in management systems where young stock are intermittently or seasonally present. These include horses, beef and sheep farms and dairy herds with seasonal calving.

The risk of animal manure as a source waterborne infection depends not only on pathogen presence but also the ability of these organisms to survive in the environment. Their ability to survive in water has been investigated as mentioned above. Survival in the environment outside of water has been reported in a limited number of studies. *C. parvum* infectivity has been assessed after exposure to environmental parameters [80-83]. Oocysts lost infectivity after 30 minutes of drying under laboratory conditions [81] and after 1-4 days in summer and winter conditions in a barn [83]. Infectivity of moist oocysts was lost after exposure to 37° C for 5 days or longer or 15 - 20° C for 2 weeks or longer [80]. Studies using sentinel chambers containing *C. parvum* oocysts and exposed to different farm environmental conditions indicate that freeze-thaw cycles, higher temperatures, and low moisture contribute to loss of viability of oocysts [82]. *Giardia* survivability has not been as thoroughly studied but is expected to parallel *C. parvum* survivability. *E. coli* O157 has been reported to live for months in manure [44, 45] but spreading manure on pasture or forage crops was not considered a risk factor for infection on farms [28, 84].

While the potential exists, the number of pathogens entering watersheds from farms has not been assessed. Use of indicator organisms such as fecal coliforms or fecal streptococci to assess the risk of fecal contamination in water has been used but has limitations. A lack of correlation between the presence of fecal indicator organisms and the presence of protozoan parasites, and occasionally *E. coli O157* in contaminated water has been reported [6, 11]. Multiple species shed the indicator organisms in feces and multiple sources may contribute to watershed contamination. The source of fecal contamination cannot be accurately determined without the use of advanced and expensive serological or genetic typing systems. Without source tracking the relative contributions from different activities within watersheds including farms and the effectiveness of specific control measures cannot be accurately assessed.

At the watershed level, a multiple barrier approach has recommended to enhance water quality by decreasing particulates, excess nutrients, chemical, and microbial contaminants. Standard barriers or control points include drinking water treatment and source water protection from community and agricultural runoff. Best Management Practices (BMP) designed to decrease contaminants by enhancing stream-edge and field barriers have been added in agricultural watershed programs [85].

Quality Assurance programs have been promoted on livestock farms to address food safety issues and promote livestock health and production. The New York State Cattle Health Assurance Program (NYSCHAP) is one example of a preventive herd health program.

It is an integrated disease prevention program which utilizes a farm's team of animal health advisors to develop a farm-specific herd health plan to address infections of environmental, animal health, public health, and food safety concern. Risks are evaluated and farm management or disease control interventions are designed by animal health advisors who have training in disease pathogenesis and who are knowledgeable of a farm's health history and disease risks. By integrating the concepts promoted by farm quality assurance programs and the multiple barrier approach used in watershed protection, additional control points can be added to protect water quality.

The first barrier or control point addresses biosecurity issues and the potential for pathogen import to the farm. The second barrier addresses break the cycle of pathogen amplification in the animal operation. The third barrier is the appropriate collection and treatment of animal waste and prevention of contamination of the food and water sources, and the final barrier is control of pathogen export from the farm. BMP's to support the third and fourth barriers are developed in conjunction with additional farm environmental advisors providing expertise in soil and water conservation, crops and nutrient management. The first and second control points will be addressed below.

**On- Farm Control Points: Sources and Amplification of Pathogens**

*Sources to Farms*

The wide host range and environmental persistence of *C. parvum, Giardia sp.* and *E. coli O157* put farm animals at risk for infection as well as being potential sources of infection. Because of the difficulties in source tracking pathogens carried by multiple hosts, the risks from different sources cannot be accurately addressed so all potential sources must be taken into account and an evaluation made of their potential presence and importance on a farm. Pathogens can be introduced to a farm by infected animals (livestock or other) or transferred by feed, water, equipment or clothing contaminated by viable cysts or oocysts.

Feces from wild mammals including mice, racoons, white-tailed deer, farm rodents [86, 87], domestic livestock, companion animals, and humans are all possible sources of *C. parvum* to livestock farms [20, 88]. Flies and geese may act as transport hosts [89, 90]. *Giardia sp.* can be spread by an even broader number of hosts. The host range of *E. coli* O157 was listed above. Cattle manure, feces from other wild and domestic ruminants, and potentially fecal contaminated water and feed are potential sources of *E. coli* O157 infection to farms [28].

*Amplification on Farms*

Amplification of infection occurs as more animals become infected and environmental buildup occurs. Protozoa do not multiply in the environment but can be environmentally stable in water and to a lesser degree, manure; therefore, the animal's environment can become an additional source of infections if not managed properly.

Several studies have attempted to define risks associated with infection of *C. parvum* in calves on dairy farms [71, 91]. Risk of infection on farms increases with increased number of cattle [71, 91], and number of species as well as total number and management of other agricultural animals present [91]. Because *C. parvum* infects most calves at less than 30 days of age, preweaning management factors were more important than post weaning management for decreasing risk of infection [91]. Preweaning farm management factors associated with decreased risk of *C. parvum* infection include [91]:

- use of ventilation in calf rearing areas (drying)
- daily disposal and cleaning of bedding and daily addition of bedding (to prevent oocyst buildup in the calve environment)
- feeding of milk replacer.

Atwill et al. investigated sources of infection to dairy calves in a large persistently infected California dairy [55]. Most calves were infected between 17-21 days of age. Adult periparturient dairy cattle was not detected to be shedding oocysts and the maternity area environment did not appear to be a source of infection. Viable *C. parvum* oocysts were present on porous surfaces of wooden calf hutches but not in maternity pens in a survey of environmental sources. The hutches had been steam cleaned between calves and left to dry for 1- 4 weeks in ambient temperatures ranging from 29-39°C. Spray from cleaning adjacent dirty hutches or flush water which moved manure from under the older calves toward the younger calves could have been a potential source of contamination to the cleaned hutches and to newborn calves entering the facility. The life cycle is direct so oocycts are infective at time of excretion. Contact with other and especially older calves can increase risk of infection. A calf's contact with its own manure could also serve to amplify infection.

Flush water was also found to be a risk for *E. coli* O157 infection on farms [70]. Risks for *Giardia* infection are being studied but have not yet been published [92]. Any potential for fecal-oral contact with manure or an infected environment including feed and water present a risk for this infection also.

**Management Suggestions**

General management recommendations have been made to prevent and control *C. parvum* infection cycles on farms[88]. These practices focus on decreasing the potential for oral contact with feces or fecal contaminated fomites and generally optimizing health to increase resistance to infection. These general best management practices have the added benefit of decreasing the risk of infection from many different enteric agents - not just *C. parvum*.

Farm biosecurity practices reduce risks of pathogen introduction to farms from outside sources including other farms and livestock, people, wildlife, pests including rodents, birds and insects, and contaminated feed and surface water. Suggested biosecurity practices include:

- Purchase feed from sources which control quality and minimize fecal contamination from rodents other livestock.
- Use a water source for livestock that has a low risk of transfer of pathogens.
- Avoid transport of manure onto the farm by requesting any visitors to use a boot-cleaning bath or wear plastic boots. Avoid contact between calves and clothing. Clothes with obvious fecal contamination should be changed between farms.
- If manure is brought onto the farm, do not allow it to enter the barns or calf housing facilities and protect feed and water sources from fecal contamination by livestock, pets, rodents, or human sewage. Minimize movement of feces between livestock groups of different ages by manure and feed handling equipment, foot traffic and clothing, and surface runoff.
- Purchase replacement livestock from farms with a food health history. Avoid purchase from co-mingled sources such as sales barns.

On farm control management practices prevent amplification of existing or introduced infection. The calf-housing environment, facilities, and feeding and watering equipment, if not cleaned thoroughly to remove manure after use by older calves, can become a source of infection to incoming baby calves. Breaking the cycle of environmental contamination and calf infection depends on minimizing the opportunity for ingestion of feces by basic good hygiene practices as described above.

- For birthing, provide a clean and dry maternity area free of contact with other older calves and their manure.
- An "all-in, all-out" calf rearing strategy may be helpful in breaking a cycle if stringent disinfection is used between groups.
- *C. parvum* oocysts are not killed by common disinfectants and can remain infective in the environment for months under the conditions of moderate temperatures and moisture. Heat and drying limit viability.
- Raise calves in a clean, dry and well ventilated environment. Provide clean bedding and replace bedding frequently to prevent buildup of infectious agents.
- Prevent each calf's contact with its own manure, manure of other calves, and adult manure.
- Segregate calves by age. Prevent direct contact between calves for at least the first 2-3 weeks of life. Feed and handle calves starting with the youngest and working to the oldest calf groups; always segregate and handle sick calves last.
- Provide feed and water free of fecal contamination by livestock, pets, rodents, wildlife, and humans.
- Institute a rodent and fly control program
- Reduce the potential for runoff water to carry contaminated manure into and from areas used to house young animals

General good health and nutrition decrease an animal's susceptibility to infection.

- Provide sufficient colostrum within the first 6 hours of birth and preferably within 2 hours of birth.
- Provide a vaccination program designed by the farm's veterinarian and other animal health advisors. A new vaccine for *C. parvum* is being evaluated and shows promise in decreasing the number of organisms shed in feces but does not prevent infection [93].
- Provide clean, dry, comfortable, well ventilated housing with appropriate animal densities in each area.

The environmental management of E coli O157 on farms has been reviewed [28]. This agent is widespread and has been found in free ranging deer, birds, flies, sheep, dogs, humans, a horse and in cattle herds. In cattle it acts like transient normal flora with short blooms of shedding primarily during the summer months and with intestinal clearance in 1-2 months. A long term reservoir species has not been identified. Environmental proliferation is thought to play a role in livestock infection so the only potential for farm level control is feed and water management. Specific control interventions have not been defined. On farm chlorination of water is being studied as a potential control effort but those studies are not yet completed. Manure spreading on pastures and forages has been assessed as a risk factor but does not appear to be an important part of the on- farm infection cycle.

The third barrier is restriction of movement of contaminated feces into watercourses. To minimize surface and ground water contamination, prevent runoff from animal housing and exercise lots, store manure from animals six months and younger separately from the rest of the herd and apply it to non-hydrologically sensitive areas. If calf manure cannot be safely stored in an area that restricts leaching or runoff from the pile, combine the calf manure with the manure from the rest of the herd, then apply this manure according to best management practices. Combining cow and calf manure under these circumstances may provide sufficient dilution and land treatment of protozoan pathogens while avoiding risks of creating a point source of contamination from the storage of calf manure. Given the heat sensitivity of *C. parvum*, composting processes that heat the entire manure pile above 140°F should kill *Cryptosporidium parvum* and *Giardia* in the manure. Incorporate manure into soil that it is exposed to freeze-thaw cycles. This practice can significantly reduce the viability of *Cryptosporidium parvum* oocysts and *Giardia* cysts in manure.

**Summary**

While farms may be a potential source of microbial contamination of watersheds, the number of waterborne disease outbreaks directly linked to farms has been limited. Given the number of hosts potentially shedding protozoan and enteric bacterial pathogens into the environment, farms can be recipients and amplifiers of pathogens present in the environment as well as a potential source of infection. Best Management Practices have been reported which can help to decrease levels of infections on farms for *C. parvum* and other enteric pathogens. These used in conjunction with BMP's to enhance field and stream edge protection should decrease the risk on watershed contamination from livestock sources.

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# Sources of Pathogens in a Watershed: Humans, Wildlife, Farm Animals?

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**Introduction**

There is increasing concern regarding the impact of water-borne pathogens on human health. In particular, farm animal feces/manures have come under increasing scrutiny as a potential source of pathogens. For the majority of pathogens, there are multiple hosts/sources, including humans, companion animals (*e.g.*, dogs, cats), wildlife, and farm animals, such that few generalization can be made across watersheds regarding the predominant source(s).

Indicator organisms

Fecal coliforms (or generic *Escherichia coli*) are used extensively as indicators of potential pathogen contamination, primarily because specific pathogen testing protocols are too time-consuming, expensive, and/or insensitive to be utilized for monitoring purposes. For example, bacterial pathogens are typically cultured on semi-selective agar media followed by biochemical and serological identification, while protozoan parasites are typically concentrated, stained and enumerated microscopically. Rapid, relatively inexpensive genetic and immunological methods are currently being developed, but are not yet commercially available. A major limitation of fecal coliform testing is that there are no established relationships between fecal coliform and pathogen contamination. In the context of waste water treatment, specific relationships are unnecessary because it is reasonable to assume that, at any given time within a given human population, some percentage of individuals will be shedding pathogens. In the context of watersheds, however, the absence of such relationships seriously limits the reliability of standard microbial testing.

Fecal coliforms (including generic *E. coli*) are excreted by all warm-blooded animals, including birds and mammals. The numbers typically excreted by healthy animals vary from $10^5$ organisms/gram feces for cows to $10^7$ organisms/gram feces for waterfowl; humans and companion animals typically excrete $10^6$ - $10^7$ organisms/gram feces (Schueler, 1999). The potential for fecal contamination from any particular source is a function of multiple parameters including: adequacy of septic/sewage treatment, animal population densities and total fecal/manure production, proximity to surface waters, surface hydrology, survival, etc. Consequently, watersheds must be evaluated on a case-by-case basis.

Recent studies suggest that "genetic fingerprinting" techniques may provide a mechanism for identifying the predominant source(s) of fecal contamination in a watershed. One such technique, referred to as ribotyping (see Glossary), has been proposed by several investigators as a means of discriminating between different sources of generic *E. coli*. Ribotyping has recently been used to distinguish human from nonhuman *E. coli* contamination in the Apalachicola Bay, FL (Parveen et al., 1999). Similarly, researchers in Washington State (Checkowitz, 1998) used ribotyping to differentiate generic *E. coli* contamination in a creek from livestock (hobby farms) vs. companion animals vs. humans (septic systems). Note, however, that in this study 1,639 individual isolates were analyzed. The reliability/sensitivity of genetic fingerprinting techniques is dependant on comprehensive sampling protocols which provide adequate representation of all potential sources of fecal contamination. In addition, it is unclear whether there are unique ribotypes associated with specific animals such that data can be extrapolated to other watersheds or geographical areas, or whether data are site specific. This question must await further analysis and development of a ribotype data base.

<u>*Escherichia coli* O157</u>

The vast majority of *E. coli* strains are harmless. However, a few strains cause diarrhea in humans; these are classified as enterotoxigenic (ETEC), enteropathogenic (EPEC), or enterohemorrhagic (EHEC) *E. coli* (see Glossary). Although there is significant potential for water contamination by ETEC and EPEC strains from farm animals---these are frequently the cause of scours in calves---they are not considered a major health threat for humans because they are self-limiting. EHEC, typically referred to as *E. coli* O157:H7 (see Glossary), is a serious health threat, particularly in children. It causes bloody diarrhea and, if not treated promptly, can result in kidney failure and death.

Although human-to-human contact and contaminated food are the predominant modes of *E. coli* O157 transmission, there does appear to be limited potential for water-borne transmission. It is unclear, however, to what extent dairy/beef herds, or wildlife, are a source of water contamination. Note that in those instances where water-borne outbreaks of hemorrhagic colitis have been documented, they have generally been attributed to direct human contamination of a recreational body of water (Ackman et al., 1997).

*E. coli* O157:H7 was unknown prior to 1982, when it was associated with a multistate outbreak of hemorrhagic colitis. In 1986, it was recovered from healthy dairy cows, suggesting that dairy/beef herds could serve as a reservoir (Martin et al., 1986). Numerous researchers have since documented the presence of *E. coli* O157 in cows/beef cattle or associated with the farm environment: water, birds, flies, rodents and companion animals (Hancock et al., 1998). Studies indicate, however, that shedding by cows/beef cattle is transient and that concentrations do not exceed approx. $10^5$ organisms/gram feces (Shere et al., 1998; Zhao et al., 1995). Limited data suggests that deer also harbor *E. coli* O157 (Rice et al., 1995; Keene et al., 1997), although the author is unaware of any data on prevalence or concentrations. Once in the environment, *E. coli* O157 cells can survive in bovine feces/manure or water for several weeks (particularly at lower temperatures). However, unlike in food, there is no evidence for proliferation; numbers decrease continuously because there are no substrates to support growth. Collectively, these data suggest that, after accounting for dilution and mortality, *E. coli* O157 concentrations in surface waters from agricultural sources are likely to be relatively low; insufficient data exist to draw any conclusions regarding wildlife.

At present, the risk from water-borne transmission, regardless of source, cannot be estimated because no quantitative data are available establishing the minimum number of organisms required to cause infection in humans. Based on studies with infant rabbits, a minimum dose of approx. $10^5$ *E. coli* O157 cells are required to cause diarrhea (Center for Disease Control, website). Based on epidemiological data, other researchers have speculated that lower doses may be sufficient to cause disease in children. Consequently, there are currently too many knowledge gaps to assess the risks associated with watershed contamination by *E. coli* O157.

Similar to generic *E coli.*, "genetic fingerprinting" techniques have been developed to track specific *E. coli* O157 strains. The most frequently utilized method is referred to as restriction fragment length polymorphism (RFLP) or pulsed field gel electrophoresis (PFGE; see Glossary). This method produces a series of unique DNA fragment patterns, referred to as restriction endonuclease digestion profiles (REDP). This method has been utilized to identify different *E. coli* O157 strains on one or more dairy farms (Faith et al., 1996; Rice et al., 1999). In at least one instance, it has also been used to document transmission from cattle to humans associated with an on-farm outbreak (Louie et al., 1999). However, the author is unaware of any published studies utilizing PFGE to document sources of water contamination.

<u>*Cryptosporidium parvum*</u>

Another important water-borne pathogen is *Cryptosporidium parvum*, the causal agent of cryptosporidiosis. *C. parvum* is a widespread protozoan parasite afflicting over 80 mammalian species, including humans. Several outbreaks of cryptosporidiosis have occurred in the past decade, the most severe in Milwaukee, WI where over 400,000 people were infected. Water-borne *C. parvum* oocysts (the infectious agent outside the host) present a serious public health threat because of the low infectious dose (approx. 130 for adults) and their resistence to standard chlorination treatment. Immuno-deficient individuals (*e.g.*, AIDS, cancer patients) are particularly at risk because there are no effective treatments for the disease.

Although infections can result from human-to-human contact, contaminated drinking or recreational waters are believed to be an important mode of transmission, with humans, wildlife, and farm animals all potential contributors. An extensive multi-state survey of dairy farms indicates that virtually all herds with >100 cows are infected with *C. parvum* (Garber et al., 1994). New-borne calves are the most susceptible and can excrete several billion oocysts if they develop scours. Older animals can continue to shed for up to four months, although at lower levels (Atwill et al., 1997; author, unpublished data). Although few studies have been conducted of wildlife, limited data suggests that feral animals are potential contributors to watershed contamination, particularly where animals congregate at the edge of streams, creeks, etc. (Atwill et al., 1997). Watershed monitoring studies appear to confirm the contribution of both farm animals and wildlife, although oocyst concentrations downstream of dairy or beef farms were several fold higher than upstream, with the highest concentrations observed during calving (Hansen and Ongerth, 1991; Ong et al., 1996). Sewage outflows from waste water treatment plants have also been documented to contain substantial numbers of oocysts, particularly in the absence of tertiary treatment (States et al., 1997).

Once in surface waters, oocysts are extremely persistent. Oocysts possess a tough outer wall which is resistant to many common disinfectants. Laboratory studies indicate that oocysts can remain viable for several months in waters, particularly at lower temperatures. Less in known about fate/survival *in-situ*. Limited data suggests that oocysts are susceptible to filtering, predation and/or microbial decomposition. Oocysts appear to be readily filtered from estuarine waters by oysters (Fayer et al., 1999) or, alternatively, ingested/digested by rotifers (Fayer et al., 2000).

Despite the relative abundance of information regarding sources, survival and infectious dose, risk assessment remains problematic for several reasons. One, the majority of published data documenting fecal sources are expressed as percent of animals infected. In the absence of quantitative data, it is difficult to estimate total numbers of oocysts excreted into the environment. Two, several species of *Cryptosporidium*, other than *C. parvum*, have been described which are infectious to birds, reptiles, and/or some mammals. Current standard microscopic detection/enumeration methods, however, cannot differentiate between most of these species. Consequently, oocysts observed in natural water samples must be considered, at best, presumptive *C. parvum*. Three, current microscopic detection/enumeration methods do not distinguish viable from nonviable oocysts. Several viability testing methods have been developed (*e.g.*, viability staining, excystation, mouse bioassay, cell culture), however, all have major limitations or drawbacks which limit their application to routine water monitoring.

Because of the inherent limitations of current detection methods, considerable effort has been devoted to developing genetic protocols to overcome these limitations. The primary genetic method utilized for *C. parvum* detection is referred to as PCR-RFLP (see Glossary). This method utilizes DNA primers to amplify different regions of the genome; there are currently at least sixteen different protocols. Recent comparative studies indicate, however, that not all protocols are equally valid or reliable (Sulamain et al., 1999).

An important result of genetic characterization has been the elucidation of two different *C. parvum* genotypes with distinct transmission cycles. Genotype I ("human") is infectious only to humans, while genotype II ("bovine") is infectious to humans, calves, and laboratory mice (Peng et al., 1997). Utilizing this protocol, analysis of oocysts extracted from oysters (harvested from the Chesapeake Bay) indicates that the predominant genotype in these waters is the "bovine" genotype. By comparison, of the five oocyst samples remaining from the Milwaukee epidemic, all were the "human" genotype. Although these genetic methods allow for differentiation between some species and "human" vs. "bovine" genotypes, the ability to distinguish between oocysts from different mammalian hosts has not yet been demonstrated.

A limitation of PCR-RFLP protocols is the inability to distinguish between different oocyst types in a mixture. An alternative approach, referred to as TaqMan® PCR (see Glossary), allows for detection of a specific DNA sequence unique to a particular strain or genotype. Protocols have been developed with theoretical detection limits of approx. 100 oocysts/mL. Preliminary information, however, suggests that this method may also be unable to distinguish among oocysts from farm animals vs. wildlife (*e.g.*, deer).

**Glossary**

Enterohemorrhagic *E.coli* (EHEC): This pathogen secretes shiga toxins (verotoxins). Symptoms are bloody diarrhea and hemolytic uremic syndrome.

*E. coli* O157:H7: The primary serological type of EHEC in the USA and Europe; O111 is the dominant serological type in Australia. O157 refers to the cell membrane lipopolysaccharide antigen while H7 refers to the flagellar antigen. Note that *E. coli* O157 is not detected by the standard water testing protocol for generic *E. coli*.

Enteropathogenic *E.coli* (EPEC): This pathogen invades the microvilli of the small intestine and causes diarrhea.

Enterotoxigenic *E.coli* (ETEC): This pathogen is most commonly responsible for "travelers' diarrhea". It colonizes (but does not invade) the proximal small intestine and secretes enterotoxins.

Polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP): The polymerase chain reaction is a method for amplifying specific fragments of DNA. In PCR-RFLP specific segments of genomic DNA are amplified, the segments fragmented with one or more restriction enzymes, and the fragments separated by gel electrophoresis. The unique patterns of DNA fragments allows for differentiation of genotypes or strains.

Restriction fragment length polymorphism (RFLP)/pulsed field gel electrophoresis (PFGE): Genomic DNA is fragmented with a specific restriction enzyme (e.g., *Xba* I is commonly used for *E. coli* O157) producing a series of DNA fragments of variable size. These fragments are separated by pulsed field gel electrophoresis to produce a pattern, called a restriction endonuclease digestion profile (REDP). Comparison of REDPs from different locations/animals allows for tracking of specific strains.

Ribotyping: Genomic DNA is fragmented with a one or more specific restriction enzymes producing a series of DNA fragments of variable size. After separation by gel electrophoresis, fragments are hybridized with DNA probes specific to ribosomal RNA genes. Only those DNA fragments which hybridize are detected. Comparison of DNA profiles from different locations/animals allows for tracking of specific strains.

TaqMan®: DNA primers and probes are selected which bind to a very specific segment of the genome. PCR methods are then used to amplify that specific DNA segment in an environmental sample (*e.g.*, water, manure). If the segment is absent, no reaction occurs. In theory, very small differences in DNA sequence can be detected. Note that since this is a direct detection method, gel electrophoresis is not required.

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## Session 5

# Manure Management Practices

# Manure Management on Swine Farms: Practices and Risks

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Biographies for most speakers are in alphabetical order after the last paper.

**Overview of Swine Production Systems**

The swine industry began a transition from outdoor, extensive systems to indoor, intensive production in the late '60's and early '70's. Many "farrow-to-finish" operations housed pigs from birth to market weight. Animals were grouped into four production phases: 1) breeding/gestation; 2) farrowing; 3) nursery; 4) grow-finish. Within each production phase, animals were often housed in large rooms or barns with a wide variation in age and body weight. This approach helped to keep building and ventilation costs down, but by the mid '80's producers realized that housing pigs in single age groups greatly improved health and growth performance, even though separate rooms and ventilation systems were required. This production system is referred to as All-In-All-Out (AIAO). Further refinement of the AIAO approach resulted when producers realized that by moving age groups to separate farms, transmission of disease was reduced even further. Throughout the late 90's, this new system, called multiple-site production became a standard practice for the majority of hogs produced in the country.

Over this same time period, swine farms have been increasing in size to help offset diminishing profit margins. In addition, many of the nursery and grower-finisher units are now operated under contract. The contract requires the producer to own the buildings, care for the pigs, pay most of the utilities, and dispose of the manure. But another individual or company owns the pigs and provides the feed.

These trends, which have been driven by economics and the need to maximize health and productivity, have many environmental implications. On the positive side, multiple site production spreads the production of manure over many locations, compared to that of a farrow to finish operation. In addition, the grouping of animals by age and weight means that diets can be formulated precisely, which helps to reduce excretion of nutrients. In the past, only two diets were fed during the grow-finish period (45 lbs. to 250 lbs.); now, diets may be changed as many as seven times (personal communication, Joe Garber, Wenger's Feeds, 2000). Some producers even group pigs by gender and formulate separate diets for each sex. In addition, general improvements in productivity and efficiency mean that less feed is required to produce a pound of pork, which also reduces nutrient wastes.

The recent changes in swine production have also created some environmental challenges. Even though production phases are distributed over large areas, some of the individual units, particularly the sow units, are significantly larger than that of previous farrow to finish operations. Manure output can often surpass several million gallons per year. Odor from the application of manure and from the building can cause conflict in the community. And now, all of the feed and therefore all of the nutrients are imported to the hog production unit, causing a significant nutrient surplus in hog production regions.

**Overview of Manure Storage Systems**

In the Northeast, swine manure is stored in an anaerobic state. Nursery and grow-finish facilities generally have deep pit storage under totally slatted buildings. Sometimes, the pits are shallow "pull-plug" arrangements that allow producers to drain the manure to outside storage systems on a frequent basis. Sow units almost always have shallow pits with outside storage systems. The storage units are earthen ponds, approximately 12 feet deep, with about two-thirds of the depth below grade. The ponds are lined with high-density polyethylene, typically .060 inches thick. Beneath the liner, a network of drainage tiles carries surface water away from the structure. The outlet from the drainage tile is monitored on a regular basis to watch for leaks.

Because manure is removed completely at least once per year from storage systems in the Northeast, sludge build up is generally not a problem. Solids may accumulate in areas several hundred feet from the pump-out ports, or when gutters are shallow and not recharged after draining, or when feed waste is excessive. Agitation or removing manure from several locations throughout the storage facility will generally prevent solids problems.

In the Southeast, manure is most often stored in anaerobic lagoons. The design and operation of a lagoon is significantly different from that of anaerobic storage system. For a given volume of manure, lagoons are larger than anaerobic storage facilities, and the dry matter content of lagoon liquid is lower because of the frequent addition of flush water. The higher dilution rate and the warmer temperatures in the South support the biological decomposition of organic material. As such, the emission of ammonia and hydrogen sulfide is higher than that of an anaerobic storage system. But the release of volatile organic compounds from well-functioning lagoons is lower, so odors are somewhat lower as well.

**Application of Manure from Anaerobic Storage and Lagoons**
Lagoons are sometimes built in two stages; solids settle in the primary stage, and liquids drain from the top of the primary stage into the secondary stage. Whether there are one or two stages, only the liquids are land-applied on a frequent basis – usually through an irrigation system onto a warm season grass. If the lagoon is designed and functioning properly, the accumulation of sludge will not require removal for at least 10 to 15 years. Sludge will accumulate more rapidly if manure-loading rates are too high, if insufficient dilution water is added, or if feed wastage is excessive.

The application rate of manure is generally nitrogen-driven for both lagoons and anaerobic storage systems. Because the ratio of N:P in manure is lower than that required by most cropping systems, phosphorus will eventually accumulate in soil when hog manure is applied from either lagoons or anaerobic storage systems. For the anaerobically stored manure, the phosphorus deposition begins in the early years of manure application. For lagoons, since only the liquids are irrigated, phosphorus is less of a problem initially. However, because the phosphorus concentration of sludge is fairly high, producers face a significant challenge when sludge must be land applied.

In the Northeast, most or all of the manure produced on contract nursery or grower-finisher units is applied on the home farm. Large sow units, however, usually produce an excess of manure causing the application of manure to sometimes become a disposal issue. Manure is often surface-applied to increase nitrogen volatilization, and crop yields are projected at the upper limit, in order to maximize manure application rates. For example, many producers will surface apply manure in the fall, to maximize nitrogen volatilization prior to crop planting. Nitrogen losses are often high enough to permit a second application in the spring before planting. This approach may keep nitrogen in balance, but it will hasten the soil deposition of phosphorus.

The environmental concerns associated with phosphorus accumulation in the soil will be addressed in other papers. However, it's important to note that under present swine production systems there are no immediate and completely effective solutions to the problem of excess phosphorus, or for that matter, the excretion of other nutrients.

**Variation in Nutrient Content of Swine Manure**
Producers are advised to provide their own manure analysis to determine an accurate concentration of nutrients in the manure. Sampling manure after thorough agitation or from several loads throughout the pump-out process will provide a good representation of nutrient values.

Table 1: Estimated Nutrient Concentrations in Swine Manure

| | Farrow | Nursery | Grow-Finish | Breeding-Gestation |
|---|---|---|---|---|
| Dry matter, % | 4-6 | 4-6 | 4-6 | 4-6 |
| Total N, lb/1000 gal | 15-55 | 23-56 | 32-57 | 25-54 |
| $NH_4$-N, lb/1000 gal | 8 | 15 | 19 | 11 |
| P, lb/1000 gal | 12-18 | 15-18 | 18-26 | 18-25 |
| K, lb/1000 gal | 11-36 | 23-35 | 25-38 | 25-34 |

Adapted from Midwest Plan Service (1979) and Sutton et al. (1996).

Table 2: Nutrient Concentrations in Swine Manure from 23 Pennsylvania Farms

| | Farrow | Nursery | Grow-Finish | Breeding-Gestation |
|---|---|---|---|---|
| Dry matter, % | 2.4 | 5.9 | 6.5 | 4.2 |
| Total N, lb/1000 gal | 26.6 | 39.2 | 47.9 | 31.1 |
| $NH_4$-N, lb/1000 gal | 18.4 | 27.2 | 31.8 | 22.2 |
| P, lb/1000 gal | 8.3 | 17.0 | 23.9 | 15.1 |
| K, lb/1000 gal | 11.5 | 20.0 | 20.7 | 11.5 |

Adapted from Kephart et al. (1999).

Note that the data presented in Table 2 from Pennsylvania swine farms are similar to the values in Table 1, but not always within the expected range. This reinforces the observation that nutrient concentration, and in particular, dry matter content, is quite variable. In the 78 samples checked on the Pennsylvania farms, dry matter content averaged 5.2%, but ranged from .59% to 18.2%. In the Pennsylvania study, at least three samples were taken from each storage facility and pooled for the final analysis. Samples were also analyzed for nutrient content according to depth of sample. Concentrations of most nutrients increased with sample depth. This relationship was most evident for phosphorus, as depth of sample was strongly correlated with concentration ($P < .01$, $r = .86$). Correlation coefficients between depth and concentrations of other nutrients were also statistically significant ($P < .01$), but not as high: Total N ($r = .74$), ammonium N ($r = .57$), $K_20$ ($r = .42$). Note that the concentrations of the most soluble nutrients were not as highly correlated with depth of sample.

**Partial Solutions to Nutrient Imbalance and Nutrient Excretion**

The use of lysine and other amino acids in swine diets enable the feed manufacturer to decrease the amount of protein, and therefore the nitrogen, in the diet. This practice can reduce nitrogen excretion by more than 20% (Lenis, 1989; Koch, 1990; Hansen and Lewis, 1993). Unfortunately it decreases the N:P ratio in the manure even further. The use of dietary phytase, an enzyme that enhances the digestion of plant-borne phosphorus, can reduce phosphorus excretion by at least 20% (Cromwell, 1990). Some researchers have also shown that phytase may improve the availability of protein, starch, and several trace elements (Kies, 1998).

Injecting manure under the soil or incorporating it at the time of land application will reduce nitrogen losses (volatilization, and possible run-off) resulting in a N:P ratio more closely aligned with what the crops require. This practice also reduces ammonia and odor emissions.

**Summary**

The use of amino acids can economically reduce nitrogen excretion. Unfortunately, reductions in manure nitrogen further reduce the ratio of N:P, which is already lower than that required by most crops. Phytase can reduce phosphorus excretion, but methods are needed for further reductions, or for extracting P from the manure.

Many producers now surface apply manure to increase nitrogen losses to the air. But in the near future, phosphorus regulations or limits on ammonia emissions may require producers to conserve as much nitrogen as possible. Equipment is needed to provide fast and economical injection or incorporation of manure without destroying conservation practices.

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# Manure Management on Poultry Farms: Practices and Risks

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Biographies for most speakers are in alphabetical order after the last paper.

## Introduction

Good manure management on poultry farms is fundamental in minimizing nutrient losses to the environment. In addition, manure management is important to minimize nuisance litigation related to generation of odors, insects and vermin, runoff, or leachate that offends neighbors or passersby, or otherwise endangers the environment.

Many different systems can be successfully used for storing and managing poultry wastes. The character of waste involved, the level of moisture content, the soil type and other site conditions are important factors in determining suitability of any particular waste management system. The individual grower must weigh the advantages and disadvantages of each method and decide which one best fits into the overall operation, and which best meets local, state, and federal regulations. Regional characteristics such as depth to groundwater, soil type, year-round climate, and other factors also influence methods of manure management chosen. Regardless of the system chosen, success will largely depend upon proper operation and maintenance. It is up to the grower to establish a regular inspection and maintenance schedule to keep the waste management system functioning properly to protect the environment.

# Overview of Modern Poultry Waste Management Systems

## Relationship of Poultry Housing to Waste Management

Waste management systems are closely related to the type of production house involved. House types are generally designed for layers, pullets, broilers/turkeys, or breeder chickens/turkeys, and are typically either high-rise or single-floor.

The high-rise layer house is normally 40 to 60 feet wide. Sidewalls may be constructed of a drop curtain (natural ventilation), a drop curtain with auxiliary fans, or a windowless wall with light and air control (mechanical ventilation). The watering system typically consists of cups or nipples. Solid or semi-solid manure is collected and stored in a pit under the house. It may be removed any time during the laying or growing cycle but is normally removed when the flock is moved out. Figure 1 shows the high-rise concept, which minimizes the amount of daily labor needed to manage the waste system.

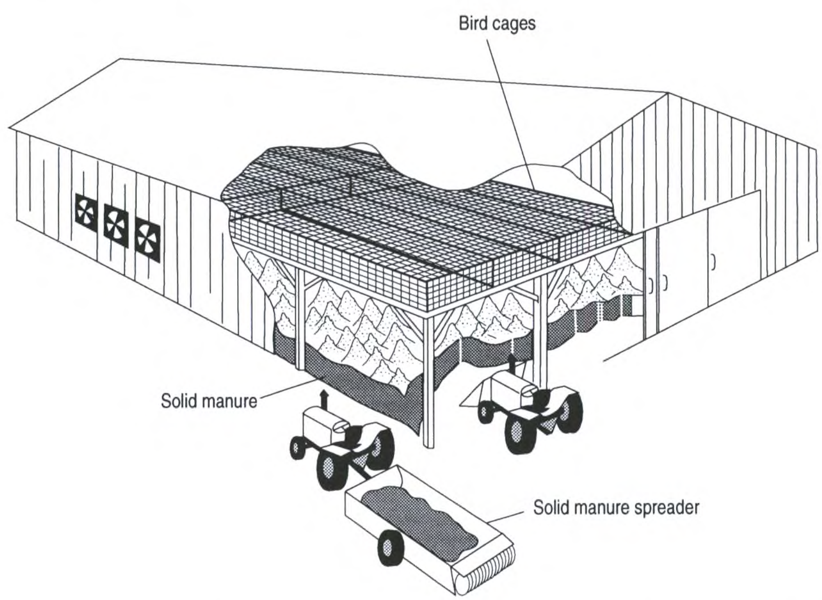


**Figure 1. High-rise layer house concept (Source: *Agricultural Waste Management Field Handbook*, Natural Resources Conservation Service)**

Waste drops directly to the lower floor of the high-rise layer house. If the storage area (lower floor) is properly ventilated, rows of dry mounds or "cones" of manure will form on paved or unpaved earthen floors for a year or longer before removal. Some states may require paving to provide greater insurance against groundwater contamination. Others may allow compacted clay floors to be used. Control of all excess water is required to help keep manure dry and make clean-out easier. The volume and moisture content of the solid or semi-solid manure can be influenced by leaking waterers, high humidity, or extent of ventilation. Drinker leakage, blowing rains (with open-sided houses), and groundwater intrusion can turn the manure piles into an unmanageable slurry mix.

Design and management of the total building ventilation system can either aid in drying the manure or cause moisture to accumulate to problem levels. The high-rise system works best with lower level exhaust fan ventilation, which pulls fresh air in through controlled inlets on the top floor; over the birds on the top floor; and down past the manure, taking moisture, stale air, and odors out of the building. Interior circulation fans may also be used in the pit area to improve circulation and promote manure drying (Figure 2).

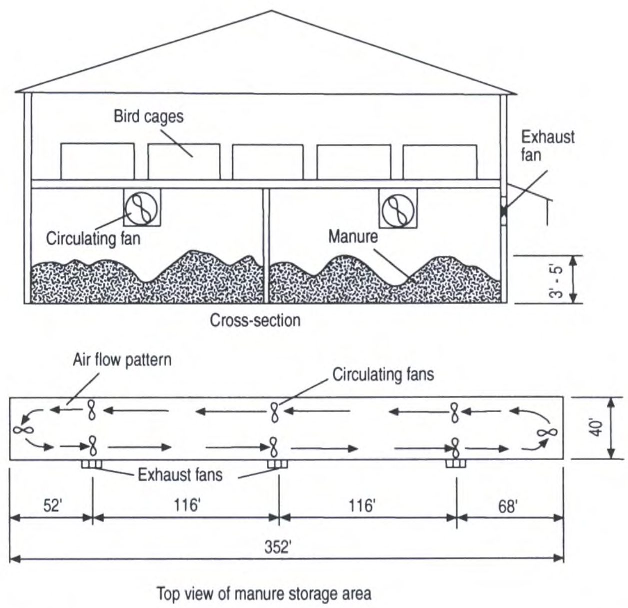


**Figure 2. Ventilating the manure pit in a typical high-rise layer building (Source: *Livestock Waste Facilities Handbook*, MWPS–18)**

Moisture can also be absorbed into the manure from the earthen floor surface, or wicked from the manure into the soil, depending on surrounding soil moisture conditions. Maintaining the manure cones at less than 45% moisture assists in fly control. Manure from the high-rise building can be directly land applied, composted, ensiled for feed, dried in drying beds, or mixed with additional water and used to generate biogas.

A standard single-story stair-step layer house is 30 to 60 feet wide. Sidewall construction may be a drop curtain, a drop curtain with auxiliary fans, or a windowless wall with light and air control (mechanical ventilation). The watering system may be cups or nipples. Manure is removed with a scraper or by flushing to a lagoon. Flushing is typically done daily for 20 minutes at a rate of 500 to 1,000 gallons of water per minute. Scraping is done two to three times per week. The manure from either mode of removal can be delivered to a storage tank or pond, or to a treatment lagoon. For a flush system, settling tanks or channels can be used to remove the solids, while the effluent is discharged into a holding pond or to a lagoon. Undercage paved collection channels are usually mechanically scraped, with solid or semi-solid manure collected over a two-day period. Liquids may evaporate from these shallow alleys between scrapings. Figure 3 shows a wide-span caged-layer house with collection channels (gutters) for flushing or scraping. Figure 4 shows a mechanical scraper system for removing manure from under the cages.

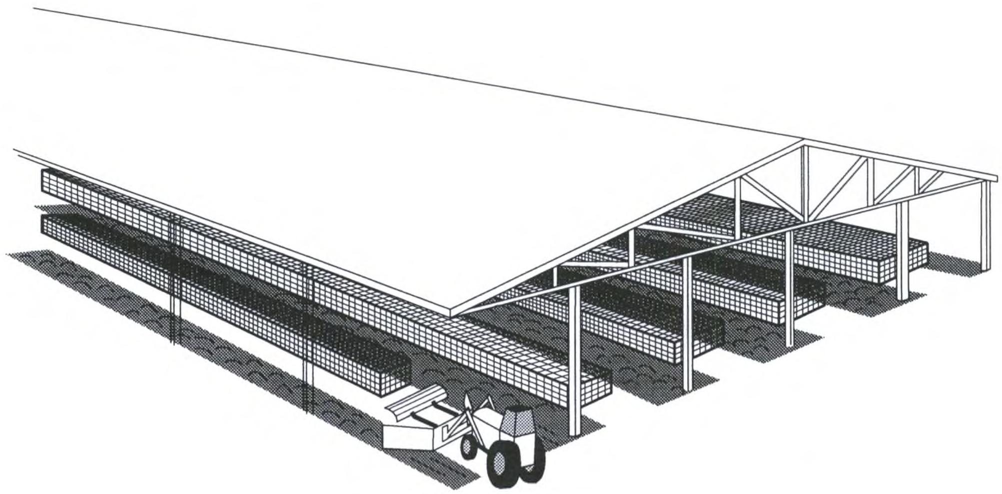

**Figure 3. Cage layer building concept with collection alleys ( gutters) for scraping or flushing (Source: *Agricultural Waste Management Field Handbook*, Natural Resources Conservation Service)**

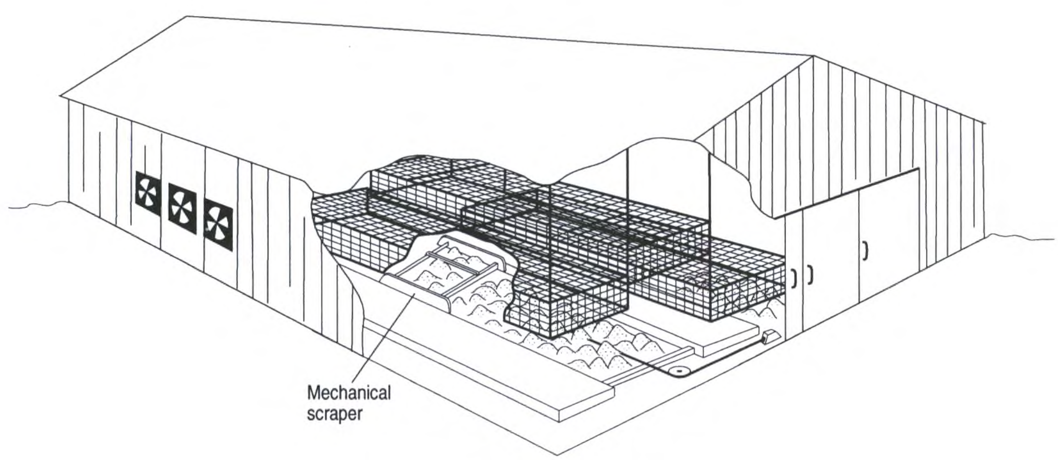


**Figure 4. Mechanical scraper beneath layer cages for manure removal from building (Source: *Agricultural Waste Management Field Handbook,* Natural Resources Conservation Service)**

In fully automated cage systems, the manure may be removed by a belt system that runs under each tier of cages. Proper management of the system can greatly reduce manure moisture before the manure is removed from the house. Some systems have special ventilation ducts to assist in drying the manure. This system could be used very effectively in a manure composting operation with minimum labor input. Collection alleys are not necessary with a belt cleaning system.

Wet manure from cage birds over belts, scrapers, or flush manure channels is handled as a sticky semi-solid or a liquid, depending on the amount of water in the manure. Wet manure will become anaerobic very quickly and will contribute to high odor levels, especially when it is disturbed and spread.

Broilers and turkeys are typically grown on a litter floor housing system. The litter base (sawdust, wood shavings, peanut or rice hulls, or similar materials) may be changed after each flock, or a built-up litter-based system may be utilized. In some parts of the United States, the built-up litter may be used for 2 to 3 years before cleaning. Figure 5 shows a house cross-section that may be used in the production of broilers and turkeys. Clear-span-truss construction facilitates clean-out. Dry litter (manure + litter base) from birds is handled and stored as a solid material.

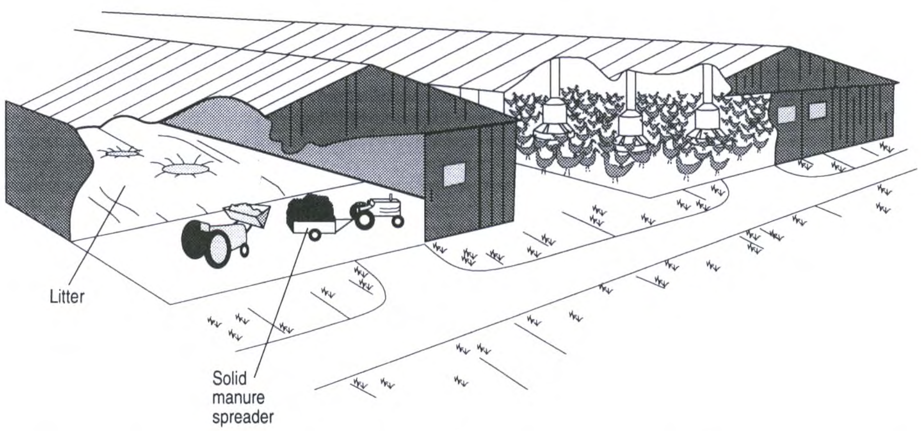


**Figure 5. Building with litter floor system used for broilers and turkeys (Source: *Agricultural Waste Management Field Handbook,* Natural Resources Conservation Service)**

## Manure Storage [1]

Poultry manure storage allows for optimum use of labor and equipment and provides a means of nutrient retention. Proper manure storage provides environmental protection and may help offset storage costs by allowing more effective use of nutrients as fertilizer. Storage also provides future opportunities for the sale of litter for feed or compost feedstock or other off-farm sales. However, depending on the type of storage method or structure selected, the capital cost can negate any economic gain.

Poultry manure storage systems can range from temporary piles to permanent roofed structures. The type of system most useful to an enterprise is dependent on the quantity of manure to be handled, manure moisture content, the frequency or timing of manure removal, the capital investment required, and outside environmental and social factors. Local Cooperative Exten-

[1] A full discussion of both temporary and permanent poultry manure storage facilities is given in NRAES–132, *Poultry Waste Management Handbook.*

sion offices or Soil and Water Conservation Districts usually provide assistance with selecting a manure storage facility. The Natural Resources Conservation Service (NRCS) has developed design standards and specifications for poultry manure storage structures.

### *Solid Manure Storage: Within the Poultry House*

One type of solid manure storage occurs in the poultry house in both floor litter and high-rise cage-type systems. High-rise houses for caged birds allow accumulation of manure beneath the cages in pits that can be entered with cleaning vehicles from the outside of the structure (see Figure 1). With floor litter systems, manure is mixed with the litter by bird foot action, and storage occurs on the floors through a continuous buildup of the dry litter/manure mixture (see Figure 5).

The cleaning frequency of either system is determined by the quality of the manure or manure litter in the house and the amount of remaining storage space available. Wet manures will require more frequent removal than dry manures. Typically, deep-pit and high-rise houses are cleaned once or twice per year. On the other hand, floor systems might be partially cleaned of wet manure "cake" after every flock but not totally cleaned for a year or more. Poultry manure should be maintained in a dry state so that nutrients are conserved, insects and odors are controlled, bird welfare is enhanced, and handling and storage costs are minimized.

### *Solid Manure Storage: Outside the Poultry House*

Storage outside the house is required only when manure must be removed from inside and no land is available for immediate manure application. Cleaning out high-rise pits can usually be scheduled to allow manure field applications when needed without additional storage. Caged bird systems with manure removal by belts or scrapers do not provide in-house storage. Floor litter houses are partially cleaned between flocks, while whole-house clean-out is determined by litter management schedules of poultry integrators.

The storage method chosen must protect manure from prolonged contact with rainwater. This requires a surface that sheds water. A deep, well-rounded stockpile of compacted litter, manure, and associated material will shed water. However, the edges of the pile at the ground surface may become saturated and cause surface water and groundwater pollution. Caged-bird manure will readily soak up moisture and should be stored only under cover with confining walls.

All storage systems should be separated from seasonal high groundwater by a minimum of 4 feet of soil or a water-resistant liner of compacted clay, plastic, or concrete. Locate the storage to avoid wells, normally wet areas, runoff or drainage pathways, and other areas of running or standing water. It is also a good idea to provide a grassed buffer around the entire storage area.

Careful storage site location must consider insects, birds, and rodents that can transmit or transfer avian diseases. Storage receiving manure from many different sites should not be located near a poultry production facility.

Floor manure litter contains both wet and dry organic materials that produce heat when stored in confined piles. Storage structures and compact piles may be subject to spontaneous combustion.

### *Liquid, Slurry, and Semi-Solid Manure Storage*

Wet manure removed from under caged birds by mechanical scrapers and belts, or by flushing with water cannot be stacked and requires containment storage. Manure liquids and slurries that are mostly water (less than 12% solids) require containment in tanks or basins constructed of materials impervious to water transfer. Semi-solid manure (12 to 20% solids) does not readily flow like water but still needs containment walls to keep the manure in a manageable mass, and to prevent pollutant losses to the environment. Semi-solid manures can be handled with bucket loaders and open spreaders. Liquid manures must be pumped and spread with tank trucks, tank wagons, or irrigation equipment.

Manure that is stored in tanks or storage ponds is normally anaerobic and can be expected to generate considerable odor in storage. It is particularly odorous during spreading. If odor is likely to be a problem at the farm site or during spreading, wet storage should not be used, or methods of advanced treatment such as aerobic treatment should be adopted.

Liquid and slurry manure storage can be a constructed concrete or lined steel tank aboveground or below ground or an earthen basin (Figures 6 and 7). Tanks can be open-topped or covered with a roof or top. Earthen basins are usually open-topped but can be covered with a geotextile fabric. Open-topped storage structures collect rainwater, which increases the volume of material to be handled and dilutes nutrients. Open-topped structures are also significant sources of odor, especially when manure enters the structure at the top and when the manure is mixed during unloading. Bottom loading through gravity or pressurized pipe may assist in odor control when manure dries on the storage surface and forms a floating crust.

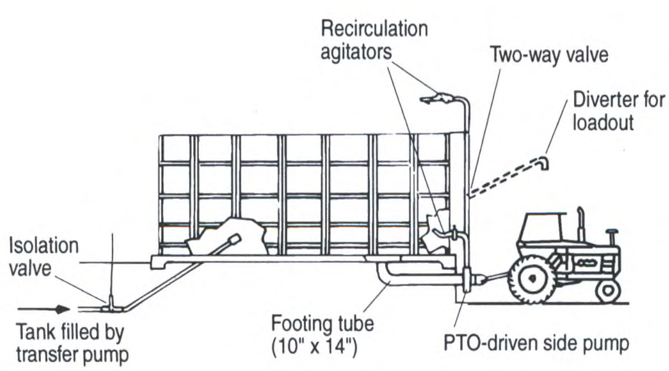


**Figure 6. Aboveground manure storage tank**

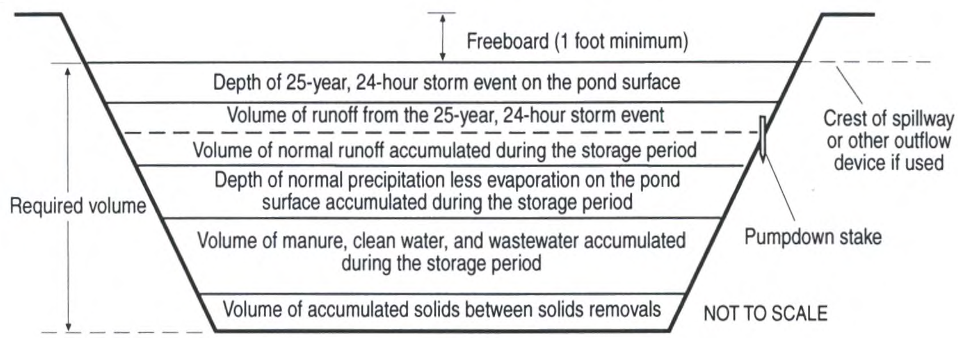


**Figure 7. Cross-section of an earthen storage basin showing the volumes that must be accounted for in the design (Source: *Agricultural Waste management Field Handbook,* Natural Resources Conservation Service)**

Semi-solid manure storage can be a tank or basin fitted with a sloped driveway to allow tractor or bucket loader entrance for unloading. The storage is usually open at the top. The entrance of rain and runoff may cause some of the manure to become liquid, which cannot be easily handled with the loader bucket. Methods of allowing water to flow away from the manure, through directed floor slopes and perforated dams, are not very effective with poultry manures. A roof, combined with site grading to direct runoff away from the structure, is an effective means of preventing excessive water in the storage.

Wet manure storage structures and basins are subject to high loading pressures on the sidewalls and banks. These pressures increase with manure depth. Wall failure allows the entire contents of the storage to escape and flow overland, which may cause environmental and property damage. Standards and specifications for manure storage construction have been developed by the NRCS to ensure design and construction procedures that will avoid structural failure. Although maintenance assistance is currently not a part of the NRCS plans, good maintenance is essential to a successful operation. For more information on earthen storages, see *Earthen Manure Storage Design Considerations,* NRAES–109.

## *Manure Storage Maintenance*

Maintenance procedures for manure storage are highly dependent on the type of structure and the properties of the manure being held. Maintenance can be described as "efforts to ensure that dry manures are kept dry and wet manures are kept contained". Maintenance of solid manure storage systems includes preventing drinker water spillage, optimizing the effectiveness of house ventilation systems, securing outside stack plastic covers from the wind, repairing any damage from wind or machines to permanent structures, and monitoring stored manure temperatures with appropriate control measures employed in fire emergencies.

Maintenance of liquid and semi-solid manure storage systems includes periodic inspection of walls to identify cracks or buckling, periodic inspection of earthen banks to identify erosion or animal burrows, and removal of waste in a timely manner so as to keep the design freeboard and storm trapping volume available (Figure 7). Other maintenance efforts should be identified during the design stage and become part of a maintenance plan. Structural designs developed by the Natural Resources Conservation Service are accompanied by an operations and maintenance manual.

## Manure Production and Characteristics

Manure properties are influenced by several factors:

- bird species,
- bird age,
- diet and nutrition,
- bird productivity, management, and
- housing, ventilation, drinker systems, nutrition, and other environmental factors.

### *What is "Manure"?*

The waste management system will collect bedding or litter, water, soil, grit, feathers, nonutilized dietary minerals, and other materials that must be handled as "manure." The term "manure" generally includes raw feces, urine, waste feed, spilled water, absorptive bedding used in poultry houses, and any other waste material that is part of the waste stream from production houses.

### *Poultry Manure Production*

Table 1 lists estimated manure production, as excreted by poultry. Data in this table represent averages from a wide database of published and unpublished information on poultry manure. Total manure production is presented per 1,000-bird capacity per day based on the weighted average daily live weight of the bird during its production cycle. Since manure production is generally based on the live weight of the bird, manure amounts may be increased or decreased proportional to the bird live weight. Each farm may have slightly different manure production rates due to factors already mentioned. Table 2 lists commonly used manure characteristics, as excreted.

*Moisture Considerations*

Table 3 lists manure and wastewater produced from various types of waste storage and treatment systems for commercial layer production facilities. Production amounts can be highly influenced by leaking waterers, rainfall surplus added to open storage pits and lagoons, and whether or not fresh water is used for flushing or cleaning manure collection alleys. Table 4 lists manure and wastewater characteristics, as removed from storage systems

**Table 1.** Manure production, as excreted

| | Live weight (lbs) | | Total manure production per 1,000 birds per day | | |
|---|---|---|---|---|---|
| Bird type | Market | Average | (lbs) | ($ft^3$) | (gallons) |
| Commercial layer | | | | | |
| Hen | 4.0 | 4.0 | 260 | 4.2 | 32 |
| Pullet | 3.0 | 1.5 | 97 | 1.6 | 12 |
| Broiler | 4.5 | 2.25 | 177 | 2.8 | 21 |
| Roaster | 8.0 | 4.0 | 315 | 4.9 | 37 |
| Cornish | 2.5 | 1.25 | 99 | 1.5 | 12 |
| Breeder | 7.0 | 7.0 | 552 | 8.7 | 65 |
| Turkey | | | | | |
| Poult | 5.0 | 2.5 | 113 | 1.8 | 13 |
| Grower hen | 16.0 | 10.0 | 452 | 7.1 | 53 |
| Grower tom, light | 22.0 | 13.0 | 588 | 9.3 | 69 |
| Grower tom, heavy | 30.0 | 17.0 | 769 | 12.1 | 91 |
| Breeder | 20.0 | 20.0 | 905 | 14.3 | 107 |
| Duck | 6.0 | 3.0 | 328 | 5.3 | 39 |

NOTE: Data in this table represent averages from a wide database of published and unpublished information on poultry manure. Total manure production is presented per 1,000-bird capacity per day based on the weighted average daily live weight of the bird during its production cycle. Since manure production is generally based on the live weight of the bird, manure amounts may be increased or decreased proportional to the bird live weight. Each farm may have slightly different production rates.

**Table 2.** Typical manure characteristics, as excreted

| Manure characteristics | Commercial layer | Broiler | Turkey | Duck |
|---|---|---|---|---|
| Density (lbs/$ft^3$) | 62 | 64 | 63 | 62 |
| TS[a] (%) | 25 | 26 | 25 | 27 |
| VS[b] (%) | 19 | 19 | 19 | 16 |
| COD[c] (ppm) | 176,000 | 197,000 | 236,000 | 169,000 |
| | | (lbs/ton) | | |
| TKN[d] | 27 | 26 | 28 | 28 |
| $NH_3N$ | 6.6 | 6.7 | 8.1 | 7.4 |
| $P_2O_5$ | 21 | 16 | 24 | 23 |
| $K_2O$ | 12 | 12 | 12 | 17 |
| Ca | 41 | 10 | 27 | 29 |
| Mg | 4.3 | 3.5 | 3.1 | 4.1 |
| S | 4.3 | 2.0 | 3.3 | 3.6 |
| Na | 3.6 | 3.5 | 2.8 | 3.5 |
| Cl | 20 | 18 | 18 | 20 |
| Fe | 2.0 | 1.9 | 3.2 | 2.8 |
| Mn | 0.16 | 0.20 | 0.10 | 0.17 |
| B | 0.05 | 0.06 | 0.06 | 0.06 |
| Zn | 0.14 | 0.084 | 0.62 | 0.48 |
| Cu | 0.02 | 0.02 | 0.03 | 0.03 |

Sources: ASAE; Department of Biological and Agricultural Engineering, North Carolina State University
NOTE: All values are on a wet basis (as excreted)

[a] TS = total solids (100 – TS = moisture or water content)

[b] VS = volatile solids; the portion of total solids driven off as volatile (combustible) gases

[c] COD = chemical oxygen demand; a measure of the oxygen-consuming capacity of inorganic and organic matter present in water or waste

[d] TKN = sum or organic and ammonia(um) nitrogen, as measured by the laboratory Kjeldahl procedure

**Table 3.** Typical commercial layer waste production, as removed from storage

| Bird type | Live weight (lbs) | | Total waste production per 1,000 birds per day | | |
|---|---|---|---|---|---|
| | Market | Average | (lbs) | ($ft^3$) | (gallons) |
| | | | Undercage collection alley-scraped manure[a] | | |
| Hen | 4.0 | 4.0 | 155 | 2.5 | 19 |
| Pullet | 3.0 | 1.5 | 58 | 0.9 | 7 |
| | | | High-rise, deep-pit stored manure[b] | | |
| Hen | 4.0 | 4.0 | 108 | 2.1 | 16 |
| Pullet | 3.0 | 1.5 | 41 | 0.8 | 6 |
| | | | Liquid manure slurry[c] | | |
| Hen | 4.0 | 4.0 | 356 | 6.1 | 46 |
| Pullet | 3.0 | 1.5 | 134 | 2.3 | 17 |
| | | | Anaerobic lagoon liquid[d] | | |
| Hen | 4.0 | 4.0 | 587 | 9.4 | 70 |
| Pullet | 3.0 | 1.5 | 220 | 3.5 | 26 |
| | | | Anaerobic lagoon sludge[e] | | |
| Hen | 4.0 | 4.0 | 108 | 1.7 | 13 |
| Pullet | 3.0 | 1.5 | 41 | 0.65 | 5 |

Source: Department of Biological and Agricultural Engineering, North Carolina State University
NOTE: Production amounts can be highly influenced by leaking waterers, rainfall surplus added to open storage pits and lagoons, and whether or not fresh water is used for flushing or cleaning manure collection alleys.

a Manure scraped from paved alley and collected within two days

b Annual manure accumulation stored on unpaved surface

c Manure, excess water usage, storage surface rainfall surplus; does not include fresh water for flushing

d Manure, excess water usage, lagoon surface rainfall surplus; does not include fresh water for flushing

e No manure solids removal prior to lagoon treatment/storage

Manure tanks, pits, or earthen storage basins receive scraped manure, excess water spillage, and surface rainfall surplus for storage until spreading. Tanks and pits that can be covered usually receive less water, have a higher solids and nutrient content, and result in less slurry volume to handle than open earthen storage basins. Such storages are usually designed for four to twelve months= accumulation, depending on the amount of storage needed for an acceptable nutrient management plan.

**Table 4.** Typical commercial layer waste characteristics, as removed from storage

| Manure characteristic | Undercage collection alley-scraped manure[a] | High-rise, deep-pit stored manure[b] | Liquid manure slurry[c] | Anaerobic lagoon liquid[d] | Anaerobic lagoon sludge[e] |
|---|---|---|---|---|---|
| Density (lbs/ft$^3$) | 62 | 51 | 58 | 62 | 62 |
| TS[f] (%) | 35 | 53 | 11 | 0.49 | 17 |
| VS[g] (%) | 25 | 32 | 7.4 | 0.22 | 7.3 |
| COD[h] (ppm) | 270,000 | 286,000 | 106,000 | 2,950 | 28,600 |
| | | | (lbs/ton) | | |
| TKN[i] | 28 | 34 | 57 | 6.6 | 21 |
| $NH_3N$ | 14 | 12 | 37 | 5.6 | 6.5 |
| $P_2O_5$ | 32 | 51 | 52 | 1.7 | 77 |
| $K_2O$ | 20 | 26 | 33 | 10.3 | 9.8 |
| Ca | 41 | 76 | 33 | 1.1 | 47 |
| Mg | 5.5 | 5.7 | 4.0 | 0.34 | 12 |
| S | 7.1 | 4.8 | 4.0 | 0.61 | 7.1 |
| Na | 2.8 | 3.3 | 4.8 | 1.8 | 3.3 |
| Cl | 4.0 | 6.0 | 6.6 | 3.4 | 2.4 |
| Fe | 2.4 | 2.8 | 1.7 | 0.060 | 4.8 |
| Mn | 0.29 | 0.44 | 0.38 | 0.0069 | 1.6 |
| B | 0.022 | 0.036 | 0.030 | 0.0092 | 0.035 |
| Zn | 0.31 | 0.35 | 0.39 | 0.016 | 1.1 |
| Cu | 0.034 | 0.058 | 0.073 | 0.004 | 0.14 |

Source: Department of Biological and Agricultural Engineering, North Carolina State University

NOTE: All values are on a wet basis (as excreted)

a Manure scraped from paved alley and collected within two days

b Annual manure accumulation stored on unpaved surface

c Manure, excess water usage, storage surface rainfall surplus; does not include fresh water for flushing

d Manure, excess water usage, lagoon surface rainfall surplus; does not include fresh water for flushing

e No manure solids removal prior to lagoon treatment/storage

f TS = total solids (100 – TS = moisture or water content)

g VS = volatile solids; the portion of total solids driven off as volatile (combustible) gases

h COD = chemical oxygen demand; a measure of the oxygen-consuming capacity of inorganic and organic matter present in water or waste

i TKN = sum or organic and ammonia(um) nitrogen, as measured by the laboratory Kjeldahl procedure

Grit is a poultry feed ration additive that aids digestion. When used excessively, grit will separate from manure. Dietary calcium can also separate from manure and reduce both the flow of manure to holding tanks and the capacity of holding tanks to store manure. This may present handling challenges for liquid storage and handling systems.

Anaerobic lagoons (those that provide treatment without oxygen) are designed for biological treatment. The relatively large surface areas of lagoons often collect more surplus rainfall than dry manure stacks or liquid manure storage tanks. As a result, relatively large liquid volumes with comparatively dilute nutrient contents result from lagoon treatment. Bottom sludges are usually handled with liquid slurry equipment and are removed infrequently. Some nutrients such as calcium, phosphorus, zinc, and copper may be concentrated in lagoon sludges.

*Litter Considerations*

Table 5 lists litter characteristics, as removed from production houses. Table 6 lists manure and litter production, as removed from various meat-type bird production facilities. Litter amounts are presented as tons per 1,000 birds. Bedding or litter materials (typically sawdust, wood shavings, peanut hulls, or rice hulls) are initially placed on floors to a depth of 2 inches or more (depending on the poultry integrator company) in production houses. The differences in management required by the different integrator companies, described earlier in this paper, will influence the litter nutrient values, as will changing the amount or type of litter used. The values supplied in Tables 5 and 6 are given as guides. Where litter will be used as fertilizer or for other purposes, it is wise to test the litter for nutrient content.

Moisture management in the production facilities can affect litter characteristics. As the litter becomes wetter (lower solids content), more ammonia will be released, and the nitrogen content of the litter will decrease. As litter dryness increases, increasingly dusty conditions will exist within the facility. A number of factors influence litter moisture. When fed in excess, certain dietary ingredients (especially salt) cause birds to consume and excrete large amounts of water, resulting in wet litter conditions. Some drugs stimulate excess water consumption and excretion. Environmental conditions, such as wet and humid weather or very cold temperatures, can cause wet litter if the house heating and ventilation system is not able to eliminate moisture effectively. Waterers, foggers, and evaporative cooling pads, if not managed and maintained carefully, can contribute greatly to wet litter problems. Ideally, litter moisture should be maintained at 20 to 25%.

Around waterers and feeders, additional manure and moisture tend to form crusted or caked areas of litter that have different handling and nutrient characteristics than the other house litter. This manure cake typically represents about 30 to 35% of the total litter. The manure cake around waterers is usually wetter and has a lower nutrient content than the total litter. But the area around feeders is often drier and has a higher nutrient content due to feed spillage. The cake may be removed with crusting equipment after each flock of birds.

Table 7 gives estimates of manure and litter volumes that have been removed from production facilities to an outside uncovered stockpile on an earthen surface for storage up to six months before field spreading. The litter mass removed from the stockpiles is, in most cases, only slightly less than that taken directly from the production facilities. Absorption of rainwater in the stockpiles is offset by a reduction in solids due to composting action. Covering the stockpile or storing the litter inside a roofed structure reduces losses and preserves a higher-quality litter. Covering the stockpile also reduces the potential for nutrient leaching or nutrient loss to the environment in runoff.

**Table 5.** Typical litter characteristics, as removed from production houses

| Bird type | Density (lbs/ft³) | TS[a] (%) | VS[b] (%) | TKN[c] | $NH_3N$ | $P_2O_5$ | $K_2O$ | Ca | Mg | S | Na | Cl | Fe | Mn | B | Zn | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (lbs/ton) | | | | | | | | | | | | | |
| Broiler | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 32 | 79 | 63 | 71 | 12 | 69 | 47 | 43 | 8.8 | 12 | 13 | 13 | 1.2 | 0.79 | 0.057 | 0.71 | 0.53 |
| Manure cake[e] | 34 | 60 | 47 | 46 | 12 | 53 | 36 | 34 | 7.0 | 9.2 | 10 | –[f] | 1.2 | 0.69 | 0.044 | 0.60 | 0.41 |
| Roaster | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 29 | 76 | 59 | 69 | 16 | 70 | 47 | 41 | 8.4 | 14 | 13 | –[f] | 1.6 | 0.76 | 0.047 | 0.68 | 0.49 |
| Cornish | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 30 | 68 | 53 | 59 | 12 | 57 | 59 | 41 | 22 | –[f] | –[f] | –[f] | –[f] | 1.1 | –[f] | 0.92 | 0.61 |
| Manure cake[e] | 34 | 54 | 42 | 62 | 17 | 39 | 39 | 30 | 14 | –[f] | –[f] | –[f] | –[f] | 0.67 | –[f] | 0.50 | 0.46 |
| Breeder | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 50 | 69 | 29 | 37 | 8.0 | 58 | 35 | 83 | 8.2 | 7.8 | 8.3 | –[f] | 1.2 | 0.69 | 0.034 | 0.62 | 0.23 |
| Turkey poult | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 23 | 80 | 62 | 40 | 9.6 | 43 | 27 | 26 | 5.1 | 6.1 | 4.7 | 1.8 | 2.0 | 0.53 | 0.038 | 0.46 | 0.39 |
| Grower | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 32 | 73 | 53 | 55 | 12 | 63 | 40 | 38 | 7.4 | 8.5 | 7.6 | 12 | 1.4 | 0.80 | 0.052 | 0.66 | 0.60 |
| Manure cake[e] | 35 | 55 | 44 | 45 | 20 | 47 | 30 | 26 | 5.4 | 6.3 | 5.5 | –[f] | 1.2 | 0.56 | 0.038 | 0.47 | 0.48 |
| Breeder | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 50 | 78 | 34 | 35 | 7.6 | 47 | 18 | 72 | 4.6 | 7.4 | 4.3 | –[f] | 1.0 | 0.43 | 0.031 | 0.50 | 0.40 |
| Duck | | | | | | | | | | | | | | | | | |
| Whole litter[d] | 50 | 37 | 24 | 17 | 3.6 | 21 | 13 | 22 | 3.3 | 3.0 | 3.0 | –[f] | 1.3 | 0.37 | 0.021 | 0.32 | 0.04 |

Source: Department of Biological and Agricultural Engineering, North Carolina State University

NOTE: All values are on a wet (as is) basis

[a] TS = total solids (100 – TS = moisture or water content)

[b] VS = volatile solids; the portion of total solids driven off as volatile (combustible) gases

[c] TKN = sum of organic and ammonia(um) nitrogen as measured by the laboratory Kjeldahl procedure

[d] Annual manure and litter accumulation; typical litter base is sawdust, wood shavings, or peanut hulls

[e] Surface manure cake removed after each flock

[f] Data not available

**Table 6.** Typical litter production, as removed from production houses

| Bird type | Live weight (lbs) | | Total litter production per 1,000 birds sold (tons) |
|---|---|---|---|
| | Market | Average | |
| Broiler | | | |
| Whole litter[a] | 4.5 | 2.25 | 1.25 |
| Manure cake[b] | 4.5 | 2.25 | 0.4 |
| Roaster | | | |
| Whole litter[a] | 8.0 | 4.0 | 2.6 |
| Cornish | | | |
| Whole litter[a] | 2.5 | 1.25 | 0.625 |
| Manure cake[b] | 2.5 | 1.25 | 0.06 |
| Breeder | | | |
| Whole litter[a] | 7.0 | 7.0 | 24.0[c] |
| Turkey poult | | | |
| Whole litter[a] | 5.0 | 2.5 | 1.0 |
| Grower hen | | | |
| Whole litter[a] | 16.0 | 10.0 | 8.0 |
| Manure cake[b] | 16.0 | 10.0 | 2.5 |
| Grower tom, light | | | |
| Whole litter[a] | 22.0 | 13.0 | 10.0 |
| Manure cake[b] | 22.0 | 13.0 | 3.3 |
| Grower tom, heavy | | | |
| Whole litter[a] | 30.0 | 17.0 | 14.0 |
| Manure cake[b] | 30.0 | 17.0 | 4.4 |
| Breeder | | | |
| Whole litter[a] | 20.0 | 20.0 | 50.0[c] |
| Duck | | | |
| Whole litter[a] | 6.0 | 3.0 | 4.25 |

Sources: Department of Biological and Agricultural Engineering, North Carolina State University and Department of Agricultural Engineering, University of Delaware

a Annual manure and litter accumulation; typical litter base is sawdust, wood shavings, or peanut hulls

b Surface manure cake removed after each flock

c Tons/1,000 birds/year

**Table 7.** Typical litter volume after open stockpiling

| Bird type | Live weight (lbs) | | Total litter production per 1,000 birds sold[a] (tons) |
|---|---|---|---|
| | Market | Average | |
| Broiler | 4.5 | 2.25 | 1.0 |
| Turkey grower | 25.0 | 15.0 | 11 |
| Duck | 6.0 | 3.0 | 2.2 |

Source: Department of Biological and Agricultural Engineering, North Carolina State University

a Annual house manure and litter accumulation removed to uncovered stockpile to be spread within six months; typical litter base is sawdust, wood shavings, or peanut hulls

*Nutrient Considerations*

Table 8 shows typical litter characteristics, as removed from open stockpiles. As can be seen from the table, phosphorus is conserved in open stockpiles and potassium levels are only slightly less than those of house litter. The nitrogen content, however, is about half that of broiler and turkey house litter due to the loss of ammonia caused by wetting and resulting biological activity. Again, storing litter in a dry structure will conserve nitrogen.

Table 9 estimates typical nitrogen losses between excretion and land application on a mass basis. Bedding and water dilute manure, resulting in less nutrient value per pound. Substantial nitrogen can be lost to the atmosphere as ammonia. The least nitrogen losses are associated with slurry storage pits, dry-house whole litter, and roofed storages. Deep-pit manure stacking and open stockpiled litter have moderate to high nitrogen losses. Lagoons have the highest loss.

Phosphorus and potassium losses are usually negligible, except with lagoons. Much of the phosphorus in lagoons concentrates in, and is recoverable with the bottom sludge. Moderate amounts of potassium may be lost from open uncovered stockpiles due to leaching.

**Table 8.** Typical litter characteristics, as removed from open stockpiles

| Manure characteristic | Broiler | Turkey grower | Duck |
|---|---|---|---|
| Density (lbs/ft$^3$) | 33 | 24 | 50 |
| TS[a] (% w.b.) | 61 | 61 | 49 |
| VS[b] (% w.b.) | 43 | 44 | 32 |
| | | (lbs/ton) | |
| TKN[c] | 33 | 32 | 22 |
| $NH_3N$ | 6.9 | 5.5 | 4.8 |
| $P_2O_5$ | 77 | 70 | 41 |
| $K_2O$ | 32 | 30 | 22 |
| Ca | 63 | 45 | 34 |
| Mg | 8.2 | 7.1 | 5.2 |
| S | 10 | 7.4 | 4.5 |
| Na | 6.6 | 5.7 | 5.4 |
| Cl | 13 | 8.0 | _[d] |
| Fe | 1.8 | 2.1 | 1.5 |
| Mn | 0.70 | 0.76 | 0.56 |
| B | 0.039 | 0.042 | 0.031 |
| Zn | 0.63 | 0.63 | 0.50 |
| Cu | 0.29 | 0.42 | 0.05 |

Source: Department of Biological and Agricultural Engineering, North Carolina State University

NOTE: All values are on a wet basis (as is). Annual house manure and litter accumulation removed to uncovered stockpile to be spread within six months; typical litter base is sawdust, wood shavings, or peanut hulls

[a] TS = total solids (100 – TS = moisture or water content)

[b] VS = volatile solids; the portion of Total Solids driven off as volatile (combustible) gases

[c] TKN = sum of organic and ammonia(um) nitrogen as measured by the laboratory Kjeldahl procedure

[d] Data not available

**Table 9.** Typical nitrogen losses during handling, storage, and treatment

| System | Nitrogen lost[a] (%) |
|---|---|
| Solid | |
| Paved collection alley, scraped[b] | 30–40 |
| Deep pit[c] | 40–50 |
| House litter[d] | 25–35 |
| Open stockpiled litter[e] | 60–75 |
| Liquid | |
| Slurry storage[f] | 20–30 |
| Lagoon[g] | 75–85 |

Source: Department of Biological and Agricultural Engineering, North Carolina State University

a Nitrogen lost during handling, storage, and treatment compared to as-excreted manure nitrogen

b Manure scraped from layer undercage paved alley and collected within two days

c Annual layer manure accumulation stored on unpaved surface

d Annual manure and litter accumulation; typical litter base is sawdust, wood shavings, or peanut hulls

e Annual house manure and litter accumulation removed to uncovered stockpile to be spread within six months

f Manure, excess water usage, storage surface rainfall surplus; does not include fresh water for flushing

g Anaerobic lagoon liquid and sludge

### *Sampling and Testing*

The values in Tables 1 through 8 are estimates based on averages from large databases. Actual farm-specific manure production and characteristics may vary considerably from the averages. As-excreted values may vary up to 30% from the average due to bird productivity, age, or diet. Variances of 25% for dry-house litter to as much as 60% for open liquid manure or lagoon systems are common because of differences in management or environmental factors. For these reasons, where possible, samples of the actual farm manure, litter, or wastewater should be collected and analyzed by local laboratories or testing facilities to provide more accurate information for planning, design, and land application.

The results from a regular sampling program should be entered into a farm-specific records database. Once actual farm averages have been developed, they should be useful in making management decisions.

## Regional Differences in Production Practices

Commercial poultry production practices are inclined to be quite similar across the United States, with a few exceptions. Generally, differences tend to be climatically related, especially with regard to ventilation, and the appropriateness of spreading of wastes ("organic fertilizer") on fields.

Ventilation is a critical issue in producing poultry in houses. The challenge in hot weather is to provide sufficient air exchange in production houses to keep them from getting too warm. If this is accomplished, the secondary issue of providing enough fresh air will generally take care of itself.

The challenge in cold weather is to provide enough air exchange to remove ammonia, dust, and other air impurities without requiring an undue amount of supplemental heating, or chilling of birds in the house. This becomes relatively more difficult in production houses in colder climates than for those in warmer. Because of these climatic differences and critical nature of ventilation control, houses in cold climates will generally rely more on fan ventilation, especially in winter, and those in warmer climates will attempt to provide sufficient ventilation with moveable "curtain walls", and minimal fan boosted ventilation. As evaporative cooling has become more popular for hot weather use, housing systems have tended to become more standardized across the various production areas.

Perhaps greater regional differences in poultry housing are seen in manure handling systems. As farm nutrient management planning has come to be recognized as important to environmental quality issues, more states are limiting the time of year that nutrients can be applied to fields. Often limitations are related to the ability to sustain a growing crop on waste application fields, and whether or not application fields are frozen or covered in ice or snow.

Anaerobic and aerobic treatment systems that employ simple designs tend to work best in warm weather. Thus, these systems are more easily utilized in year-round warm climates.

Because of climatic influences, poultry housing systems that collect manure for long term holding (such as deep pit layer houses) or scraper systems in layer or breeder houses, with storage of manure in concrete or earthen pits, are more common in areas of the U.S. where winters are cold. This allows manure to be held until Spring or Fall when it can be applied to row crops or pastures when plant growth will occur and utilize waste nutrients according to a nutrient management plan.

Systems of housing that employ in-house flushing, or pit recharge systems for waste removal, tend to be found in warmer states such as those in the deep southern U.S. In these areas, anaerobic treatment lagoons work well year round for reducing waste strength, recycling effluent for waste removal, and the excess effluent can be applied (generally through irrigation) and utilized on growing pastures or fields for a longer period of the year than in northern locations. In addition, operational problems related to system/equipment freezing are not as significant as in cold climates.

## Disposal of Poultry Mortalities

A by-product of even the most successful poultry production operations is dead birds. Despite improved health and production practices, intermittent mortality is to be expected in commercial flocks. Regardless of the cause of the mortality, proper disposal of carcasses is required to ensure biosecurity, protect the environment, and avoid offending others with nuisance conditions.

Two general categories of carcass disposal are: [1] normal mortality (typically about 0.1% per day, with fluctuation up to 0.25% not uncommon); and [2] disposal of large portions of the flock or a whole flock (usually associated with sacrifices due to contagious disease outbreak or death due to power outages or other catastrophes). Normal mortality is generally more easily handled because of the steady "flow" of material through the disposal system.

Methods for disposal of dead birds are burial, incineration, rendering, and composting. The method chosen must be compatible with the individual grower's situation and management capabilities and must comply with state laws. Fabricated pits for burial have been used in many areas, but questions have been raised about their impact on groundwater quality, and they have been prohibited in many states. Incineration is perhaps the most biosecure method of disposal, but it tends to cause odor and maintenance problems, and it tends to be slow and expensive. In addition, there may be regulatory issues in some states. For producers located close to a rendering plant or pickup route, this process can be an attractive and economical method for disposal of normal and catastrophic mortality. However, there are biosecurity risks associated with transporting carcasses to a rendering plant or with farm pickup systems. Also, some rendering plants may not be able to handle large quantities of carcasses from catastrophic events. Composting of dead birds is gaining popularity, but it requires investment in new facilities and has not received unconditional approval by regulatory authorities in all states. However, composting (Figure 8) has become the method of choice for disposal of normal mortality losses on many poultry farms.

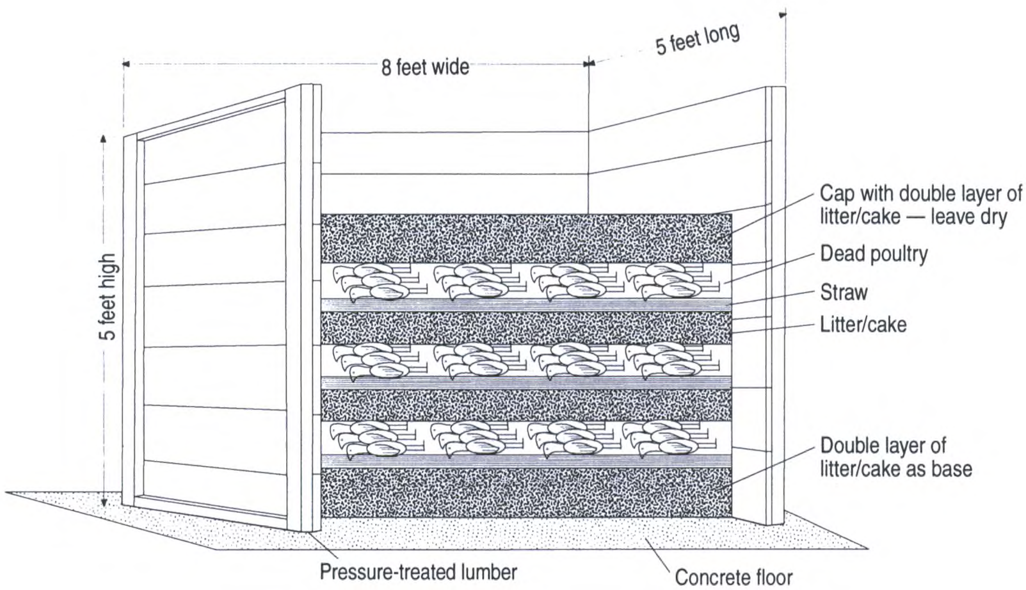


**Figure 8. Layering arrangement for routine composting of normal mortalities**

## Summary

Poultry waste management systems are closely related to the type of housing used. Birds grown for meat are typically produced on floor litter systems, and produce a "dry" waste. Birds grown for breeder purposes, or to produce eggs are produced in housing systems that may produce a "dry" waste, or due to method of manure collection, removal, and treatment may be quite wet, or even "liquid". The waste handling (and housing) system chosen will depend upon grower preference, the character of waste involved, the level of waste moisture content, the soil type and other site conditions. The individual grower must weigh the advantages and disadvantages of each method and decide which one best fits into the overall poultry operation, and which best meets local, state, and federal regulations. Regional characteristics such as depth to groundwater, soil type, year-round climate, and other factors also influence methods of manure management chosen. Regardless of the system chosen, success will largely depend upon proper operation and maintenance.

Nutrients contained in poultry waste must be incorporated into a nutrient management plan. Tabular values for different categories of poultry waste are available, but wastes are highly variable from farm to farm. Tabular values are useful as estimates, but good nutrient management will require that samples of the actual farm manure, litter, or wastewater be collected and analyzed to provide more accurate information for planning, design, and land application plans.

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# Manure Management on Dairy Farms: Practices and Risks

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Biographies for most speakers are in alphabetical order after the last paper.

A dairy manure handling system is a cost item that must meet many requirements. The ultimate goals of a manure handling system should include:

- enhance management and worker productivity
- be cost effective
- be environmental friendly
- be safe for workers and visitors
- complement on farm biosecurity measures

Many observers would argue that on most farms the priority items are how the system works and how much it costs. Often it seems that too little attention is given to the affect of the system on neighbors or the environment; safety for workers or visitors; or biosecurity requirements for control of disease spread. A death or serious injury resulting from a manure handling system suddenly makes us aware of safety considerations. A visit from the regulatory community or subpoena from the court reminds us of our obligation to be a good neighbor. The spread of a disease through the herd, because of excessive cross contamination between manure and feed or water, emphasizes the relationship between manure handling and animal health.

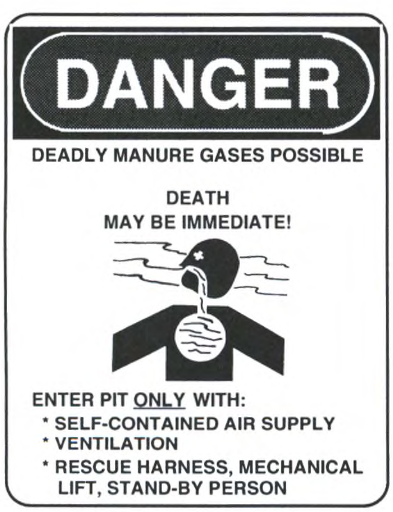
A farmer or her teenage son going out to spread the daily load of manure may still be seen as bucolic and part of country life. A week of 12-hour days with two contract twin screw 3000 gallon tankers going up and down the road presents a different picture. Environmental protection requirements will continue to be high on the minds of the general public. As dairy facilities become larger and more complex the public will notice and the expectation for environmental protection will increase. Larger manure handing systems with more components, larger equipment, more hours of use, and more people involved will further highlight the importance of reducing hazards involved with manure systems. Larger herds increase the cost of an infectious disease and the complexity of controlling its spread throughout the herd.

The manure handling system is an integral part of any dairy facility design and management plan. Therefore, the best manure handling systems are usually developed as part of an overall plan for new construction, renovation or expansion. A well-planned system will be compatible with the type of housing and will include manure and wastewater from outside animal areas, the milking center, youngstock facilities, and silage effluent. It should also be compatible with anticipated changes in housing and management over the next 8-10 years.

A well-designed and installed manure handling system will include backup plans to allow continuous operation even if a key component malfunctions. Readily available spare parts or replacement equipment are required for dairies handling large amounts of manure or utilizing complex treatment or handling systems. Advanced thought should be given to how a large manure spill, resulting from a damaged storage or broken pipe, can be contained before large quantities of manure can run off the property or reach nearby streams or lakes.

### Hazards

Manure systems present hazards from asphyxiation, poisoning, drowning, and machinery entanglement or entrapment. Pumps, pits and tanks can easily contain poisonous gases that will not be apparent until someone enters the tank and is overcome. Multiple deaths have occurred as a result of failure to follow appropriate procedures for working in these confined spaces. **Do not enter manure sumps, pits or storage tanks without appropriate safety apparatus and procedures.** No tool, pump part, or farm chore is worth a human life!




Another common hazard is failure to provide adequate guarding at manure tank openings and pushoff ramps to prevent entry by people, tractor scrapers, or cows. All open storages or openings into storages must have adequate fencing, guards, or covers to prevent visitors, including small children, from gaining entry. **Everyone has an obligation to design,**

**supply, buy, operate, and maintain manure storage and handling systems that are safe for workers and visitors.**

## Complete Information

A brief paper in a proceeding cannot be considered a comprehensive resource on the variety and complexity of designing and managing a dairy cattle manure system. The reader is encouraged to make use of material available from a wide variety of education, government and private sources. These would include Natural Resource, Agriculture and Engineering Service (NRAES), Midwest Plan Service (MWPS), Natural Resources Conservation Service, Dairy Practices Council (DPC), American Society of Agricultural Engineers (ASAE), local cooperative extension offices, conservation districts, private consultants and equipment suppliers.

An excellent up-to-date reference on dairy cattle manure is *Guideline for Dairy Manure Management from Barn to Storage* (Weeks, 1998) available from NRAES or the DPC. A dated but comprehensive reference on manure treatment and handing systems is *Livestock Waste Facilities Handbook*, MWPS - 18.

## Manure Characteristics

Dairy cattle manure as it comes from a milking cow offers a challenge for handling and storage. Its often said that its "too thick to pump and too thin to shovel."

The following material is abstracted from Weeks, 1998:
Manure is the feces and urine from farm livestock containing waste products from digestion and other bodily processes and is often described as:

- sticky (viscous)
- smelly (odorous)
- soupy, normal, stiff or dry.

Characteristics of manure are also affected by

- diet, development (age) and health of animals
- time (because of bacterial action)
- temperature (because of drying, bacterial action, freezing)
- added bedding materials and other materials
- added water and other liquids

Fresh dairy cattle manure is about the same density as water (about 62 pounds per cubic foot or 8.3 pounds per gallon). Addition of typical amounts of organic bedding materials or waste feed does not appreciably change this value. On the other hand sand laden manure from barns using sand bedding often weighs about 75 pounds per cubic foot or 10 pounds per gallon. Hauling and lifting equipment used with sand laden manure must account for this increase in density. Sand laden manure in a 5000 gallon tanker would weigh 25 tons. This is 4.25 tons more than 5000 gallons of liquid manure without sand bedding.
*Sand laden dairy cattle* manure presents a perplexing challenge to the managers, designers and suppliers of manure handling systems. Depending on moisture content, sand will settle

out in storages and pipes. The abrasive nature of sand reduces the service life of bearings, impellers, housings, pipes, scraper blades, cables, etc. Efforts to address the challenges of handling sand laden dairy cattle manure have included management changes; storages designed to allow clean out with both liquid pumps and front end loaders, back hoes or drag lines; and development of a specialized sand manure separation system based on a sand washing device. (Wedel and Bickert, 1994) (Stowell and Bickert, 1995)

**Manure Production**

Predicting quantity and quality of dairy manure is difficult and table values sometimes seem inadequate. In general modern high producing dairy cattle produce more manure than older tables suggest. Historically a thumb rule of manure production 8% of body weight was used for lactating dairy cattle. Recent studies would indicate that this value may be closer to 10%. (Weeks, 1998) Low producing cows, dry cows, growing heifer and calves will likely produce less. Use of table values must always be done with discretion and adjustments for local conditions. Table 1 provides an example of manure production from different categories of animals in a herd with 80 milking cows and representative dry cows and replacements.

Table 1 Manure production from all animals in atypical dairy herd with 80 milking cows plus dry cows and replacements. (Weeks, 1998)

| Dairy Group | Number | Average Weight | Manure Factor (%) | Daily (lb) | Production ($ft^3$) |
|---|---|---|---|---|---|
| High milking cows | 20 | 1,350 | 10.0 | 2,700 | 43.6 |
| Mid milk production | 40 | 1,350 | 8.5 | 4,590 | 74.0 |
| Low milking cows | 20 | 1,400 | 8.2 | 2,240 | 36.1 |
| Dry cows | 20 | 1,450 | 8.0 | 2,260 | 36.5 |
| Bred Heifers | 25 | 1,000 | 7.8 | 1,950 | 31.5 |
| Young stock | 45 | 500 | 7.5 | 1,690 | 27.3 |
| Total | 170 | - | - | 15,430 | 249.0 |

**Moisture Content**

Weeks(1998) describes dairy cattle manure by the following three categories:
*Solid manure* (16% or more solids) contains considerable fibrous bedding, easily travels up a gutter cleaner chute, and is easily handled with a front-end loader and a conventional or flail manure spreader. In most cases it can be stacked. Excess water (e.g. precipitation, from leaking waterers or runoff from roofs) must be kept out of the manure.

*Semisolid manure* (12%-16% solids) generally contains some bedding and can be handled with a front-end loader and a conventional or flail spreader. It will flow to some extent, but is too thick to agitate and pump from storage with liquid manure handling equipment. Increased amounts of bedding, or waste feed, make semisolid manure more solid. Precipitation or groundwater should be continuously drained away from the storage, otherwise semisolid manure becomes the consistency of liquid manure.

*Liquid manure* (12% or less solids) usually contains little or no bedding, and water may be added so that the manure can be agitated into a liquid consistency and handled with a liquid manure pump and a liquid manure spreader. If liquid manure is handled with irrigation equipment, considerable quantities of water must be added. Special high-pressure chopper pumps and large-orifice irrigation nozzles are also necessary.

The liquid manure category includes a wide variety of consistencies and sources. It can vary from semi-solid manure scraped from a freestall barn and mixed with milking center wastewater to more dilute water and manure mixtures from flush barns, to colored water that is washed off an outside lot during a rain storm. Unscreened dilute mixtures of manure water can still contain large particles that will plug pumps, screens and irrigation nozzles.

**Sources of Manure**

Manure on a dairy farm originates from four major areas:
*Tie stall barns* - cows spend considerable time restrained in bedded stalls with manure removed using mechanical gutter cleaners or gravity flow gutters. Manure will vary from solid to semi-solid depending on management of milking center washwater bedding and waste feed.

*Freestall barns* - cows rest in bedded freestalls and walk on concrete alleys to feed and water. Manure is deposited on concrete alleys as cows move about and is removed by scraping, flushing or falling through slotted floors. Manure will vary from semi-solid to liquid depending on bedding and waste feed management and manure removal method.

*Bedded pack barns and bedded pens* - animals are kept on a thick layer of organic bedding and manure removed periodically as a "solid type" material. In addition to the bedded manure there may also be manure produced in unbedded concrete alleys or outside yards where cows eat and drink.

*Outside housing* - can vary from rotationally grazed pastures, vegetative sacrifice or exercise lots, concrete feedlots, dirt exercise areas or large dirt corrals. Consistency of manure will vary from manure carried in water runoff in humid areas to dry dusty powder from corrals in arid areas.

**Handling Systems**

A complete manure handling and storage system allows for collection and removal of manure from animal housing areas, treatment if necessary, transport to storage system, short and long term holding or storage, transport to cropland, and land application.

*Collection systems* include gutter cleaners and gravity flow channels in tie stall dairy barns and tractor scrapers, automatic alley scrapers, flushing, and slotted floors in freestall dairy barns. Outside yards, lots, and feeding areas can be cleaned with scrapers or in some instances flushing. Bedded pack and pen areas are cleaned with tractor loaders.

*Tractor scrapers* with rubber edges or made from sections of large rubber tires provide less wear and polishing of concrete and tend to squeegee the floor. Metal blades or buckets with down pressure are more effective under freezing conditions. Manure may be pushed off an elevated lip directly into a spreader or pushed into a storage or collection gutter. In some cases it is pushed to an area with a buck wall to facilitate loading with a bucket loader.

*Automatic freestall alley scrapers* are labor savers and frequent operation provides cleaner alleys and cows. The cost and time required for maintenance of alley scrapers is often less than the total cost (labor, machinery, maintenance, injured animals) of daily tractor scraping. Unattended operation of alley scrapers where very small or new born calves could be dragged away by the slow moving blade is not recommended. Alley scrapers must discharge through a hole, over a collection channel, or off the edge of a storage. Locate and guard the drop off point for the manure to assure that people, animals or equipment will not inadvertently fall in.

*Flush cleaning* is a low labor method that allows for frequent cleaning and results in drier alleys and cleaner cows. Important components of flush systems are adequate water supply, water disposal system, elevations, slopes, pumps and pipes. Systems can successfully operate much of the year, even in cold climates, if adequate facilities are available to take care of storage of extra water. Access for tractor scraping is recommended for periods when the flushing system can not be used. The most common problems with flushing systems are the quantity of water required and separating solids for reusing water. First time flushing system users are often overwhelmed by the amount of water that must be handled and the need for more dilution water in recirculating systems than expected. Criteria for satisfactory flushing include alley slope, water volume per flush, flow rate, duration of flush, velocity of water, and depth of water. In general, a 3-inch depth of water and 5 feet per second velocity are recommended. A 3% alley slope is often considered ideal. Steeper slopes will require more water and a higher flow rate, shallower slopes will require a high rate of water to maintain velocity. Water can be supplied from tip tanks, reservoirs with large gates that open or delivered through large pipes from high volume pumps or elevated holding tanks or ponds.

*Slotted floors* provide a method for immediate removal of manure from the animal area. Once beneath the floor, manure may be stored in an underfloor tank or removed by an automatic scraper, flushing, or a gravity flow channel. Excellent ventilation at all times is critically important in slotted floor barns with underfloor manure holding. Manure stored under barns can result in gas, odor and moisture problems in barns that are not adequately ventilated. Under-ventilation often occurs during cold winter months as a result of efforts to raise interior temperatures to minimize manure freezing or for operator comfort. During extreme hot weather, increased microbiological activity in the stored manure can increase the release of gases. During agitation and clean-out, keep animals (especially young animals that are close to the floor) and people out of enclosed barns and provide maximum ventilation if a manure tank is located under the floor. Floors may be configured with long parallel slats and slots, or oblong holes in a so called waffle pattern. Given a choice of any type of slotted floor or a solid surface, animals will migrate to the solid surface. Slotted floors allow urine to drain quickly away and manure is pushed through the slots by animal traffic. The result is a drier environment for the cows' hoofs. In extremely cold situations manure will eventually freeze and not go through the slots. Provide access for a tractor scraper to remove manure during cold weather.

*Removal systems* move manure from the barn to the field for immediate application or to storage. For immediate field application the manure may be loaded directly into a manure spreader from a gutter cleaner discharge or push off lip, or loaded with a front end loader. More liquid manure, may be pumped from a collection channel, sump, or small tank that holds a day or two manure accumulation. If manure is to be pumped into a liquid spreader, wastewater from the milking center is usually included to make agitation and pumping easier. Manure can be conveyed to a storage located at the barn by the gutter cleaner, tractor scraper, large piston pump, centrifugal pump, gravity flow pipe or gravity flow channel. Manure can be transported to satellite storages located away from the barn by trucks, large spreaders or pipelines.

**Manure storage systems**

Manure can be stored at the barn or near the cropland where it will be utilized. If manure must be transported long distances, it is often more effective to provide satellite storages near the cropland. This allows the manure to be moved to the storage during low labor periods and makes for more efficient spreading. Liquid manure, especially if solids have been removed, can be pumped long distances through buried or temporary pipes to satellite storages. The storage must be compatible with the form manure is removed from the barn.

*Heavily bedded manure* can be easily stacked in three sided bunker type storages or on simple hard surfaced or packed crush stone or fly ash stabilized pads. Storages should be designed to prevent clean water from running into them and to direct any leachate or runoff water from the storage away from streams to vegetative filter areas or holding ponds.

*Liquid manure* can be stored in properly designed concrete or steel tanks; concrete, clay or membrane lined in-ground storages; and in some cases earth storages. It is critical that storages be located and constructed to assure that manure will not seep through storage walls or bottom to ground or surface water. Consult the USDA Natural Resource Conservation Service or a qualified soils engineer regarding location and design of in-ground manure storages. An annual inspection and maintenance program should be in place to assure continued safe operation of any type manure storage. **Liquid storages require appropriate signs, guards and fences to protect workers and visitors from unintended entry and possible loss of life.**


**Treatment Systems**

Various treatment systems have been proposed for use with dairy cattle manure. Typical reasons for treating manure include: ease of storage or transport, reducing odor potential, extracting energy, and concentrating, partitioning or removing nutrients. A comprehensive discussion on manure treatment *Manure Treatment and Handing Options* by Peter Wright is found later in this proceedings.

*Solids separation* will allow easier handling of liquid material, allows for recycling of water for flushing, and can provide a useful by-product. Separation systems can be categorized as gravity, screens, extruders, centrifuges, and cyclones. Various additives have been proposed to enhance the separation process. Settling tanks or basins use gravity and time to allow larger particles of liquid manure to settle or float out. Screens normally require some method to prevent particles from plugging or blinding the screen openings. This may be accomplished by sloping the face of the screen so material slides off or with mechanical scraping or vibration. Screens require a dilute material similar to that obtained with flushing systems. Extruders use screws, plungers, or belts to pack manure against a perforated cylinder, box, belt or plate. Liquid is forced out through the holes and the solids are discharged out the end. These devices tend to provide a drier solid and some will work with a less dilute, slurry consistency manure. Centrifuges may be compared to cream separators and use a rotating chamber to force solids to the outside for removal. Cyclone separators are similar to dust collectors. A very dilute flow of manure is introduced into a conical chamber that encourages large particles to separate from the liquid.

*Anaerobic digestion* or biogas production has been used by some farms as a method to extract energy from manure and reduce odor that results from long term liquid storage. The biogas process converts complex organic material such as manure into biogas and low odor effluent. A heated digester with a 15-25 day detention time is normally required. The primary constituents in biogas are methane (natural gas), carbon dioxide and trace gases. Originally the primary interest was in energy production, usually electricity. Economics tended to favor farms with more than 200-400 cows. Even at this size most farmers chose not to bother with the extra expense and management requirements. Recently there has been interest is biogas digesters as a method to solve odor and nuisance problems associated with storing and handling large quantities of dairy manure. The process does not significantly change the amount of manure or the nutrient content, but does alter the form of the nitrogen. The effluent will be more liquid and homogeneous as a result of the digestion process.

*Composting* is another form of manure treatment that dairy farmers consider to improve handling, enhance marketability, or reduce odor and nuisance problems. Composting is an aerobic process that requires a material with good porosity, 40-60% moisture content and proper carbon to nitrogen ratio. Some form of mixing and or aeration is required to provide satisfactory composting. The process generates its own heat, reaching temperatures of 120-140°F. When properly done, composting will eliminate most odors and result in a stable easily handled dry humus like material. Dairy manure or separated solids may require some form of dry carbonaceous material such as straw, sawdust or wood chips to provide porosity and maintain the desired moisture content and carbon nitrogen ratio. Some dairy farmers have found an additional income source by charging municipalities or industries to take materials such as paper, cardboard, tree trimmings, etc. This is then mixed with the manure and after composting either spread on land or sold as compost.

**Land Application**

*Solid or semi-solid dairy cattle manure or separated solids* are land applied with tractor pulled or truck mounted box or V bottom spreaders. Manure may be spread whenever it is removed from the barn or periodically throughout the year from manure storages. The manure is applied to the surface of crop or pasture land. Some managers choose to cover the manure immediately by plowing or disking to minimize nitrogen volatilization and odor losses. Spreaders are loaded directly from barns during cleanout using front end loaders, pushoff lips, gutter cleaner discharges, cross conveyors or gravity flow discharge pipes. Manure storages are unloaded into spreading equipment using front end loaders or gravity discharge pipes.

*Liquid manure and wetter semi-solid dairy cattle manure* is land applied using tractor pulled or truck mounted liquid tankers. The manure may be applied to the surface. To minimize odor and ammonia volatilization manure can be injected below the surface with special attachments. Manure tankers are loaded using centrifugal type liquid manure pumps, augurs, or gravity discharge pipes. Dairy manure storages can form thick floating crusts in addition to sludge layers of thicker manure. To agitate and homogenize the manure, special agitators or recirculating unloading pumps are required.

When liquid manure must be transported long distances it may be hauled to the field in large over the road trailers and then directly pumped into field spreaders or discharged into small holding containers for reloading.

*Very liquid dairy cattle manure or liquids from solid separators* can also be pumped through portable or fixed pipelines to fields for application to the surface using special large orifice irrigation sprinklers or drag hose systems. While a variety of irrigation systems can be used the most common is a traveling big gun type sprinkler. Liquid manure is supplied to the sprinkler with a large diameter soft or hard hose system. The sprinkler is attached to a wagon that is pulled across the field with a cable and winch or by the supply hose being wound up on a large powered reel. Problems with irrigation include, plugged nozzles, application of excess manure nutrients, runoff of liquid manure resolution from applying manure faster than the ground can absorb it and dispersion of odors off the farm. (Jarrett & Graves, 1999) (NRAES, 1994)

An alternative to irrigating liquid manure is to hook the delivery hose to a special tractor pulled device. The device will either inject the liquid manure directly into the soil or discharge the manure close to the ground in front of a tillage tool such as a disk harrow or field cultivator. The tractor is driven back and forth across the field in a pattern so that the hose is pulled along without being run over by the tractor.

**Biosecurity**
Manure can become a means for transfer of diseases around a farm. Diseases that can move between animals by the "fecal oral" route can be transmitted by the mismanagement of manure. Typical paths include sharing common equipment (front end loaders, scrapers, tractors) between manure removal and feeding chores. Manure scrapping and hauling routes that allow spillage from equipment, tires etc. directly onto feed floors, feed storage or where feed vehicles travel can be another path. Manure handing equipment or manure from infected animals that move through or among susceptible animals is another path of infection. The people responsible for herd health on a dairy farm must be included in decisions concerning manure handling and evaluate the likelihood of biosecurity problems.

**Environmental Affects - land , air, water**
There are various ways that manure handling systems affect the environment near and away from a dairy farm. The tendency is to focus on water pollution. However, dairy farms also can affect land and air quality.

Organic, nutrient and microbiologic constituents in manure can cause pollution if there is an uncontrolled release of dairy cattle manure into ground or surface waters. Obvious points of release include leakage from storages or pipes to ground water. Residuals from manure can also be carried to ground water as the result of excessive application of manure to cropland or accumulations of leachate from barnyards or load out areas.
Surface water pollution can result when there is over application of manure (typically from irrigation) and direct runoff to drainage systems. Rainfall events can flush manure from fields, outside animal yards or piles of manure and also cause liquid storages to over top. Catastrophic failure of a liquid storage structure is another potential source of water pollution.

Excessive quantities of manure resulting from heavy applications to crop fields or intensively populated dirt exercise areas can degrade soil quality. In arid climates, salt build up can occur.

Odors and ammonia emissions from barns, surfaces where there are manure accumulations, or manure storages can affect air quality. Spraying manure thorough the air, as in irrigation systems, can result in gases and particulates and aerosols being carried off the farm in the air. Before land applied manure is incorporated, odors, ammonia or other gases can also escape to the air.

**Summary**

The dairy farm of the future will have more cows kept in a more concentrated area. A larger percentage of feed nutrients will be hauled to the production unit from someplace else. Non-farm people and regulators will be more aware of, and more interested in dairy production systems. Odor problems and concern about the destination of "waste products" from the farm will intensify. The siren call of black boxes, quick fixes and magic powders will continue. Highly focused regulators and politicians looking at one small portion of this big picture will continue to look for the "one size fits all fix." Even after spending millions of dollars municipal sewage treatment plants end up putting more and more of the final product from their "treatment systems" on the land, where mother nature provides the ultimate disposal/utilization. "Everything has to be someplace!" A dairy/crop farm with adequate cropland would seem to be the ideal model for municipalities and industries to be following instead of the other way around. Animals eat crops to produce milk. Manure (and many of the nutrients) are discharged from the animals and subsequently used to grow crops to feed to the cows. If the manure is kept out of surface water resources there is no need to worry about the oxygen demand nature of this organic material. The same material that competes with fish for oxygen in water enhances soil structure when applied to cropland.

Manure handling problems resulting from more animals in one place and the decreasing distance between animals and people require more than technology to solve. Decisions and policy beyond the control of the farmers, as diverse as transportation subsidies and pricing and land use planning have resulted in major dislocation between crop production and milk production. Successful managers will have a more global view of their operations. They will understand the relationships between feeding strategies, housing strategies, manure handing strategies, feed production strategies and being a good neighbor. A well-planned manure handling system can result in a more efficient and environmentally friendly dairy

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**Additional Information Sources**

ASAE 2950 Niles Road, St. Joseph, MI 49085-9659. (616) 429-3852 http://asae.org

DPC - Dairy Practices Council, 51 E. Front Street, Suite 2, Keyport, J 07735. (732) 203-1947 www.dairyp.org

MWPS - Midwest Plan Service, 122 Davidson Hall, Ames IA 50011 (800) 562-3618 www.mwpshq.org

NRAES - Natural Resources Agriculture and Engineer Service, 152 Riley-Robb Hall, Ithaca, NY 14853-5701 (607) 255-7654 www.nraes.org

NRCS - Natural Resources Conservation Service, National Technical Information Service, US Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161 703 487 4600 www.nrcs.usda.gov/

# Manure Treatment and Handling Options

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Biographies for most speakers are in alphabetical order after the last paper.

Agriculture is a vital component of any society. In North America agriculture provides wholesome cheap food to consumers. Farms are also important environmentally. Open space, wildlife habitats, and aquifer recharge can be important environmental benefits of farms. However, excess nitrates in the ground water, pathogens in the drinking water and excess nutrients, BOD, and sediment in surface water can have a negative effect on the environment. Farms can affect the environment through odors, as well as produce gases that contribute to the greenhouse effect and acid rain. Society has recognized some of these negative effects and is asking farms to improve. To maintain a competitive industry we need to be able to provide feasible alternative practices based on science and good engineering that allow productive agriculture while minimizing the effect on the environment.

There are a wide variety of farms. They vary in their resources and their environmental concerns. Some farms have access to more capital, skilled labor, management ability, land resources, water resources, and markets than other farms. Different manure treatment and handling methods will be needed to match the resources and needs of different farms.

Depending on the location and the management's personal values, each farm can have different environmental concerns. Those in a watershed that supplies drinking water may be more interested in controlling pathogens and phosphorus. Those upstream of a fresh water lake may be more concerned with sediment and phosphorus. Those with close or sensitive neighbors may be more concerned with odors. Those in a porous aquifer may be more concerned with nitrogen leaching and pathogens. Others may only be concerned about BOD loading that cause fish kills locally. Nutrient loading far downstream may be a concern to some farms. Manure treatment methods will be required to deal with each of these issues.

Some farms are interested in mass reduction to facilitate manure movement off their farm. Development of by-products that can be sold at a profit off the farm could help some farms maintain profitability while improving the environment.

There are many management issues that affect the choice of a manure treatment system Some of these issues include the desire to 1) minimize environmental damage, 2) maximize nutrient value, 3) minimize neighbor problems, 4) minimize damage to the land, 5) minimize cost and 6) minimize frustration. Although society may order these issues one through six, farmers may order them six through one. Manure management alternatives need to address these concerns.

There will need to be a variety of treatment methods that work with the variety of resources the farms may chose to allocate to them. Table 1 describes some manure management alternatives that either are being used or are proposed.

**Table 1: Manure Management Alternatives**

| Manure Management Alternative | Advantages | Disadvantages |
|---|---|---|
| **Daily Spreading** is being practiced by many farms. Manure and other wastes are spread as they are produced throughout the year. | Capital costs are low. Environmental effects are hidden. Odor problems are minor. Labor and equipment use is steady. | Total costs may be high. Nutrient and pathogen losses during times of saturated soils may provide excessive delivery to waterbodies. Field accessibility may be a problem. |
| **Storage** to reduce spreading during periods of high nutrient loss and times when fields are inaccessible. Required in many areas, encouraged in all areas. | Nutrient management can be easier. Efficiencies in handling can be obtained to keep costs down. Manure can be spread when needed. Storage of solids is safer environmentally than liquid storage. | Odors are a big problem when spreading especially from a liquid storage. Large handling equipment needs to be available. Labor and equipment needs peak. Non-earthen storage can be very expensive. Dry storage may need an expensive roof or runoff controls. Catastrophic failure of liquid storage or heavy rainfalls right after spreading can cause peak pollutant discharges. |

| Manure Management Alternative | Advantages | Disadvantages |
|---|---|---|
| **Odor Control** of stored liquid manure is a major need. Chemical and biological treatments have been tried and proposed. | Would allow spreading of the manure during the growing season and eliminate neighbor complaints. | No technology has yet shown that it can significantly reduce odors without significant costs. |
| **Solid Separation** of the manure solids mechanically can produce a "solid" portion (15-30% DM) and a "liquid portion" (4-8% DM). | Liquids are easier to handle. Solids can be recovered for bedding, soil amendment, or exported off the farm. | High capital and operating costs. Maintenance of the equipment is a problem. Marketing of the solids may not be successful on all farms. |
| **Composting** dryer manure directly, or by adding bedding or an amendment to wetter manure, a biologically decomposed product can be produced successfully on some farms. | An excellent way to treat dryer manure. Odor reduction is an important advantage of well managed composting. Equipment for solids handling is available on most farms. Material may be marketed. | High moisture contents of some manure makes conventional composting difficult. Sales may depend on expensive specialized mixing equipment and good management. Composting outside on large areas can create runoff losses. Composting inside may take a large capital expense. |
| **Biodrying** of the manure by recycling dry compost as the amendment to composting, and using the heat generated in the aerobic decomposition to dry the manure/compost mix with forced air has been proposed. | Odor reduction, volume reduction, and weight reduction would occur. Equipment for solids handling is available on most farms. Storage of solids is safer environmentally than liquid storage. Material may be marketed. | Management of drying process will be critical. Costs of operation may be high. Material handling may be excessive. Additional amendment may be required. Winter operation may require closed buildings. |
| **High Solids Anaerobic Digestion** would produce a decomposed residual and produce methane gas. Heat from the gas or from an engine generator could be used to dry the material for recycling within the system. This system has been tried experimentally on dairy manure. | Odor reduction, volume reduction, and weight reduction would occur. Equipment for solids handling is available on most farms. Storage of solids is safer environmentally than liquid storage. Material may be marketed. Energy production would meet the needs of the farm and allow excess to be sold. | Management of digestion and drying process will be critical. Capital costs will be high. Electric utility connections may be difficult. Material handling may be excessive. Additional amendment may be required. |

| Manure Management Alternative | Advantages | Disadvantages |
|---|---|---|
| **Anaerobic Digestion** takes as produced manure and digests it, producing an odorless effluent that has reduced solids content while retaining the nutrients. Methane gas is recovered that can be used to run an engine generator. | Odor reduction and energy recovery will occur. Effluent is reduced in solids content and can be further reduced easily by mechanical solid separation. Demand for the anaerobically digested solids is greater than raw solids. | Management of digestion process will be critical. Capital costs will be high. Electric utility connections may be difficult. Diluted manure will require a large digester and more heating. |
| **Lagoon Treatment** of manure from the farms consists of diluting the manure, removing solids mechanically or allowing them to settle in large shallow pools then flow to a facultative lagoon to be recycled as flush water to dilute more manure. Liquids and solids are periodically removed from the system. | Odors are reduced and solids are separated. Works well with a flush system to remove manure from barns. Solids may be marketed. Liquids can be easily irrigated. Management is relatively easy. | Solid harvesting and dewatering can be difficult or expensive. Exposure of large surface areas may result in extra water volumes. Impermeable soils on moderately flat terrain are required to keep cost down. Aeration is sometimes required. |
| **Sequencing Batch Reactors** to reduce the COD, N, in the liquid effluent and concentrate the P from the manure have been proposed. A large tank(s) would alternately fill, react, settle and decant a treated liquid and concentrated sludge. Mechanical separation and dilution would precede the process. | Odors, Nutrients and COD would be reduced in the liquid effluent which could be spray irrigated at hydraulic loading rates on crop fields. High P solids could be exported so that a dairy would not be tied to a large land requirement based on manure disposal limits. | Capital and operating costs may be high. |
| **Total Resource Recovery** by combining the plug flow methane production process with solid separation, and hydroponically recovering the nutrients would eliminate the waste and maximize production of useful by products. | Odors would be controlled. Energy would be recovered. Nutrients would be recycled. There would be no waste. | Capital costs will be very high. Operating costs may not offset by-product sales and savings in a cheap energy, cheap nutrient situation. |

Some of these existing and potential treatment methods have not yet been implemented on a farm. The time to implement in Table 2 gives relative estimates of when these systems could be available for farm use. Each system may be appropriate for some farms and not others. The size of the farm may determine the applicability of one system over another. The system and the specific pollutant(s) they will treat need to be balanced with the specific pollutant control needed on the farm, and the needs of the farm for an efficient manure handling system. The management skills of the farm as well as the closeness (and marketing skills of the operator) to a market will also have an influence on the choice of a system. Table 2 lists some of the characteristics of each system.

The descriptions above provide background and a basis for comparing these manure management alternatives. Without a regulatory incentive to control nutrients, pathogens, or odors, it will be hard for an economically rational farm manager to increase production costs to implement some of these alternatives.

Concentrating research on those alternatives that will provide odor control, P concentration, and pathogen control at a reasonable cost should be a priority. More documentation of the costs, pathogen removal, and phosphorus concentration are important for any alternative considered.

## System Descriptions:

## Daily Spreading

**Description:** Spreading manure and wastewater daily as it is produced is a low capital cost, low management option. Many farmers continue to daily spread most of their manure. Nutrient management to reduce fertilizer use can be difficult unless careful records and accurate spreading tactics are used. Spreading close to the source of the manure has caused soil buildup of excess phosphorus on many farms. Unfortunately, soils, particularly those close to the barns, may have already been saturated with phosphorus, contributing to the water quality problems. While odor issues are generally not a serious problem on daily spread sites, runoff and leaching losses during saturated conditions can add to the nutrient loading of a watershed.

**Environmental Impact:** There are a number of important questions which need to be answered in order to document the environmental effects of daily spreading. Critical among them is the transfer rate between soluble P and bound P in the soil. Manure applications must be managed in such a way that almost all of the P is adsorbed in the soil and bound so that it cannot readily escape. Field and laboratory research will need to determine the appropriate spreading rates and frequency on different soils.

A continual year round spreading on fields regardless of the conditions can incrementally deliver a major portion of the nutrients to the environment. Pathogen losses during saturated moisture conditions can occur. Losses from large runoff events may be less than from farms spreading stored manure depending of the timing of the spreading in relationship to the runoff event.

**Table 2: Relative Characteristics for Manure Treatments**

**Scale: 1 = poor 10 = good**

| Characteristic | Daily spread | Liquid Storage | Odor Control | Solid Separation | Compost | Biodrying | High Solids Methane | Methane | Treatment Lagoons | SBR | Total Resource Recovery |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Runoff and leaching | 1 | 4 | 5 | 5 | 6 | 7 | 7 | 6 | 8 | 9 | 10 |
| Odors | 5 | 1 | 5-10 | 2 | 9 | 9 | 9 | 10 | 8 | 10 | 10 |
| Small farm | 5 | 3 | ? | 2 | 5 | 7 | 6 | 3 | 6 | 4 | 5 |
| Large farm | 2 | 7 | ? | 6 | 2 | 5 | 6 | 8 | 8 | 7 | 6 |
| N reduced | 5 | 4 | n/a | 5 | 4 | 4 | 4 | 6 | 7 | 10 | 10 |
| P export | 2 | 1 | n/a | 3 | 5 | 5 | 5 | 4 | 6 | 9 | 10 |
| Pathogen control | 1 | 3 | ? | 3 | 7 | 7 | 7 | 6 | 5 | 8 | 10 |
| Nutrients recycled | 5 | 8 | 6 | 7 | 4 | 4 | 4 | 9 | 2 | 2 | 10 |
| Compaction | 1 | 5 | 6 | 6 | 8 | 8 | 8 | 9 | 9 | 10 | 10 |
| Capital Costs | 9 | 3-7 | ? | 5 | 7 | 4 | 2 | 2 | 4 | 3 | 1 |
| Operating Costs | 5 | 7 | ? | 5 | 3-8 | ? | 3-8 | 3-8 | 5-7 | 2-4 | ? |
| Material sales | 2 | 3 | 4 | 6 | 9 | 10 | 10 | 7 | 6 | 8 | 10 |
| Time to implement | 10 | 9 | 1-9 | 9 | 9 | 5 | 3 | 7 | 7 | 3 | 1 |
| Simplicity | 10 | 8 | 1-9 | 6 | 7 | 5 | 2 | 2 | 5 | 3 | 1 |

**Manure Handling Options** will have different relative values on different farms. Of course every farm is different both in their resources and their goals. This scale is an attempt to compare the systems with each other. For a specific farm it would have to be reevaluated to reflect actual conditions for that farm.

**Economics:** There are many misconceptions about the cost of daily spreading. Some studies have shown a wide range of costs. When no fertilizer credit is taken for the manure and inefficient methods are used to spread it the costs approach $200 per cow per year. Efficient spreading and using the fertilizer value of the manure can produce a positive value on some farms. The average farm in one study in western NY lost $75 per cow per year on their spreading operation.

**Land Requirements:** Daily spreading is a relatively land-intensive operation, especially if phosphorus limitations are placed on the spreading rate. Specialized application vehicles to move more manure further may be needed.

**Management Strategy:** This alternative can be implemented on individual farms, and in many cases can be accomplished using existing manure spreading equipment. Custom spreading may be appropriate for fields at considerable distances from livestock housing. Additional record keeping will be needed on most farms.

**Acceptability:** Because it is a traditional manure management practice, farmer and community acceptance of this alternative is likely to continue to be high. However, longer hauling distances, less efficient use of nitrogen with P balancing, and pathogen concerns may discourage this option.

## Storage

**Description:** Storing manure and wastewater to spread it at an environmentally appropriate time can reduce the total loading of nutrients to a watershed. However, most farmers don't limit their spreading from a storage to times when the environmental effects will be minimized. Labor and equipment availability results in considerable application during the fall, winter and early spring. Nutrient management to reduce fertilizer use is easier when spreading from a storage. Records can be kept and spreading patterns in each field observed to be sure of more uniform coverage. There can be cost savings both in reduced fertilizer use as well as efficient use of equipment when spreading from a storage. However unroofed liquid storages may gain considerable precipitation that also needs to be spread. Roofed systems for dry manure can be expensive. Odor issues are a serious problem when spreading stored manure.

**Environmental Impact:** Management is the key to reducing the environmental impact of spreading stored manure. Odor problems create a continued pressure to avoid the warmer times of the year to spread. Catastrophic failures can result when liquid storages are breached, or when a large runoff event washes all the manure off the land after the manure storage was emptied on to many fields.

**Economics:** Storage can be an economic positive for the farm by allowing efficient spreading operations and the use of the manure as a fertilizer. Incorporating the manure to preserve the ammonia as a fertilizer is an option for all of the manure when spreading from a storage. Delays in planting or other operations due to the time it takes to complete the manure spreading operation can cause a large loss in net farm income. Weather variability makes spreading a year's worth of manure in the spring prior to planting a difficult task.

**Land Requirements:** Spreading from a storage can take even more land than daily spreading if it is incorporated, as the nitrogen can be utilized more completely. This will make it a relatively land-intensive operation, especially if phosphorus limitations are placed on the spreading rate. Less nitrogen will need to be added to a phosphorus balanced rate if it is incorporated. Specialized application equipment to move more manure further may be needed.

**Management Strategy:** This alternative can be implemented on individual farms, and in some cases can reduce spreading costs. Custom spreading may be appropriate on some farms. Management is very important when unloading a storage to prevent spills or overloading of fields. Odor control of the stored manure is an issue that each farm with stored manure needs to consider.

**Acceptability:** Because of the increase in foul odors the community may not accept this practice even when it can be shown to improve water quality. Farms that can reduce their spreading costs, or improve the ease of spreading operations may be willing to put up with some odor complaints. People will be less and less willing to accept the odors as the spreading is concentrated more in the warmer months and concentrated on larger farms.

## Odor Control

**Description:** Many processes have been proposed to treat stored manure to reduce the objectionable odors. These include some of the treatment process contained in this document as manure management alternatives. Other biological, physical, and chemical proposals include: specific enzymes and bacteria, aeration, chemical reactants, heating, drying, raising the pH, chemical masking, magnetism, and electric currents. So far a process that is effective yet low cost has not been found. Research continues world wide to provide a solution.

**Environmental Impact:** Odor control is essential to allow farms to spread on land close to residences and during the summer. Potential leaching and runoff concerns during the cooler wetter times of the year are pushing those farms interested in water quality into a conflict with their neighbors as they attempt to spread manure during the summer. Spray irrigation on growing crops of an odorless manure would be the best method of manure application to provide nutrients to the crop while minimizing environmental losses.

**Economics:** The value of odor control is a hard quantity to define. Avoiding neighborhood conflicts, increased quality of life, and avoiding potential law suits does have a value. Regulations on odor emissions are a real possibility in the future. These regulations will make some form of odor control needed on many farms.

**Management Strategy:** Although there are some management techniques to reduce odors and avoid neighbor conflicts, the odors from stored manure without treatment will challenge even the best managers.

**Acceptability:** Any system that is low cost and easy to manage will be adopted rapidly by farms.

## Mechanical Solids Separation

**Description:** Separating and hauling the separated solids from the manure produced on each farm could potentially allow for the export of approximately 20% of the phosphorus. There are a number of separators commercially available. Most require the addition of extra water. The screw press separator manufactured by Fan seems to work on slurry manure without additional water added and provides a fairly dry product. It will produce at least one cubic foot of 30% solid manure for every minute of operation on a dairy farm. That rate will handle about one cow's daily manure production per minute. This rate may be increased, depending on the size of the solids, the moisture content of the manure slurry, and the internal wear on the auger vanes. A truck mounted unit or units could go from farm to farm on a regular schedule separating the manure for export, or composting. A storage facility on each farm would need to handle the daily manure produced as well as the liquid remainder. This system is being used in Europe.

**Environmental Impact:** Since the amount of phosphorus in the separated manure solids is 20% of the total phosphorus in the manure, removal of the solid produced from the separator would only reduce the loading of phosphorus by 20%. It would have no effect on the pathogens. Nitrogen would also be removed by 20%.

**Economics:** The separation equipment costs about $30,000 for each machine. If permanently installed on a farm it would take another $25,000 for the building pipes and plumbing. One machine would be required for each 500 cows assuming an 8-hour day. The ownership costs which include depreciation, insurance, a 15-year life, and interest at 10% would be $3.50 per hour. The Fan separator uses 4 kW to turn the auger, and 0.15 kW to run a vibrator to keep the manure entering smoothly. Assuming a 10 hp manure pump motor uses 8 kW, the electrical use per 500 cows would be 8.3 hours times 12.15 kW or 102.5 kW hours per day. Maintenance on the separator is estimated at $2.50 per hour. The economics of truck mounted multiple units would have to be explored. Liquid manure handling equipment would need to be obtained for each farm left with the liquids.

**Land Requirements:** Two small three to four day storages for each farm would be needed to store the manure until it was separated and then to store the liquids until they could be spread. Vehicle access to these storages would be needed if portable separators were to be used.

**Management Strategy:** Farms that are not large enough to justify a dedicated separator could use a private operator to set up an operation to separate the manure, haul the solids to a central site for composting or high solids anaerobic digestion, and then market the product. The profit from the sales if any could be split between the farmer and the private operator. Large farms could use the outside expertise to market the solid by-product.

**Acceptability:** The farmers would need to convert to a liquid manure spreading system. If all the solid manure were to be moved off the farm, this would not be that big a burden. The storage and spreading of the liquid is a little easier to manage than handling a solid. More uniform applications could be expected as well as slightly more N retention since the liquid portion will infiltrate into the ground sooner. There may be a slight odor reduction because the liquid manure will infiltrate into the ground quicker.

## Composting

**Description:** Composting is an aerobic decomposition process that is an established on-farm manure management method. The energy liberated during the decomposition process raises the compost temperature to accelerate decomposition and evaporate water, resulting in a dried, stabilized product in 3 to 6 months. A primary constraint on composting is the requirement for a relatively dry manure or a dry bulking amendment to create adequate porosity in high moisture manures. This requirement can be reduced or eliminated via the use of solid separation technology (see above) and/or recycling dried product in the mixture (see Biodrying).

Shared mobile composting equipment could make composting more feasible on small farms. Transport to a centralized facility for composting will depend on the tradeoff between equipment ownership and manure transportation costs. Product marketing would likely be a centralized function performed by a private contractor, who would also provide equipment maintenance and management services.

**Environmental Impact:** Export of the compost product would result in removal of phosphorous and nitrogen from the farm. To the extent compost was used on the farm, phosphorus would remain while nitrogen would be reduced through ammonia volatilization by 30 to 70%. In either case the high temperatures achieved during composting would greatly reduce or eliminate pathogens. The amount of manure composted could include only the excess intended for export, or it could include the entire manure stream as a way to treat manure before returning it to cropland. Application rates could be limited to the phosphorus required by the crop, so that nitrogen fertilizer would need to be imported. Odors will be controlled with proper management.

**Economics:** The economics of on-farm composting have been documented through a number of studies, including case studies from throughout New York State. Combined amortized capital and operation costs typically range from \$5 to \$20/ton. The value of the compost product will offset that cost to a limited degree, although marketing expenses will also need to be considered. Tradeoffs between material transport (bulking amendment and manure) and equipment transport will be analyzed for specific clusters of farms to determine the optimal scale of a facility. Marketing of compost could become a problem since there is and almost unlimited supply of raw materials.

**Land Requirements:** The composting site(s) could be outdoor windrow systems. These would have to be designed with adequate water quality protection measures. Retention ponds and pasture irrigation systems have been used successfully for runoff management at other farm composting facilities. Typical windrow composting operations require one acre for every 3000 yards of material. Including some space for runoff management, approximately 1.5 to 2 acres would be required for a 50-cow dairy. Some producers of higher solid manure have used in-channel composting effectively to compost manure in 21 days. These systems require a building where compost is treated in three-foot high concrete channels. Air is blown into the compost and automatic turners mix and move the material through the system.

**Management Strategy:** Several management options are possible for this technology. In the scenarios proposed, a subsidized private contractor could manage the manure for several farms, either moving equipment to individual on-farm sites or hauling manure to a centralized facility. In a decentralized processing scenario, equipment would need to visit each site regularly, with increased frequency during the summer and early fall to provide relatively dry finished compost for storage and sale the following spring.

**Acceptability:** Composting is an established manure management approach, and multi-farm implementations already exist in the Northeast. Several sites operate centralized facilities collecting manure from many farms, while one operation contracts compost turning and management services for several farms. Although these existing models demonstrate widespread acceptance of composting by farmers and private businesses, they also provide indications of the critical issues for community acceptability. Centralized facilities, because of their larger impact on the immediate neighborhood, are more likely to raise concerns about odor and traffic. If economic and transportation analysis suggests a centralized solution, these concerns must be carefully addressed.

## Biodrying

**Description:** If managed carefully the heat generated by aerobic composting can provide the energy to reduce 12% DM manure to a 60% DM residual. Forced air composting, under a roof, with the air flow controlled carefully would optimize this process. Composting works best with an initial moisture content below 70%. Recent applications of composting operations that have used forced air to compost six foot high layers of manure in 21 days have shown the feasibility of this process. Recycled compost at 40% dry matter could be spread in the alleys of dairy farms about 3 inches thick to absorb one days production of 12% DM manure. The mixture could be scraped into a shed, piled 6-8 feet deep and aerated to produce 40% DM compost in 3 weeks. This recycle loop could be continued indefinitely. One third of the compost produced each day would not be needed to be recycled and would be stock piled for sale or land application on the farm. This process could potentially compost all of the manure produced with little additional amendment needed. The compost would be reduced one half in volume and one sixth in weight from the original manure due to water loss and solid conversion to gasses. Mechanical biodrying systems have been pilot tested for swine manure.

**Environmental Impact:** Pathogen control and odor control would be substantial. Heat produced during the compost process has been shown to reduce pathogen viability substantially. The aerobic nature of the composting process produces few odors if managed correctly. Storing and spreading a high solids product should reduce the runoff potential and eliminate the potential of a catastrophic failure from the storage system.

**Economics:** The capital cost for this system would consist of a three-sided composting shed with an aeration system installed in the floor. Most farms have the needed material handling equipment on the farm. The additional material handling, amendment if needed, and power for the aeration equipment would be the operating costs. These costs may be offset by sales of the product or by use of the compost as bedding.

**Land Requirements:** The composting shed would need to be large enough for 21 days storage of the compost manure mix piled 6-8 feet high. Additional storage for the excess compost could be provided on a pad with controls for rainwater runoff.

**Management Strategy:** Although the air control/temperature feedback system may need to be automated to optimize moisture removal, the rest of the system is well within the management capabilities of most dairy farm operators. Solid handling of odorless compost should make manure spreading much easier.

**Acceptability:** If successful this system would likely be adopted by many small and medium sized farms that have yet to adopt to liquid storage systems. Farmers and the community will enjoy the odor and pathogen reduction.

## High Solids Anaerobic Digestion

**Description:** This system would take the manure produced on the farm, mix it with the dried by-product and send it through a high solids anaerobic digester. The system would produce a stabilized pathogen free by-product much like compost available to export off the farm. All the phosphorous from the manure would be in this by-product.

Manure at 12% solids would be mixed with 50% solid by-product to make a 28% solid material that would be placed in a closed tank and heated to thermophilic temperatures. This will produce methane which, when generated for electric use on the farm, will also produce the heat needed to both heat the digester and to help dry the effluent from the digester. The effluent would need to be dried in a roofed structure with aeration and waste heat from the generator. Most of the dried by-product would be reused in the process but ultimately a steady flow of 5 cubic yards per day per 100 cows of 50% solids would be produced to be marketed off the site.

This process has not been used on a farm but has worked in large-scale operations in previous research activity by Professor William Jewell at Cornell.

**Environmental Impact:** This process would package all the phosphorus produced on the farm in a stabilized, deodorized humus much like compost for export off the farm. The pathogens and weed seeds would probably be killed. The volatile nitrogen ($NH_3$) would be lost during the drying phase. The farmer would have a portion of the by-product available to use on the farm for fertilizer or organic matter amendments. Application rates would be limited to the P required by the crop, so that nitrogen fertilizer would need to be imported.

**Economics:** This system may be put on a single farm or at a central site. The advantages of placing it on each individual farm include: the ability to use the electricity generated on the farm to replace electricity being purchased; the equipment needed to handle the high solid materials are generally already on the farm; and transportation costs would be limited to those used to export the final by-product off the farm.

A central system would find some economies of scale in building the digester tanks and in the engine generator to use the methane. The expertise needed to run the system and market the by-product could be concentrated at one site.

The capital costs would be high for this system. They would include a closed vessel for the digestion, an engine generator, and a drying shed. These costs could be as much as $200,000 for a 150 Animal Unit farm.

The operating costs may provide a break even or better situation on a single farm resulting in savings from electricity generated and bedding produced. A centralized site may have difficulties selling the electricity and have added transportation costs to move the dried material back to farms for bedding.

**Land Requirements:** The area this system would take up would include a 20 foot high by 15 foot diameter vessel and a 70 x 100 drying shed for a 100 cow dairy. This should not be a significant constraint on most farms.

**Management Strategy:** This technology would be about the same complexity as existing anaerobic digestion systems. We can expect those farmers with an above average management ability being able to operate the system with ease, while those farms that are not managing well will find running the system to be a burden. Handling the manure as a solid would mean that most of the equipment to move the material would already be on the farm and the operator would be familiar with the operation of it. An outside service person could used to check the systems on a regularly scheduled basis if enough farms were using the system. At a central site a manager with the capabilities of a sewage plant operator would be required to run the operation efficiently.

**Acceptability:** There would be some disadvantages to this system on the farm. This system would potentially reduce the amount of recycled nitrogen and phosphorus to the land. The nitrogen deficit would have to be imported. It would add another enterprise that would have to be managed on the farm. The advantages include electricity and bedding cost savings and odor control. Good managers who were provided the capital cost should benefit from this system.

The community should accept this low odor processing. There would be an increase in truck traffic especially at a multi-farm site. This system would provide pathogen control, phosphorus export.

## Anaerobic Digestion

**Description:** These biological treatment systems take manure as produced at 12% DM and heat it with waste heat from the engine generator, then anaerobically digest it in an enclosed insulated trough for about 20 days. The manure is continually being fed in and an odor reduced effluent at about 8 % DM is continuously released. Methane is produced that is used to power an engine which drives a generator. Electricity produced exceeds the average dairy farm consumption of electricity providing the possibility of power sales. The effluent with all of the nutrients still in it could be stored to apply to the land.

**Environmental Impact:** The anaerobic process does reduce most pathogens. The extent of this reduction depends on the temperature regime in which the digester is operated. Most are run mesothermically but thermophillic digesters are possible. Odor reduction is another benefit of this process. The slight liquification and the enhanced ability to separate the solids mechanically after digestion can make the effluent easier to pump and irrigate. With the odor reduced, spray irrigation on growing crops is a real possibility. This has the potential to reduce runoff and leaching losses.

**Economics:** There are economies of scale with this system. Farms with over 1000 Animal Units would be more viable and may make a profit with these systems. Smaller farms may not make a profit. Design modifications to reduce the capital costs will continue. Centralized systems must overcome transportation costs to be profitable. In cheap energy times the sales of power may not produce enough of a cash flow to warrant use of this system.

**Land Requirements:** The size of the digester needs to be large enough for 20 - 30 days of hydraulic retention time. The engine generator and solid separation system, if used, would require a building to house them. The total volume of manure is not significantly reduced with methane generation.

**Management Strategy:** Management of these systems is difficult for most farms. While the ordinary monitoring could be done with existing personnel on the farm, when problems develop like engine failure or reduced gas production in the digester, farm labor may not have the expertise or be available to fix them. A private design and maintenance organization should be able to provide this service for a group of farms.

**Acceptability:** Although these systems have been installed and demonstrated for over twenty years, few farms have continued operating them. Cheap energy and the high capital costs are economic disincentives. Maintenance demands also caused existing systems to be abandoned. The need for odor control at a low cost may make them more popular in the future.

## Treatment Lagoons

**Description:** Lagoons provide treatment as well as storage. The treatment occurs by building a biomass of organisms that will decompose the manure either aerobically, anaerobically or faculatatively. These systems often use flushing to dilute the manure and recycle the biomass. Some systems use mechanical separation to remove the solids. Some systems use managed shallow pools to separate the manure solids into aquatically stabilized solids. The solids can then be harvested, dried, screened and sold as a soil amendment. The system recycles the biologically active liquid to move the manure through the lagoons.

**Environmental Impact:** Although the amount varies, the phosphorus can be concentrated in the solids so that up to 75% of it can be removed. Although there is no specific knowledge of pathogen reduction, this may be significant since the retention time in the system is long. There is no temperature increase above ambient in this system. Odors are much reduced when this system is operating correctly. Ammonium nitrogen is lost into the air from this system.

**Economics:** The lagoon system and recycling pump for flushing would be a relatively low capital cost on a favorable site. A flat site with low permeability soil would keep the costs of installation down. Steep sites that require an artificial liner would be much more expensive. The operating costs may be offset by the sale of the product. If the barns were set up for flushing, additional labor savings could be obtained as the recycled water would clean the barns. Retrofitting a flushing system into a flat barn would be very expensive. An existing 2% slope on the alley's would be ideal. A method to further treat or spread the extra wastewater would need to be provided.

**Land Requirements:** The land requirements for the lagoon treatment system would be high. A 150 Animal Unit operation would need about one acre of ponded area and storage for 1 million gallons of effluent.

**Management Strategy:** The operation could be managed by the farmer. In some cases, a company interested in marketing the solids may manage the system for a share of the solids. The capital costs for the installation and a management fee would be paid to this company and the profits from the sale of the solid by-product would be split between the company and the farmer.

**Acceptability:** This process should be acceptable to the farmer once the initial capital cost is taken care of. The effluent to be spread or treated in a wetland will need to be managed. The system includes over winter storage and does reduce odors. This system would be most efficient operated on the farm in conjunction with a flushed housing. By potentially removing a larger portion of the phosphorus and reducing odors, this system may become more popular with farms.

## Sequencing Batch Reactor

**Description:** Certain microorganisms store phosphorus under alternating aerobic - anaerobic conditions. Biological phosphorus removal creates fluctuations in the oxygen content of a wastewater to encourage this excess P uptake by microbial biomass. During the anaerobic stage some of this phosphorus-enriched biomass is withdrawn as a sludge. This is an established treatment technology for municipal wastewater, but has not been applied often to agricultural wastes. In order to achieve adequate settling of the solids, manure collected as a semi-solid would need to be diluted prior to treatment. Much of the effluent from the system would be recycled as dilution water.

**Environmental Impact:** In this application the phosphorus enriched sludge would be dried into a marketable product. Export of the product would result in removal of phosphorous and nitrogen from the watershed. Effluent from the system (beyond that required for dilution) may be suitable for direct discharge, or might require spray irrigation fields.

**Economics:** This is an expensive option, with costs similar to those of a conventional wastewater treatment plant on a BOD basis. Professor Carlo Montemagno at Cornell is currently developing this system at a pilot scale, to establish feasibility and costs for agricultural manure applications

**Land Requirements:** Siting requirements would be similar to those of a wastewater treatment plant. If spray irrigation of the effluent were necessary, land requirements could increase significantly. However land needed to spread manure would not be required as the effluent would be the exportable solids and the very dilute liquid.

**Management Strategy:** As envisioned, manure in excess of crop phosphorus needs would be hauled off site perhaps under contract with a private operator. Management of these systems is difficult for most farms. While the ordinary monitoring might be done with existing personnel on the farm, monitoring to prevent problems from developing might best be done with a private design and maintenance organization. Cost could be low if they were able to provide this service for a group of farms.

**Acceptability:** On farms that need both odor control and phosphorus balancing, this system may be required to stay in business. Farms just meeting odor control may see the high cost as a disadvantage. If energy and nutrient prices increase this system will not be the preferred treatment system.

## Total Resource Recovery

**Description:** This system in essence creates a high value recycling system for the manure nutrients. The liquid stream from a solids separator would be diluted and used to grow plant proteins hydroponically that could then be fed to the animals. On-farm production of a high nutrient feed would reduce the need to import extra feed onto a farm and into the watershed. The diluted manure could come from several different treatment systems. An anaerobic digestion system operated at thermophilic temperatures preceding the hydroponics system would provide pathogen and odor control. The hydroponics system would be contained in a greenhouse environment and potentially be used to grow bacteria, simple and complex plants.

**Environmental Impact:** By reducing the import of nutrients this intensive recycling program could improve the nutrient use efficiency on the farm significantly. This would eliminate the extra phosphorus loading onto the fields. Pathogens and odors would be completely controlled if the system was preceded by a thermophilic anaerobic digester. Caution should be exercised before using untreated diluted manure, which could potentially recycle pathogens to animals through the feed.

**Economics:** Depending on the operating costs, this system could be very feasible. A high protein feed, bedding or soil amendment from the fibers, and energy are produced. There would be no waste discharge. The capital cost would be high. A 150 Animal Unit farm could expect the initial costs to be on the order of $250,000. Professor Bill Jewell at Cornell is currently evaluating the feasibility of this system at pilot scale, and those results should provide the necessary information for a field scale pilot system.

**Land Requirements:** A 150 Animal Unit farm would need about 2 acres of greenhouse production. The anaerobic digester and the engine generator would also need a building space.

**Management Strategy:** This system would be very intensely managed. The green house would have to be managed by an expert. One scenario would be for the farmer to enter into a partnership with an individual or a corporation with this expertise. If successful, this strategy would provide a range of opportunities for local economic development, including services related to greenhouse production, digesters, and composting of separated solids.

A centralized site would provide the opportunity for economies of scale on the digester, and better management and production of the protein supplement. Transportation cost of the manure and the difficulty of selling the electricity produced would be the disadvantages.

**Acceptability:** This system could not be adopted by the farmer on his own. The hydroponics production would be a complex and new skill to learn. With the right partner, this system should be accepted by the farmers. The potential economic advantages are attractive.

This system should be seriously considered for the future. The capital costs will be high but it would achieve the goal of pathogen, odor, and phosphorus control. It should increase the economic viability of the area with the creation of jobs and cheap energy.

## Conclusions

- There are advantages and disadvantages to each system that may be more or less important to each farm.

- The lagoon treatment system and the SBR would work very well with a flushing system to clean the barns.

- Gently sloping topography and relatively impermeable soils on farms using earthen storage will keep the initial costs low.

- Farms that don't need all the nutrients in the raw manure may benefit from the nutrient losses of the SBR, or lagoon treatment.

- The anaerobic digester system would be best for a farm that had high electric costs and could use the nutrients for crop production.

- Nutrient utilization and by-product sales are important in reducing the cost of a manure handling system. Marketing the separated solids or other by-products and fully utilizing the nutrients in the manure can help pay for odor treatment systems.

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# The Bion Nutrient Management System: A Biology-Based Treatment Alternative

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## Introduction

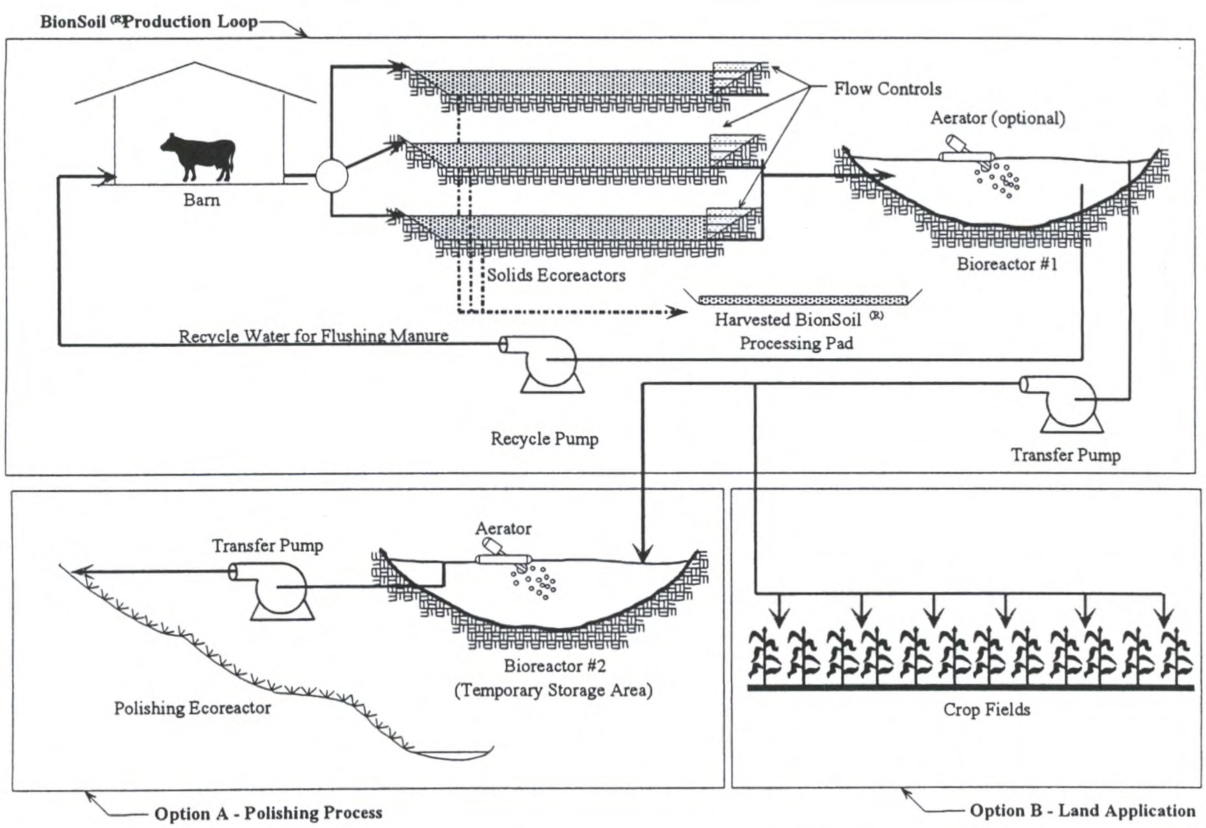
The continued consolidation of the animal agricultural industry, along with a trend toward farm specialization, has outpaced the advancement of farming practices relating to the handling of waste products. Farmers continue to import more nutrients than they are capable of disposing of in a manner acceptable to either government regulators or the general public. The continued use of short-term manure storage and anaerobic lagoons combined with the use of sprayfields and field application is neither cost effective nor environmentally sound. In addition to environmental concerns the increasing quantity of manure produced on dairy and hog farms today leads to concerns about odor, poor public perception, increased trucking costs, increased production costs, potential legal liability.

To address these concerns, Bion Technologies, Inc. (Bion) developed a patented waste treatment technology which eliminates the problems associated with manure management in large scale agriculture operations in a simple and cost effective manner.

The Bion Nutrient Management System (NMS) is a biological treatment system derived from the activated-sludge technology practiced in the wastewater industry. While municipal wastewater treatment systems are designed to treat large volumes of low strength waste, the NMS system is capable of effectively treating very high strength waste. The premise behind a conventional wastewater treatment process is to build a microbial population that will live and thrive under a strict set of constraints. In order to treat the waste quickly, the majority of treatment facilities operate aerobically and incorporate a great deal of mechanical complexity. These systems tend to be very expensive to construct and operate which are undesirable qualities for a system designed for farm use. The NMS system relies on a mainly facultative microbial population derived from the bacteria naturally present in the waste stream to metabolize the biochemical oxygen demand (BOD) and assimilate the nutrients found in the organic material. Wastes which have been treated in the system include manure, silage leachate and milkhouse waste.

The NMS system can be divided into two distinct operational components; the BionSoil® Production Loop and the Polishing Ecoreactor (Figure 1).

**Figure 1. Bion NMS System Schematic**




The BionSoil® Production Loop is designed to convert the waste into a stable product to be removed from the wastestream and is common to all of the farms where the NMS technology is used. The Polishing Ecoreactor is designed to treat the water to near discharge standards by bioconverting the remaining BOD and removing residual nutrients. The exact configuration and layout of the system components is arranged to meet the needs of the farm but the fundamentals of the system remain constant.

**Solids Ecoreactors**

To begin the treatment process, wastes are moved from the barns and collection areas to one of the Solids Ecoreactors (SEs). Solids ecoreactors are shallow basins designed to capture the solids in the wastestream. Typically, three SE cells are constructed to provide sufficient solids storage capacity within the system and to improve operational flexibility. In the SEs, the microbial population and the fiber from the wastestream settle or are filtered out by the previously accumulated solids in the cell. The SEs are designed with a length to width ratio that is conducive not only to promote removal of the solids, but also to cause channels to form in the deposited material which will allow fresh flush water to continue to circulate throughout the cell, thereby constantly exposing fresh microbes to the accumulated wastes. Once the biomass/manure solids mixture is deposited in the SE, the biomass will continue to grow, assimilate nutrients, consume the remaining BOD, and attack cellulosic materials in the manure as an energy source. This process is defined as curing. The available BOD and nutrients are used as the resulting solids become mature and stable. The rate limiting step in this process is the metabolism of BOD since nutrients are available in excess and there will not be sufficient time for cellulosic degradation to be a significant factor.

Once the first SE cell has been filled to capacity the flow will be switched to a second SE. The first cell is drained of free standing water and the solids are removed, resulting in a material known as BionSoil®. Typically, the solids ecoreactor cells are designed with the capacity to contain the solids generated over a 6 month period of time. Effluent from the SE is drained through the flow control device to the primary Bioreactor.

**Bioreactor**

Bion has developed a method used to size the bioreactor in a manner which will ensure that the biomass which develops which will be most suited to metabolizing the waste stream being presented to it. The system is managed in such a way as to provide a high degree of operational flexibility without loss of treatment effectiveness. The combination of aerobic, anaerobic and facultative bacterial populations in the system ensures that the biomass has the ability to rapidly adapt to any change in operating conditions. This combination also means that the system will convert wastes rapidly in the manner of an aerobic system without the associated high operating costs.

Rather than the bioreactor being periodically emptied as with a standard lagoon, a minimum process volume is left in the system to ensure adequate biomass concentration to effect treatment. In the majority of dairy systems the use of additional mechanical aeration is not necessary. Because hog waste has almost twice the BOD of dairy manure (NRCS), all of the hog manure based systems have been designed with some mechanical aeration in the system. Mechanical aerators have also been used in some dairy systems where there is a limited amount of space available or the farm has expanded to a size larger than planned for in the original design.

In addition to being constructed to contain the minimum process volume, the bioreactor is often sized to contain a sufficient storage volume to eliminate the need for spreading or irrigation of waste water during the winter months. When temporary waste storage volume is available, waste is transferred from the bioreactor to storage.

**Recycle Water**

In order to provide constant treatment, water from the bioreactor is used to flush the barn alleys which washes the manure into the solids ecoreactors. This flushing action helps to break the manure into smaller particles and exposes the fresh wastes to the microbe-laden bioreactor water. Farms without a treatment system often do not use, recycled water to flush the barns because of odor concerns and the high solids content in the water. Because of the efficiency at which the SE cells are capable of solids removal, farms with the NMS are able to use water from the bioreactor which contains less than 1 percent solids and is virtually odor free. Those farms which have chosen the NMS technology often retrofit their operations to include the use of a flushing system for the barns. When a farm does not chose to flush the barns, the recycled water is combined with the influent waste stream in a reception pit before being transferred to the solids ecoreactors.

The solids production loop is designed to divide the waste into a solids and a liquid stream. The solids fraction becomes BionSoil and the liquid fraction is suitable for field application or further treatment in the polishing ecoreactor.

**BionSoil**

When one of the SE cells becomes filled the flow is diverted to a second SE cell, and the free water is allowed to drain through a flow control structure to the bioreactor. The solids are then removed and stacked alongside the cell to continue curing. Typically, a system will produce 10 cubic yards of BionSoil for each milking cow and 1 cubic yard for each finishing hog. As part of their contract with the farmer, Bion removes the BionSoil from the farm removing a large percentage of the excess nutrients with it. There is a demand for BionSoil in the landscape, nursery, and the organic fertilizer markets. BionSoil has been proven to have characteristics which are beneficial for growing plants and for use as a fertilizer. BionSoil has been approved by the Northeast Organic Farming Association of New York (NOFA-NY) for use on certified organic farms. Testing by the Soil Foodweb Inc. in Oregon has shown that BionSoil contains large numbers of protozoa and a large active fungal biomass (Table 1). It is likely this diversity of living material in the soil which promotes good root growth and slow release nutrient value to the plants.

**Table 1. Typical BionSoil Analytical Results**

| | |
|---|---|
| Moisture | 66.1% |
| Total Nitrogen | 7.50 lbs/cubic yard |
| Total Phosphorus | 1.11 lbs/cubic yard |
| Potassium | 1.15 lbs/cubic yard |
| Calcium | 5.23 lbs/cubic yard |
| Magnesium | 1.77 lbs/cubic yard |
| Iron | 5.00 lbs/cubic yard |
| Zinc | 0.11 lbs/cubic yard |
| Copper | 0.03 lbs/cubic yard |
| Active Bacterial Biomass | 69 μg/gram |
| Active Fungal Biomass | 160 μg/gram |
| Flagellates | 31,978 individuals/gram |
| Amoebae | 39,949 individuals/gram |
| Ciliates | 319 individuals/gram |

A recent trial completed by the University of Georgia documented that BionSoil outperforms conventional 10-10-10 fertilizer in growth trials of peach orchards. The young peach trees were larger, greener and ready for intensive peach production sooner that those treated conventionally (Couvillon).

Growth trials conducted by the Plant and Soil Science Department at Utah State University (Newhall) show that the yields achieved by using BionSoil are comparable to those of conventional ammonium nitrate fertilizer. Grain corn grown with BionSoil produced 77% more bushels per acre than compost, and barley grown in BionSoil produced 12% more bushels per acre than the conventional fertilizer and 42% more than traditional manure compost.

**Effluent Water**

Excess water from the Bioreactor is eliminated from the system either through irrigation or further treatment in the Polishing Ecoreactor (PE). Increasingly, regulations require that waste only be applied to fields at levels balanced with the needs of the crop. The high levels of phosphorus in manure mean that wastes are having to be applied to fields further from the farm than is economically viable. The ability of a waste treatment system to reduce the amount of nutrient in the waste stream as well as the volume of waste which needs to be applied will allow the farm to utilize the nearest acreage for waste disposal. This will not only reduce the cost of trucking waste to the distant fields but also save the cost of labor and liability.

In addition to lower nutrient content, the NMS system provides the farmer with a liquid effluent containing fewer solids, allowing more efficient pumping to satellite lagoons or an expanded variety of irrigation options such as center pivots or hard hose reels. When compared to a standard storage lagoon, the water from the NMS contains only a fraction of the nitrogen, phosphorus and potassium loads (Table 2). The effluent can therefore be applied to fewer acres than untreated waste and often using hydraulic rather than nutrient based application rates.

**Table 2. Typical Waste Nutrient Analysis**

| | As Excreted (1) (mg/L) | From Storage(2) (mg/L) | NMS Effluent (mg/L) | Reduction from "As Excreted" (%) |
|---|---|---|---|---|
| Nitrogen | 5,578 | 2,169 | 839 | 85 |
| Phosphorus | 855 | 723 | 156 | 82 |
| Potassium | 3,217 | 2,289 | 699 | 78 |

(1) NRCS
(2)Wright

**Polishing Ecoreactor**

Following primary treatment in the BionSoil production loop, waste effluent from the primary bioreactor can be further treated in the Polishing Ecoreactor (PE). The PE has been designed to reduce the amount of liquid which needs to be irrigated from the farm as well as further reducing the nutrient load in the effluent. The polishing process consists of a second stage Bioreactor (B2) and a constructed wetland area. B2 is an aerated basin designed to further the treatment process by stimulating microbial growth and has a longer retention time than the solids production loop. Water in B2 is pumped into the constructed wetland area during the active growing season. The wetland area is a flooded vegetated area in which nutrients are removed from the waste stream by means of a vegetative-microbial complex. This stage of the treatment process is designed to contain all of the effluent and has both wet and dry areas to promote nitrification/denitrification. The wetland area has the appearance of a native wetland, which provides habitat for wildlife, and in general presents an attractive environmental image.

At present vegetation within the system is not mowed or removed from the wetland. Further testing is needed to determine the rate of phosphorus buildup within the system. In the future it may be necessary to harvest a crop with a high rate phosphorus uptake or to periodically remove the top layer of soil to eliminate excess nutrients.

**Pathogens**

In the fall of 1999 in cooperation with the University of North Carolina at Chapel Hill, Bion began a research program to determine the effect of the NMS treatment system on pathogens with Dr. Mark Sobsey and doctoral candidate Vince Hill. They had previously published data on the levels of microbial indicator organisms found in the sprayfield irrigation water of anaerobic swine lagoons (Hill and Sobsey, 1998). Preliminary results from the Bion NMS swine system indicate that the indicator organisms were 96-99% lower in Bion's sprayfield irrigation water than those published for anaerobic lagoons. While the available data is directly related to hog systems, similar results are expected from the dairy systems.

Analysis of BionSoil for parameters required by the EPA Part 503 regulations has shown that there are no detectable populations of *Helminth* ova, enteric viruses, E.coli or *Salmonella* in the dairy or hog based BionSoil.

**CASE STUDY: DREAM MAKER DAIRY**

Dream Maker Dairy (DMD) currently milks approximately 325 cows plus replacements (500 Animal Units). DMD owns approximately 100 acres adjacent to the barns, approximately 60 acres of this were existing crop fields (hay and corn). DMD, unlike most dairy operations, does not grow its own feed for the herd. Instead, DMD purchases all of its feed from local farms near the dairy. Prior to installing the NMS system, DMD paid an outside contractor to haul and spread manure onto nearby crop fields. DMD evaluated many manure management options and decided to install the Bion NMS process because the system is designed to remove nutrients from the waste stream and requires minimal daily maintenance.

The Bion NMS was installed in phases. The first phase was initiated in the spring of 1996, when one SE cell and one bioreactor was constructed. Recycled water from Bioreactor 1 (B1) was pumped to a distribution channel to flush the manure into the system. The topography of the site was sufficient to allowed the waste material to flow by gravity into the system.

The second phase of the project began in the summer of 1997 and was completed in Spring 1998. The second phase consisted of constructing a center berm, which divided the original SE cell into two cells. A new B1 was constructed as well as a second bioreactor/temporary storage area, and containment berms for the wetland area. The new B1 was positioned so that the SE cells could completely drain by gravity. The barns were equipped with flush tanks, which allowed the barn alleys to be cleaned with recycled water from B1. The containment berms for the wetland area were constructed during the fall 1997 so that plants would have time to become established prior to the system being charged with water treated in the BionSoil production loop. Construction was completed and the system was started in June 1998.

A sampling program was initiated in June 1998 in cooperation with the State University of New York at Buffalo to track system performance. Water samples were collected from key locations throughout the system and were analyzed for a number of parameters including BOD, Total Kjeldahl Nitrogen and Total Phosphorus. A summary of the sampling results is presented in Table 3 below. Results indicate a dramatic decrease in nutrient loading as the waste stream moves through the treatment process. A comparison of "As-Excreted" data and samples from the wetland portion of the Bion NMS system shows that 99% of the BOD, 98% of the total nitrogen, and 98% of the total phosphorus are removed from the wastestream. Sampling continues and will provide additional insight on the mechanisms involved in the removal of nutrients in the Bion NMS process.

**Table 3. Dream Maker Dairy Analytical Data**

| **Sample Location** | **BOD** | | **Nitrogen** | | **Phosphorus** | |
|---|---|---|---|---|---|---|
| | (mg/L) | (lbs/1000 gal) | (mg/L) | (lbs/1000 gal) | (mg/L) | (lbs/1000 gal) |
| As Excreted[(1)] | 19,784 | 165 | 5578 | 46.3 | 855 | 7.1 |
| Bioreactor #1 | 2,353 | 19.6 | 617 | 5.1 | 119 | 1.0 |
| Recycle/Flush Water | 193 | 1.6 | 48 | 0.4 | 10 | 0.1 |
| Bioreactor #2 | 1,095 | 9.1 | 250 | 2.1 | 77 | 0.6 |
| Wetland #1 | 130 | 1.1 | 56 | 0.5 | 15 | 0.1 |
| Wetland #2 | 118 | 1.0 | 64 | 0.5 | 15 | 0.1 |
| Wetland #3 | 98 | 0.8 | 44 | 0.4 | 9 | 0.1 |

(1) NRCS

**Conclusions**

As of January 2000 Bion is managing operations of 9 dairy systems and 7 swine NMS systems in New York, North Carolina, Illinois, Florida, and Utah. Three additional systems are scheduled to be constructed in New York and Vermont in the summer of 2000.

Bion is continuing to develop operational data from the systems and is aggressively pursuing the development of the NMS technology on both hog and dairy operations. Currently, the technology is being promoted to producers with more than 2000 sow equivalents or 300 milking cows. As the operational characteristics of the system are more clearly defined and

more is learned about the biological treatment mechanisms involved, the systems will be able to be designed with increased efficiencies and reduced construction costs.
University evaluation of BionSoil's plant growth capabilities and the fate of pathogens in both the BionSoil and the treatment system will expand tremendously over the next year.

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## Session 6

# Feed Management to Reduce Excess Nutrients

# Feeding Poultry to Minimize Manure Phosphorus

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Biographies for most speakers are in alphabetical order after the last paper.

## INTRODUCTION

Recent events in certain areas of the US have brought the issue of phosphorus (P) content in poultry litter to the forefront. In the Delmarva area new legislation will limit the use of excess P application to soil (based, in part, on soil P content). Given limited land for litter application in certain areas of the U.S.A. where the greatest concentration of poultry production exists today, the poultry industry and poultry producers must find strategies that reduce P in litter. The challenge of minimizing excreta P is one, that sooner or latter, will have to be faced by the poultry industry nationwide. Different strategies exist to reduce excreta P but the most effective is a multi-strategy approach.

Changes made to the feed can have a great impact on the amount of P that is excreted by broilers and accumulated in litter. Several feed and management related strategies will be discussed that have the potential for decreasing excreta P significantly. 1) The first strategy is formulating feeds and feeding birds closer to their P requirements. To do this, several issues must be addressed which would include: establishing P and calcium (Ca) requirements under commercial conditions and management systems; use of phase feeding systems with a maximum number of phases taking into consideration practical and economic constraints; use of ingredient knowledge on nutrient content and its variability within ingredient; use of rapid analytical techniques at feed mills to determine actual P and Ca content in ingredients; etc. 2) The second strategy is the use of feed additives that maximize the availability of P for broilers. These feed additives would include enzymes, such as phytase, and/or enzyme "cocktails" and vitamin $D_3$ metabolites. Feed formulated with enzyme(s) addition must take into account the increased availability of nutrients when feed additives are used. 3) The third strategy is to use new ingredients that are low in phytate P (PP) such as the high available P (HAP) corns currently being developed and tested.

## FEED FORMULATION

In formulation of diets for commercial use, several factors have to be considered. Among these factors are: ingredient variability; availability of nutrients within an ingredient and changes in that availability due to processing, growing season, soil where ingredients were grown or where ingredients were mined and processed; specific plant genotype; bird strain; requirements that change with physiological factors such as sex and age; environmental factors or stressors such as heat or density; and the mixing accuracy within a specific system in a feed mill. Formulators need to have these factors in mind when determining the nutrient levels to use in diets. Together, these factors can lead to errors that have dictated the use of safety margins in formulation that are in place to prevent deficiencies from occurring.

Minimizing formulation safety margins will lead to feed formulation that is closer to requirements. For this to happen formulators need increased knowledge about ingredient nutrient content and its variability; use of near infrared reflectance (NIR) technology or other rapid analysis techniques at the feed mill for rapid analysis of ingredients for real time formulation; minimizing mixing "errors" through changes in ingredient delivery systems; formulation of diets for specific strains and physiological phases that should be as narrowly defined as possible; and possibly seasonal formulation. Cost of implementation, availability of information and technology, and previous lack of economic or legislative incentives to overcome implementation costs have resulted in very limited use of new technologies to minimize safety margins.

### Ingredient Selection and Variability

Before getting into ingredient selection issues and how they affect P retention, it is important to clarify terms (related to P) before one goes any further. Book values, such as those found in NRC (1994) for nonphytate P (nPP) levels in plant ingredients are often referred to as being available P (aP) values. This misuse of the aP term has led to confusion as to the meaning of terms. Available P refers to the P that is absorbed from the diet into the animal. Retained P refers to the P that stays in the body (i.e., feed P minus excreta P).

Ingredient selection can plays an important role in the potential to decrease excess levels of most nutrients. This is the case with P. In most formulation systems inorganic sources of P are generally assumed to be 100% available by poultry. This belief is not correct since inorganic sources of P are clearly not 100% available. Inorganic sources of P vary in greatly in availability (Weibel *et al.*, 1984; Potchanakorn and Potter, 1987; Potter *et al.*, 1995; De Groote and Huyghebaert, 1996; Van Der Klis and Versteegh, 1996). Monocalcium phosphate has a relatively higher bioavailability than dicalcium phosphate, with the lowest bioavailability being seen with deflourinated phosphate, regardless of publication. This is consistent among experimental trials done in the same research unit (Weibel et al., 1984) as well as among researchers (Weibel *et al.*, 1984, Potchanakorn and Potter, 1987; Potter *et al.*, 1987; De Groote and Huyghebaert, 1996) and bioavailability assays (Potchanakorn and Potter, 1987; Potter *et al.*, 1995). Researchers have found that the experimental conditions under which P availabilities are determined affect absolute P availability results (De Groote and Huyghebaert, 1996) and thus commercial application of these data must be done carefully. P availability also appears to change due to the physical form of the diet (Sandberg et al., 1987), with pelleted diets having lower P availability. This is possibly, in part due, to decreases in endogenous phytase activity brought about by enzyme inactivation due to the heat associated with pelleting. The extensive use of absolute P bioavailabilty data (CVB, 1994) in commercial feed formulation in Europe should be questioned and perhaps a relative bioavailability system should be applied instead (De Goote and Huyghebeart, 1996). Data presented by Van Der Klis and Versteegh (1996) demonstrates that nonphytate P and available P are not synonymous . These authors found that of the total P in corn 24% was nPP but 29% was available to broilers. Similarly, of the total P in SBM, 39% was nPP but 61% was available to broilers.

Actual P and phytate P content in different ingredients varies somewhat between different published papers and publications (NRC, 1994; Van Der Klis and Versteegh, 1996; Nelson *et al.*, 1968). Data are still limited (Nelson *et al.*, 1968) as to the variability in phytate P content within an ingredient and how soil and environmental factors may affect this content (Cossa *et al.*, 1997). Work done by Cossa *et al.* (1997) showed, in 54 corn samples, a total P content of 3.11g/kg on a dry matter basis and reported a standard deviation (SD) of 0.28 with low and high values of 2.55 and 3.83 g/kg, respectively. Average phytate P was 2.66 mg/kg (SD of 0.34) with low and high values of 1.92 and 3.54 g/kg DM, respectively. These researchers found no apparent differences between locations and early, medium and late varieties of corn on the phytate P content of the corn. There is also limited information on potential variability in the availability of phytate P (Van Der Klis and Versteegh, 1996; Cossa *et al.*, 1997) (Table 2) within an ingredient and on how diet manufacturing process may affect this availability (De Goote and Huyghebeart, 1996).

Another strategy to maximize P retention from feeds is the selection of plant based ingredients. New plant genotypes are being developed that contain lower levels of phytic acid and thus of phytate P, as is the case in the new high available phosphorus (HAP) corn (Stillborn, 1997; Stillborn, 1998). This new genotype contains the same level of total P as normal corn varieties. In HAP corn only 35% of the total P is phytate P versus 75 to 80% in other corn varieties. Chick studies have shown that the P in HAP corn is indeed more available (Ertl *et al*., 1998; Kersey *et al*., 1998; Huff *et al*., 1998). Other key ingredients are currently being selected for high availability of P. Soybean phytic acid content could be reduced (13, Raboy and Dickinson, 1993) with a concomitant decrease in phytate P from 70% to 24% of total P through breeding efforts (Raboy *et al*., 1985). Another strategy being implemented is the incorporation of fungal phytase gene(s) into plants such that phytase is expressed in the seed at high levels (Stillborn, 1998). Work has been done in chicks with transgenic canola meal (Ledoux *et al*., 1998) and soybean meal (Denbow *et al*., 1998). Results from these chick trials showed that similar levels of added endogenous phytase and added exogenous phytase were effective in improving PP utilization. Processing is still a concern in terms of inactivation of phytase regardless of how it is added to the diet. Post expansion and/or pelleting application of exogenous phytase to feed can be done (Aicher, 1998) thus avoiding heat inactivation of the enzyme. This would not be possible with transgenically incorporated phytase.

From a practical standpoint, the use of new ingredients in commercial diets poses some challenges. New ingredients must be identified from planting to actual incorporation into diets. The logistics and economics of accomplishing this are still being worked out. The simplest solution so far is for feed manufacturers to contract fields for planting specific genotypes. This solution still leaves some of the logistical and economic challenges unanswered. In a feed mill, bin space for ingredients is always at a premium and thus new ingredients would, in most cases, displace other ingredients.

NIR technology for quick determination of protein, fat, and fiber exists and has been in place in some commercial mills in the U.S.A. for several years. Application of NIR for amino acid and digestible amino acid predictions has been developed (van Kempen and Simmins, 1997) but so far it is not used much in commercial mills in the United States. Other potential applications for NIR are determinations of organically bound Ca and P. This technology has the potential to allow for feed formulation based on real time ingredient nutrient content beyond protein, fat, and fiber. This would allow for much closer formulation, under commercial mills situations, to actual requirements and would allow for smaller formulation safety margins.

**Phosphorus Requirements**

There is limited information as to the P requirements of broilers (NRC, 1994; Van Der Klis and Versteegh, 1996; Gillis *et al*., 1949; Fritz *et al*., 1969; Twining *et al*., 1965; Lillie *et al*., 1964; Van Der Klis and Versteegh, 1997a) but no conclusive values have been established apart from those published by NRC (1994). The values proposed by NRC (1994) are recommended levels and reflect only information published through the peer review process. Thus, it does not include levels used with success commercially. NRC (1994) recommendations for nPP from hatch to 3 weeks of age appear to be well supported both under controlled experimental conditions as well as under commercial conditions. It is in the grower and finisher phases that NRC (1994) recommended levels for Ca and nPP exceed those used successfully in the field and shown to be adequate under experimental conditions (Skinner and Waldroup, 1992; Waldroup, 1998). Although NRC (1994) recommends a nPP level of 0.30% from 42 to 56 days of age, commercial use levels during this age period (42 to 50 days of age) can be 0.17% or lower. Establishing minimum adequate levels for nPP under defined conditions is a necessity if one is to maximize the effect of feed additives in decreasing excreta P.

It is imperative that certain factors be defined when requirements are being determined. The factors that most affect P requirements are dietary Ca level (and Ca:P ratio), level and type of vitamin D in the diet, and the presence and amount of plant P in the diet (Fritz *et al.*, 1969;Twining *et al.*, 1965; Van Der Klis and Versteegh, 1997a; Van Der Klis and Versteegh, 1997b; Davies *et al.*, 1970). Plant P in the diet should be at least defined by analysis as total P, and nPP. Age (Lillie *et al.*, 1964; Van Der Klis and Versteegh, 1997b) and strain (Lillie *et al.*, 1964) of the birds also have an effect on P requirements. The more closely diets can be formulated for poultry of specific ages, the lower the P excretion will be. To accomplish this, phase feeding systems should be implemented. These systems should maximize, within economic logistical constrains, the number of feeding phases.

### Preliminary Results on Phosphorus Requirements in a Four Phase Feeding System

Several trials have been done to determine more accurately what the available phosphorus needs of broilers grown in a four phase feeding system are (Angel, Applegate, Dhandu, Ling, unpublished data). The four phases studied were: starter, hatch to 18 days of age; grower, 18 to 32 days of age; finisher, 32 to 42 days of age; and withdrawal, 42 to 49 days of age. Two more studies are needed to finalize this work.

So far this research has shown that nPP can be reduce (versus average commercial usage levels) by 5% in the grower diet and by 15% in the finisher diet without affecting bone strength or performance. Withdrawal phase requirements are currently being determined. Requirements for all phases need to be confirmed in a study that closely mimics commercial conditions. A study currently underway will focus on processing plant condemnations and bone breakage data to allow us to determine if the levels we have found to be adequate in floor pen studies are “really” adequate when birds go through the processing plant.

Having more accurate available phosphorus requirement information has profound consequences in terms of phosphorus nutrient management. Given the results up to date, we can potentially see a reduction of at least 10% in the amount of available phosphorus we feed broilers. This would mean at least a 10% decrease in litter phosphorus. Having more accurate phosphorus requirement information will also allow us to more fully use feed additives, such as phytase, to decrease phosphorus in poultry litter.

## FEED ADDITIVES THAT MAXIMIZE PHOSPHORUS RETENTION

Poultry diets usually contain plant-based ingredients. A high proportion of P from plants occurs in the seed as phytate P (PP). Phytate chelates other minerals and it binds to proteins and starches making them unavailable to birds. Extensive information is available on phytate and phytase (Kornegay, 1998; Parsons, 1998; Nelson, 1967; Harland and Morris, 1995). Phytase and factors affecting its activity and efficiency have been extensively discusses (see Nelson *et al.*, 1971; Simons *et al.*, 1990; Biehl *et al.*, 1995; Harland and Morris, 1995; Ravindran *et al.*, 1995; Van Der Klis *et al.*, 1997; Mitchell and Edwards, 1996; Quian *et al.*, 1996; Van Der Klis *et al.*, 1997d; Gordon and Roland, 1998; Kornegay, 1998; Parsons, 1998) and thus, the focus here will be on the potential use of several feed additives ("cocktails") together.

Work done by Zyla *et al.* (Zyla *et al.*, 1995a; Zyla *et al.*, 1995b; Zyla *et al.*, 1996; Zyla *et al.*, 1997) demonstrated that, under *in vitro* conditions simulating turkey intestinal conditions, the use of an enzymatic "cocktails" could release 100% of the PP contained in a corn-soy diet. The enzymatic "cocktail" contained a microbial phytase, acid phosphatase, acid protease, citric acid, and *A. niger* pectinase. From their work, it was clear that phytase alone could not release 100% of the PP present in a corn-soy diet. These researchers (Zyla *et al.*, 1995a, Zyla *et al.*, 1995b) found that phytase preparations are not pure phytase. These phytase preparations (both commercial and laboratory derived sources) generally contain, in varying amounts depending on the phytase preparation, acid phosphatases, acid proteases, and pectinase. These researchers found a negative correlation between purity of the phytate preparation and its capacity to release PP. Only when the appropriate balance between the different components of the "cocktail" was obtained did 100% release of PP from the corn-soy diet occur.

To determine whether the enzymatic "cocktail" developed *in vitro* would work as effectively *in vivo* an experiment was done with 7 to 21 day-old turkeys (Zyla *et al.*, 1996). These researchers fed a corn-soy-meat meal diet with a Ca level of 1.2% and an aP level of 0.6% which met NRC (1994) recommendations, a positive control diet containing 0.42% aP and 0.84% Ca (positive control), and diets containing 0.84% Ca and 0.16% aP to which enzyme preparations (phytase (1000 u/kg of diet), an enzyme cocktail, or *A. niger* mycelium) were added . They found that P retention from 31.0% in the NRC (1994) based diet, 42.8% in the positive control diet, 66.8% in the diet with phytase, 77.0% in the diet with the enzyme "cocktail", and 79.5% in the diet with the *A. niger* mycelium. Addition of acid phosphatase, pectinase, and citric acid to phytase (enzyme cocktail) also increased P retention ($P<.05$).

Questions remain as to why these researchers (Zyla *et al.*, 1995a; Zyla *et al.*, 1995b; Zyla *et al.*, 1996; Zyla *et al.*, 1997) obtained 100% release of PP *in vitro* but only 77% *in vivo*. Procedural problems may be part of the answer since analyzed TP levels in the diets where enzymes were added were higher than formulated. The authors speculated that the feed additives themselves could have been a source of P that was not accounted for. Another factor is potential differences in the time allowed for digestion *in vitro* versus actual residence time of digesta in the proventriculus/gizzard and small intestine. The *in vitro* assay consisted of two 30 minute periods simulating the action of the proventriculus and gizzard, then incubation for 240 minutes after the addition of enzymes or "cocktails" being tested. Passage rate in the small intestines of turkeys and broilers is 94.9 and 73.3 minutes, respectively (Hurwitz *et al.*, 1979). From these data, it would seem that specially in broilers, increasing the speed of the reaction could increase the release of PP *in vivo*. This could be done by looking at other enzyme combinations and increasing the accessibility of the substrate to the enzymes by decreasing particle size and the use of structural carbohydrases may help in maximizing PP release.

Other feed "additives" that need to be considered are vitamin $D_3$ and its metabolites. Not only does vitamin D stimulate P transport mechanisms in the intestine (Harrison and Harrison, 1961; Mohammed *et al.*, 1991; Biehl and Baker, 1997) but it also appears to enhance phytase activity (41, 42). Vitamin D as well as its metabolites, 25-hydroxycholecalciferol and 1,25-dehydroxycholecalciferol ($1,25(OH)_2D_3$) (43,44), have been shown to enhance phytase activity. It appears that $1,25(OH)_2D_3$ and phytase act in an additive manner rather than a synergistic one (Mitchell and Edwards, 1996; Biehl *et al.*, 1995). Mitchell and Edwards (1996) found that the addition of $1,25(OH)_2D_3$ and phytase could replace 0.2% of the inorganic P addition in the diet in 21 day-old chicks. Phytase and $1,25(OH)_2D_3$ alone could each only substitute for close to 0.1% of added inorganic P. Vitamin D metabolites have a clear role in improving P retention and their use in conjunction with other feed additives (phytase and/or enzyme "cocktails") is indicated.

**Preliminary Results on the used of a *Lactobacilus*-Based Pro-Biotic in Broiler Feed on Phosphorus and Nitrogen Content of Litter**

Some *lactobacillus*-based pro-biotics have been shown to improve growth and feed conversion in poultry. The objective of this research was to determine if broilers fed low P, Ca, and protein in a diet containing a *lactobacillus*-based pro-biotic would perform similarly to broilers fed a control (commercial levels of P, Ca, and protein) diet. If performance was not negatively effected, we wanted to determine if litter P and nitrogen (N) would decrease. To do this a series of two studies were done. The data from the first study has been summarized and presented (Angel, *et al.*, 1999a; and Angel *et al.*, 1999b), while the retention data from the second study is still being summarized. Broilers were fed a grower control diet (19.3% protein, 0.37% aP) and a low nutrient diet from 18 to 28 days of age. A finisher control diet (17% protein, 0.30% aP) and a low nutrient finisher diet were fed from 28 to 42 days of age Each diet was fed with and without the *lactobacillus*-based pro-biotic. The low nutrient diet was reduced by 12% in protein and by 18% in aP.

In both the grower and finisher phase, broilers fed the low nutrient diet had significantly lower weight gain, and feed conversion. Bones (tibia) from these birds broke easier than bones from control birds. When the pro-biotic was added to the low nutrient diet, broilers performed as well as those fed the control diet and bone breakage was also similar to that of controls. At 42 days of age birds fed the control diet weighed 5.8 lb and birds fed the low nutrient plus pro-biotic diet weighed 6.1 lb. Performance data from the second study has been summarized and supports the results of the first study.

Nutrient retention was improved when the pro-biotic was added to the diet. P retention was 22% higher and N retention was 10% higher in birds fed the low nutrient plus pro-biotic diet than in the birds fed the control diet. The addition of the pro-biotic to the low nutrient diet allowed broilers to grow as well as those fed a control diet in part because they were more efficient in retaining nutrients. Feeding a low nutrient diet with pro-biotic decreased excreta phosphorus by 33% without adversely affecting performance or bone strength. This decrease would also be seen in litter phosphorus content. Nutrient retention data from the second study is currently being summarized and is needed to corroborate data from the first study.

It is important to note that additions made to a diet that improve the availability of PP do not necessarily translate to higher P retention from the diet. The higher P availability resulting from the addition of phytase, enzyme "cocktails", and/or $D_3$ metabolites has to be associated with reduced dietary inorganic P levels if increased P retention is to occur.

## SUMMARY

Implementation of strategies to maximize P retention and thus minimize P in litter needs to be multifaceted. Numerous changes in different areas must be implemented simultaneously if P retention is to be maximized. Changes that must be considered if P retention is to be maximized are: formulation choices based on actual P levels in ingredients and on values for availability of the P in those ingredients; ingredient selection, including the use of new ingredients with low PP content; dietary nutrient balance (vitamin $D_3$, Ca:P ratios, etc.) that maximizes P retention without adversely affecting economics; use of rapid analytical methods to formulate diets based on real time nutrient content of ingredients; use of several feed additives (enzyme "cocktails" that include phytase, and $D_3$ metabolites) that together maximize PP release and absorption of P; decreased inorganic P levels in diets when feed additives that increase P availability are used; and management changes that reduce stress. Only through multifactorial changes can P retention be maximized.

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# Managing Swine Feeding to Minimize Manure Nutrients

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Swine manure, as collected in liquid or slurry form on commercial hog farms, consists of feces, urine and varying amounts of wasted drinking and wash water. Contained within the manure are significant quantities of biologically essential nutrients, mostly notably, nitrogen (N) and phosphorus (P). Other nutrients of biological importance present in swine manure include potassium, calcium, copper, zinc, manganese and other minor elements. The majority of N and P in manure originates in feedstuffs and represents N and P not retained in the pig for maintenance, growth and reproduction. The proportion of consumed N and P excreted by the pig is high. Estimated excretion rates as a percentage of intake range from 60 to 80 % (Jongbloed and Lenis, 1992; Table 1).

Table 1. Intake, excretion and retention of nitrogen (N) and phosphorus (P) in swine.

| | | Intake, lbs. | Excretion, lbs. | Retention, % |
|---|---|---|---|---|
| Starter pig (20-55 lbs.) | N: | 2.07 | 1.23 | 40% |
| | P: | .46 | .29 | 37% |
| Grower-finisher pig (55-235 lbs.) | N: | 13.93 | 9.35 | 33% |
| | P: | 2.69 | 1.81 | 33% |
| Breeding sow (19.6 piglets/year) | N: | 61.78 | 49.43 | 20% |
| | P: | 14.46 | 11.95 | 17% |

(Adapted from Jongbloed and Lenis, 1992)

As essential plant nutrients, waste N and P from swine feeding can and should be considered an asset to crop and forage production. However, the nutrients that are excreted in manure must be recycled onto cropland in a manner that is not damaging to the environment. Furthermore, limitations on the amount of available manure storage capacity, and the amount of crop acres available for application, necessitate that the levels of excreted nutrients be managed and controlled. This is also important from an economic standpoint because excess excretion of N and P is not cost effective for the swine feeding enterprise. Therefore, the goal of swine feeding management is to optimize the levels of N and P (and other nutrients) retained in the pigs being fed. In doing so, the amount of waste nutrients are kept at a manageable level such that they can be used for beneficial purposes without excess available for potential contamination of ground or surface waters. This concept has been referred to as *environmental nutrition* (Kornegay and Harper, 1997). The Following discussion offers nutrition and feeding strategies that can assist in reducing the level of nutrients excreted into swine manure.

*Minimize Feed Waste*

Excessive feed waste on commercial hog farms is a problem that can occur when operators or managers fail to recognize the importance of monitoring and preventing feed waste on a regular basis. An obvious negative impact of excessive feed waste from self-feeders and other feeding equipment is a substantial increase in feed costs per unit of pork sold. For example, in a swine finishing operation, a five percent level of feed waste may result in income loss of approximately $1.80 per hog (Harper, 1994; Table 2).

Table 2. Feed waste impacts nutrient management.

| Percent feed waste | Feed loss per pig, lb. | Income loss per pig, $ | Feed N waste per pig, lb. | Feed P waste per pig, lb. |
|---|---|---|---|---|
| 1% | 6 | .36 | .14 | .04 |
| 3% | 18 | 1.08 | .43 | .11 |
| 5% | 30 | 1.80 | .72 | .18 |
| 7% | 42 | 2.52 | 1.01 | .25 |

Based on growing-finishing pigs from 50 to 250 lb. body weight, 3:1 feed:gain ratio, 2.4% N and .60% P in the diet and $.06/lb. diet cost.

Another important problem with excess feed waste is the unnecessary addition of N, P, and other nutrients into the swine waste storage system. At a 5 % level of feed waste in a swine finishing operation, an additional .72 lbs. of N and .18 lbs. of P per hog may be added to the manure storage and distribution system (Table 2). This may be equivalent to 10 to 15 % of the total N and P in the system. Use of proper feeder designs and regular maintenance and adjustment of feeder equipment is essential to prevention of excess feed waste. Well managed swine farms make prevention of feed waste a routine objective for both economic and environmental reasons.

*Optimize Feed Conversion Efficiency*

The amount of feed consumed per unit of pig growth (feed/gain ratio or feed efficiency) has a direct impact on economic returns for swine producers. Even for producers that are feeding swine under contract with no direct costs for feed have economic incentives to optimize feed efficiency. This is because contractors typically offer bonus payments for improved feed efficiency with each group of pigs fed. In growing-finishing pigs being fed from 50 to 250 lbs., feed/gain ratio may range from very inefficient levels as high as 3.5 to very efficient levels as low as 2.5.

Improved feed efficiency has direct implications for nutrient excretion as well. As the amount of feed consumed per unit of growth is reduced the quantity of nutrients excreted is also reduced. Coffey (1992) has reported that reducing feed/gain ratio in finishing pigs by .25 units (3.00 vs. 3.25) would reduce overall N excretion by 5 to 10%. A similar report by Henry and Dourmad (1992) indicates that for each .1 unit reduction in feed/gain ratio, N output is reduced by 3%.

A number of factors contribute to optimal feed efficiency. The most predominant is genetic capacity. Selection and use of breed crosses or genetic lines of pigs with high potential for good feed conversion will have a measurable effect on feed efficiency. Environmental factors such as maintaining barn temperature within or near the "thermoneutral" zone and ventilating the barn for good air quality will also contribute to better feed efficiency. Feeding high quality diets and certain feed processing methods also have impact. For example pelleting swine diets has been shown to improve feed efficiency as compared to feeding diets in meal form. Use of growth promoting feed additives and performance modifiers may also improve feed efficiency. But use of these agents is strictly regulated and may not be feasible in all situations.

*Avoid Over-formulation of Diets*

The goal of swine nutrition is to formulate diets to contain the correct concentration of energy and essential nutrients for optimal growth or reproductive performance and carcass quality. Traditionally nutritionists have included slightly elevated concentrations of certain essential nutrients to insure that nutrient needs were met. This practice of slight "over-formulation" of diets beyond the expected nutrient requirement of the pig was regarded as a safety factor for optimal performance. A major disadvantage of this practice is that feeding dietary nutrient concentrations that are beyond the pig's true requirement results in a higher rate of nutrient excretion. For example, Dourmad and Corlouer (1993) fed grower-finisher pigs three dietary protein concentration regimes, all of which were nutritionally adequate and all of which produced similar pig growth performance. However, pigs fed the diets that were excessive in dietary protein concentration produced as much as 29% more manure N and 32% more N emissions than pigs fed the lower but more nutritionally accurate protein level (Figure 1).

A similar situation exists with P concentration of the diet. Latimer and Pointillart (1993) compared performance and P excretion of growing-finishing pigs fed diets with either

.4%, .5%, or .6% total P. The .4% dietary P level was determined to be nutritionally inadequate because pig performance was reduced. Pigs fed the .5% or .6% dietary P levels performed equally well. But, those fed the .6% P diet excreted 33% more P than those fed the .5% P diet (Figure 2).

Figure 1. Dietary protein effects N excretion. (Dourmad and Corlouer, 1993).

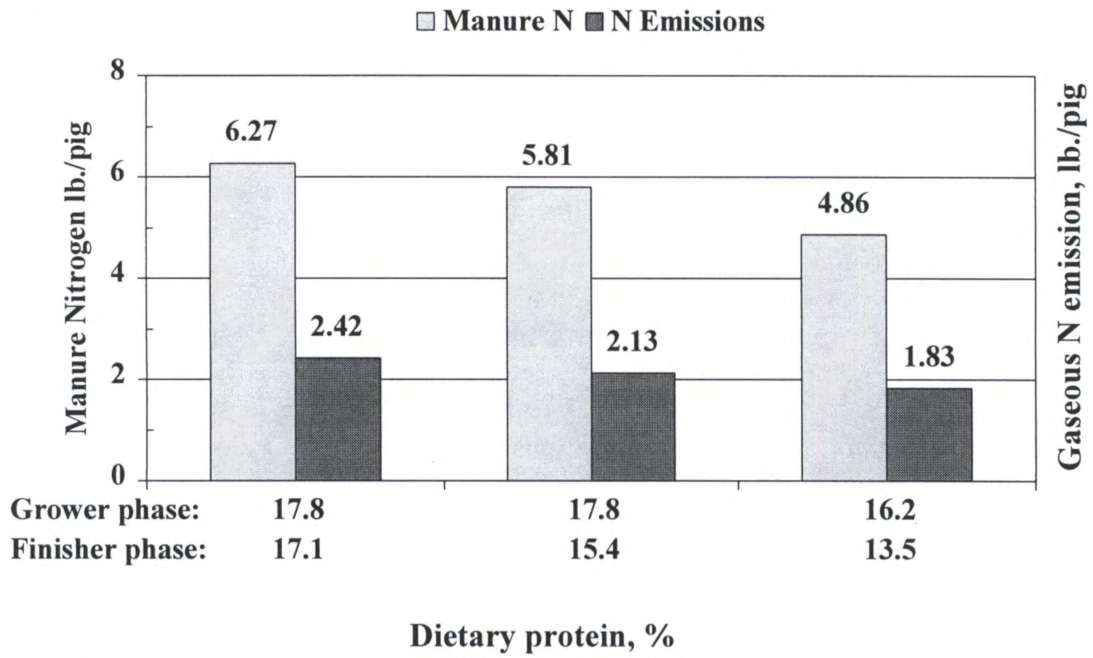
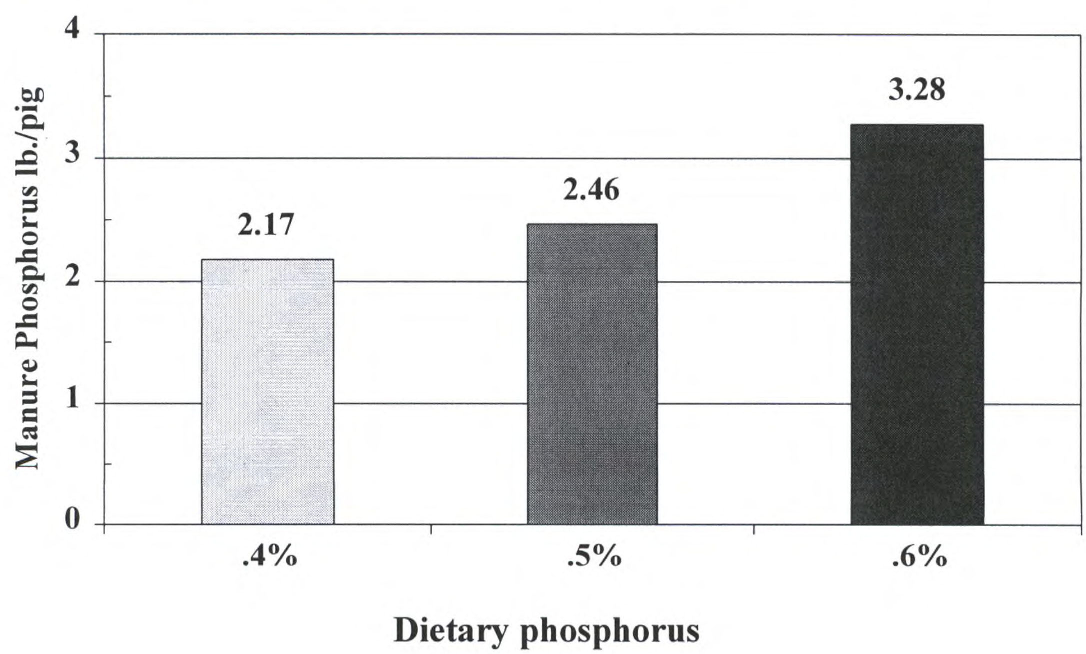



Figure 2. Dietary P level effects P excretion. (Latimer and Pointillart, 1993).



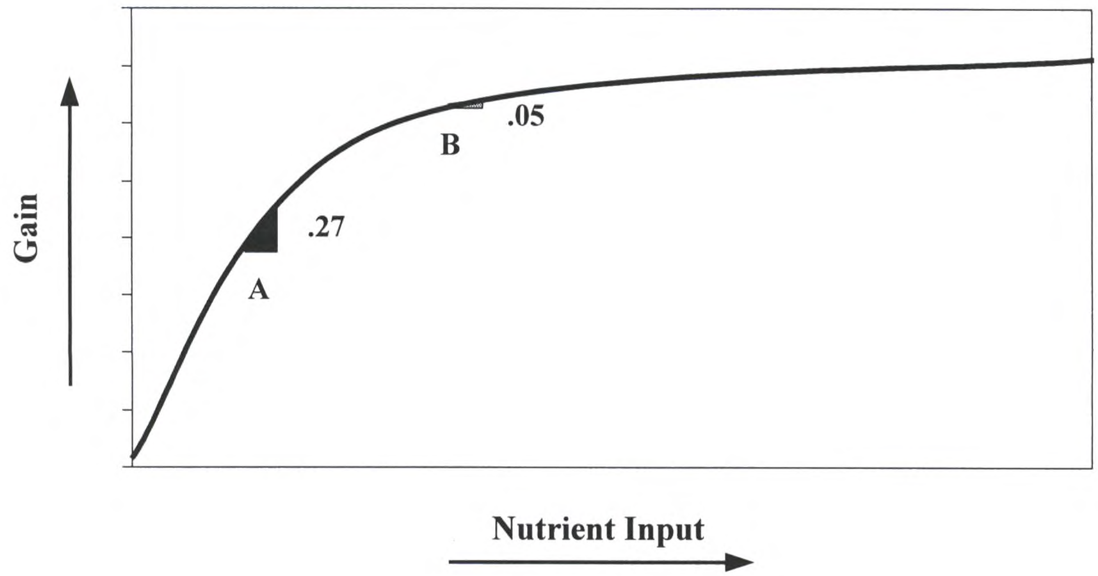
Directly related to prevention of over-formulation is accurate knowledge of pig nutrient requirements and accurate estimates of the nutrient content of feedstuffs. As the practice of swine nutrition becomes more refined, professionals formulating diets will use the best information available to optimize animal performance and minimize nutrient excretion. For example, the recently revised "Nutrient Requirements of Swine" (NRC, 1998) now includes a computer model that allows the formulator to predict nutrient requirements based on the size, sex and genetic capacity of the pigs being fed. The model also allows for adjustments with different environmental conditions in swine facilities.

*Feeding for Optimum Rather than Maximum Performance*

Professionals involved in swine feeding enterprises have begun to realize that feeding for maximum animal performance is not necessarily the best objective. Optimal growth and performance would be a better objective. In this case diets are formulated with the intent that the pig will closely approach, but not fully attain maximum performance. Under this objective, economic return over feed cost may actually be higher. And, just as important, nutrient excretion may be reduced.

The basis for feeding nutrient concentrations at levels slightly below that necessary for maximum performance response may best be explained with the concept of diminishing returns (Kornegay and Harper, 1997). As the dietary concentration of N (protein and amino acids), P or other essential nutrients increases from a deficient level to an adequate level, the pig responds with improved growth performance. However, as performance approaches a maximal level, each incremental increase in dietary nutrient concentration results in progressively smaller improvements in performance (Figure 3). At some point, increased dietary nutrient concentration cannot be justified because the magnitude of response in pig performance is too small to be economically justified. Furthermore, an additional problem will be the unnecessary increase in nutrient excretion. This concept must be balanced with the understanding that optimization of different performance traits may actually have different nutrient requirements. For example, a higher dietary protein and amino acid concentration (the significant N containing part of the diet) is required for optimal carcass leanness than is needed for optimal growth rate. This is important because market hog prices at packing plants are adjusted according to percentage of carcass lean.

Figure 3. Example of diminishing returns for nutrient inputs as the level of nutrient fed increases. At point A, one unit of input produces 0.27 units of gain, whereas, at point B, one unit of input produces 0.05 units of gain.




*Phase Feeding and Separate Sex Feeding*

Nutrient requirements as a percentage of the total diet change as pigs grow heavier (NRC, 1998). The challenge for nutritionists and swine producers is to determine how frequently or how many diet changes will be made from the nursery period (12 to 45 lbs.) and throughout the growing-finishing period up to market weight (about 250 lbs.). Historically, nutritionists and producers have chosen a less complicated approach with only a limited number of diet "phases" during grow-out. A disadvantage of this approach is that there may be extended periods during which the pigs are receiving higher concentrations of nutrients than actually required and nutrient excretion would be increased.

More frequent diet formulation changes during grow-out allow for more precision in meeting nutrient requirements of the pig. Henry and Dourmad (1992) have demonstrated that a 3-phase feeding regime can reduce N excretion in growing-finishing pigs as compared to a 2-phase or single-phase regime. In this work the 3-phase program provided dietary crude protein levels of 17% (55 to 110 lbs. pig weight), 15% (110 to 165 lbs. pig weight) and 13% (165 lbs. to market weight). Pigs fed in this manner excreted 8% less N than pigs fed a 17% protein (55 to 120 lbs. pig weight) followed by 15% protein (120 lbs. to market) (Table 3).

Table 3. Effect of feeding strategy during the growing-finishing period (55 to 230 lb) on N output.*

| | Crude Protein, % | | |
|---|---|---|---|
| Item | Single-feed 17% | Two-feeds[a] 17-15% | Three-feeds[b] 17-15-13% |
| N output, lb/day | 0.070 | 0.064 | 0.059 |
| % of two-feed strategy | 110 | 100 | 92 |

[a]Crude protein changed at 120 lb.

[b]Crude protein changed at 110 and 165 lb.

*Adapted from Henry and Dourmad (Feed Mix, May 1992).

It has been recognized for some time that gilts have a different body composition than barrows during the finishing phase and at market weight. Gilts have slightly reduced feed consumption, deposit less body fat and deposit more lean tissue during growth resulting in a higher percent lean content at slaughter. Consequently, gilts have higher nutrient density requirements than barrows (NRC, 1998).

Many intensively managed hog farms are now taking advantage of these sex differences in finishing pigs. Typically pigs are separated into uniform weight groups of gilt only pens and barrow only pens during the grower-finisher period. The benefits of separate-sex feeding are realized during the finisher phases but the most practical time to segregate the pigs by sex is going into or coming out of the nursery. Under these conditions, gilts are fed specific diets to meet their nutrient needs while barrows are fed a more economical, lower nutrient density diet that specifically meets the needs for their body composition. As with phase feeding, this allows more precise diet formulation for the specific type of pig being fed. In addition there is a reduction in overfeeding certain nutrients and a reduction in nutrient excretion.

*Use of High Quality Protein Sources and Crystalline Amino Acids*

The protein component of swine diets consists of amino acids, all of which contain N. The pig does not have a requirement for protein per se, but for the essential amino acids that are the components of protein in feedstuffs. High quality protein supplements such as soybean meal or fish meal have an abundant and well balanced supply of amino acids for the pig. Poorer quality protein supplements such as peanut meal or cottonseed meal may be used in limited quantities as protein supplements, but if excessive quantities are used, N excretion can be increased. This may be due to the fact that excessively high total protein levels may have to be fed with these ingredients in order to meet the limiting amino acid requirement of the pig. Or, protein digestibility may be poorer in some lower quality protein supplements.

Even with high quality protein supplements like soybean meal, some excess feeding of total protein and N may occur. This is because enough soybean meal must be included in the diet to meet the pig's requirement for the first limiting essential amino acid, lysine. Consequently, when meeting the pig's requirement for lysine by adding soybean meal to the diet, some excess of total protein and N is fed. The development of synthetic lysine and other crystalline amino acids has given swine nutritionists and producers a highly effective means to reduce total protein content of pig diets while still maintaining good growth performance and carcass leanness. With typical corn-soybean meal based diets, total crude protein level can be reduced up to 2 percentage units if crystalline lysine is added to the diet to balance the pig's lysine requirement with no loss in performance (Cromwell and Coffey, 1994; Table 4). Furthermore such a practice can reduce N excretion from growing pigs by up to 22% (Table 5). Even greater reductions in dietary N content and excretion may become possible as crystalline sources of other limiting amino acids such as threonine, tryptophan and methionine become more economical to use.

Table 4. Performance of finisher pigs fed low protein, lysine supplemented diets. (Cromwell and Coffey, 1994).

| Diet | Daily gain, lb. | Feed/Gain |
|---|---|---|
| 14% C.P. | 1.54 | 3.16 |
| 12% C.P | 1.36 | 3.52 |
| 12% C.P. + .15% Synthetic lysine | 1.52 | 3.18 |

Table 5. Theoretical model of the effects of reducing dietary protein and supplementing with amino acids on N excretion by 200 lb. finishing pigs.[a]

| N balance | 14% CP | 12% CP + Lys | 10% CP + Lys + Thr + Trp + Met |
|---|---|---|---|
| N intake, g/d | 67 | 58 | 50 |
| N digested and absorbed, g/d | 60 | 51 | 43 |
| N excreted in feces, g/d | 7 | 7 | 7 |
| N retained, g/d | 26 | 26 | 26 |
| N excreted in urine, g/d | 34 | 25 | 17 |
| N excreted, in total, g/d | 41 | 32 | 24 |
| Reduction in N excretion, % | - | 22 | 41 |

[a]Assumes intake of 3,000 g/d, a growth rate of 900 g/d, a carcass lean tissue gain of 400 g/d, a carcass protein gain of 100 g/d (or 16 g of N/d), and that carcass N retention represents 60% of the total N retention. Adapted from Cromwell (1994).

*Improve the Availability of Phosphorus in Feeds with Phytase*

Much of the P in grains and oilseed meals is chemically bound in molecules called phytate. Phytate is the mineral salt of phytic acid and serves as the storage form of P within plant seeds. Approximately 66% of the P in corn and 61% of the P in soybean meal is bound in phytate form. Certain rumen bacteria in cattle and sheep produce an enzyme called phytase that liberates P from phytate making it available to the animal. Nonruminant animals such as pigs do not produce intestinal phytase; therefore, phytate bound P in feedstuffs is essentially unavailable to pigs.

To meet the pig's total dietary requirement for P, inorganic P sources, such as dicalcium phosphate or deflourinated phosphate, are added to the diet. The amount of P excreted in the manure and urine of pigs is equal to the amount of total P in the diet less the amount utilized and retained by the pig. Total P excretion would be reduced if phytate bound P could be made nutritionally available to the pig and additions of inorganic phosphorus to the diet were reduced.

The concept of using microbially derived phytase to improve phytate phosphorus utilization in non-ruminants was put forth many years ago (Nelson et al., 1971). However, the low yield and slow process of producing phytase from microbes such as *Aspergillus niger* made the technology too costly. More recently, through recombinant DNA technology, strains of *Aspergillus niger* have been developed that allow production of large, economical quantities of phytase for use in the feed industry. Commercial sources of feed grade phytase have recently been approved by the Food and Drug Administration and are available to the swine and poultry feeding industries.

Animal nutritionists in Holland and other northern European countries became very interested in investigating phytase after government mandates were implemented to reduce phosphorus (P) addition to soils from animal manure. This earlier work demonstrated that addition of phytase to low-P broiler or pig diets greatly enhanced phosphorus digestibility and substantially reduced P levels in the feces (Simons et al., 1990; Jongbloed et al., 1992). The percentage reduction in manure P content ranged from 25 to 45 % when compared to adequate P diets without phytase addition.

Recent studies have demonstrated that phytase supplementation of low-P pig diets can be effective under U.S. feeding conditions as well. For example, addition of phytase over a range of 0 to 500 U/kg to low P diets produced positive dose responses in growth performance, P digestibility, bone ash and bone strength in weanling pigs (Radcliffe and Kornegay, 1998; Table 6) and growing-finishing pigs (Harper et al., 1997; Table 7). Responses to these same traits were effected in a similar manner by increasing inorganic P level in diets without phytase. At the 500 U/kg phytase dose, growth and bone traits were restored to a level similar to the positive control diet containing elevated P. Excretion of P in the manure was reduced by a factor of 20% with the 500 U/kg phytase dose.

Table 6. Phytase and inorganic-P supplementation of weanling pig diets.[a]

| Diet | | Response trait | | |
|---|---|---|---|---|
| P[b] (%) | Phytase (U/kg)[b] | Weights gain (lb./day) | P digestibility (%) | Rib shear strength (N) |
| .35 | 0 | .80 | 21.5 | 442 |
| .35 | 167 | .90 | 28.3 | 488 |
| .35 | 333 | .92 | 34.3 | 500 |
| .35 | 500 | .96 | 35.4 | 580 |
| .35 | 0 | .80 | 21.5 | 442 |
| .40 | 0 | .88 | 32.0 | 523 |
| .45 | 0 | .97 | 39.1 | 627 |
| .50 | 0 | .98 | 37.1 | 702 |

[a] Data from Radcliffe and Kornegay, 1998.

[b] Significant linear effects of increasing phytase or phosphorus (P<.01) in all traits shown

Table 7. Phytase and inorganic-P supplementation of growing-finishing pig diets.[a]

| Diet | | Response trait | | |
|---|---|---|---|---|
| P[b,c] (%) | Phytase[b] (U/kg) | Weight gain (lb./day) | P digestibility (%) | Rib shear strength (kg) |
| .38G/.33F | 0 | 1.93 | 28.7 | 1495 |
| .38G/.33F | 167 | 2.02 | 32.6 | 1580 |
| .38G/.33F | 333 | 2.05 | 37.4 | 2000 |
| .38G/.33F | 500 | 2.06 | 41.3 | 1990 |
| .38G/.33F | 0 | 1.93 | 28.7 | 14.95 |
| .42G/.37F | 0 | 2.04 | 33.9 | 1620 |
| .46G/.41F | 0 | 2.06 | 39.5 | 1880 |

[a]Data from Harper et al., 1997.

[b]Linear effects of phytase (P<.01) and phosphorus (P<.01 to .08) on all traits shown.

[c]Phosphorus levels indicated for grower (G) and finisher (F) phases.

Because the dietary Ca:P ratio can have a significant impact on P availability, researchers have assessed impact of Ca: P ratio on efficacy of phytase. In finishing pigs, Liu et al. (1996) demonstrated that 500 U/kg of supplemental phytase was more effective in restoring growth and bone strength when Ca level was reduced to provide a Ca: P ratio of 1:1 than when the Ca: P ratio was 1.5:1. The results indicate that that maintaining the dietary Ca: total P ratio within a narrow range or near 1:1 is necessary for optimal phytase responses in pigs fed low-P diets. Subsequent studies indicate that phytase also releases some phytate bound calcium. Excessive addition of inorganic calcium to phytase supplemented diets may actually interfere with P utilization due to an excessively "wide" (greater than 1.3:1) dietary calcium to P ratio.

A final note on phytase concerns temperature stability. Like most enzymes, phytase is susceptible to heat degradation. Pelleting or other feed processing methods that involve temperatures above 60 degrees Celsius is likely to result in reduced phytase activity. Fortunately, technology and equipment that allows post-pellet application of phytase enzyme is available and effective. In these systems the phytase preparation is sprayed onto the feed pellets after they have been manufactured and cooled. Several commercial feed mills in the U.S. have installed spray-on enzyme application equipment for this purpose. For diets that are to be fed in meal or mash form with no heat treatment, phytase may simply be added at the mixer.

*Summary*

A significant portion of the N, P and other nutrients fed to pigs are excreted into the manure storage and handling system. Waste nutrients in swine manure storage can be considered an asset as nutrients for crop or forage production. However, keeping the total quantity of N, P and other manure nutrients at manageable levels is important so that storage capacity and land application area remains adequate for manure nutrient application plans.

Many of the current nutrition and feeding technologies intended to optimize pig performance and economic return over feed costs also have a positive impact on reducing excessive excretion of N, P and other nutrients into swine manure storage systems. These include minimization of feed waste, optimizing feed conversion efficiency, avoiding nutrient over-formulation, feeding for optimum rather than maximum performance, phase feeding and separate sex feeding, use of high quality protein supplements and crystalline amino acids, and finally, improvement of dietary P availability with supplementation of phytase. Some of these methods will have greater individual impact than other methods. When these methods are used collectively, a substantial reduction in nutrient excretion into the swine waste stream may be accomplished.

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# Managing the Dairy Feeding System to Minimize Manure Nutrients

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**Introduction**

Applying manure nutrients in excess of crop requirements increases the risk of nutrients leaking into surface and groundwater (Fox et al., 1998; Wang et al., 1999). Reducing nutrient excretion in dairy cattle involves two main areas: lowering the levels of nutrients fed (especially purchased nutrients) above animal requirements and increasing the overall farm management. Rations have typically included safety factors for many nutrients. These safety factors are included to minimize production risk due to not being able accurately predict animal requirements, and variation in composition of the ration delivered to each group of animals in each unique production situation. Increased knowledge about the supply and requirements for nutrients in ruminants coupled with improved analytical methodology for feeds and management of critical control points in delivering the formulated diet to the intended group of animals is allowing us to decrease these safety factors.

A major factor limiting the adoption of very low safety factors is the management level required on the farm. Management's role in decreasing nutrient excretion covers many areas. High levels of management are required throughout the entire feeding system. This includes silo management, adequate feed analysis to describe the feeds fed, feeding accuracy, feed bunk management, and other areas One of the most critical variables affecting nutrient accumulation on the farm and profitability is the quality and quantity of homegrown feeds

(Wang , 1999). Homegrown feed quality includes: harvesting at the correct stage of maturity and dry matter, storage management, and minimizing variation in the feed. Tylutki et. al. (1999) simulated the impact of observed dry matter and fiber variation with corn silage at harvest. Variation observed in this feed resulted in variations in income over feed costs greater than $40,000 and nitrogen excretion of 240 pounds per 100 cows annually.

In this paper, we summarize the prediction of the supply and requirements of phosphorus and nitrogen, and feeding management required to decrease nutrient excretion. We end with an example of how to implement recommended management practices, using a case-study farm that has been implementing them.

**Accurately meeting requirements for phosphorus**

***The first step is using accurate feed composition values in ration formulation. Typical*** phosphorus levels and normal ranges for many feedstuffs analyzed by DairyOne are found in Table 1. These levels can be quite different from 'book' values. As an example, NRC (1989) reports a P level of .22% for alfalfa hay early bloom. The average analyzed value is .26%, or 18% higher than the NRC value. This demonstrates the need for laboratory analysis of feeds used in ration formulation.

One form of phosphorus is bound to phytate. In ruminants, this is not a concern as the rumen produces high levels of the enzyme phytase. Estimates of phytate digestibility in the rumen are in excess of 99% (Morse et. al., 1992). Inorganic sources of P vary in their availability. They can be ranked (from highest to lowest availability) as: sodium phosphate, phosphoric acid, monocalcium phosphate, dicalcium phosphate, defluorinated phosphate, bone meal, and soft phosphates (NRC, 1989). As can be seen in Table 1, the high protein feeds (e.g. soybeans) are high in phosphorus.

***The next step is to accurately determine P required.*** Nutrient requirements are often expressed as dietary percentages. However, this only represents the concentration of a nutrient needed when the assumed amount of dry matter intake is consumed by the animal. As we move towards decreasing nutrient excretion, diets need to be formulated and evaluated based upon the grams of nutrient fed compared to the grams required. As an example, differences in diets containing .41% P versus .40% P may appear unimportant. When this difference is computed on an annual basis per 100 cows, this difference becomes 161 pounds of additional excreted P to manage. In addition, the concentration of a diet may appear higher or lower than expected due to differences in dry matter intake. As an example, a requirement of 100 grams of P for a cow consuming 55 pounds of dry matter is a .40% concentration required. At 40 pounds of dry matter intake, the concentration required increases to .55%.

Approximately 86% of the phosphorus in dairy cattle is in the skeleton and teeth (NRC, 1989). It is a key mineral in energy metabolism, and is an essential component of blood and other body fluid buffering. Phosphorus is absorbed in the small intestine. Absorption is dependant on the P source, level of intake, intestinal pH, animal age, and the amount of other minerals in the diet. If P is fed in adequate amounts, the calcium to phosphorus ratio does not seem to be a concern. There is little published information regarding the absorption efficiency of different feedstuffs, and phosphorus recycling increases the difficulty in obtaining these numbers (NRC, 1989).

Table 1. Average Phosphorus content of feeds (adapted from Chase, 1999).

| Feed | Mean | SD | Normal Range |
|---|---|---|---|
| Legume Hay | .26 | .06 | .21 - .32 |
| Legume Silage | .32 | .06 | .27 - .38 |
| Grass Hay | .24 | .08 | .16 - .32 |
| Grass Silage | .31 | .07 | .24 - .38 |
| Corn Silage | .23 | .03 | .2 - .36 |
| Bakery byproduct | .40 | .08 | .32 - .49 |
| Barley grain | .28 | .16 | .12 - .44 |
| Beet pulp | .10 | .03 | .06 - .13 |
| Blood meal | .20 | .16 | .05 - .39 |
| Brewers grain | .62 | .06 | .56 - .68 |
| Canola meal | 1.14 | .16 | .98 - 1.29 |
| Corn, ear | .30 | .05 | .26 - .35 |
| Corn, shelled | .32 | .11 | .2 - .43 |
| Corn germ meal | .71 | .54 | .17 - 1.25 |
| Corn gluten feed | .90 | .21 | .68 - 1.11 |
| Corn gluten meal | .77 | .41 | .37 - 1.18 |
| Cottonseed hulls | .21 | .08 | .13 - .29 |
| Cottonseed meal | .97 | .28 | .69 - 1.24 |
| Cottonseed, whole | .66 | .11 | .55 - .78 |
| Distillers grains | .82 | .12 | .71 - .94 |
| Feather meal | .28 | .06 | .22 - .33 |
| Fish meal | 3.39 | 1.14 | 2.25 - 4.53 |
| Hominy feed | .56 | .21 | .36 - .77 |
| Linseed meal | .92 | .11 | .81 - 1.03 |
| Meat meal | 4.35 | | |
| Meat and bone meal | 3.05 | .98 | 2.07 - 4.04 |
| Molasses | .68 | 1.20 | up to 1.88 |
| Oats | .39 | .06 | .32 - .45 |
| Soyhulls | .17 | .12 | .05 - .29 |
| Soybeans | .66 | .11 | .55 - .76 |
| Soybean meal, 48 | .68 | .11 | .57 - .79 |
| Wheat | .47 | .23 | .24 - .69 |
| Wheat bran | 1.03 | .31 | .72 - 1.34 |
| Wheat midds | .88 | .21 | .67 - 1.08 |

Post-absorption, large amounts of P are recycled through the salvia (NRC, 1989). Excess P is then excreted in the feces (Very little P is excreted through the urine.) (INRA, 1989). Preliminary results from INRA suggests that as P levels increase with increasing levels of concentrate feeding, P begins spilling into the urine (Agabriel, personnel communication, 1999).

Much research over the last several years has focused on the impact of phosphorus on reproductive efficiency of lactating cows (Satter and Wu, 1999). Satter and Wu (1999) summarized 13 trials where P levels were varied from .32 to .61% of the diet. No differences were found in any of the trials in days to first estrus, days open, services per conception, days to first breeding, or pregnancy rate. Satter and Wu (1999) also summarized the data from several trials that varied the P level to determine differences in milk production. Again, as long as the grams of P required daily were met, no differences were seen in milk production.

In an attempt to improve accuracy in predicting dietary requirements, the Cornell Net Carbohydrate and Protein System version 4.0 (CNCPSv4.0) calculates the phosphorus (and the other macro-minerals) requirements for cattle using the INRA (1989) system. Table 2 lists the equations used for various classes of cattle and Table 3 shows example calculations based on these equations. The INRA system was chosen for macro-mineral calculations due to its factorial approach. This system describes net macro-mineral requirements by physiological function (maintenance, lactation, growth, and pregnancy). The maintenance requirements are further partitioned into endogenous fecal and urinary losses. Varying transfer coefficients (based upon body weight or physiological state) are then applied to the net requirements to calculate dietary requirements. The INRA system utilizes a Total Absorption Coefficient (TAC) to convert net P required to dietary P required. The TAC is a combination of absorption efficiency as well as P digestibility.

The mineral section of the CNCPSv4.0 can be used to evaluate mineral balances, calculate macro-mineral excretion, and optimize mineral utilization within groups. At the herd level, the mineral section predicts herd phosphorous and potassium excretion, efficiency of mineral use (product/input), and a mass nutrient balance for the feeding program.

Table 2. Equations used to calculate Phosphorus requirements (gms/d) for dairy cattle (INRA, 1989)[1].

| | Heifer | Dry cow | Lactating Cow |
|---|---|---|---|
| Maintenance | | | |
| Fecal | (23 * SBW) / 1000 | (23 * SBW) / 1000 | ((22 + (0.2 * Milk)) * SBW) / 1000 |
| Urinary | (2 * SBW) / 1000 | (2 * SBW) / 1000 | (2 * SBW) / 1000 |
| Growth | (7 * SWG) | (7 * ADG) | (7 * ADG) |
| Pregnancy | If Days Pregnant > 187 Then Pregnancy Requirement = 4 | | |
| Lactation | | | (0.9 * Milk) |
| Total Absorption Coefficient | SBW < 150, 80%<br>SBW < 250, 75%<br>SBW < 350, 65%<br>SBW > 350, 55% | 57.5% | 57.5% |

[1]Where: SBW = shrunk body weight, kg; Milk = milk production, kg/d; SWG = shrunk weight gain, kg/d; ADG = average daily gain, kg

Table 3. Phosphorus requirements (gms/d) of various classes of cattle calculated using the equations in Table 2 as applied in the CNCPS v 4.0.

| | Heifer | Dry Cow | Lactating Cows | | |
|---|---|---|---|---|---|
| Body weight, lb | 750 | 1400 | 1350 | 1350 | 1350 |
| Milk production, lb/d | 0 | 0 | 60 | 80 | 100 |
| Gain, lb/d | 2 | 0 | 0 | 0 | 0 |
| Days pregnant | 0 | 200 | 0 | 0 | 0 |
| Expected dry matter intake, lb | 15 | 28 | 42 | 48 | 54 |
| Maintenance requirement, g/d | | | | | |
| Fecal | 7.8 | 14.6 | 16.8 | 17.9 | 19.0 |
| Urinary | 0.7 | 1.3 | 1.2 | 1.2 | 1.2 |
| Growth requirement, g/d | 6.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Pregnancy requirement, g/d | 0.0 | 4.0 | 0.0 | 0.0 | 0.0 |
| Lactation requirement, g/d | 0.0 | 0.0 | 24.5 | 32.7 | 40.9 |
| Total Absorption Coefficient | 65.0 | 57.5 | 57.5 | 57.5 | 57.5 |
| Total requirement, g/d | 22.9 | 34.6 | 74.0 | 90.2 | 106.3 |
| Dietary concentration, % of DM | 0.34 | 0.27 | 0.39 | 0.41 | 0.43 |

Satter and Wu (1999) report survey data showing the average lactating dairy cow is fed a diet containing .48% P. As seen in Table 3, this level is in excess of that required to produce 100 pounds of milk. Figure 1 represents the relationship between three P dietary concentrations to daily milk production and the percent of the 1989 Dairy NRC recommendations. It is evident in this Figure that a diet containing .55% P results in severe P over-feeding over this range of milk production. The .45% level also results in excesses over most of this range.

**Meeting requirements for Nitrogen**

Ration formulation/evaluation systems using the CNCPS model (CNCPSv4, CPM Dairy, DALEX) to more accurately match sources of N with animal requirements partition protein supply into five pools:

1. A fraction: rapidly available non-protein nitrogen
2. B1: rapidly available true protein
3. B2: intermediate ruminal degradation rate
4. B3: slowly degradable
5. C: indigestible, bound to lignin.

These pools are calculated from feed analysis as shown in Table 4.

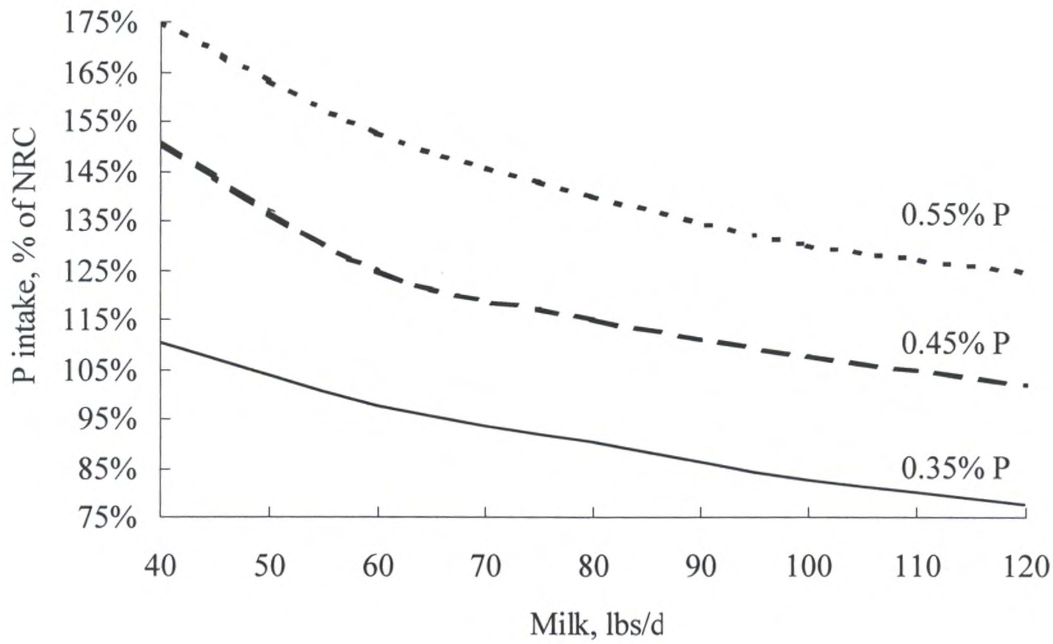


Figure 1. The relationship between daily phosphorus requirement and three levels of intake to milk production (adapted from Chase, 1999).

Table 4. CNCPS protein pools from feed analysis (Sniffen et. al., 1992).

| Analytical result and the pool it contains | Protein Pool A[1] | B1[2] | B2[3] | B3[4] | C[5] |
|---|---|---|---|---|---|
| Crude Protein | X | X | X | X | X |
| Soluble Protein | X | X | | | |
| N-bound to NDF | | | | X | X |
| N-bound to lignin | | | | | X |

[1] A protein = Soluble Protein - NPN
[2] B1 protein = Soluble Protein – A protein
[3] B2 protein = 100 – A protein – B1 protein – B3 protein – C protein
[4] B3 protein = N-bound to NDF (NDICP) – C protein
[5] C protein = N-bound to lignin

The purpose of these pools is to predict dietary N required to maximize rumen microbial growth, and the amount needed to supplement microbial protein to meet animal metabolizable protein requirements. This is accomplished by predicting microbial growth from ruminally-degraded carbohydrates, based on their digestion and passage rates. Then metabolizable protein and amino acids are predicted from intestinally available microbial protein. In order to meet the amino acid demand of high producing cows, feeds are included as needed that have a low ruminal protein degradability to supply feed amino acids to the small intestine to supplement the bacterial amino acids.

Nitrogen requirements need to be viewed as bacterial requirements and animal requirements. In ruminant nutrition, the objective is to maximize rumen microbial growth to supply the cow with energy and protein and then supplement the microbial supply with feed. Properly matching microbial requirements with animal requirements allows for less total protein to be fed resulting in lower nitrogen excretion.

Microbial nitrogen requirements are dependant upon the type of carbohydrate being fermented. Two primary pools of bacteria ferment feed in the rumen: those that ferment NSC, and those that ferment fiber. There is another pool that ferments amino acids; however they represent a small proportion of the total microbial population. Microbes that ferment NSC prefer peptides (B1 and some B2 protein) as their nitrogen source. Adequate peptide levels act as a growth stimulant. In the absence of peptides, they can meet their nitrogen requirements with ammonia (A protein). Fiber fermenting microbes rely strictly on ammonia as their nitrogen source. CNCPS v4 predicts that inadequate ruminal ammonia decreases microbial protein and reduces fiber digestibility (Tedeschi et al., 2000). Excess ruminal ammonia is absorbed through the rumen wall. Some is recycled back to the rumen; the remaining is excreted in urine and milk.

The animal requires protein for maintenance (tissue turnover, scurf, and metabolic fecal), pregnancy, growth, and lactation. Protein supply in excess of requirement is excreted primarily in the urine. This excretion requires energy to convert the excess ammonia to urea, resulting in decreased animal performance (growth or lactation).

Nitrogen excretion in CNCPSv4.0 is predicted by partitioning N excretion from the predicted N balance into feces and urine:

1. Fecal nitrogen (gms/d) = (FFN + BFN + MFN)
2. Urinary nitrogen (gms/d) = (BEN + BNA + NEU + TN)

Where:

- FFN = fecal nitrogen from indigestible feed;
- BFN = bacterial fecal nitrogen, primarily bacterial cell wall;
- MFN = metabolic fecal nitrogen;
- BEN = excess bacterial nitrogen;
- BNA = bacterial nucleic acids;
- NEU = metabolizable nitrogen supply – net nitrogen use (i.e., inefficiency of use); and
- TN = degraded tissue nitrogen.

## Minimizing nutrient excretion through ration and management strategies

### *General principles*

Methods that can be used to minimize nutrient excretion include short-term (can be implemented within days or weeks) and longer-term (require one or more crop years to implement). Implementation of these changes must be done so that milk production, growth, reproduction, and animal health are not compromised. These methods revolve around two areas: 1) decreasing N and P inputs brought on the farm by more accurately formulating rations, and 2) improving the efficiency of nutrient utilization through improved feed and crop management strategies.

*Short-term methods*

1. Use more accurate ration formulation to decrease P fed to NRC or INRA requirements where possible. This will decrease P excretion and ration cost, as P is an expensive nutrient. Even though P levels are decreased to recommended levels, many groups will be overfed P due to the P levels in the forages and concentrates fed to meet energy and protein requirements.
2. Use more accurate ration formulation to decrease N fed to rumen and animal requirements. To accomplish this, feed carbohydrate and protein fractions must be known and combined optimally to maximize rumen microbial growth. Programs using the CNCPS such as CPM-Dairy, DALEX, and CNCPSv4.0 can be used to accomplish this.
3. Modify grouping strategies to improve accuracy of ration formulation. Logical alternative grouping strategies need to be investigated for each farm. Through proper grouping, it may be possible to reduce N and P and ration cost while maintaining milk production and body condition replenishment goals. As Figures 1 and 2 show, the nutritional needs of lower producing cows can be met with lower ration N (figure 2) and P (figure 1). A cow producing 120 pounds of milk may need an 18% crude protein diet while a cow producing 60 pounds only requires 14% crude protein. These values may even be lower if ration formulation maximizes ruminal microbial production and N supplementation by matching feed carbohydrate and protein fractions.

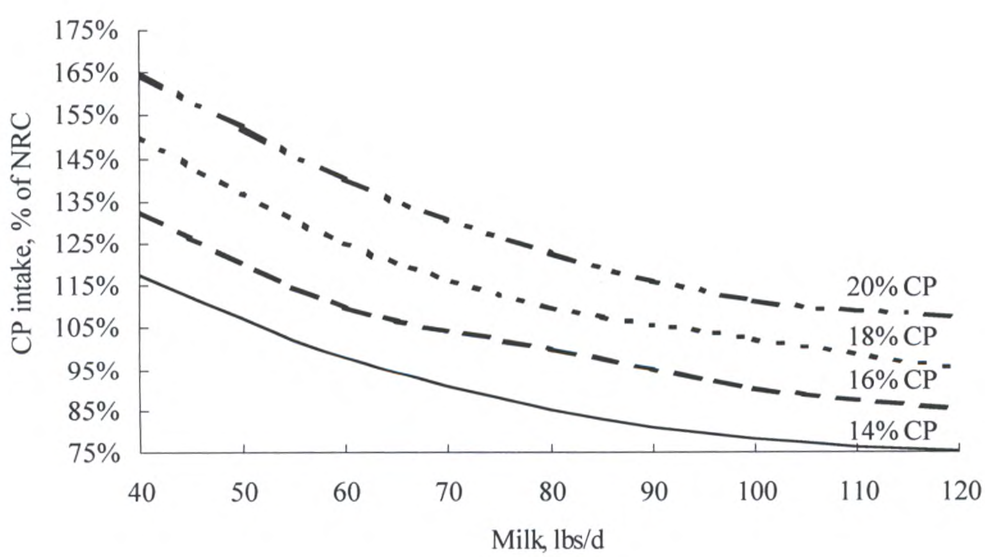


Figure 2. The relationship between daily crude protein requirement and three levels of intake to milk production (adapted from Chase, 1999).

4. Obtain Feed analysis as needed to accurately represent the feeds being fed. In order to decrease nutrient excretion, ration safety-factors need to be reduced in addition to matching protein and carbohydrate feed fractions. To accomplish this, a routine feed analysis protocol needs to be followed. A farm specific feed database should be developed that includes forages as well as concentrates. As is seen in Table 1, the laboratory-analyzed values for P vary considerably. Similarly, protein and NDF in forages (Tylutki et. al., 1999) and concentrates (Kertz, 1998) can vary greatly.
5. Determine dry matters as needed to account for individual feed variation. Tylutki et. al. (1999) simulated the impact of NDF and dry matter variation in corn silage using the average values and standard deviations as sampled on a 500-cow farm. The impact of improper forage analysis and lack of control over the dry matters at feeding resulted in a large annual variation in nutrient excretion (242 pounds N excretion and 64 pounds of P excretion), feed inventory required (61 tons of corn silage), and income over feed costs ($21,792) per 100 cows annually. The majority of variation was due to changes in the corn silage dry matter. Our current recommendation is to determine dry matters of all silages at least twice weekly (more often if wide fluctuations in intakes are observed)., then adjust as fed formulas as needed.
6. Improve feeding accuracy. Most farms assume that what is being mixed and fed is what is supposed to be fed. In many cases, this is not a valid assumption. Tylutki et. al. (1999) evaluated the impact of varying feeding accuracy ± 3%. The addition of feeding error increased annual variation in P excretion (18 pounds), corn silage inventory (9 tons), and income over feed costs ($19,148) per 100 cows annually. Feeding accuracy needs to be tracked to identify sources of variation, as well as to manage inventory. Commercial software and hardware is available that can be linked to the mixer scales to track this information.
7. Monitor dry matter intake to improve accuracy of ration formulation and animal performance.
    a. Track intakes. Proper ration formulation relies on many inputs from the farm, including animal body weight, feed inventory, and actual dry matter intakes. To decrease nutrient excretion, actual dry matter intakes must be known in order to ensure adequate grams of nutrient are provided. The data can also be used as a diagnostic tool. For example "our close-up dry cows are consuming 21 pounds of dry matter, and we are experiencing high levels of post-calving metabolic disease". Are they related? If so, why are we only achieving 21 pounds of intake?"
    b. Improve feed-bunk management to increase intake, and consistency of animal performance. This includes: daily cleaning, pushing feed up several times daily, and all other good management practices. More consistent performance allows the ration to be more accurately formulated for milk production level.
    c. Make ration changes to improve accuracy. By increasing the dry matter intake 5%, ration nutrient concentrations can be lowered. Chase (1999) calculated that by increasing intake 5%, it is possible to decrease diet crude protein about one percentage unit to achieve the same pounds of crude protein intake. This would result in higher inclusion rates of homegrown feeds, thus decreasing purchased nutrients.

8. Control the level of refusals. Most farms' feed refusals from the lactating herd are fed to replacement heifers. From a bio-security viewpoint, this is not a good practice. From a nutrient excretion viewpoint, this is an expensive practice. Mineral and protein levels that are adequate for lactating cows do not fit most replacement heifer groups. The amount of refusals must be at a level that is consistent with farm management to achieve maximum dry matter intake, however extremely high levels need to be avoided.
9. Use the proper 'tools' to track the impact of changes in ration formulation and feeding management. These 'tools' include:
    a. Milk production,
    b. Milk components,
    c. MUN's,
    d. Manure analysis. Manure needs to be analyzed two ways. The first is to determine what is not being digested by the cow. If large fiber particles or corn grain is evident, rations and feeding management need to be addressed. The second is to analyze manure that is being spread. As N and P levels are decreased in the rations, the levels found in manure will decrease as well. Most of the change in nitrogen will be found in the ammonia N pool. Tracking this analysis over time will provide an index of how consistent nutrient excretion is.

*Long-term methods*

1. Improve silo management. Silo capacity and management can play a significant role in decreasing nutrient excretion.
    a. Have adequate capacity to store separately different crop types and quality. Many farms in the Northeast have varying soil types that are best suited for different crops. The storage system must be able to handle each crop type individually (e.g., corn silage, grass silage, alfalfa silage, and different qualities of each). This will allow the nutritionist to better match protein and carbohydrate pools with specific groups of animals. An example of this would be to feed high quality alfalfa silage and corn silage to the high producing cows and feed the grass silage to lower producing cows and heifers.
    b. Minimize storage losses. During expansion, most farms will over-fill bunk silos for several years until additional capacity can be built. This over-filling results in poorer management of the bunk silo. Tylutki et. al. (1997) and Kilcer (1997) calculated the feed requirements, storage capacity, and storage losses for a 500-cow farm. They found that when the height of the corn silage pile was increased, dry matter storage losses increased (losses were calculated to be in excess of 35%) because of reduced ability to properly pack the silo during filling. By decreasing storage losses, inventory would have been high enough to allow higher home grown forage levels to be fed, thus decreasing purchased nutrients.
2. Match cows/crops/soils. Alfalfa and corn are not always the best choices for dairy producers due to soil constraints. The farms nutritionist and field crops consultant

need to work together to determine what is the best mix of crops to grow and how they can be fed to maximize production and minimize nutrient excretion.

3. Increase the amount of homegrown feeds in the ration. Increasing the amount of homegrown feeds in the ration decreases the amount of purchased nutrients. To accomplish this, homegrown feeds need to be of high quality to maintain or improve production and animal health.
    a. Impact of Forage quality. To increase the amount of forages in the rations, forage quality must be high. Maximum intake from forages can be expected when alfalfa is 40% NDF, grasses are 55%, and corn silage is 40-45% (Chase, personnel communication). A cow is limited in forage NDF intake to (1 to 1.1% of bodyweight (Mertens, 1994). As an example, a 1400 pound cow at 1.1% NDF capacity can consume 28 pounds of dry matter from grass at 55% NDF but only 24 pounds at 65% NDF. This four pounds of dry matter difference would have to be made up with purchased feeds.
    b. Impact of Grains. Homegrown grains (protein sources) decrease the amount of purchased nutrients. Most dairy farms do not have an adequate land base to produce their own grain; therefore, they should maximize forage quality and choose purchased concentrates that accurately supplement their forages.
4. Add more land or export nutrients. After all of these areas are addressed, nutrient excretion will still be in excess of crop requirements on most dairy farms. Increasing the land base to increase homegrown feed production and being able to utilize the manure N and P for crop production will be required. Chase (personnel communication, 1999) calculated the required land base for the 500-cow farm described by Tylutki et. al. (1997) to spread manure based on P recommendations. The resulting required land base was three times the current land base.

*Case study*

McMahon's EZ Acres is a 500-cow dairy farm located in Homer, NY. It is owned by two brothers in partnership. Four years ago, the herd was moved into a new facility from four old tie-stall barns. Since then, milk production has increased (milked 2x with no rBST) and herd health has improved. This change has been the result of a step-wise consolidation. In 1992, a bunk silo complex with a commodity building was built. This eliminated the use of numerous tower silos. Barns were then setup as production groups and a TMR was delivered twice daily. In 1996, a transition calf barn and a heifer barn were added at the site of the new complex. In 1998, the farm added milk metering and cow identification to the parlor. The farm has been a cooperator with this project since 1997 (Tylutki and Fox, 1998).

In 1997, baseline data was collected and an initial analysis of the herd and cropping system was conducted (Tylutki and Fox, 1997; Bannon and Klausner, 1997; Kilcer, 1997). It was concluded from this analysis that increased bunk silo capacity and improved bunk silo management were required. In addition, an increase in acreage of intensively managed grasses would allow for a higher proportion of homegrown feeds in the rations. The farm has been adopting these recommendations since then.

Since April 1999, rations for all groups have been formulated with CNCPSv4.0 by the farm's herd nutrition consultant. Most of the short and long-term strategies to lower N and P excretion described in this paper have been implemented by the consultant and farm management. These include:

*Short-term methods implemented*

1. Phosphorus levels in all groups have been decreased to CNCPSv4.0 computed requirements. Lactating cows currently are consuming a diet with .41% P (1 gram in excess). Non-lactating animals range in P excess from 2 to 10 grams with low levels of supplemental phosphorus used.
2. Protein levels have been lowered and are matched with carbohydrate feed fractions to optimize rumen microbial growth as computed by the CNCPS model. Lactating cow diets currently contain only 40 grams of metabolizable protein in excess of requirement (1% excess).
3. Lactating Cows are currently grouped by level of production. Further refinements in the grouping strategies are being explored.
4. Intensive feed analysis is being conducted as part of our research project on the farm. The project is designed to describe the variation in homegrown and purchased feeds and then how to account for this variation in ration formulation and daily feeding management practices. Daily samples of all forages are being collected and analyzed for DM, NDF, and crude protein. Weekly composites are analyzed for all protein and carbohydrate and protein fractions. Results of the weekly composites are used for ration formulation. Tables 5 and 6 show the averages and standard deviations of feed analysis by feed type from the case-study farm. These samples have been collected over the past 18 months. The SD column is the standard deviation and is a statistical measure of the variability around the average. The higher the standard deviation, the greater the variation. Variation in all feeds has been higher than anticipated. Another measure of variation is the coefficient of variation (CV). It is calculated as the standard deviation divided by the average. Calculating the CV for several of the feeds in Table 5, we find a range of 6.5 to 25.0% for phosphorus with homegrown feeds showing the highest variation and 2.7 to 33.2% for crude protein. Methods to account for this variation in ration formulation are being examined.
5. Dry matters of silages are determined at least twice weekly. If a large change is observed either in refusals or in bunk appearance, dry matters will be determined daily until they are consistent. Dry matters are charted by the feeder. The chart is used to look for patterns in changes. If a sample is greater than five units different from the last sample, another sample is taken and analyzed that day. The feeds in Table 6 with "at feeding" as part of their name illustrate the wide range in dry matters observed and the need to track dry matters on a regular basis. The corn silage standard deviation shows that the dry matter ranged from 18.2 to 43.4% as it was fed from the bunk silo (the average ± 2 standard deviations).

Table 5. Selected feed analysis averages and standard deviations from the case study farm (1999 data).

| | Dry matter | | Crude Protein | | Soluble Protein | | NDF | | Fat | | Phos. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. | SD | Avg. | SD | Avg. | SD | Avg. | SD | Avg. | SD | Avg. | SD | n |
| Corn meal | 89.0% | 1.5% | 8.8% | .6% | 21.7% | 14.5% | 11.6% | 1.7% | 4.2% | .2% | .28% | .02% | 17 |
| Hi Moist Shell Corn | 71.1% | 5.7% | 8.2% | 1.0% | 26.9% | 9.6% | 10.4% | 1.2% | 4.1% | .3% | .31% | .02% | 7 |
| Corn Silage[a] | | | 7.6% | .5% | 58.7% | 4.6% | 50.0% | 2.8% | 3.8% | 1.1% | .20% | .03% | 27 |
| Grass hay | 89.3% | 8.4% | 7.5% | 2.5% | 23.0% | 9.4% | 68.3% | 3.8% | 2.5% | .4% | .20% | .05% | 15 |
| Grass Silage[a] | | | 20.5% | 3.7% | 61.7% | 9.1% | 55.0% | 8.4% | 6.9% | 1.2% | .39% | .06% | 3 |
| MMG silage[a] | | | 17.4% | 3.1% | 55.6% | 11.8% | 53.4% | 7.7% | 5.2% | .7% | .39% | .05% | 23 |
| MML Silage[a] | | | 20.5% | 2.9% | 58.7% | 13.1% | 51.9% | 6.4% | 4.4% | 1.2% | .37% | .04% | 6 |
| Whole cotton | 87.3% | 3.7% | 24.6% | 2.0% | 24.9% | 6.9% | 54.7% | 6.2% | 19.7% | 3.4% | .65% | .08% | 17 |
| Soy 48 | 88.9% | .7% | 53.5% | 1.5% | 25.3% | 9.4% | 11.7% | 2.0% | 3.9% | 8.1% | .74% | .06% | 15 |

[a]The forage results are from the composites of daily samples. Within each sample, there are three to seven individual samples. Dry matter values for home grown forages are summarized in table 6.

Table 6. Homegrown forage dry matter and NDF averages and standard deviations from the case-study farm.

| | | Dry Matter | | NDF | |
|---|---|---|---|---|---|
| Feed Type | N | Avg. | SD | Avg. | SD |
| Corn silage at harvest[a] | 1057 | 26.2% | 3.5% | 50.0% | 16.0% |
| Corn silage at feeding[a] | 376 | 30.8% | 6.3% | 49.6% | 7.6% |
| Grass haycrop at harvest[b] | 29 | 26.0% | 4.2% | 58.4% | 7.9% |
| Grass haycrop at feeding[a] | 141 | 33.4% | 12.7% | 57.5% | 6.3% |
| Legume haycrop at harvest[b] | 9 | 21.8% | 8.3% | 49.8% | 19.4% |
| Legume haycrop at feeding[a] | 63 | 46.7% | 13.1% | 42.0% | 7.7% |
| Mixed haycrop at feeding[a] | 77 | 41.7% | 27.2% | 44.1% | 14.8% |

[a]1998 forages.
[b]1999 forages.

6. In 1998, the farm began using EZ Feed. EZ Feed is a commercial software package that interacts with the scale head on the mixer. It records the actual pounds of each feed added to the mix and time spent loading and unloading each feed/batch. Daily reports can be printed that list for each feed the formulated and actual pounds fed by batch. The use of EZ Feed resulted in the farm changing feeders to improve accuracy. It was calculated that greater than $20,000 was being lost due to over-feeding. The current feeder typically is within .3% of expected amounts (<150 pounds total over-feeding with approximately 60,000 pounds fed daily).
7. EZ Feed is also used to track dry matter intakes of each pen. Feed refusals from the lactating and dry cows are loaded into the mixer by pen and recorded.
   a. Intakes for the lactating cows are charted by the feeder daily. Charts are used to compare expected intakes with observed and intake versus milk production.

Intakes of dry cows are analyzed weekly. It was discovered in April that far-off and close-up dry cows were consuming below expected levels. Rations were adjusted for both groups and the far-off dry cows were moved to another location. Intakes of both groups now are 5% greater than expected values.

b. A feeder checklist was developed. The feeder walks each feed bunk each morning prior to feeding and scores the bunk. Feeding level is adjusted based on changes in cow numbers and this feed bunk score. The farm feeds once daily and pushes feed up every two hours.
c. Ration formulas are reviewed and adjustments made as needed. Time between ration formula adjustments ranges from weekly to monthly depending on inventory and trends in dry matter intake. As an example, weather changes resulted in observed intakes that were 12-15% greater than trend for two weeks. During this time, ration formulas were adjusted based on the higher intakes. When intakes returned to near expected levels, ration formulas were again adjusted based on intake.

8. Given the accuracy of the current feeder, refusal goals have been lowered. A current goal for lactating and close-up dry cows is 3-5% refusal.
9. In August 1999, a milk sampling method was implemented allowing for group composites to be taken weekly. These weekly samples are analyzed for fat, protein, SCC, and MUN. Fat is charted weekly by group. Each is evaluated weekly for changes compared to the trend. Bulk tank milk production is calculated daily and evaluated for trends, and 150-day milk by lactation group is calculated and charted.
10. Since December 1, 1999, weekly manure samples have been collected and analyzed from the lactating cows. Total nitrogen has averaged 40 pounds per 1000 gallons and phosphate equivalent has ranged from 9 to 11 pounds per 1000 gallons.

*Long-term methods*

1. During the 1999 cropping season, several changes in crop harvest and storage were made. Hay crop silage was stored with grass in one bunk silo, and alfalfa in another; in previous years, they were stored in either bunk by cutting: all first cutting in one bunk, second in another, etc. regardless of hay type. This allowed each forage to be harvested at desired dry matter levels. To accomplish this, a driveway and apron had to be constructed behind the bunks. An unexpected benefit of this was discovered during corn harvest. There are no back walls on the bunks and historically, a steep slope was made while filling. This resulted in poor packing and an impossible slope to keep covered. With the new apron, the corn bunk could be extended and a slope maintained for packing that has allowed for adequate covering. Four 12-foot bags were also filled with corn silage in order to decrease bunk silo height. In 1998, the bunk was measured at 26 feet tall; in 1999, it is 13 feet tall.
2. The farm has been working with their agronomist to increase grass production on the poorer, more erodable hillside soils and maximize corn silage and alfalfa yield on the valley soils. The farm has gone from zero grass acres in 1996 to greater than 225 in 1999.
3. In November 1999, the farm began moving towards higher levels of forage in the diet. The highest level achieved in the lactating cow diets was 48%, a level never achieved on

this farm before. Further, increases in these levels were planned; however given the current low inventory of hay silages they were decreased.

4. The land base has increased greater than 15% since 1997. As more land becomes available, it will either be rented or purchased.

**Conclusions**

Nutrient excretion is affected primarily by four factors: feed quality (homegrown and purchased), quantities of homegrown feeds, ration formulation, and ration delivery. Farm management directly controls three out of these four with some control over ration formulation. Homegrown feeds (quantity and quality) are the most important factors. Increasing the quantity and quality of homegrown feeds allows for higher inclusion levels during ration formulation. In cases such as phosphorus, there is a gram for gram replacement opportunity (increase homegrown P one gram, reduce purchased P one gram).

Many of the steps discussed in this paper revolve around decreasing the safety factors used in rations. Removing these safety factors requires high levels of farm management to decrease the risk of production fluctuations. If large levels of variation are present in forages, large variations in milk production will be observed. Avoiding these fluctuations requires that a forage sampling and dry matter determination protocol be developed and followed.

Accomplishing a reduction in nutrient excretion requires a team effort including the farm's nutritionist, crop consultant, management, and employees. This requires a Total Quality Management approach where all concerned share a vision for the farm. This includes sharing the farms financial and environmental goals with all parties so that the farm can meet its goals and is sustainable.

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## Session 7

# Fate of Land-Applied Nutrients and Pathogens

# Nutrient and Pathogen Transport in the Watershed

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Biographies for most speakers are in alphabetical order after the last paper.

### Introduction

Many of the issues associated with phosphorus (P), nitrogen (N), and pathogens in the environment – potential sources, problems, impacts, and management – have been addressed in the previous papers. However, a major issue facing watershed planners today is how land use at the management scale (i.e., fields or farms) relates to the quantity and quality of watershed outflow. In fact, the *transport* processes within a watershed are what tie management to watershed outflow. Under humid-climate conditions, the dominant hydrologic transport processes result in relatively well-defined areas of the watershed, sometimes of limited areal extent, contributing much of the nonpoint-source sediment, P, N, and possibly pathogens, to watershed outflow. So from the perspective of management, it is critical that we develop concepts, sampling protocols, and modeling tools to define, delineate, and assess the impacts of what we will term *critical source-areas* (CSAs). These are the watershed areas having the highest priority for control, treatment, or remediation.

### Background

The importance of the source-area concept in developing effective approaches to water quality management has generally been only recently accepted. There are, however, a limited number of earlier references to this need. For instance, Dunne (1978), one of the original field-based investigators of the variable-source-area runoff generation process, stated, "The transport of fertilizers, herbicides, or animal wastes, for example, can be highly dependent upon where the material is placed in relation to the runoff source areas." – note his specific use of the terms *transport* and *source areas*. In a study in Vermont, Kunkle (as referenced in Betson and Ardis, 1978) concluded that, "...because of the runoff processes involved, upland contributions of bacteria to streams were small compared to contributions from land surfaces near channels, the channel itself, or direct inputs." Here, there are more indirect, but still obvious, references to *transport* and *source areas*. Nonetheless, this has not historically been a prevalent view.

Relevant to a phrase within the topic of this meeting, *Managing Nutrients...,* Shuyler (1994) stated, "Nutrient management should reduce soluble nutrient transport and (yet) provide enough nutrients to produce a realistic crop yield." When concerned with the ...*Animal Agriculture* part of the meeting title though, as well as the session in which this paper appears, *Fate of Land-Applied Nutrients and Pathogens*, we must recognize that nutrient management (as well as that of pathogens) sometimes takes on aspects of nutrient disposal (via animal wastes), when, because of large animal numbers, manure must be applied to the land surface such that nutrients contained therein are in excess of crop needs. Under these conditions, it is critical that we have the capability to predict nutrient and pathogen *transport* within and from a watershed, because the transport processes are what move these components through the watershed to their point of impact, or *fate*. Only when we consider a particular point of impact does the subject of transport become important – if there is no defined point of impact, or concern with *fate*, the sources of N, P, or pathogens might be considered to be relatively benign.

Development of a comprehensive nutrient and pathogen management strategy – one that encompasses the beneficial use of both nutrients (to meet crop needs), as well as a disposal component (when nutrients are in excess of crop needs or when pathogens occur on the land surface) – must address downgradient water quality impacts. A management strategy that addresses both use and disposal should be capable of integrating effects at the local scale where the particular management is implemented (i.e., the field), with the scale of the logical management unit (i.e., the farm), and finally with the larger scale at which results of the strategy are sampled and evaluated (i.e., the watershed). A management strategy developed in this way must accommodate the concept of transport, as well as its interactions with and controls on CSAs.

**Pathways of transport**

The singlemost important factor necessary to define transport pathways and CSAs is knowledge of water movement within the watershed, i.e., the hydrologic cycle. This is because moving water can translocate contaminants from their source-areas of application (typically on or within the soil zone), to or through zones of reaction and sinks within the watershed (in either the surface or subsurface), and finally to positions where they are removed from the watershed (generally streamflow but possibly via ground water). To determine flow components of the hydrologic cycle relevant to the problem of nutrient and pathogen management, we must first define the dominant interactions between these components and the natural flow system. The important nutrients from animal agriculture that are transported by a watershed's flow system to affect downgradient water quality are N and P. And finally, transport of pathogens from animal wastes applied to the land surface is a related concern.

Hydrologic controls on the transport of N and P within a watershed are different – in some ways they are opposed. In the case of P (and also pathogens), surface runoff, with its associated water-borne sediment, is the primary flow component of concern. With reference to P movement, there is also some concern with potential for subsurface transport. However, this route is considered to be of importance only in sandy or well-drained (highly permeable) soils having high water tables, or under conditions when soils are artificially drained. There is also a concern with soils having preferential flow pathways (i.e., cracks, wormholes, etc.), but again, there must be a high water table or artificial drainage involved to provide a connection to the stream. In the case of N transport, the concern is usually with nitrate ($NO_3$), a soluble species. Here, the subsurface flow system is of primary importance since $NO_3$ is generally moved into the subsurface by infiltrating water and ultimately exported from the watershed via subsurface flow.

To confuse the issue further though, all flow components within the hydrologic cycle are closely connected under the humid-climate upland watershed conditions being considered here. Rainfall, soil moisture, evapotranspiration, ground water recharge, surface runoff, and ground water discharge to the stream all respond at the same time scales, both event-based and seasonal. Finally, both surface and subsurface waters are important within and from these watersheds. The rural population of the Northeast relies almost entirely on ground water for water supply, so effects of nutrients (especially $NO_3$) on ground water quality is of concern. This same ground water is also the dominant source of streamflow, up to 70-80% of annual flow (Gburek et al., 1986). So the subsurface-derived flow, combined with surface runoff, provides the water for the larger downgradient rivers, impoundments, and estuaries important to fisheries, recreation, and water supply. Thus, development of management strategies to protect surface and ground water quality implies quantification of disparate but interactive hydrologic flow components and corresponding delineation of CSAs controlling losses of both nutrients and pathogens.

### Watershed hydrology – Response verses flowpaths

Even though there is an obvious need to define flowpath controls on contaminant transport through a watershed, our present views of hydrology, and consequently of how contaminants move within the watershed context, remain slanted by tradition. Research into watershed hydrology was originally founded on the concept of quantifying watershed-scale response to inputs – when rain occurs, the watershed produces a storm hydrograph; when a well is pumped, the ground water table drops. Because water quality was not then a concern, early hydrologists gave little or no consideration to pathways of water movement when attempting to quantify these responses.

Our concern with water quality beginning in the late 1960's required an alternative view; however, this view was not immediately embraced. Quantifying contaminant transport requires knowledge of pathways of water movement, not simply watershed response. We must specify where within the watershed contaminants are introduced, what CSAs they move through and how fast, and finally where they exit the watershed – all controlled by *transport*.

Thus, we must understand and define the transport processes and their controls on flowpath geometry linking all points of the watershed land surface to the watershed outlet, through both the surface and subsurface systems.

### A hydrologic basis for nutrient and pathogen transport

The transport and CSA aspects of strategies for nutrient and pathogen management can be developed within the context of dominant characteristics of northeastern upland watershed hydrology – variable-source-area watershed response as it controls surface runoff generation and its related contaminant transport, and bedrock layering and fracturing as it controls ground water flow and related contaminant transport within shallow aquifers. These strategies must also address effects of the riparian zone, and describe relevant interactions between all flow components at the watershed scale.

At the most basic level, the intersection of surface runoff and ground water recharge source-areas with areas of fertilizer or animal waste application over the landscape is what creates the initial CSAs controlling loss of P, N, and pathogens from a watershed. The situation may become more complicated though, when pathways of flow (transport) from these CSAs are considered; the contaminants may undergo transformations downgradient that alter their concentration and/or mass by dilution, reaction, or sink types of processes, adding an additional control on contaminant export.

### Surface runoff and phosphorus/pathogen transport

Surface runoff, the primary vehicle for P and pathogen transport, is the direct result of rainfall impacting the land surface. Generation of surface runoff was traditionally thought to be a soil-controlled phenomenon occurring over the entire watershed, and techniques developed to predict storm runoff (e.g., the curve number) were based on this assumption. This process is generally referred to as infiltration excess runoff, and occurs because the infiltration capacity of the soil is less than that of rainfall intensity. More recently however, partial-area hydrology, which then evolved to variable-source-area (VSA) hydrology (Ward, 1984), has become accepted as a descriptor of humid-climate watershed response to precipitation. In this case, runoff is termed saturation excess runoff, and is generated because there is limited storage capacity in the soil. Available porosity is already filled either because of high near-stream water tables or typically wet areas on the landscape (e.g., geologic contacts, areas of convergence, or fragipan soils)

The basic premise of VSA hydrology is that there is a contributing subwatershed within the topographically defined watershed which varies in time – it expands and contracts rapidly during a storm as a function of precipitation, soils, topography, and ground water level and moisture status. VSA runoff is dominated by saturation overland flow and also rapidly responding subsurface flow. The remainder of the watershed provides little or no runoff, only infiltration and ground water recharge. Since surface runoff is the mechanism for P and pathogen transport, the intersections of the VSA with soil/fertility/management combinations that produce excess P or pathogens at the land surface control their loss from the watershed. For loss to occur, there must be coincident available P (or pathogens) and surface runoff to move it to the watershed outlet.

Soil P levels can be high over much of the watershed, but these high-P areas are "activated" to become a source of P to the watershed outlet only by occurrence of surface runoff. The runoff generation portion of a CSA is not easily controlled, but soil P levels in areas conducive to surface runoff formation can be monitored and controlled. Thus, management to limit P loss from a watershed should be focused on areas where runoff is likely to occur that are coincident with high P levels in the soil. This concept is currently being incorporated into the Phosphorus Index (see Gburek et al., 2000), a topic that will be addressed in subsequent papers from this conference.

**Ground water and N transport**

Ground water flow systems have traditionally been analyzed in terms of deeper water supply aquifers and homogeneous media. Flowpaths developed for these analyses extend deep into the subsurface and are regular in form, while associated travel times are considered to be at scales of years, decades, and even centuries. However, concerns with nonpoint source pollution from agriculture have required us to focus on the characteristics of the shallow surficial aquifers, those most easily and more likely affected by overlying land use. In the Northeast, this leads directly to the need to consider the effects of bedrock layering and fracturing on patterns of flow and contaminant transport, as well as the shallow aquifer's interactions with the surface water flow system.

At the larger scale, the land surface is typically underlain by relatively conductive layers of soil and rock, which are, in turn, underlain by less permeable strata. The more permeable layers forming the surficial aquifer can range from a few meters to tens of meters thick. Ground water moving within the more conductive surficial layers generally forms an unconfined aquifer, i.e., the water table is the upper boundary of the saturated zone. Further, nearly all ground water regions of the eastern U.S. have some degree of fracture control on flow within the shallow bedrock. Bedrock fracturing, when it occurs, exaggerates the hydrogeologic characteristics of the layered aquifer even more, producing extremes in the properties governing flow and transport – very high hydraulic conductivity and relatively low specific yield. The result of these conditions is that the flowpaths tend to be even more constrained within the shallower zones of the aquifer. The shallow zone of fracturing may be overlain by relatively thick glacial deposits or regolith, or by only a thin soil. In all cases though, ground water within the shallow fracture zones is affected directly by overlying and immediately upgradient land use.

Pionke and Urban (1985) developed a comprehensive nitrogen budget within a 7.2 km2 upland agricultural watershed in east-central Pennsylvania, and showed that $NO_3$ leaving the root zone in percolate at the watershed scale matched that observed in the stream at the watershed outlet. Gburek and Folmar (1999b) extended this finding to show that the $NO_3$ balance could be maintained down to a subwatershed scale of approximately 0.5 $km^2$. Thus, at a variety of watershed scales, $NO_3$ leaving the root zone should be expected to appear in streamflow over the long term. Schnabel et al. (1993a) and Gburek and Folmar (1999a) showed that streamflow patterns of $NO_3$ are controlled by land use distribution and the layered and fractured geologic system. In total, this research emphasizes the need to focus on subsurface flowpaths to understand nitrate movement and develop corresponding management strategies.

Because of the layering and fracturing prevalent in upland watersheds of the Northeast, ground water quality within the surficial aquifer is strongly affected by land use positioning within the watershed. Land use over only the most upland watershed positions controls water quality within the deeper regional aquifer, while land use distribution over the remainder of the watershed affects water quality patterns within the shallower fractured layers.

From the total watershed perspective, this discussion indicates the potential, or lack thereof, to manage N loss from a watershed. Basically, the subwatersheds producing higher $NO_3$ concentrations in a stream are those having higher source-area inputs of N to the ground water. The simple answer to reducing N output from a watershed is reducing or managing the N applied to the land surface to minimize loss through the root zone.

**Riparian zone considerations**

Elevated levels of $NO_3$ are expected in ground water recharge from agricultural land use, but the resultant high concentrations of $NO_3$ in ground water may be attenuated enroute to becoming streamflow if the ground water flows through riparian ecosystems (Lowrance et al., 1984; Correll and Weller, 1989). The riparian zone (RZ) is that portion of the watershed where subsurface flow intersects the land surface, usually in near-stream positions, causing high water tables and soil moisture levels. Under humid-climate conditions, ground water convergence to the stream is the prime cause of these high-moisture, high-water-table, riparian conditions effective for nitrate reduction, but aquifer configuration and its controls on the ground water flow system geometry at the watershed-scale also influence the potential for $NO_3$ removal (Schnabel et al., 1993b).

Cooper (1990) concluded that catchment hydrology, particularly flowpaths through the RZ, determine the control of near-stream environments on pollutant flux. Whether riparian zone processes can substantially reduce nitrogen discharge into a stream depends on both the areal extent of the RZ and the hydrologic linkages between upland nitrate sources (i.e., farm fields) and the RZ. A variety of linkages with varying degrees of complexity are possible on a watershed, ranging from landscape positions with short, shallow, direct paths between cropped areas and riparian zones, to those with deep flow paths through limited riparian zones. When flow paths are direct and shallow, nearly all agricultural drainage passes laterally through the RZ before discharging to the stream. In contrast, when flow paths are less constricted, more of the ground water discharge can bypass some or all of the RZ, either as deeper flow before converging to the channel, or as loss to a deeper ground water system.

As emphasized throughout this paper in other scenarios, flow path and transport definition is critical – here, subsurface flowpaths describe delivery of recharge from the agricultural land use to and through the RZ. Of prime importance is the origin of those flowpaths passing through the RZ, because only land uses from which these flowpaths originate have the potential to be affected by RZ processes. High recharge conditions typical of springtime, results in the most flow passing through the RZ. Lower recharge conditions, more typical of summer and early fall, result in a generalized lowering of the water table over the watershed, and consequently, less flow (and fewer pathways) passing through the active RZ. In evaluating potential RZ effects under these conditions though, the hydrologic status of the watershed must also be considered. The high-recharge configuration represents springtime conditions when denitrification processes are less effective because of cooler temperatures, and residence times within the RZ are also shorter because of higher flowrates. Conversely, when potential for denitrification is greater (summer temperatures and longer residence times), more of the ground water bypasses the RZ. Thus, the effectiveness of local biochemical RZ processes must be integrated with watershed-scale hydrologic conditions to fully evaluate the potential for a landscape to attenuate $NO_3$ inputs to the ground water.

**Implications for nutrient and pathogen management**

The concepts presented provide the basis for describing transport and related source-area on nutrient and pathogen loss from the watershed – for loss to occur, there must be available nutrients and/or pathogens as well as water movement to carry them to the watershed outlet. As an example, soil-P levels may be high over much of the watershed, but these high-P areas become a source of P to the stream only by concurrent occurrence of surface runoff.

At the watershed scale, relatively few processes and parameters form the critical source-areas controlling nutrient or pathogen loss – even fewer may be efficiently or readily manageable. In the case of P management, runoff generation itself is not easily controlled at the watershed scale in humid-climate regions, but P levels in areas contributing to P loss via storm runoff can be measured, monitored, and controlled. Erosion may be more manageable, particularly by manipulating cover directly or indirectly through a conservation practice, such as modified tillage. Phosphorus loss may be managed by controlling P fertility level in the primary surface runoff zones, and sediment-related P by controlling erosion and/or P fertility level in the primary erosion zones. Levels of soil P further from the stream may be of less concern since there is less chance of runoff occurring from these areas.

Selection of remediation methods for controlling P export from a watershed should not cause or aggravate other water quality problems though. Phosphorus control strategies based on reducing surface runoff losses by increasing infiltration rate or disposing of excess P in non-runoff zones may well increase $NO_3$ recharge to ground water, especially where applications of manure or organic materials are the primary source of the excess P. Under these conditions, remedial approaches must be developed and selected to optimize control of P loss relative to achieving N control objectives.

In those watershed positions where P or pathogen loss is not of concern because of minimal surface runoff, management of N from fertilizers and animal wastes becomes critical. N is much less likely than P to be built up or stored in the soil system. Thus, the simple fact is that N excess within the soil in all nitrogen CSAs (the recharge zones) must be carefully controlled to reduce N inputs to the ground water and subsequent export from the watershed. The CSAs for N involve most of the watershed area because they are the inverse of the VSA for runoff. An alternative to management of N in the soil within the nitrogen CSAs is restrictions on types of land use and management – that approach would be less preferable.

**Summary**

Nutrient and pathogen management strategies must be developed considering the watershed, as well as the farm and field scales. Hydrologic processes that dominate at the watershed scale determine which farms or fields have the potential to contribute most of the exported nutrients or pathogens. Other watershed elements, such as the riparian zone, exist between the individual fields and the watershed outlet that alter the timing, amount, and concentration of the nutrients exported – again though, these are primarily a function of the structure of the watershed-scale flow system. Here, we have delineated P and N CSAs from the hydrologic perspective – considering transport processes – that are not predictable using a field- or farm-scale approach. Only after the hydrologic (runoff and recharge) source-areas are established at the watershed scale can we consider the smaller scale soil, chemistry, and nutrient use information within the farms and fields to define the nutrient and pathogen CSAs.

We remain far removed from development of a single nutrient and pathogen management strategy that can account for all contaminants, as well as all hydrologic implications. Modeling tools and field data are simply not available to integrate all aspects of the hydrologic cycle from the flow perspective alone, much less from that of water quality. However, we can draw conclusions based on what has been shown. Hydrologic implications are that to control P loss, we control P application and build-up primarily in near-stream zones. Levels in the soil at distance from the stream are of minimal concern since there is only a limited chance of runoff occurring to move P from that location to the stream. Thus, the most obvious control from the P point of view is to apply animal wastes on landscape positions at distance from the stream – the further the better.

Concern with nitrate is different though – we must control N in areas of ground water recharge. The ideal animal waste disposal strategy should provide for N in the soil at amounts needed by the plants, both in timing and areal distribution. If excess wastes are applied though, nitrate escaping crop uptake will easily move with any water available to move it. In this case, the management strategy becomes <u>disposal</u> (i.e., excess N), and should be limited to those portions of the landscape which do not affect ground water zones critical to water supply. Lastly, if we can identify those flowpaths that pass through the RZ, we can apply the excess N to watershed areas having the best chance to be affected by RZ processes, thereby realizing maximum reduction of input concentrations.

When all flow components of the hydrologic cycle are intimately connected, as in humid-climate upland watersheds, we must consider interactions between these components when developing effective animal waste management strategies. Management must account for interactions between areas of nutrients and pathogens applied to the landscape, source areas of ground water recharge, patterns of ground water movement and associated contaminant transport, surface runoff source areas and associated transport, and riparian zone controls. To accomplish this, we must continue to do a better job in accurately portraying the hydrologic flow system. External and internal boundaries, controlling geometries, hydraulic properties, major flowpath patterns, and areas of recharge, subsurface discharge, and surface runoff must all be defined and integrated into any nutrient or pathogen management strategy applied to part or all of the watershed.

Finally, the most critical problem of all may be interfacing this objective and technical approach to management with the interests of landowners. The purely hydrologic analysis presented implies that different levels of management for different parts of the watershed may be the most efficient approach to minimize contamination of ground water and/or surface runoff. Thus, there may be differing levels of management suggested from field to field and/or farm to farm. A major challenge in implementing a nutrient or pathogen management strategy derived from these hydrologic implications may be to demonstrate to the affected landowners that the results will be of sufficient benefit to override the apparent inequities associated with its application over the watershed.

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# Source Risk Indicators of Nutrient Loss from Agricultural Lands

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Source risk describes the potential availability of agricultural nutrients to transport mechanisms, such as erosion, runoff and leaching. The combination of source and transport risks quantifies the potential for diffuse losses of nutrients from land to water, and is key to site risk assessment tools such as the Phosphorus Index (Lemunyon and Gilbert, 1993), as well as more recently, the Nitrogen Index (Heathwaite et al., 2000).

The two elements of greatest concern to agricultural and environmental managers, phosphorus (P) and nitrogen (N) behave quite differently in the environment. Whereas N is highly mobile and easily transported via multiple pathways, the affinity of P to soil constituents imposes conditions that restrict its potential for transport. In the past, this affinity supported a perspective that equated P loss with particulate P removal by erosion. Although erosion certainly represents the most drastic means of transporting P from land to water, transport of dissolved P in runoff, and even leachate, is now seen as a major concern. Discrepancies in the chemistry of these elements result in very different approaches to source risk assessment for N and P.

This paper examines source factors, i.e., indicators of source risk, controlling nutrient loss from agricultural lands, with particular emphasis on P, which is currently receiving concentrated scrutiny in research and regulatory arenas.

**Nitrogen Source Factors**
Nitrogen source factors are the key control of N losses from agricultural lands, as N transport is extremely difficult to manage (Beegle, 2000). For instance, research conducted by Sharpley and Smith (1994) revealed that transport-oriented management simply shifted the pathways by which N was removed from soil. Specifically, imposition of conservation tillage practices on wheat production reduced runoff losses of N but increased leaching losses (Figure 1). Such a "zero sum gain" simplifies the assessment of N source risk; N in excess of crop requirements is likely to be lost. This view is illustrated by Figure 2, which shows the coincidence of agronomic and leaching thresholds for N, based upon research on N fertilization of cereal crops in England (Lord and Mitchell, 1997 as reported by Sharpley and Lord, 1997).

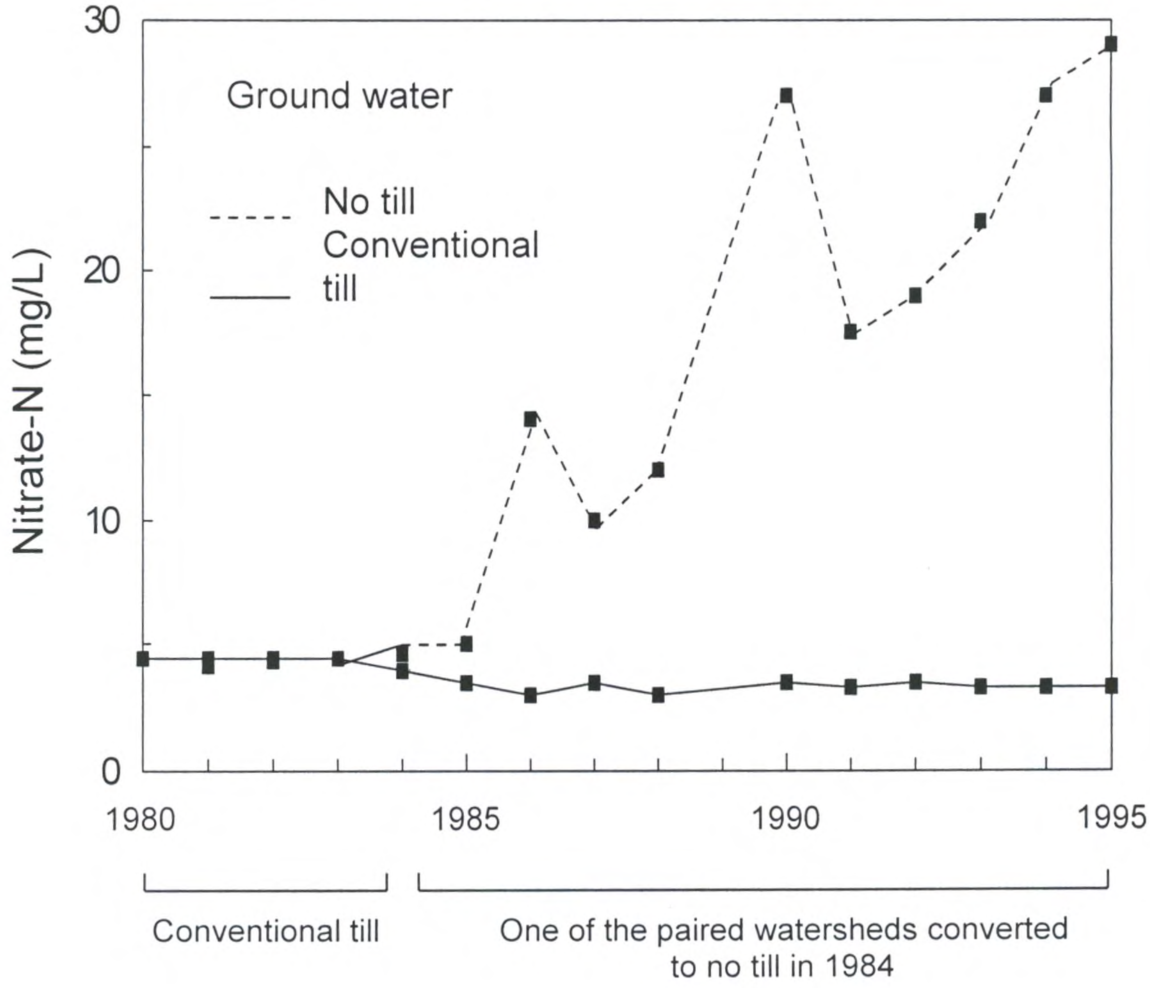



Figure 1. Mean annual nitrate-N concentration of ground water and dissolved and total P concentration runoff as a function of tillage management of watersheds in Oklahoma, U.S. (data adapted from Sharpley and Smith, 1994).

The risk of nitrate leaching is rooted in cropping system management. Nitrogen source risk assessment must therefore involve consideration of form, rate, timing and method of N application (Sharpley et al., 1998a). For instance, residual soil organic N, which can mineralize when weather conditions favor microbial activity, must be considered in order to assess temporal variation in nitrate leaching from soils. Similarly, crop selection and rotation influence the amount of N in the soil profile, hence source risk, and can also influence transport potential by affecting soil water dynamics. For example, legumes that do not require supplemental N inputs can effectively scavenge residual N from soil that is related to previous crops, thereby reducing source risk (Mathers et al., 1975; Muir et al., 1976).

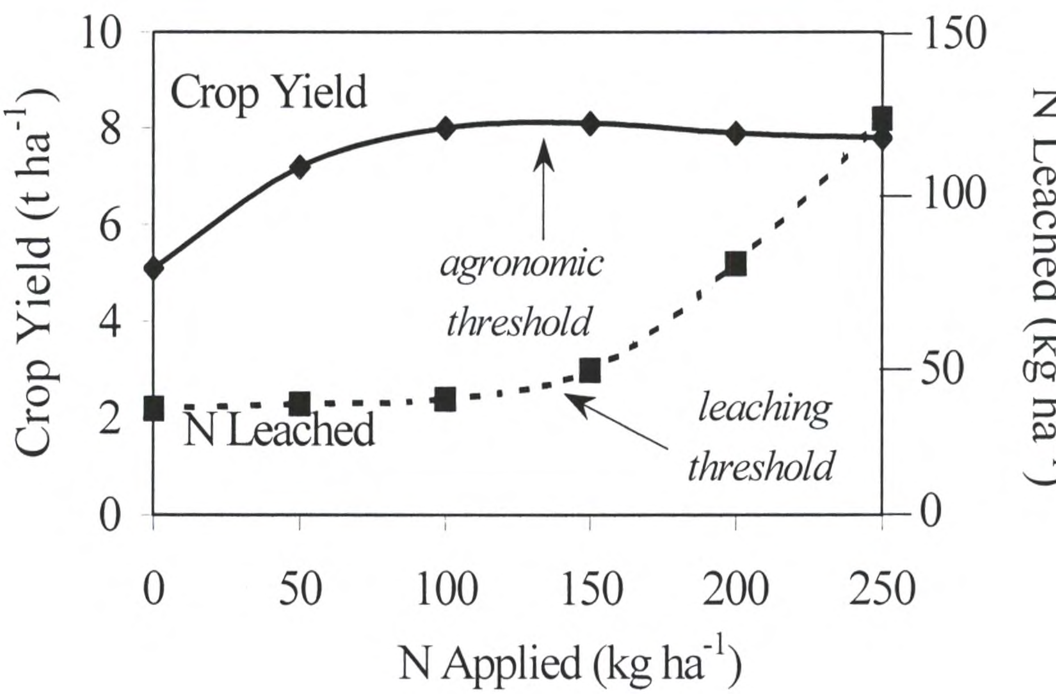



Figure 2. Relationship of N application to crop yield and N leaching, illustrating coincidence of agronomic and environmental thresholds (adapted from Sharpley and Lord, 1997).

The importance of cropping system management to source risk is further illustrated by Figure 3, which overlays hypothetical root development for several crops with predicted N leaching patterns (adapted from Sharpley et al., 1998b). Continuous cropping with corn results in root development that does not overlap with periods of high transport potential (leaching), resulting in increased availability of soil N to sub-surface waters. However, rotational cropping of corn-winter wheat-alfalfa results reduced source risk due to improved efficiency of N retention derived from deeper root distribution at times when leaching risk is higher.

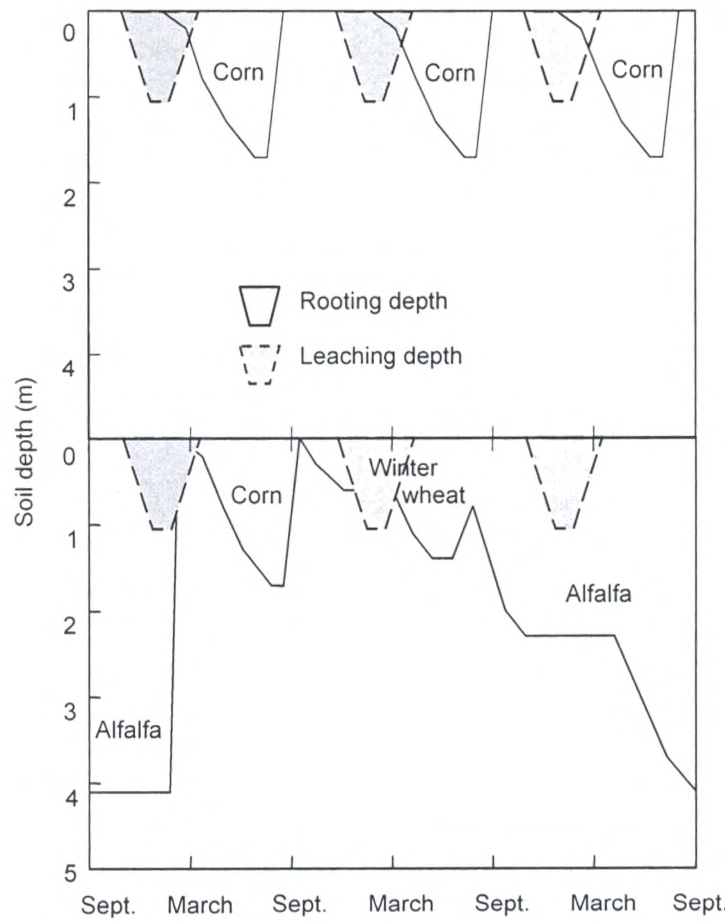



Figure 3. Typical root development of continuous corn and corn-winter wheat-alfalfa rotation in relation to soil drainage over a three year period (adapted from Sharpley et al., 1998b).

**Phosphorus Source Factors**
As our understanding of P source risk has grown, attention has focused on the paucity of soil-specific data linking soil P with the potential for P loss (Sharpley et al., 1999). Given the absence of such data, a common approach has been to adapt agronomic soil P standards to source risk assessment, following the rationale that soil P in excess of crop requirements is vulnerable to removal by surface runoff or leaching. This rationale applies to N, as described above. Since agronomic standards already exist for soil test P, such an approach requires little investment in new research and can be readily implemented. However, it is clear that we must be careful how we interpret soil test results for source risk assessment.

Interpretations presented on soil test reports (e.g., low, medium, optimum, high) were established based on the expected response of a crop to P. Some would simply extend the levels used for interpretation for crop response and say a soil test that is above the level where a crop response is expected is in excess of crop needs and therefore is potentially polluting (Figure 4). But, it cannot be assumed that there is a direct relationship between the soil test calibration for crop response to P and runoff or leachate enrichment potential (source risk). What is crucial to our estimation of source risk is the interval between the threshold soil P value for crop yield and runoff/leachate P (Figure 4).

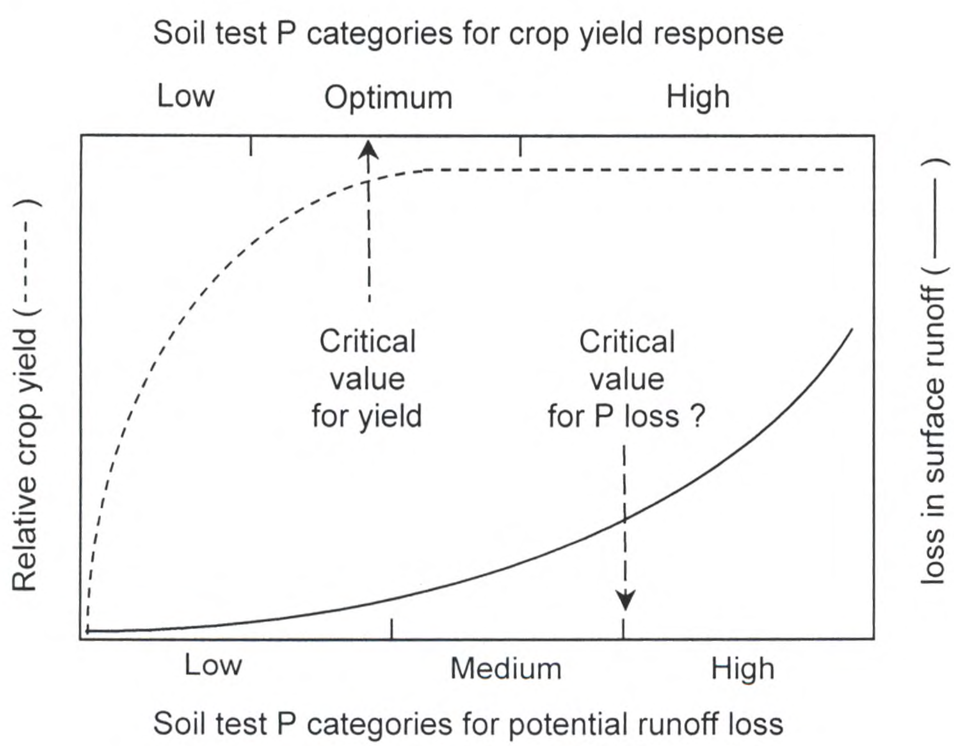



Figure 4. As soil P increases so does crop yield and the potential for P loss in surface runoff. The interval between the critical soil P value for yield and runoff P will be important for P management.

*Environmental soil testing for P*

The relationship between soil test P and surface runoff P, shown by the lower curve in Figure 4, is based on studies using traditional soil test methods that estimate the plant availability of soil P. Although these soil test methods show promise in describing the relationship between the level of soil and surface runoff P, they have several drawbacks.

For example, soil test extraction methods were developed to estimate the plant availability of soil P; therefore they may not accurately reflect soil P release to surface or subsurface runoff water (Sharpley et al., 1996).

Soil sampling depths can also be problematic. For routine soil fertility evaluation it is generally recommended that soil samples be collected to plow depth, or the zone of greatest root concentration, which is roughly 6-8 inches deep. When soil testing is used to estimate soil P loss, however, it is the surface inch or two that comes into direct contact with runoff that is important (Sharpley et al., 1996). One exception is the need to consider the amount of subsoil P in soils with high water tables where shallow lateral flow and leaching loss may be a concern. Consequently, different soil sampling procedures may be necessary for a soil test that is used to estimate the potential for P loss in surface runoff. To overcome the limitations of traditional agronomic soil tests and sampling techniques, a variety of approaches are being developed to better represent the amount of P in soil that can be released to runoff water, and, more specifically the amount of P (e.g., algal available P) that is of environmental concern (Sharpley, 1993).

One environmental measure of soil P, developed in the Netherlands by Breeuwsma and Silva (1992) to assess P leaching potential, is soil P saturation (percent saturation = available P / P sorption maximum). The role of soil P saturation as an indicator source risk derives from the observation that soil P saturation is strongly correlated to P desorption, such that P desorption increases at higher degrees of soil P saturation (Sibbeson and Sharpley, 1997). Indeed, many studies have correlated soil P saturation with P in runoff (Pote et al., 1996, 1999; Sharpley, 1995), as well as with P in leachate (Hesketh and Brookes, 2000). In the Netherlands, a threshold soil P saturation of 25% has been established above which the potential for P movement in surface and ground waters becomes unacceptable (Breeuwsma and Silva, 1992).

Unfortunately, source risk measures such as soil P saturation are not offered by most soil testing laboratories. Opportunities exist to relate readily-available soil test data to environmental measures such as soil P saturation. For instance, Kleinman et al. (1999) found a strong correlation between Morgan's extractable P and soil P saturation (Figure 5). Similarly, soil P saturation may be estimated using Mehlich 3 extractable elements, rather than acid, ammonium oxalate extractable elements as is currently standard (Figure 6). As concern over the precise measurement of source risk mounts, soil testing laboratories may need to explore the development of pedotransfer functions, i.e., equations that relate data we *have* to data we *need*, to estimate source risk.

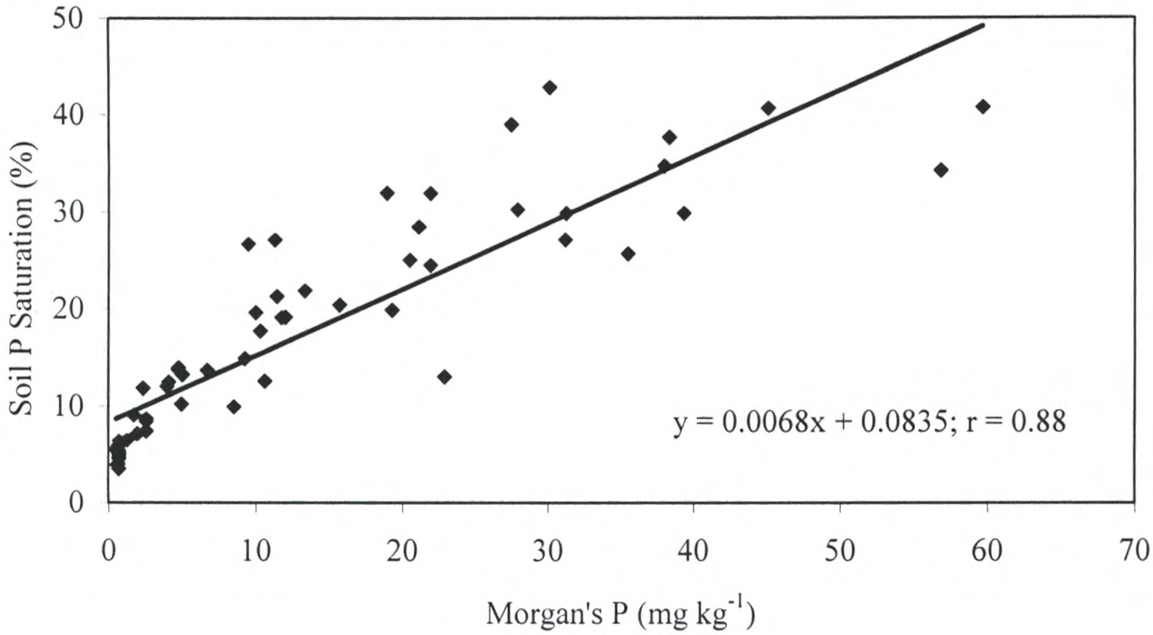



Figure 5. Relationship of Morgan's P (agronomic soil test) to soil P saturation (environmental soil test) (adapted from Kleinman et al., 1999)

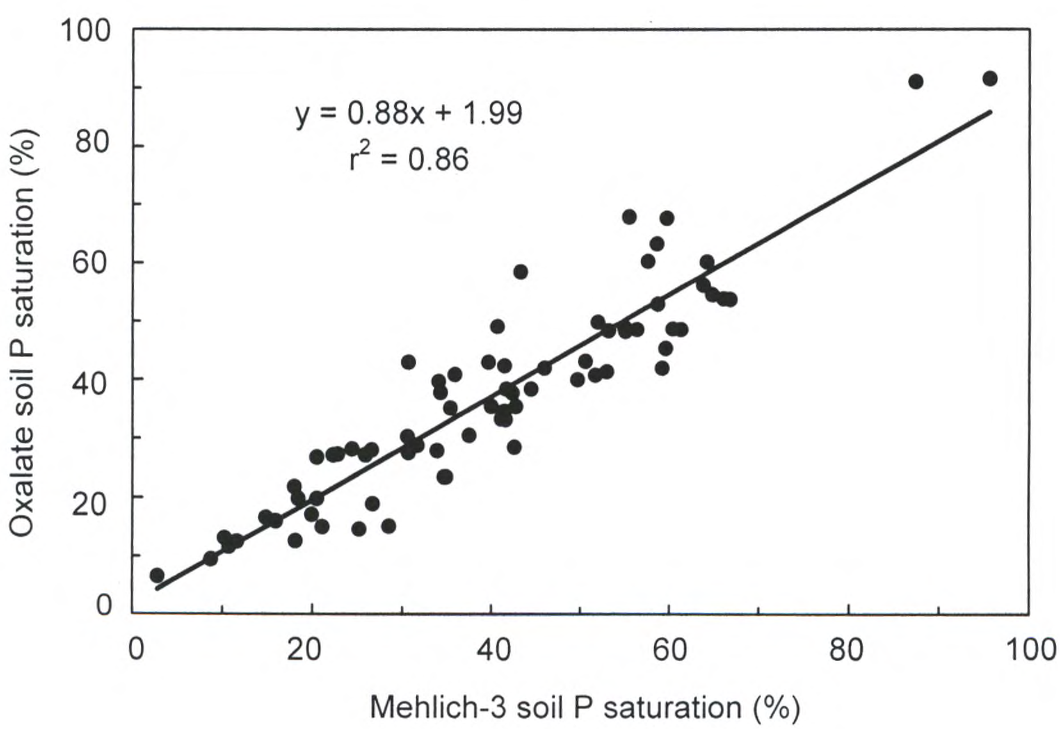



Figure 6. Relationship between soil P sorption saturation calculated from Mehlich-3 and oxalate extractable P, Al, and Fe.

A variety of soil extracts have been evaluated as indicators of source risk by relating extract P to P in surface runoff or sub-surface leachate. Ryden and Syers (1975) stated that to establish the relationship between P additions, fertilizer additions and P in particulate or aqueous phases of runoff, a desorption or "support medium should reflect the cation status as well as the ionic strength of the aqueous phase of the system". With the possible exception of macropore flow, the longer residence time of sub-surface leachate as it flows through the soil implies that a soil extractant of higher ionic strength is required than would be used for surface runoff. Soil extractions with water and 0.01*M* $CaCl_2$ have shown promise in estimating the dissolved P concentrations of surface runoff and sub-surface leachate, respectively (Figure 7) (McDowell and Condron, 1999;

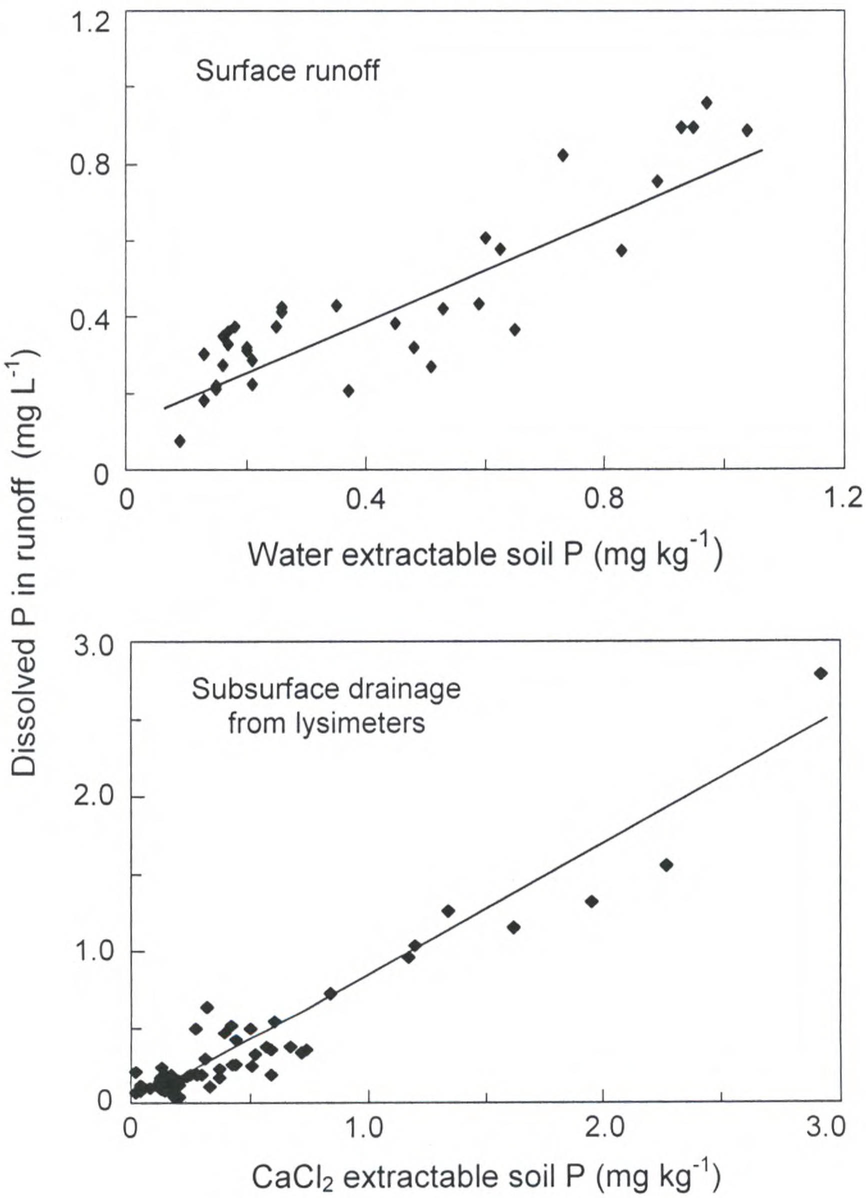
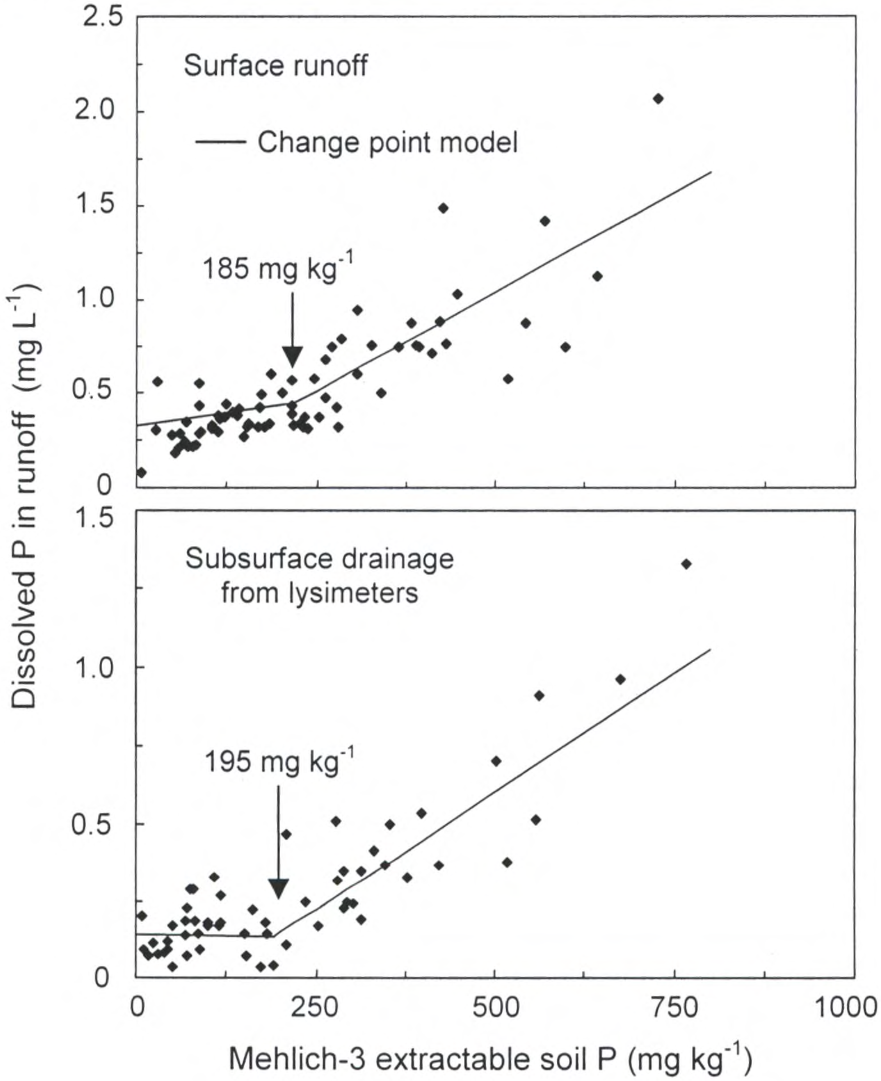



Figure 7. Relationship between the concentration of dissolved P in surface runoff and subsurface drainage from 30 cm deep lysimeters and the water and $CaCl_2$ extractable soil P concentration, respectively of surface soil (0 - 5 cm) from an central PA watershed (see Sharpley et al., 1999).

McDowell and Sharpley, 1999). Using these desorption mediums in conjunction with Fe-oxide strips and gels can determine the quantity of desorbable P in runoff or soils the medium and long-term (Freese et al., 1995; Sharpley, 1993).

*Threshold analysis*

Threshold analysis of soil P data represents an important step in source risk assessment. One innovative environmental approach uses a split-line model to determine a threshold, termed a "change point," in soil P concentration. The change point separates the relationship between soil phosphorus and dissolved P in runoff into two sections, one with greater P loss per unit increase in STP concentration or percent saturation than the other (Heckrath et al., 1995; Hesketh and Brookes 2000; McDowell and Condron 1999). McDowell and Sharpley (1999) showed that a similar change point occurred between STP concentrations of the 0 – 5 cm soil layer and dissolved P in either surface or sub-surface runoff (Figure 8). The change point identifies a critical soil P level that should not be exceeded, and has potential for use in threshold identification of source risk.



Another approach to threshold identification employs P sorption isotherms that are generated under experimental conditions in the laboratory. The basis for this approach is the assumption that a fundamental property of a soil with a low degree of P saturation is a standard, L- or H-type Q/I curve (see McBride, 1994). Figure 9 illustrates such a curve, divided roughly into two integral stages: an initial, steeply-sloped, "fixation" stage in which the proportion of soluble P additions that are sorbed is high; and, a "saturated" stage of gradual slope in which the proportion of soluble P additions that are sorbed is significantly lower relative to the first stage.

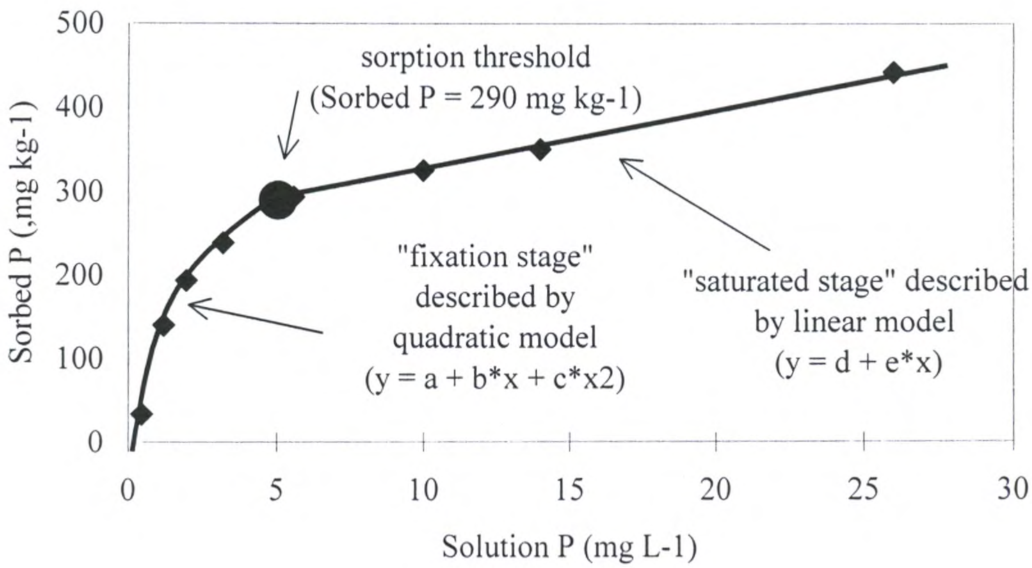



Figure 9. Description of P sorption isotherm by segmented regression. Sorption threshold identifies the intersection of quadratic and linear models

The sorption threshold for an "unsaturated" soil (i.e., a soil with both "fixation" and "saturated") is estimated by determining the point that joins the "fixation" stage with the "saturated" stage of the sorption isotherm. The ordinate value of this join point, the sorbed P value, represents the remaining capacity of a soil to bind soluble P before the P sorption efficiency significantly declines.

Figure 10 illustrates P sorption isotherms for three soils, representing low (Figure 10c), intermediate (Figure 10b) and high soil P saturation (Figure 10a). Notably, as soil P saturation increases, presumably due to increased P loading, the magnitude of the fixation stage (i.e., the sorption threshold value) decreases. Sorption isotherms of soils with high degrees of P saturation (Figure 10a) manifest near-linear relationships (i.e., only the "saturated" portion of the sorption isotherm) and, therefore, possess low P sorption efficiencies. Soluble P added to these "P-saturated" soils is more likely to be removed by runoff or leaching due to the lowered P sorption efficiency.

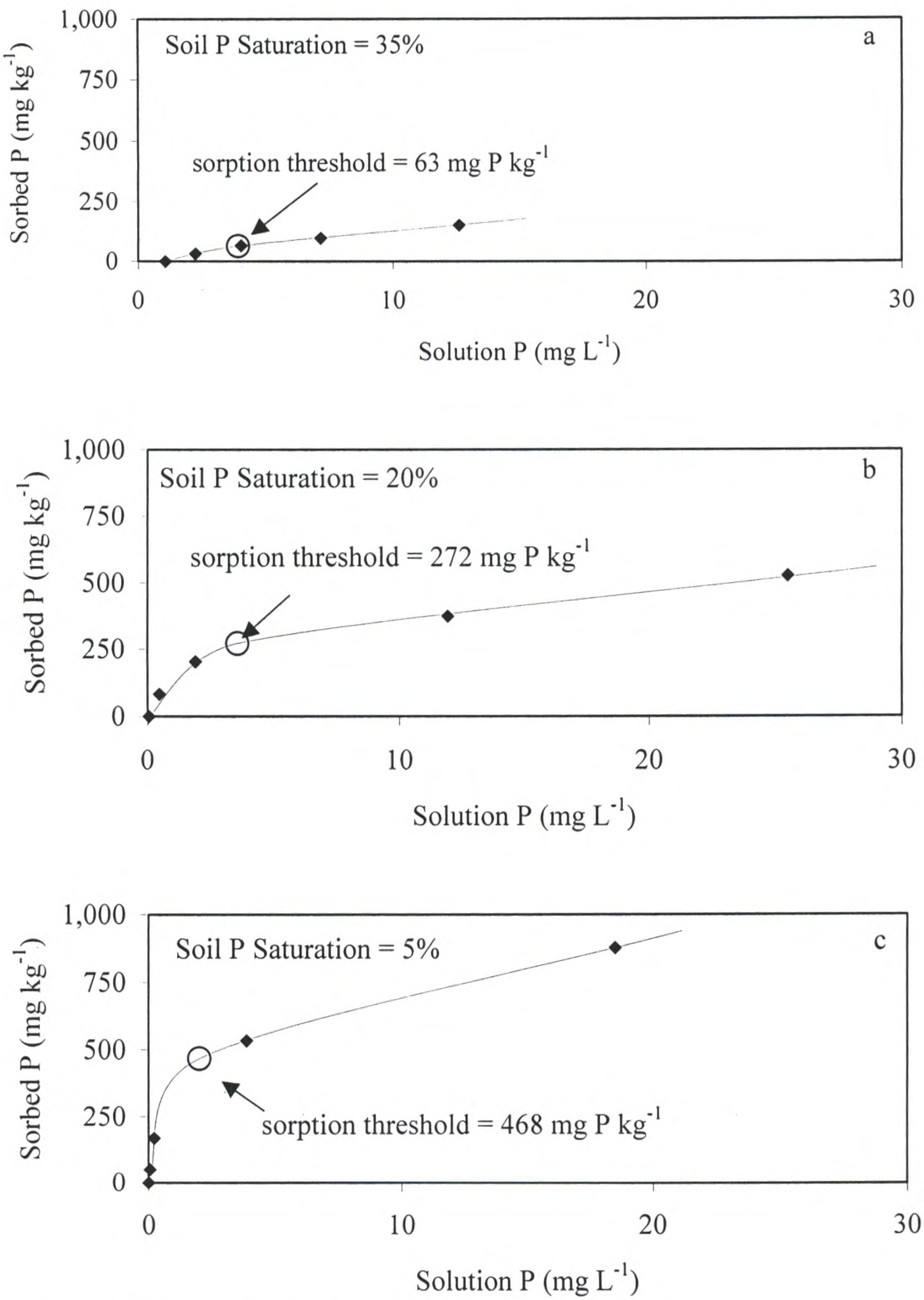



Figure 10. Sorption thresholds of three soils with varying degrees of P saturation.

*Soil-Specific Nature of Source Risk*
As mentioned earlier, source risk is highly soil specific. A number of studies relating soil P to runoff P have shown the relationships to be dependent on soil properties such as pH, mineralogy and texture. For instance, Sharpley (1995) found the relationship of Mehlich III P and dissolved P in runoff to be related to soil type as differentiated texture (soil P saturation was related to dissolved P in runoff for all soil types by a single regression equation). This study also found calcareous soils to release significantly less P to runoff than non-calcareous soils with similar Mehlich 3 P levels. Indeed, much attention is now focused on the differential release of P from calcareous and non-calcareous soils to runoff, as highlighted by work in Arkansas, Pennsylvania and New York under the National Phosphorus Project (see Sharpley et al., 1999 for a description of the project). At this time, however, further research is required before definitive generalizations can be made concerning calcareous and non-calcareous soils and P source risk.

*Role of management in P source risk*
Much attention has focused on the relationship between soil P and dissolved P losses. This relationship is certainly fundamental to our understanding of source risk, particularly over the long-term since soil P levels are comparatively recalcitrant. However, the near-term effects of P application, either in manure or mineral fertilizer, generally overwhelm the contribution of soil P to source risk (see Sharpley, this proceedings).

The relative contribution of P additions to source risk is highly time dependent. Over time, added P reacts with the soil, reducing its availability to runoff or leaching waters. Thus, runoff and leaching events that occur near the time of application remove much more added P than events that occur later. Figure 11 shows a typical decay-type curve, relating timing of surface manure application to dissolved P concentration in runoff. Curve parameters vary with factors such as amount and placement of the P addition.

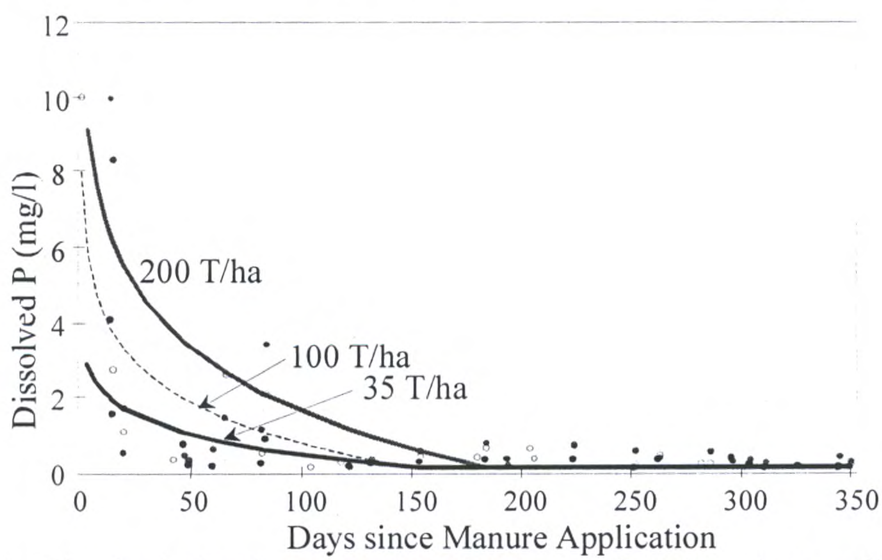



Figure 11. Dissolved phosphorus concentration in runoff vs. days since application and application intensity (data presented in Klausner et al., 1976, and interpreted by Brookes et al., 2000).

Incorporation of added P increases interactions between P and the soil, reducing the availability of that P to transport mechanisms. Surface application of P (e.g., top-dressed manure) greatly increases source risk relative to methods that incorporate added P (e.g., drilling of manure). This applies both to overland transport via surface runoff as well as to sub-surface transport by preferential, or macropore flow: the higher the concentration of P at the soil surface the higher the concentration of P in runoff and leachate. Indeed, deep cultivation can serve to dilute surface P, hence lower source risk (Sharpley, 1999), although the trade off between lowered surface P levels and increased potential for erosion must be assessed.

In addition to application methods, a number of management practices are now being explored to control source risk. The use of phosphorus immobilizing soil and manure amendments (PISMAs) is receiving considerable attention, particularly given the success of alum in simultaneously limiting P solubility and ammonia volatilization in poultry litter (Moore et al., 1999). Stout et al. (1999) examined the utility of low-cost, coal combustion byproducts as PISMAs, with special focus on the combined implications of these PISMAs to agronomic and environmental indicators of soil P. The addition of FBC fly ash and FGD gypsum to soils of near-neutral acidity (pH = 7.2) resulted in significant declines in water-extractable P (environmental indicator) and negligible declines in Mehlich III P (agronomic indicator). The authors conclude that these PISMAs can effectively control source risk (i.e., potential for dissolved P loss) without reducing the availability of P to crops.

**Conclusions**

Source factors for P and N play an important role in the risk of diffuse nutrient losses from agricultural lands. Because of the differing mobility of P and N in the environment, source factors are much more important to N loss potential than to P loss potential, as P loss is restricted primarily to critical source areas where high P availability and high transport potential overlap. Measurement of source risk requires an understanding of nutrient sources, soil properties and cropping system management. As new management practices, such as PISMAs, are targeted to source risk control, these too must be accounted for in risk assessments. Ultimately, true control of source risk requires balance of nutrient inputs and outputs at the farm gate.

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