Poultry Litter in the Potomac Headwaters:
How Can We Reach a Long-term Balance?

Submitted to:

Potomac Headwaters Resource Alliance

In partnership with:

West Virginia Rivers Coalition

Submitted by:

Evan Hansen

Downstream Strategies

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PROJECT SUMMARY

In the Potomac headwaters of West Virginia, an agricultural and forested area located along the state's eastern border, recent growth in the poultry industry has focused attention on the potential environmental consequences of excessive poultry litter accumulation and use. Numerous government agencies have linked surface water and, potentially, groundwater impairment to the large quantities and current management of nutrients and pathogens in poultry litter, other types of livestock manure, and commercial fertilizers. Government agencies and farmers have responded with programs designed to improve water quality.

This report focuses on nutrients, and in particular on nitrogen and phosphorus. After litter, manure, or commercial fertilizers are applied on agricultural land, nitrogen and phosphorus can be lost to rivers, where the ensuing nutrient enrichment can lead to algal blooms, the growth of undesirable organisms, oxygen depletion, and fish kills. Recent data find high nitrogen levels in several streams in the Lost River watershed, a portion of the region with a high density of poultry houses. Although not linked conclusively or exclusively to nutrients from agriculture, algae growth has also been found locally in several rivers in the region. But nutrients can also contribute to problems far downstream: the Potomac River empties into the Chesapeake Bay, and nutrients from the headwaters region in West Virginia complicate solutions for reducing nutrient levels in the Bay. Recently, outbreaks of *Pfiesteria piscicida* have been identified in the Bay; excess nutrients are linked with these outbreaks. In addition to these surface water problems, nitrogen may also leach into groundwater, with potential human health effects.

West Virginia's poultry industry has grown rapidly in the last decade, and farmers in Grant, Hampshire, Hardy, Mineral, and Pendleton Counties—the five counties of the headwaters region—raise almost all of the state's poultry. In 1997, the industry produced about 100 million birds, which were fed with poultry feed imported from other states. The birds transformed this feed into an estimated 140 thousand tons of nutrient-rich poultry litter: a combination of manure and bedding materials such as sawdust. Most of this litter is applied locally to agricultural land as fertilizer for pasture and field crops. Some is exported to surrounding counties and states. The current, fundamental dynamic of the region's poultry industry is the importation of nutrients in feed, the transformation of feed into litter, and the local use of these imported nutrients when poultry litter is applied on agricultural land. When these imported nutrients are overapplied, this dynamic leads to excess nitrogen losses to surface water, groundwater, and the atmosphere, as well as the buildup of soil phosphorus to high levels and ensuing phosphorus losses.

Government agencies and farmers have begun to implement a range of improved litter management practices at the farm level. In particular, the U.S. Department of Agriculture's Natural Resources Conservation Service, together with other federal and state agencies, has implemented a program to assist poultry farmers through grants and low interest loans. The signup period for this program ends as this report is published, in February, 1999. As of October, 1998, the most recent month for which data are available, 212 farmers had signed contracts and pledged to implement nutrient management plans and conservation practices on 36,000 acres. At that point, the program covered about 10 to 15% of the region's total crop and pasture acreage.

By assisting individual farmers, this program focuses attention on nutrient flows found on individual farms. But while solutions to water quality problems must be dealt with one farm at a time, an assessment of nutrient flows at broad geographic scales over the long term is also valuable.

An analysis at a broad scale can help to develop priorities, to assess the overall magnitude of changes that must be made, and to provide a baseline for measuring progress. A long-term assessment is especially valuable for addressing the buildup of phosphorus in the soil year after year as phosphorus-rich poultry litter is applied to farmland. While many soils in the Potomac headwaters region are still deficient in phosphorus and will respond well to phosphorus applications during this buildup period, they cannot absorb this level of fertilization indefinitely. Eventually, to avoid phosphorus-related water quality problems, application rates must come into line with nutrient uptake, and management practices should be guided by the P index

This report responds to these two needs: it assesses broad geographic scales—the region as a whole, each of the region's counties individually, and one watershed within the region—and it focuses on the long term. This report asks a fundamental question: **Given the quantity of nutrients generated by the concentrated poultry industry in the Potomac headwaters of West Virginia, how can we ensure a long-term nutrient balance?**

To answer this question, the report presents a model of nutrient uptake on agricultural land and a model of nutrient generation by poultry. These models are then used in a series of linked calculations.

These calculations first determine the capacity of each area's agricultural land to recycle nitrogen and phosphorus: the nutrient uptake capacities. Then, these figures are converted to poultry production capacities such that the nutrients in the poultry manure equal the nutrient uptake capacities. Finally, the model is expanded to include exported litter and additional significant nutrient sources: cattle manure, commercial fertilizers, and municipal and industrial sludge.

To perform these calculations at broad geographic scales, the model strips away unnecessary details so that only the essentials remain. Model inputs include a number of estimates, and conservative estimates are used to ensure that the nutrient uptake capacities and poultry production capacities are upper bounds: the most nitrogen and phosphorus that each area's agriculture can use, and correspondingly, the most broilers and turkeys that can safely be raised in each area. When problem areas are identified using conservative estimates, more refined estimates will only reinforce the results; therefore, a critical reading of an upper-bound analysis such as this will most usefully focus not on the precision of the estimates, but on whether or not the estimates are conservative and the simplifying assumptions are reasonable.

Nutrient uptake capacities and nutrient generation

Based on a model of nutrient uptake and losses on cropland and pasture, the analysis first calculates upper-bound nutrient uptake capacities for the Potomac headwaters region as a whole; Grant, Hardy, Hampshire, Mineral, and Pendleton Counties individually; and the Lost River watershed, located within Hardy County. These capacities are shown in Table A-5 in Appendix A of the report and are not shown here.

Figure 5 in the report, reproduced here, compares these capacities with the nitrogen generated by broilers and turkeys in each study area. For the region as a whole, current nitrogen generation by broilers and turkeys roughly equals the upper-bound nitrogen uptake capacity. Results vary by county. In the areas in which poultry industry is most concentrated—Grant, Hardy, and Pendleton Counties and the Lost River watershed—current nitrogen generation by broilers and turkeys exceeds or roughly equals the nitrogen uptake capacities. In the Lost River watershed, the imbalance is most striking: Nitrogen generation totals over 250% of the uptake capacity. These results suggest that, if all litter generated in these areas were applied within the area in which it is generated, excess nitrogen will be lost to rivers, groundwater, and the atmosphere. Recent water quality sampling in the Lost River watershed documents elevated nitrogen levels downstream of agricultural areas, supporting this conclusion.

Figure 5: Nitrogen uptake capacities compared with nitrogen generated by broilers and turkeys

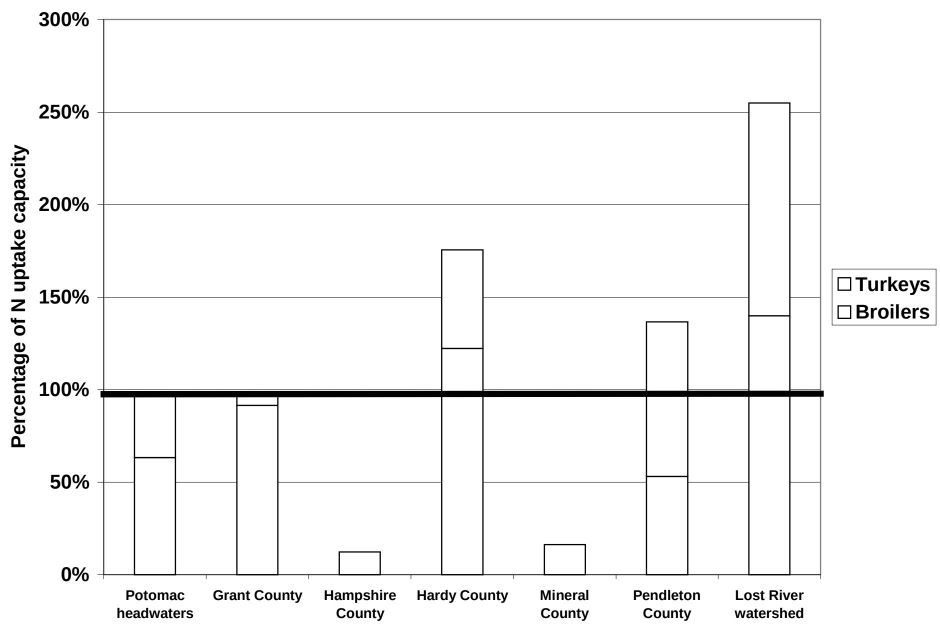
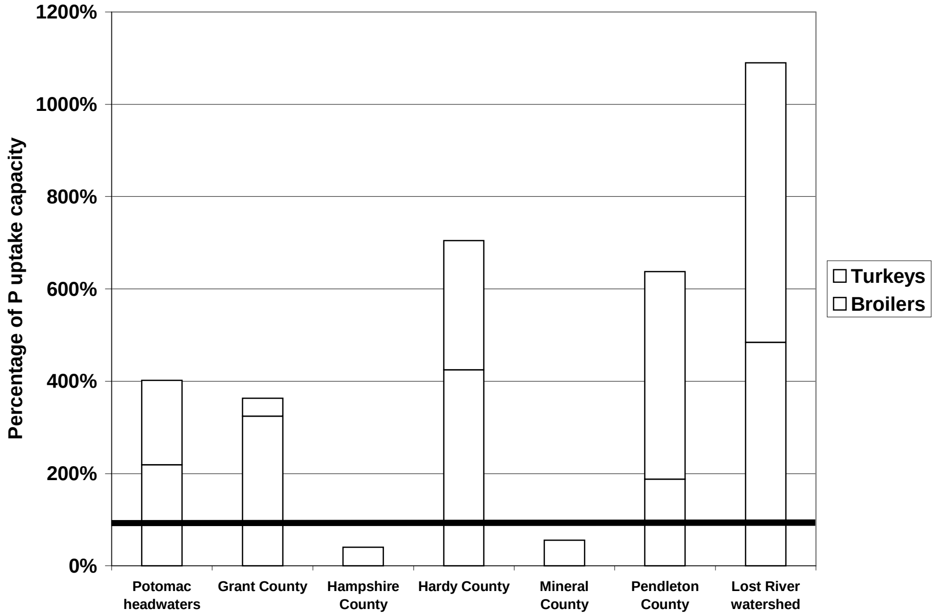


Figure 6 in the report, also reproduced here, presents a similar comparison of upper-bound phosphorus uptake capacities with phosphorus generation by broilers and turkeys. According to these results, generation significantly exceeds the uptake capacities in all areas except Hampshire and Mineral Counties, the two counties in which the poultry industry is relatively small. In the Lost River watershed, phosphorus generation by broilers and turkeys totals eleven times the calculated uptake capacity. The phosphorus results have two major implications. First, the significant imbalance suggests that soil phosphorus levels are likely to increase year after year if most poultry litter were applied to agricultural land within the area in which it is generated. This can be beneficial over the short term. But the second implication is that, for a balance to be achieved in the long term, phosphorus applications will need to be many times lower than the amount of phosphorus generated in poultry litter. Both of these implications suggest a need for exporting significant quantities of poultry litter from areas with excess generation and for finding alternative litter uses.

Figure 6: Phosphorus uptake capacities compared with phosphorus generated by broilers and turkeys



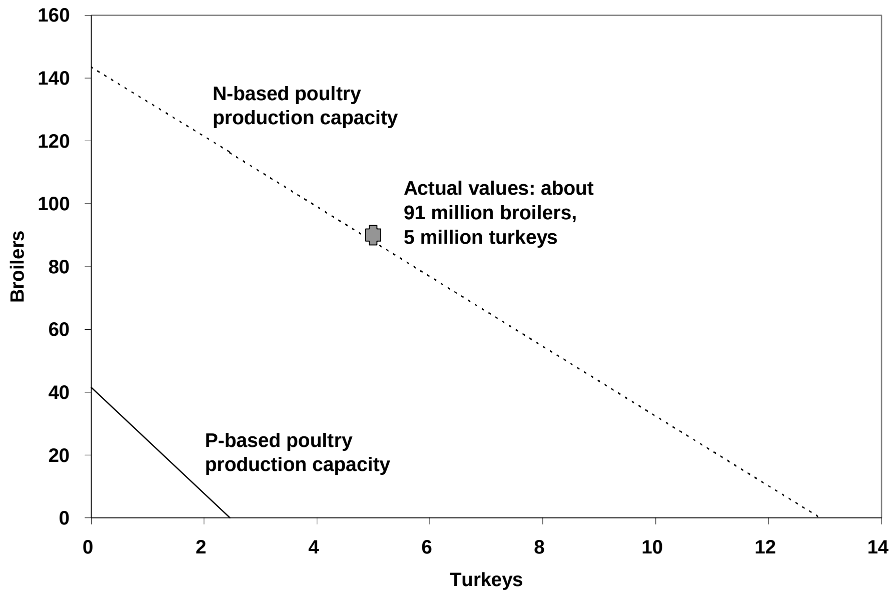
Poultry production capacities and poultry production

The analysis then goes one step further to look at upper-bound poultry production levels implied by each calculated nutrient uptake capacity. Figures 7 through 13 in the report illustrate these poultry production capacities for each study area. Figure 7, for the Potomac headwaters region, is reproduced below.

The poultry production capacities identify the range of broiler and turkey production levels that can be sustained such that the nutrients in their manure just equal the nutrient uptake capacities for a given study area. In the graphs, points that fall below and to the left of the poultry production capacity lines represent production levels that fall within the poultry production capacities. Two production capacities are shown for each area: one based on the nitrogen uptake capacity and one based on phosphorus. Each area's phosphorus-based line falls below the nitrogen-based line; therefore, phosphorous emerges in these graphs as the long-term limiting factor.

For comparison with the production capacities, these figures also plot the estimated actual broiler and turkey production levels in each area. The results of this comparison mirror the results for the nutrient uptake capacities: For the region as a whole, poultry production levels roughly equal the nitrogen-based poultry production capacity and greatly exceed the phosphorus-based capacity. In the major poultry-producing counties, actual production levels roughly equal or exceed the nitrogen-based production capacities, and greatly exceed the phosphorus-based capacities.

Figure 7: Potomac headwaters poultry production capacities (million/year)

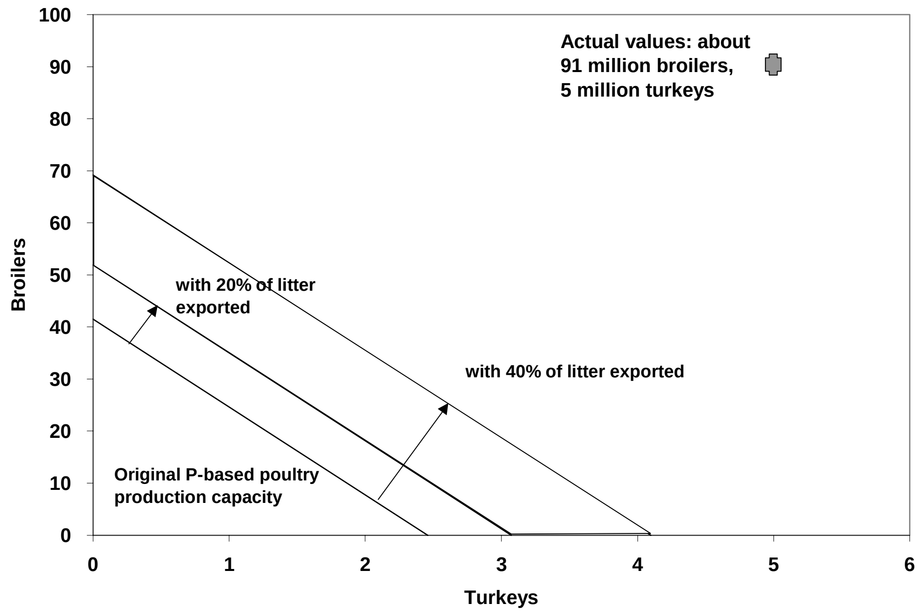


Other nutrient flows

The analysis then expands the model to include other important nutrient flows: cattle manure use, sludge applications, commercial fertilizer use, and poultry litter exports. Accounting for the use of cattle manure, sludge, and commercial fertilizer use decreases the upper-bound poultry production capacities shown above. In essence, a portion of the nutrient uptake capacities are "used up" by these nutrient sources and are unavailable to be met through broiler and turkey litter. But accounting for poultry litter exports has the opposite effect: The more litter is exported, the greater the poultry production levels that can be sustained while not exceeding the nutrient uptake capacities.

To evaluate the long-term possibility of achieving a nutrient balance through poultry litter exports, the analysis calculates the effect of exporting 20% and 40% of generated poultry litter from the region. These results are calculated for phosphorus. As illustrated in Figure 17 of the report, reproduced here, even if 40% of litter is exported from the region, current broiler and turkey production levels still greatly exceed the revised phosphorus-based poultry production capacities. At these rates, poultry litter exports alone are not sufficient to achieve a long-term nutrient balance.

Figure 17: Potomac headwaters phosphorus-based poultry production capacity after litter exports (million/year)



Conclusions and recommendations

This analysis begins to address the need to plan for a long-term nutrient balance, given the quantity of nutrients generated by the concentrated poultry industry in the Potomac headwaters. The model results suggest a number of conclusions, which are listed below with recommendations.

Conclusion 1: Nutrient generation by poultry exceeds or roughly equals the nutrient uptake capacities of the region's major poultry-producing areas.

While clear differences are found among the areas in the region, the major poultry-producing areas—Grant, Hardy, and Pendleton Counties and the Lost River watershed within Hardy County—show common results. Conservative calculations show that nitrogen uptake capacities are significantly exceeded in Hardy and Pendleton Counties and in the Lost River watershed. In these areas, excess nitrogen is being generated; if land applied, this excess nitrogen will end up either in surface water, groundwater, or the atmosphere. In Grant County and in the Potomac headwaters region as a whole, nitrogen generation by poultry roughly equals the nitrogen uptake capacities.

Similar calculations show that phosphorus uptake capacities are significantly exceeded in all of the major poultry producing areas and in the region as a whole. This imbalance suggests that soil phosphorus levels are likely to increase year after year if most poultry litter is applied to agricultural land within the area in which it is generated. In the short term this may be beneficial. But for a balance to be achieved in the long term, phosphorus applications in these areas will need to be significantly less than the amount of phosphorus generated by poultry in these areas.

Recommendation: Efforts that address nutrient generation and use should focus on those areas that are most strikingly out of balance.

Hardy County and particularly the Lost River watershed within Hardy County require the most immediate attention. Pendleton and Grant Counties also show significant need for assistance. These areas generally correspond to the high priority areas identified for assistance by the Natural Resources Conservation Service and other cooperating agencies through the Potomac Headwaters Land Treatment Watershed Project. Through this project, many farmers have signed long-term contracts and have begun to receive technical assistance, grants, and loans to improve their management of poultry litter. Future efforts in these regions must focus on the remaining growers, especially those who use the least proper management practices, and on the proper distribution of litter throughout the watersheds.

Recommendation: To minimize nitrogen losses and ensure a long-term phosphorus balance, pasture and crop management practices must improve over time.

The relative nitrogen and phosphorus content of poultry litter does not generally match the nutrient needs of plants; therefore, when litter is applied to satisfy nitrogen needs, phosphorus is generally over-applied. Field data show that some soils in these areas already contain high and very high levels of phosphorus. Eventually, litter applications on pasture and cropland should be limited to meet phosphorus requirements and should be guided by the phosphorus index. Additional nitrogen applications, presumably from commercial fertilizers, would be required. Recommendations for litter application rates will eventually need to be based on these new conditions.

On pasture, rotational grazing, in which fields are fenced into smaller areas and livestock are rotated through these areas, shows promise as a management technique that can rejuvenate pasture plants and improve production while applying fewer nutrients. This technique may prove to be valuable if litter applications on pasture are limited to meet phosphorus requirements. Rotational grazing and other improved pasture management practices should be more vigorously promoted in the region. The U.S. Fish and Wildlife Service’s Partners for Wildlife Program should be expanded and fully utilized as called for in the President’s Clean Water Action Plan.

Conclusion 2: Litter exports can play an important role in approaching a nutrient balance.

Considerable quantities of poultry litter are already being exported out of the region. The analysis demonstrates that exports of 20 to 40% of generated litter from the region as a whole—an ambitious goal for the future—would be an important step toward balancing nutrient generation with uptake. Litter exports, while not the only long-term solution, clearly can play an important role in approaching a nutrient balance.

Recommendation: Agencies should continue to promote poultry litter exports.

Poultry litter is a nutrient-rich resource that is in demand in areas outside the region. If economic barriers to long-distance transport can be overcome, exports can be increased. Agencies have already begun programs to promote litter exports.

For example, the Potomac Interagency Water Quality Office in Moorefield established a telephone hotline in 1996 that links farmers who have litter surpluses with prospective buyers. This hotline has helped facilitate the export of thousands of tons of poultry litter from the region.

Although they are not currently given, state subsidies toward transportation costs of exporting poultry litter should be considered, especially if the exports will significantly improve the nutrient balance and prevent the need for other costly government programs.

Support for existing programs must be sustained, and promising new opportunities must be identified and funded. Once programs show significant potential, they must go beyond demonstration projects and be implemented fully.

Recommendation: Particular emphasis should be placed on composting, which can create local jobs and place more money in farmers' pockets.

Because composted litter contains more nutrients per unit weight compared with raw litter, it may prove to be a more economical alternative for export. The Natural Resources Conservation Service and other partners have established a poultry litter composting demonstration project in Fisher. If large quantities of poultry litter were converted from a waste material into a valuable product through composting, local jobs would be created.

Conclusion 3: Litter exports alone will not balance phosphorus generation and uptake in the long term.

Based on conservative calculations, phosphorus generation by poultry alone in the region is four times the phosphorus uptake capacity. In the Lost River watershed, generation and uptake are most significantly out of balance: Generation by poultry totals eleven times the uptake capacity. Even if 40% of the region's litter were exported, the phosphorus in the remaining litter would still greatly exceed the phosphorus uptake capacity. Phosphorus generation is so far out of balance in the region's major poultry producing areas that expanded litter exports alone will not be sufficient to balance phosphorus generation and uptake in the long term.

Recommendation: Alternative methods for balancing nutrient generation and uptake must also be promoted.

Poultry litter is sometimes used as cattle feed; this alternative use can help to balance flows in the region because litter fed to cattle is not returned directly to agricultural land. Research may demonstrate the feasibility of incinerating poultry litter, processing litter into wood products, or using litter as a component of new road surfacing products.

Shifting the region's crop mix or implementing new management practices could increase phosphorus uptake on farmland. In woodlands with phosphorus-deficient soil, litter applications can promote tree growth, sequester carbon, and reduce atmospheric concentrations of carbon dioxide, a greenhouse gas. Also, feed additives, genetically engineered feed, or new feed formulations could minimize the phosphorus content of poultry litter; poultry integrators should conduct research into these alternatives.

While these options may prove to play a role in achieving a long-term nutrient balance, each also has its own problems and uncertainties. Research must continue so that a realistic mix of methods can be found that will balance nutrient generation and uptake.

Conclusion 4: More comprehensive data and more detailed assessments will be useful in the future.

An upper-bound analysis such as this one outlines general patterns and allows agencies to identify broad needs for initiatives. Over time, however, more detailed information will be needed and more detailed evaluations should be conducted.

Recommendation: Collect more data.

Better data are required to refine the nutrient uptake and poultry production capacities presented in this report. Particularly helpful would be accurate and current data for poultry and cattle production by county and watershed, the percentage of cattle raised in confinement, the portion of pasture accessible to manure spreaders, the disposition of nitrogen in litter applied to pasture and cropland, the current average soil phosphorus levels found in each study area, commercial fertilizer use, sludge spread by septage haulers, and deer consumption of pasture plants.

Recommendation: Conduct more detailed evaluations.

More detailed evaluations can focus on particular areas within the region, or on particular nutrient cycles and pathways. For example, a more detailed evaluation of the Lost River watershed could help to set goals for litter exports from the watershed or to generate new crop or pasture management recommendations that take current soil phosphorus levels into account. A more detailed model of nitrogen cycles and losses on pasture could help to refine the calculation of nitrogen uptake capacities and could help to refine litter application recommendations.

Most fundamentally, the analysis suggests that we have a choice: To achieve a long-term nutrient balance, either agencies and farmers can continue to improve their efforts to curb the poultry industry's environmental effects, or the scale of poultry production in the region must ultimately be limited.

The poultry industry has developed into the region's most economically important industry. Hundreds of farmers raise millions of birds each year; jobs are provided not only for these farmers but also for others whose businesses are linked to the industry. The significant capital investments made by farmers require many profitable years of production to pay off. Clearly, rather than reducing the current scale of the poultry industry, the most realistic option is to continue to improve nutrient management practices, increase litter exports, and promote alternative litter uses.

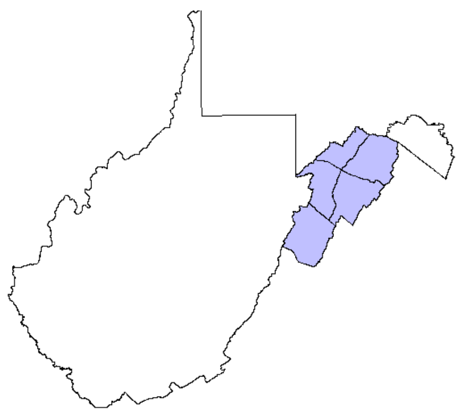
Efforts currently under way by agencies and farmers to address the environmental problems associated with concentrated poultry production are an extremely valuable first step. These activities are important; over time, they should help to minimize excess nitrogen applications and improve water quality by minimizing nitrogen losses. But it is unclear now whether these efforts will be sufficient in the long term, especially in terms of preventing future phosphorus losses.

Preserving the long-term prospects for this industry requires addressing its long-term environmental impacts.

1. INTRODUCTION

In the Potomac headwaters of West Virginia, an agricultural and forested area located along the state's eastern border, recent growth in the poultry industry has focused attention on the potential environmental consequences of excessive poultry litter accumulation and use (see Figure 1). Numerous government agencies have linked surface water and, potentially, groundwater impairment to the large quantities and current management of nutrients and pathogens in poultry litter, other types of livestock manure, and commercial fertilizers (Smith, 1992; Mathes, 1996; PVSCD, et al., 1996; USEPA and WVDEP, 1998a, b, and c; USEPA, 1998; Ator et al., 1998). Government agencies and farmers have responded with programs designed to improve water quality (PVSCD, et al., 1996; NRCS, 1998a).

Figure 1: The Potomac headwaters region of West Virginia

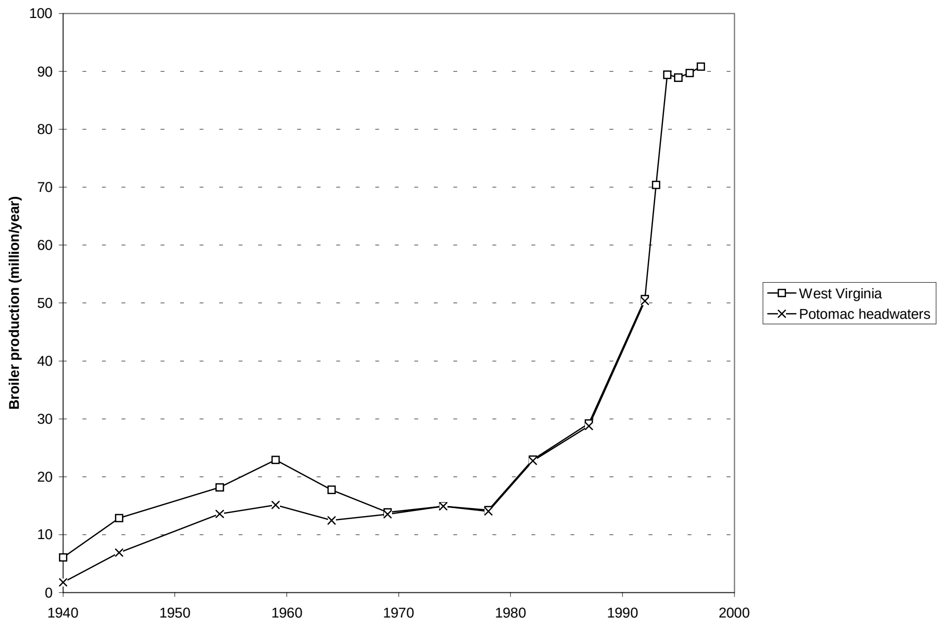


Note: The region includes Grant, Hampshire, Hardy, Mineral, and Pendleton Counties.

This report focuses on nutrients, and in particular on nitrogen (N) and phosphorus (P). After litter, manure, or commercial fertilizers are applied on agricultural land, N and P can be lost to rivers, where the ensuing nutrient enrichment can lead to algal blooms, the growth of undesirable organisms, oxygen depletion, and fish kills. Recent data find high N levels in several streams in the Lost River watershed, a portion of the region with a high density of poultry houses (Gillies, 1998). Although not linked conclusively or exclusively to nutrients from agriculture, algae growth has also been found locally in several rivers in the region (Smith, 1992). But nutrients can also contribute to problems far downstream: the Potomac River empties into the Chesapeake Bay, and nutrients from the headwaters region in West Virginia complicate solutions for reducing nutrient levels in the Bay. In the entire Potomac River watershed, about 19% of N loadings and 22% of P loadings from manure originate in West Virginia (NRCS, 1998b). Recently, outbreaks of *Pfiesteria piscicida* have been identified in the Bay; excess nutrients are linked with these outbreaks. In addition to these surface water problems, N may also leach into groundwater, with potential human health effects.

West Virginia's poultry industry has grown rapidly in the last decade. Figure 2 illustrates this growth for broilers, the predominant type of poultry raised in West Virginia and the Potomac headwaters. Farmers in Grant, Hampshire, Hardy, Mineral, and Pendleton Counties—the five counties of the headwaters region—raise almost all of the state's poultry. In 1997, the industry produced about 100 million birds, which were fed with poultry feed imported from other states. The birds transformed this feed into an estimated 140 thousand tons of nutrient-rich poultry litter: a combination of manure and bedding materials such as sawdust (Basden, 1997a). Most of this litter is applied locally to agricultural land as fertilizer for pasture and field crops. Some is exported to surrounding counties and states. The current, fundamental dynamic of the region's poultry industry is the importation of nutrients in feed, the transformation of feed into litter, and the local use of these imported nutrients when poultry litter is applied on agricultural land. When these imported nutrients are overapplied, this dynamic leads to excess N losses to surface water, groundwater, and the atmosphere, as well as the eventual buildup of soil P to high levels and ensuing P losses.

Figure 2: The growth of the broiler industry in West Virginia and the Potomac headwaters



Notes: Figures are for broilers only, the predominant type of poultry raised in WV. All data through 1992 based on U.S. Department of Commerce, 1994 and previous editions of the U.S. Census of Agriculture. Data for WV for 1993-6 based on WVDA, 1997. Data for WV for 1997 from USDA, 1998. Although precise data are not available for the Potomac headwaters after 1992, the five counties rank one through four and six among WV counties for chicken inventories (WVDA, 1997). The region produces almost all WV broilers.

Poultry litter is not the only nutrient source in the region. Additional major agricultural sources include manure from other types of livestock and commercial fertilizers (Ator et al., 1998). Major non-agricultural sources include municipal and industrial sludge, human waste from septic systems, and atmospheric deposition (Ator et al., 1998). Other sources include poultry mortality (Haid and Walker, 1995) and geologic material (Gillies, 1998).

Recognizing the large contribution of poultry litter, government agencies and farmers have begun to implement a range of improved litter management practices at the farm level. In particular, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), together with other federal and state agencies, has implemented a program to assist poultry farmers through grants and low interest loans. The signup period for this program ends as this report is published, in February, 1999. As of October, 1998, the most recent month for which data are available, 212 farmers had signed contracts and pledged to implement nutrient management plans and conservation practices on 36,000 acres (Reese, personal communication). At that point, the program covered about 10 to 15% of the region's total crop and pasture acreage (U.S. Department of Commerce, 1994).

By assisting individual farmers, this program focuses attention on nutrient flows found on individual farms. But while solutions to water quality problems must be dealt with one farm at a time, an assessment of nutrient flows at broad geographic scales over the long term is also valuable. An analysis at a broad scale can help to develop priorities, to assess the overall magnitude of changes that must be made, and to provide a baseline for measuring progress. A long-term assessment is especially valuable for addressing the buildup of P in the soil year after year as P-rich poultry litter is applied to farmland. While many soils in the Potomac headwaters region are still deficient in P and will respond well to P applications during this buildup period, they cannot absorb this level of fertilization indefinitely. Eventually, to avoid P-related water quality problems, application rates must come into line with nutrient uptake, and management practices should be guided by the P index[1] (Bhumbla, et al., undated).

This report responds to these two needs: it assesses broad geographic scales—the region as a whole, each of the region's counties individually, and one watershed within the region—and it focuses on the long term. This report asks a fundamental question: **Given the quantity of nutrients generated by the concentrated poultry industry in the Potomac headwaters of West Virginia, how can we ensure a long-term nutrient balance?**

To answer this question, the report presents a model of nutrient uptake on agricultural land and a model of nutrient generation by poultry, both illustrated in Figure 3 (this model is expanded in Section 4; see Figure 14 for an illustration of the more detailed model). These models are then used in a series of linked calculations.

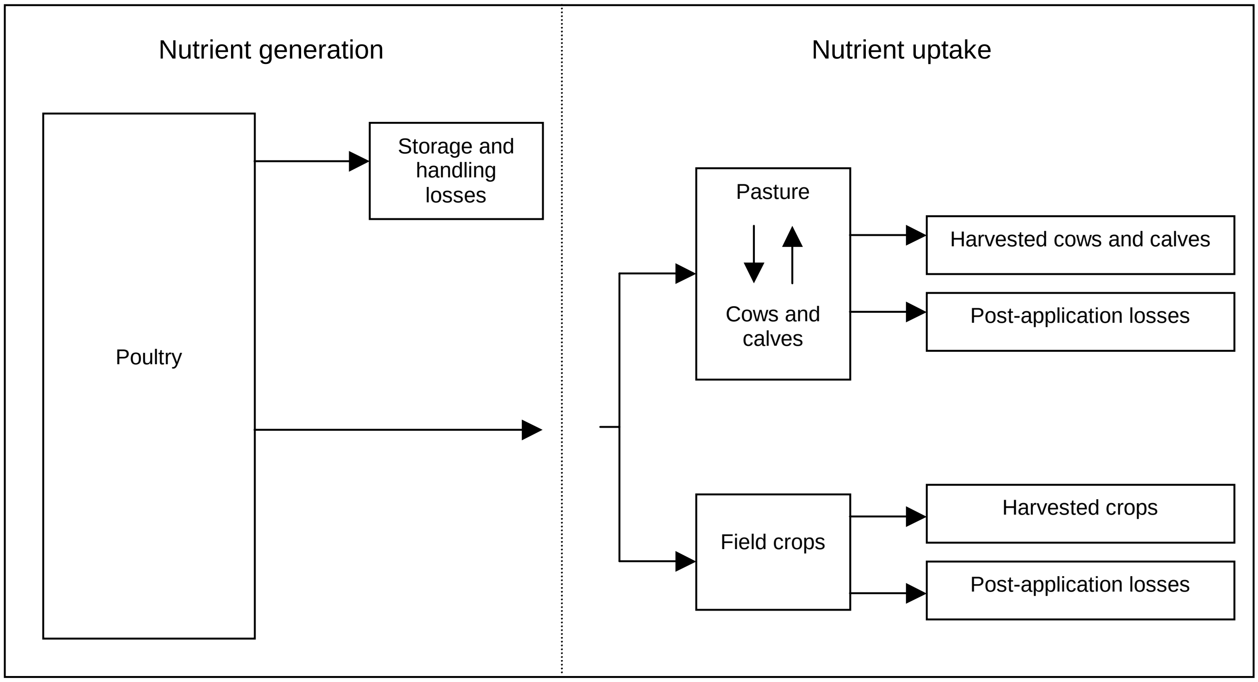
First, in Section 2, the nutrient uptake model is used to calculate nutrient uptake capacities, which are defined as the total N or P uptake on an area's farmland each year, plus unavoidable losses, such that there is no long-term buildup of soil nutrients and minimal nutrient loss to surface water, groundwater, and the atmosphere. The N and P uptake capacities account for the differences in N and P behavior in the soil and in the pathways through which losses can occur. Then, the nutrient generation model is used to calculate nutrient generation based on the current levels of poultry production; the resulting values are compared with the nutrient uptake capacities. These comparisons for each study area are the first fundamental results of the analysis.

Next, in Section 3, the analysis places a hypothetical cap on nutrient generation by setting generation in each area equal to the nutrient uptake capacities from Section 2. Using the nutrient generation model, this level of nutrient generation is converted into corresponding poultry production levels. These levels are called poultry production capacities: the maximum broiler and turkey production levels that each region can support such that the quantity of nutrients in their manure equals the nutrient uptake capacities. Poultry production capacities are then compared with current poultry production levels. These comparisons are the second fundamental results of the analysis.

Finally, in Section 4, the model is expanded to include exported litter and additional significant nutrient sources: cattle manure, commercial fertilizers, and municipal and industrial sludge. Using this more detailed model, nutrients generated by the poultry industry are assessed in a larger context that includes other major nutrient flows.

It is important to calculate nutrient uptake capacities and poultry production capacities for various geographic scales because analyses of larger areas may mask variations among smaller areas. This report therefore examines three different scales: the entire five-county Potomac headwaters region, each county separately, and the Lost River watershed within Hardy County.

Figure 3: A diagram of the basic nutrient models



Notes: Arrows represent flows of N and P. See Figure 14 for a more detailed model that includes cattle manure, sludge, commercial fertilizers, and litter exports.

To perform these calculations at broad geographic scales, the model strips away unnecessary details so that only the essentials remain. Model inputs include a number of estimates, and conservative estimates are used to ensure that the nutrient uptake capacities and poultry production capacities are upper bounds: the most N and P that each area's agriculture can use, and correspondingly, the most broilers and turkeys that can safely be raised in each area. When problem areas are identified using conservative estimates, more refined estimates will only reinforce the results; therefore, the conclusions of this analysis are useful for informing public policy and guiding future research. A critical reading of an upper-bound analysis such as this will focus not on the precision of the estimates, but on whether or not the estimates are conservative and the simplifying assumptions are reasonable.

The current study uses the most recent data available to build on and add detail to several previous studies of nutrient flows in the Potomac headwaters region. The NRCS assesses nutrient generation by confined livestock and nutrient uptake by crops and pasture for all counties in the United States (Lander et al., 1998). This report compares N and P generation with N and P uptake, and flags counties where generation exceeds uptake as those most likely to encounter problems due to excess nutrients. This comparison is similar to what is presented in Section 2 of this report; however, the NRCS report relies on older poultry data that were collected before the rapid growth of the industry. Still, this report suggests that Grant, Hardy, and Pendleton Counties—the major poultry-producing counties in the region—were already experiencing or almost experiencing a nutrient surplus.

A previous report, released in 1996, focuses on the Potomac headwaters (PVSCD et al., 1996). Although this report does not specifically compare nutrient generation with uptake, it compares poultry litter production with agricultural land for each watershed in the region. Results vary considerably by watershed, but litter production per acre is reported highest in the Lost River and South Fork watersheds. In comparison to the current analysis, this report is based on older data, focuses solely on watersheds, does not distinguish between cropland and pasture processes, and does not specifically calculate N or P uptake.

In a study of the economic feasibility of establishing centralized composting facilities, Fritsch and Collins (1993) estimate potential land application of poultry litter in each of the region's five counties. They base their calculations on the N content of the litter and N uptake on cropland and pasture. Although they do not perform a separate calculation for P, they state that P-based application rates would be roughly 75% less than N-based rates.

To summarize, this analysis uses more current data to build on these three previous studies. It considers three different geographic scales and requires a long-term stability of soil P levels in the region. Cattle manure applications, poultry litter exports, sludge applications, and commercial fertilizer use are also considered.

This analysis is fixed in time and is fundamentally based on crop and pasture data from the mid- to late 1990s. Of course, the future agricultural situation might change in ways that would affect the results; for example, the crop mix may shift or pasture may be developed into housing tracts. If major shifts such as these take place in the future, this analysis should be updated.

2. NUTRIENT UPTAKE CAPACITIES AND NUTRIENT GENERATION

The nutrient uptake model diagrammed in Figure 3 is first used to calculate the amount of N and P that each area can recycle each year without environmental degradation. These figures, called nutrient uptake capacities, are calculated for N and P on cropland and pasture, the two predominant types of land on which poultry litter is applied. Because they represent a small percentage of the land area on which litter is applied, the model does not consider uptake in vegetable and fruit production or uptake on non-agricultural land such as residential lawns or forested areas.[2]

Recall that nutrient uptake capacity is defined as the total N or P uptake on an area's farmland each year, plus some level of unavoidable losses, such that there is no long-term buildup of soil nutrients and minimal nutrient loss to surface water, groundwater, and the atmosphere.

N and P uptake capacities are different due to differences in N and P behavior in the soil and in the pathways through which losses can occur. The N uptake capacity incorporates atmospheric losses as well as losses to surface water and groundwater. Due to the tendency of N to be lost soon after application, it would be expected that N use above the uptake capacities would result in a short-term imbalance and loss of excesses to surface water, groundwater, and the atmosphere.

P behaves differently. Excess P tends to bind to soil particles, where it can build up in the soil year after year, especially in clay soils like those found in the Potomac headwaters region. P is unlikely to leach into groundwater unless soil P levels are high and the water table is near the surface; therefore, P losses are most likely to occur through soil erosion. Unlike N, P is not lost to the atmosphere. The P uptake capacity calculation recognizes that P, compared with N, is less prone to losses.

P applications on P-deficient soils are beneficial for crops, and are recommended for improving soil fertility in the short term. However, if P is overapplied year after year, soil P levels will eventually be high enough that, on average, sufficient P need only be applied to compensate for P uptake in the current season plus unavoidable losses[3]; these future P applications should also be guided by the P index. This analysis takes this long-term view and bases the P uptake capacity on replacing that which is harvested and removed or unavoidably lost.

2.1 Nutrient uptake capacities on cropland

This analysis considers nine categories of field crops: alfalfa hay, other hay, corn for grain, corn for silage, wheat, oats, barley, rye, and soybeans. For each crop and each county, nutrient uptake is calculated by multiplying nutrient content per unit of production by total production (see Appendix B for a sample calculation).

The nutrient content corresponds to the harvested portion of the plant, or the nutrients actually removed from the field. For example, the nutrient content of corn for silage is greater than that of corn for grain, because more of the corn plant is used for silage than for grain. Nutrient content data are based on a recent assessment conducted by the NRCS (Lander et al., 1998); these values are shown in Table A-1 in Appendix A. Production data are based on the average of the 1995 and 1996 growing seasons (WVDA, 1997) and are summarized in Table A-2. Uptake for the Potomac headwaters is simply the sum of the county values. Production data are not available by crop for the Lost River watershed; therefore, total uptake for the watershed is estimated based on the percentage of Hardy County cropland located in the Lost River watershed (see Table A-3 for details).

To convert uptake into uptake capacities, losses after field application are taken into account. After poultry litter is applied to cropland, the fate of field-applied N is complex. N may be lost through volatilization, denitrification, leaching, and runoff. N in the soil may also be lost through erosion. Due to this complexity, N losses are estimated at the high end of the range presented in a recent publication related to manure impacts on surface and groundwater quality (Sharpley et al., 1998). This estimate ensures that the N uptake capacities are upper bounds. Total post-application N losses are estimated to be 30% of field-applied N.[4] Note that post-application losses are in addition to losses taking place during storage and handling of litter before field application; these losses are considered below when assessing nutrient generation.

After the application of poultry litter, some P may also be lost. P losses are most likely to occur through erosion and runoff. P can leach into groundwater, although this is unlikely to occur in most soils found in the Potomac headwaters region. Generally, the potential for dissolved P losses through surface runoff and leaching increases with the amount of P in the soil (Sharpley et al., 1998). P losses are conservatively estimated to be 5% of field-applied P.[5]

Table 1 summarizes the results of these calculations after accounting for both uptake and losses: N and P uptake capacities on cropland for each study area. Hay and corn account for almost the entire nutrient uptake capacity on cropland.

Table 1: Nutrient uptake capacities on cropland (thousand pounds/year)

Area	N	P
Potomac headwaters	9,132	1,103
Grant Co.	1,310	153
Hampshire Co.	2,314	292
Hardy Co.	2,482	298
Mineral Co.	1,082	132
Pendleton Co.	1,944	228
Lost River watershed	916	110

Notes: Nutrient content data are taken directly from Lander et al., 1998 (see Table A-1). Production data are 1995-96 averages from WVDA, 1997 wherever possible, except as specified in Table A-2. Post-application losses of 30% for N and 5% for P are included in these figures. Total uptake for the Lost River watershed is estimated as 37% of the total from Hardy County based on the ratio of cropland between watershed and county shown in Table A-3.

2.2 Nutrient uptake capacities on pasture

Nutrient flows are more complex on pasture than on cropland due to the additional nutrient cycles that occur when grazing animals consume nutrients and return nutrients to the soil. Additional losses are also encountered—especially N losses from the urine and feces of pastured animals.

For the purposes of this analysis, calculating nutrient uptake capacities on pasture requires an accounting of the major outputs and losses from the pasture system. Nutrients that cycle through plants, animals, and the soil and that remain within the system do not need to be explicitly tracked. The model used to calculate pasture nutrient uptake capacities includes the following components:

- the nutrients removed when pastured livestock are harvested;
- unavoidable N losses through volatilization, denitrification, and leaching from the applied poultry litter and from the urine and feces returned to the soil by pastured livestock; and
- unavoidable P losses from the applied poultry litter.

Farmers apply nutrients to pasture at a range of application rates, depending on pasture mix, livestock type, yield goals, soil type, manure availability, nutrient management plan requirements, and other factors. Some farmers who have an excess of poultry litter may apply litter at rates greater than the needs of the pasture. At the other extreme, when a pasture contains the ideal mix of grasses and N-fixing legumes, nutrient requirements can be small (Joost, 1996). The approach used in this report, basing nutrient requirements on the removal of harvested livestock plus unavoidable losses, lies between these extremes.

Cow-calf production is the dominant pasture system in the region (Bucklew, personal communication); therefore, for simplicity, the model assumes that pasture acreage is used in cow-calf production. The model further assumes that the pasture supports, on average, one cow-calf unit on every two acres, and that feeder calves are harvested once per year at an average weight of 500 pounds (Bucklew, personal communication). Cows are assumed to weigh 1,200 pounds, and are assumed to be culled after six years (Rayburn, personal communication).

According to the equations outlined by Rayburn (unpublished manuscript), a 500-pound calf and a 1,200-pound cow contain about 13 and 27 pounds of N, respectively (see Appendix B for a sample calculation). Accounting for the assumptions that each cow-calf pair is raised on two acres, that calves are harvested each year, and that cows are culled once every six years, N output through harvested calves and cows totals about 9 pounds per acre per year.

As described above, N losses on pasture include volatilization, denitrification, and leaching. All three types of losses can occur when litter is applied and when urine and feces are returned to the soil. These losses are highly variable. To estimate losses through these three pathways, estimates are taken from experiments that track N flows on fertilized pastures grazed by beef cattle (Scholefield et al., 1991). Total N losses from these systems—including volatilization, denitrification, and leaching—range from 40% to 90% of applied N. These rates include losses directly from the applied fertilizer as well as losses from urine and feces. On average, loss rates in these systems total 57%. This analysis conservatively rounds this figure to 60%.

N uptake capacities on pasture are calculated by combining N output through harvested calves and cows, post-application losses, and the assumption that 75% of pasture acreage is flat enough to be accessible to manure spreaders[6] (Table A-4 lists total and accessible pasture acreage for each study area).

P uptake capacities on pasture are calculated using a similar method. A 500-pound calf contains about 3 pounds of P, and a 1,200-pound cow contains about 8 pounds of P. Using the same assumptions for P as for N, these figures translate into a P output through harvested calves and cows of about 2 pounds P per acre per year. Because P is lost predominately through erosion, P losses on pasture are assumed to be small. It is conservatively assumed that 5% of P applied in poultry litter is lost after field-application.[7]

Table 2 presents nutrient uptake capacities on pasture for all study areas. Results for each county are calculated based on the assumptions outlined above. Results for the Potomac headwaters region are calculated by summing the county values. The Lost River watershed figure is estimated based on the percentage of Hardy County pasture located in the Lost River watershed.

Table 2: Nutrient uptake capacities on pasture (thousand pounds/year)

Area	N	P
Potomac headwaters	3,551	406
Grant Co.	674	77
Hampshire Co.	610	70
Hardy Co.	789	90
Mineral Co.	387	44
Pendleton Co.	1,091	125
Lost River watershed	248	28

Notes: N and P export per acre are based on N and P in harvested cows and calves plus post-application losses of 60% for N and 5% for P. Total uptake for the Lost River watershed is estimated as 31% of total from Hardy County based on the ratio of pastureland between watershed and county shown in Table A-3. Total pasture areas are for 1992 and are based on U.S. Department of Commerce, 1994. Accessible percentage assumed to equal 75% of total pasture area.

2.3 Total nutrient uptake capacities

Total nutrient uptake capacities are calculated by summing the results from cropland and pasture. Figure 4 illustrates nutrient uptake capacities for N and P for each county and for the Lost River watershed. For the region as a whole, the N uptake capacity totals 12.7 million pounds per year, and the P uptake capacity totals 1.5 million pounds per year. Detailed values for each study area are listed in Table A-5.

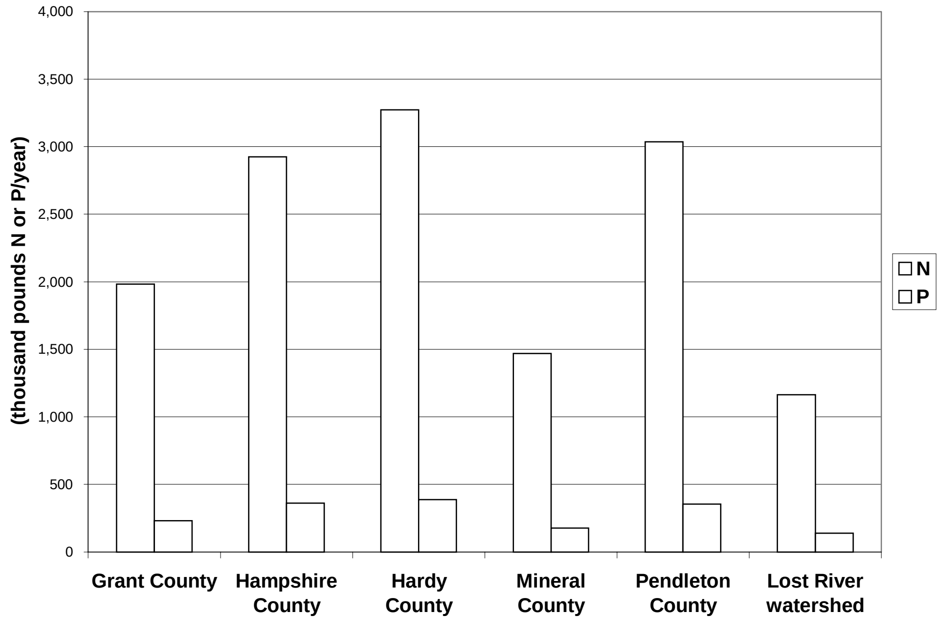
This report uses the nutrient uptake capacities in two ways. First, in the following subsection, they are compared with nutrients generated by the current populations of broilers and turkeys. Then, in Section 3, they are converted into associated poultry production capacities, and these production capacities are compared with actual poultry production levels.

2.4 Comparing nutrient uptake capacities with nutrient generation

The nutrient uptake capacities shown in Figure 4 can be satisfied by nutrients generated from a variety of animal and non-animal sources. This section considers only one of these sources: poultry. The nutrient generation model is used to calculate nutrients generated by current production levels of broilers and turkeys. Generation is then compared to the nutrient uptake capacities in each study area. Ignoring all other nutrient sources, this calculation results in highly conservative estimates of nutrient generation and generous comparisons with the nutrient uptake capacities.

Calculating nutrient generation by broilers and turkeys requires a number of assumptions about populations by study area and characteristics of the manure, the production systems, and the animals themselves.[8] Tables A-6 and A-7 summarize these assumptions. Table A-8 shows calculated N and P production by broilers and turkeys in each study area (see Appendix B for a sample calculation for broilers).

Figure 4: Nutrient uptake capacities



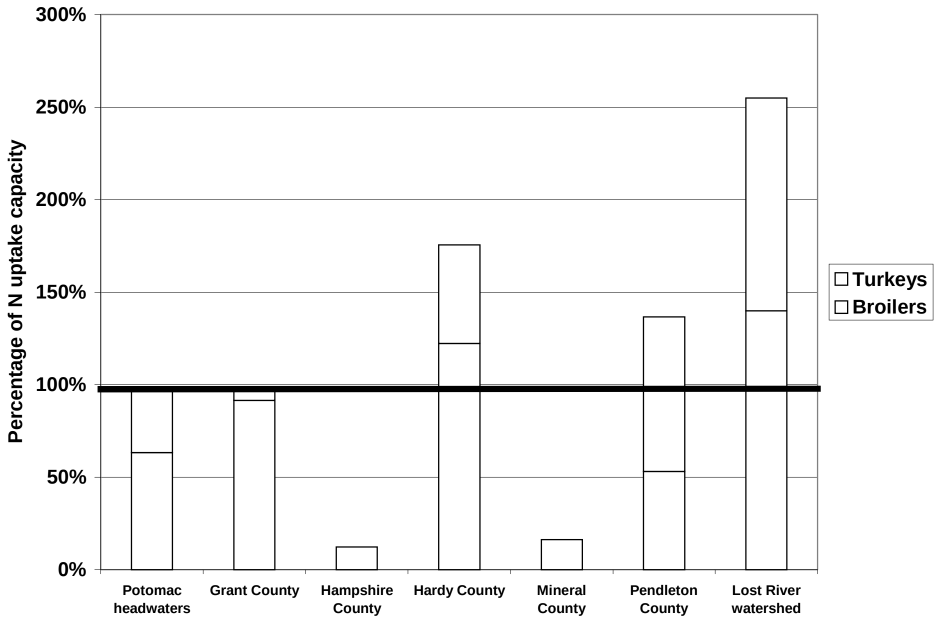
Notes: Based on uptake and losses on cropland (Table 1) and on pasture (Table 2). Detailed values are in Table A-5.

The first fundamental results of the analysis are shown in Figures 5 and 6, which illustrate nutrient generation in each area as a percentage of the nutrient uptake capacities. Figure 5 indicates that, in the major poultry-producing areas—Grant, Hardy, and Pendleton Counties and the Lost River watershed within Hardy County—and in the region as a whole, the conservative calculations of N production by broilers and turkeys exceed or roughly equal the N uptake capacities. Figure 6 shows that in these areas, conservative calculations of P production by broilers and turkeys significantly exceed the P uptake capacities. It is useful to bear in mind that, because the nutrient uptake and generation figures used here embody conservative estimates, actual N and P uptake are likely to be lower, while actual N and P generation are likely to be higher.

In the areas where generation does not exceed the uptake capacities, proper handling, distribution, and application of the litter to farmland within the area is likely to minimize current N losses to waterways and the buildup of P to critical levels in the soil. But in the areas where generation exceeds the uptake capacities, achieving a balance between generation and uptake will require other measures. For example, a balance could be approached by expanding the scale of poultry litter exports, feeding processed litter to cattle, or expanding other alternative litter uses. Another potential solution would be to use the litter locally but to increase nutrient uptake by crops or pasture by shifting the area’s crop mix. Conversely, nutrient generation could be reduced by using feed additives or genetically engineered crops as feed that reduce the P content of litter, or by limiting the scale of poultry or livestock production.

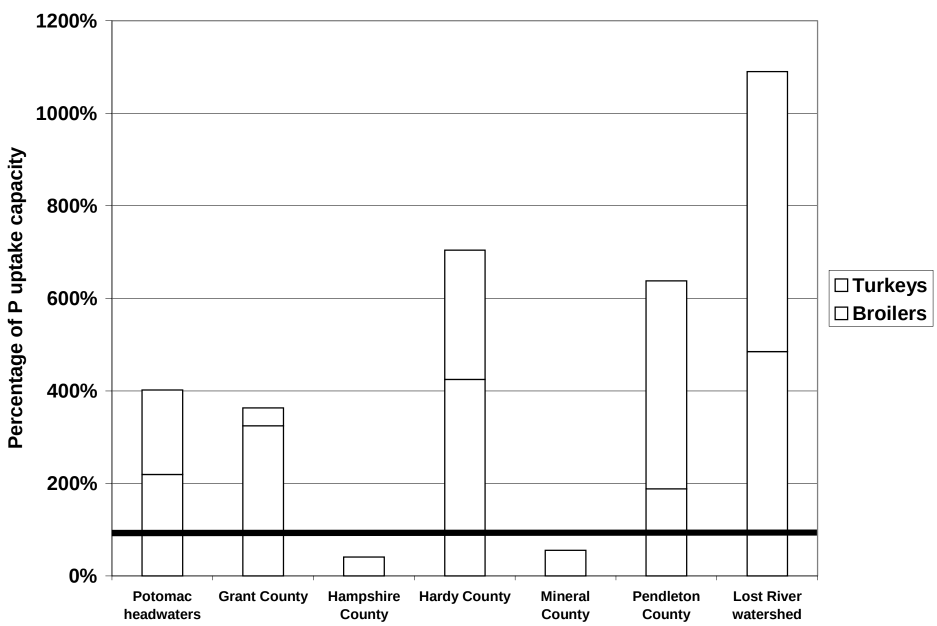
While Figures 5 and 6 allow a comparison between nutrient uptake capacities and nutrient generation, they do not indicate the maximum broiler and turkey populations that each area can safely support in the long term. The following section presents these poultry production capacities.

Figure 5: N uptake capacities compared with N generated by broilers and turkeys



Notes: N uptake capacities from Table A-5. N generated by broilers and turkeys from Table A-8.

Figure 6: P uptake capacities compared with P generated by broilers and turkeys



Notes: P uptake capacities from Table A-5. N generated by broilers and turkeys from Table A-8.

3. POULTRY PRODUCTION CAPACITIES AND POULTRY PRODUCTION

Nutrient uptake capacities are here converted into associated poultry production capacities for each area. Recall that poultry production capacities are defined as the maximum broiler and turkey production levels in each study area, such that the nutrients generated in broiler and turkey manure equal the nutrient uptake capacities. This conversion is made by applying the equations of the nutrient generation model to calculate broiler and turkey production levels, given that their nutrient output equals the nutrient uptake capacity.

Several simplifying assumptions are required. First, manure production from cattle, sheep, and swine[9] is ignored. Commercial fertilizer use and sludge applications are also left out of the model. In reality, when these nutrient sources are applied to agricultural land, they displace a portion of the uptake capacities, leaving fewer nutrients to be supplied by poultry and turkey manure. Therefore, ignoring these sources is a conservative assumption that leads to upper bounds of the region's poultry production capacities. Cattle manure use, commercial fertilizer and sludge applications, and poultry litter exports are considered in Section 4.

Broilers and turkeys represent about 99% of the region's poultry production.[10] Therefore, the model focuses solely on nutrient generation by broilers and turkeys. Ignoring nutrient generation by other types of poultry is another conservative assumption, because these other birds also generate manure that displaces a portion of the nutrient uptake capacities.

Using the same assumptions as in the previous section (see Table A-7), poultry production capacities are calculated for each area (Appendix B contains a sample calculation). Figures 7 through 13 present the results in separate graphs for each study area.

The x-axis of each figure represents turkey production and the y-axis represents broiler production. The dashed line shows the poultry production capacity associated with the N uptake capacity. It includes a range of broiler and turkey production levels; each point on the dashed line represents a pair of broiler and turkey production levels such that the N in their manure just equals the N uptake capacity. Similarly, the solid line represents the poultry production capacity associated with the P uptake capacity. In all study areas, the P-based poultry production capacity line is lower than the N-based line. Therefore, the P uptake capacity, for each study area, is ultimately the long-term limiting factor.

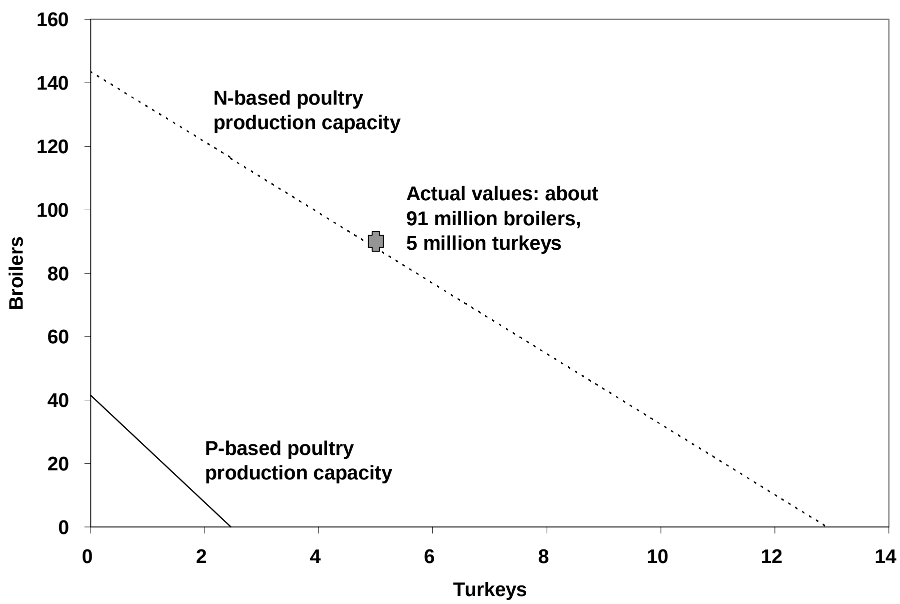
Every point that can be plotted on these figures represents a unique combination of broiler and turkey production levels. If this point falls above the N uptake capacity line, then the corresponding production levels exceed the N uptake capacity. Similarly, if this point falls above the P uptake capacity line, then the corresponding production levels exceed the P uptake capacity. Figures 7 through 13 plot estimates of actual broiler and turkey production levels in the study areas, for comparison with the N-based and P-based poultry production capacities. Table A-6 documents how these estimated actual production levels were derived.

In this approximation, which does not consider other poultry, livestock, litter exports, or the application of sludge or commercial fertilizers, Figure 7 demonstrates that actual broiler and turkey production levels in the Potomac headwaters region roughly equal the conservatively estimated N-based poultry production capacity and greatly exceed the P-based capacity. Figures 8 through 13 display results for the five counties individually and for the Lost River watershed, and allow an analysis of variations within the region. The major poultry-producing regions—Grant, Hardy, and Pendleton Counties and the Lost River watershed within Hardy County—show a similar pattern: Current broiler and turkey production levels exceed or roughly equal the N-based poultry production capacities and significantly exceed the P-based capacities. In Hampshire and Mineral counties, where poultry production is less concentrated, production levels fall below the poultry production capacities.

In the areas where current production levels fall below the production capacities, proper handling, distribution, and application of poultry litter is still required to minimize N losses and P buildup in the soil. In the areas where poultry production capacities are currently exceeded, additional measures such as those described at the end of Section 2 are required to achieve a balance between nutrient generation and use.

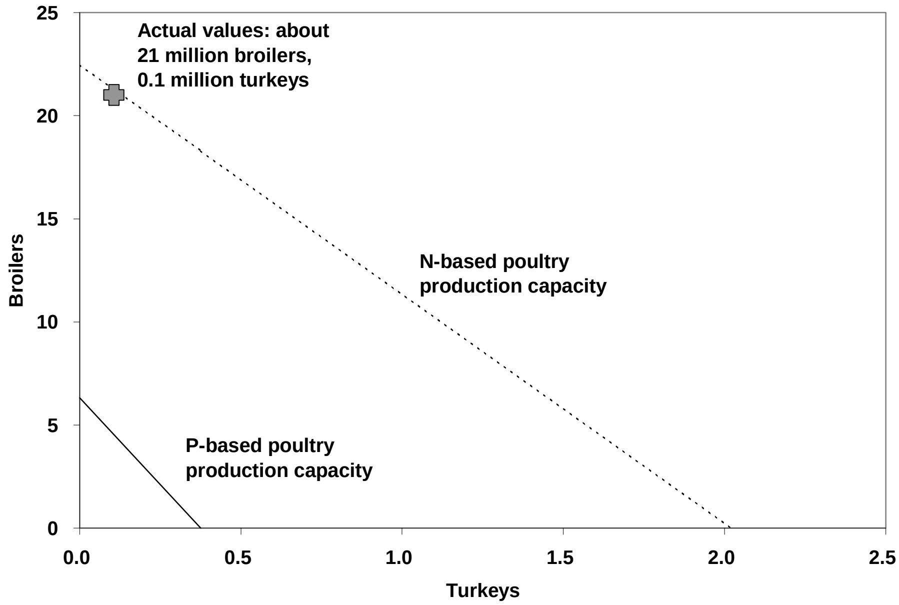
In the following section, the analysis is broadened to consider cattle manure, commercial fertilizers, sludge, and litter exports.

Figure 7: Potomac headwaters poultry production capacities (million/year)



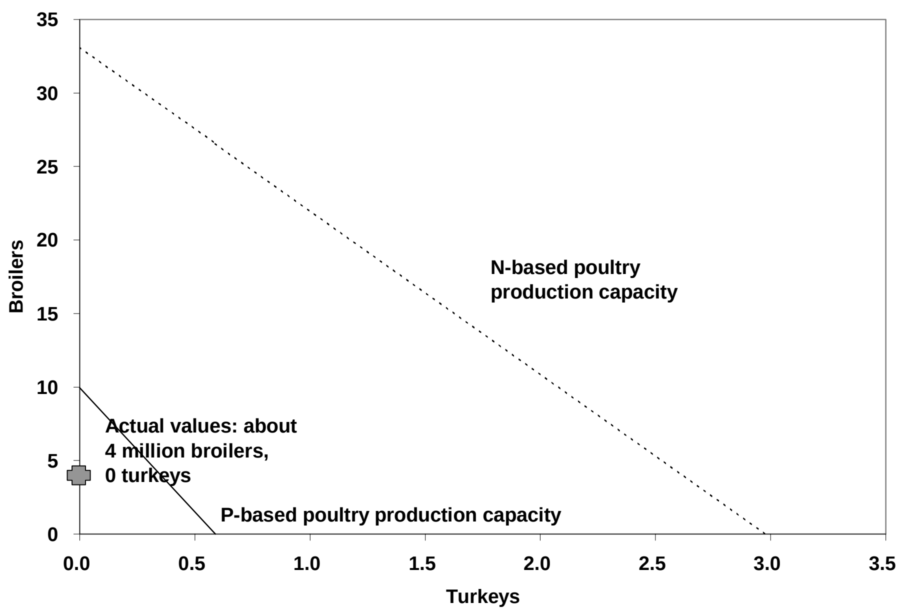
Notes: Based on N and P uptake capacities in Table A-5, broiler and turkey assumptions in Table A-7, and estimated actual production levels in Table A-6.

Figure 8: Grant County poultry production capacities (million/year)



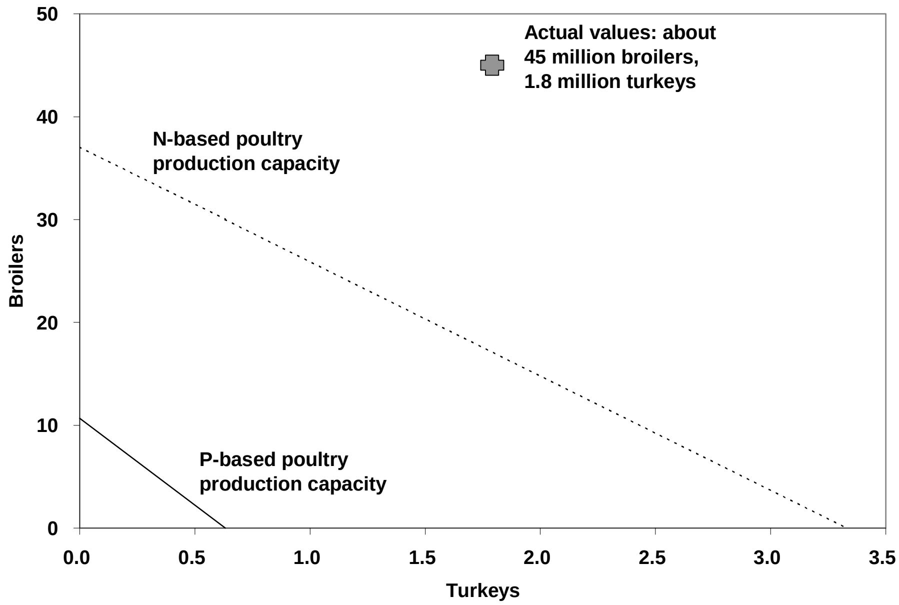
Notes: Based on N and P uptake capacities in Table A-5, broiler and turkey assumptions in Table A-7, and estimated actual production levels in Table A-6.

Figure 9: Hampshire County poultry production capacities (million/year)



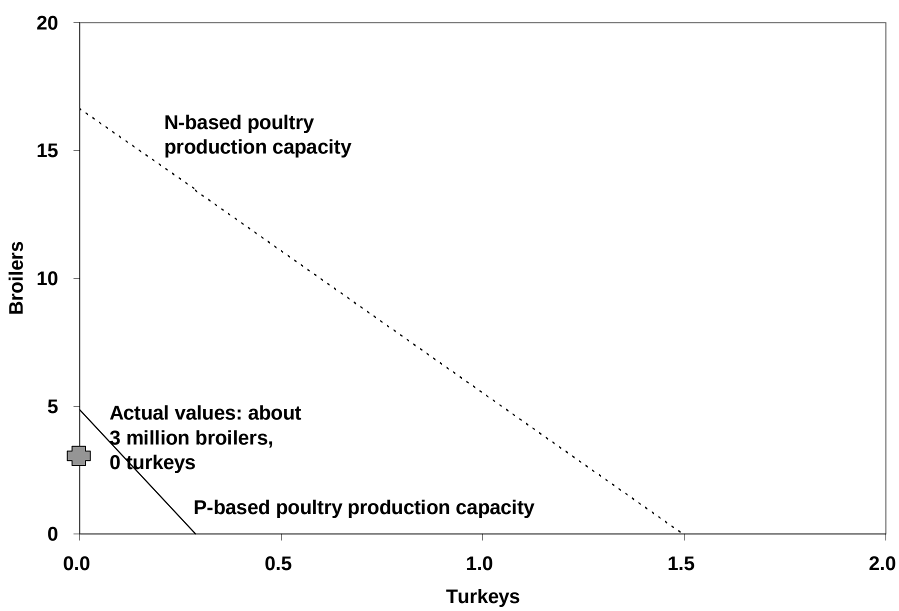
Notes: Based on N and P uptake capacities in Table A-5, broiler and turkey assumptions in Table A-7, and estimated actual production levels in Table A-6.

Figure 10: Hardy County poultry production capacities (million/year)



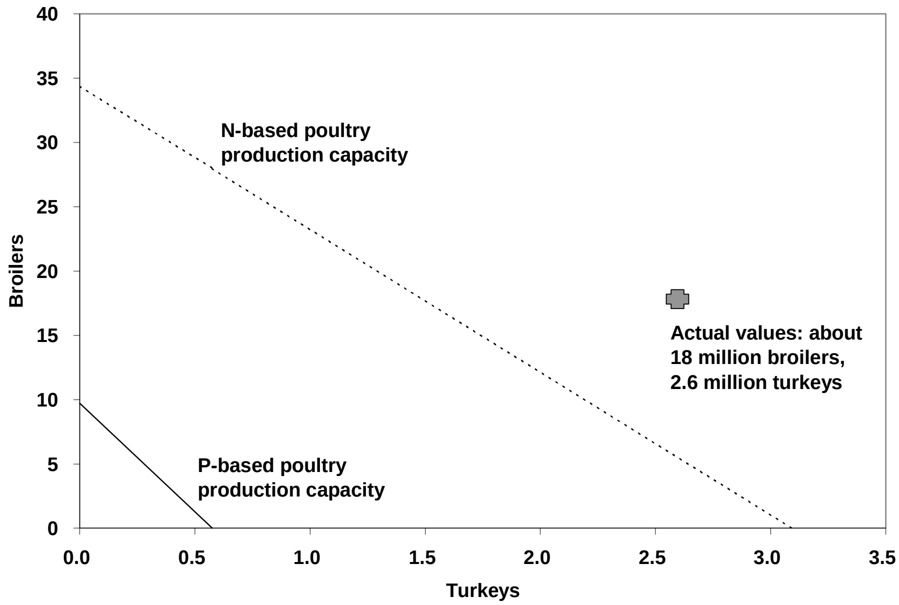
Notes: Based on N and P uptake capacities in Table A-5, broiler and turkey assumptions in Table A-7, and estimated actual production levels in Table A-6.

Figure 11: Mineral County poultry production capacities (million/year)



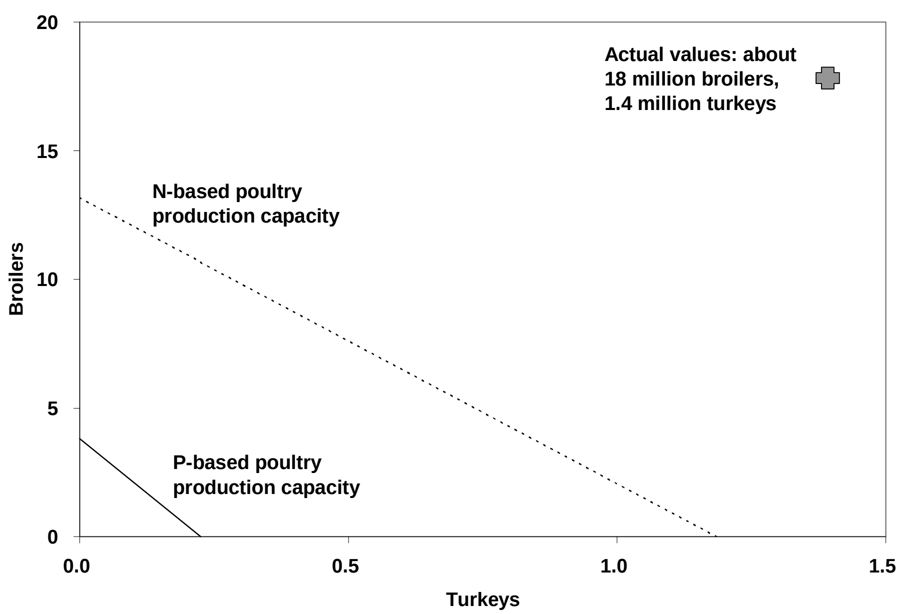
Notes: Based on N and P uptake capacities in Table A-5, broiler and turkey assumptions in Table A-7, and estimated actual production levels in Table A-6.

Figure 12: Pendleton County poultry production capacities (million/year)



Notes: Based on N and P uptake capacities in Table A-5, broiler and turkey assumptions in Table A-7, and estimated actual production levels in Table A-6.

Figure 13: Lost River watershed poultry production capacities (million/year)



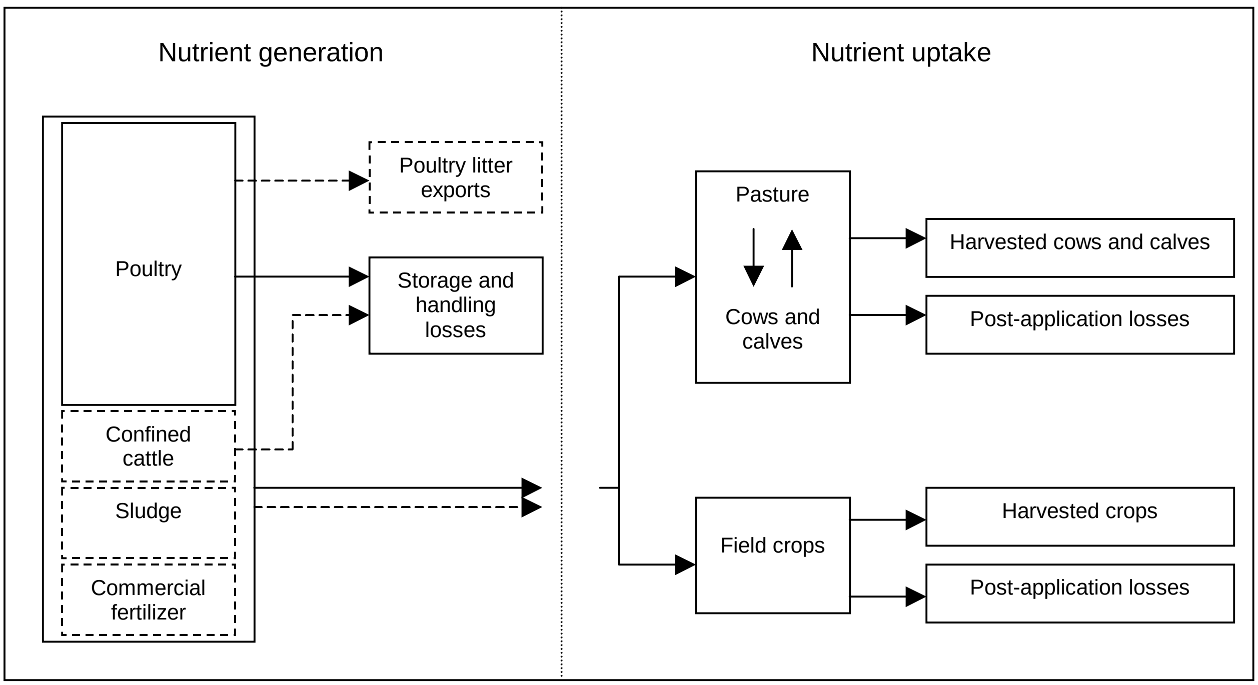
Notes: Based on N and P uptake capacities in Table A-5, broiler and turkey assumptions in Table A-7, and estimated actual production levels in Table A-6.

4. OTHER NUTRIENT FLOWS

This section extends the simple nutrient generation model presented above to consider four additional nutrient flows: the use of cattle manure, sludge, and commercial fertilizer, and the export of poultry litter. Figure 14 illustrates this more detailed model.

Recall that nutrient uptake capacity is defined as the total N or P uptake on an area's farmland each year, plus some level of unavoidable losses, such that there is no long-term buildup of soil nutrients and minimal nutrient loss to surface water, groundwater, and the atmosphere. Using this definition, these four additional flows do not alter the nutrient uptake capacities. However, these flows affect the poultry production capacities: the broiler and turkey production levels that the region can sustain while not exceeding the nutrient uptake capacities.

Figure 14: A diagram of the detailed nutrient models



Notes: Arrows represent flows of N and P. See Figure 3 for the basic model that does not include cattle manure, sludge, commercial fertilizers, or litter exports.

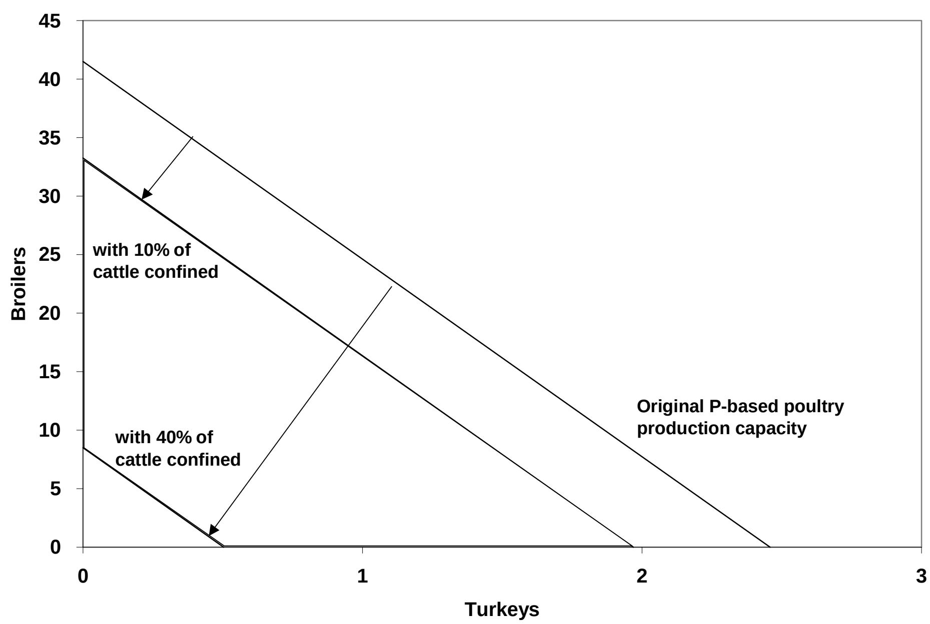
For simplicity, this section demonstrates the effect of these other nutrient flows on the Potomac headwaters region as a whole; calculations are not made for the counties individually or for the Lost River watershed. Also, this section focuses on the P-based poultry production capacities because, in all study areas, these P-based capacities are more limiting than the N-based capacities. Although they are not included in this section, the same type of analysis could also be done for the counties, the Lost River watershed, and for N.

4.1 Cattle manure

Recall that the poultry production capacities shown in Section 3 do not account for manure generated by cattle.[11] This omission clearly overestimates the broiler and turkey production levels that the region can sustain. While it would not be appropriate to account for the nutrients generated by pastured cattle because these cattle simply cycle nutrients through the pasture system,[12] manure produced by confined cattle is typically collected and spread on farmland.

No estimate of the percentage of cattle raised in confinement is available.[13] Still, Figure 15 illustrates how the P-based poultry production capacity shown in Figure 7 for the Potomac headwaters region would change if confined cattle were included in the model. This diagram demonstrates the effect of two different assumptions for the percentage of cattle confined: 10% and 40% (see Table A-6 for a breakdown of cattle populations by study area and Table A-7 for assumptions related to the characteristics of cattle manure, the production systems, and the cattle themselves). As illustrated in Figure 14, if nutrient uptake were set to equal the nutrient uptake capacity, then including nutrients generated by confined cattle would require a corresponding reduction in the nutrients generated by poultry. Assuming that somewhere between 10% and 40% of all cattle are confined, the new P-based poultry production capacity will be within the shaded area shown in Figure 15 (see Appendix B for a sample calculation).

Figure 15: Potomac headwaters P-based poultry production capacity after cattle manure applications (million/year)



4.2 Sludge

When municipal and industrial sludge are applied to farmland, nutrients in the sludge displace a portion of the nutrient uptake capacities. Therefore, when sludge is accounted for in the model, poultry production capacities are reduced. Table 3 shows the sources of sludge in the region, as well as the amount of N and P in sludge that is applied to pasture. Because these data exclude septage haulers and the U.S. Navy site in Sugar Grove, for which data are not available, they underestimate the total amount of N and P that is land applied through sludge applications.

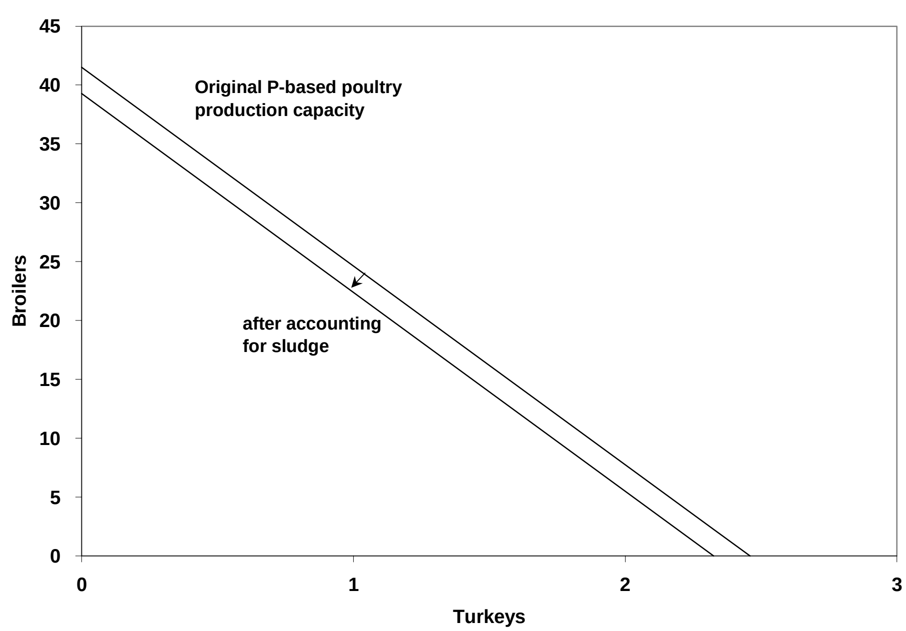
Table 3: N and P sludge applications (thousand pounds/year)

Area	N	P	Sources included	Sources excluded
Potomac headwaters	193	82	All sources listed below	All sources listed below
Grant Co.	25	13	City of Petersburg	A&S Septic Service
Hampshire Co.	1	2	City of Romney	Cox's, Carrol's, Peacemaker's Septic Services
Hardy Co.	136	59	Wampler Foods, Hester Industries	Helman's Septic Service
Mineral Co.	32	8	Upper Potomac River Commission	Wagoner's Septic Service
Pendleton Co.	N/A	N/A	None	U.S. Navy/Sugar Grove

Notes: Based on WVDEP, 1998. Amount land applied and nutrient content of sludge in Table A-9. N/A: Data not available for the only sludge source in the county. Figures are based on an average of 1996 and 1997 land applications.

Comparing these figures to the nutrient uptake capacities listed in Table A-5, N applied through sludge in the entire region totals 2% of the N uptake capacity and P applied through sludge totals 5% of the P uptake capacity. Variations by area are significant. For example, in Hardy County, where sludge from the poultry integrators Wampler Foods and Hester Industries are spread, N applied through sludge totals 4% of the N uptake capacity and P applied through sludge totals 15% of the P uptake capacity. Figure 16 illustrates the effect of including sludge in the analysis (see Appendix B for a sample calculation). This figure is similar to the previous figure that accounts for cattle manure, but in this case, with specific data rather than a range, the original P-based poultry production capacity drops to a single line rather than to a shaded area.

Figure 16: Potomac headwaters P-based poultry production capacity after sludge applications (million/year)



4.3 Commercial fertilizer

Data on commercial fertilizer use are not available by county. Table 4 illustrates the number of acres on which commercial fertilizers are applied in the Potomac headwaters, and not the actual application volumes. The 41 thousand acres of cropland in the region correspond to 42% of total cropland (97 thousand acres) in 1992, and the 10 thousand acres of pasture correspond to 5% of total 1992 pasture (215 thousand acres) (U.S. Department of Commerce, 1994).

Table 4: Commercial fertilizer use (thousand acres, 1992)

Area	Cropland	Pasture	Total
Potomac headwaters	41	10	51
Grant Co.	5	1	6
Hampshire Co.	13	4	17
Hardy Co.	10	2	12
Mineral Co.	5	2	6
Pendleton Co.	9	2	11

Notes: Data from U.S. Department of Commerce, 1994. Fertilizer use for Lost River watershed cropland estimated as 37% of total from Hardy County based on ratio of cropland between watershed and county. Totals may not match due to rounding.

These data are from 1992, when the broiler industry was roughly half its current scale. Therefore, commercial fertilizer use may have shifted from this time due to the large quantities of additional poultry litter generated since the time the data were collected. Still, the data suggest that, when the region was producing 47 million broilers per year (WVDA, 1997), farmers applied commercial fertilizer to close to one-half of all cropland. Data on commercial fertilizer use are needed to determine its effect on poultry production capacities.

4.4 Poultry litter exports

When poultry litter is exported, the nutrients contained in that litter leave the area in which they are generated. Exports are therefore an effective strategy for raising the poultry production capacities. As illustrated in Figure 14, the more litter is exported, the more birds can safely be raised because a smaller portion of the nutrients in their manure is applied locally. Especially in areas where soil P levels are not high, poultry litter is a valuable resource as a fertilizer. Litter may also be exported after conversion to other types of resources.

Government and private efforts are under way to promote litter exports to other counties within West Virginia as well as to neighboring states. However, data that track the total volume of litter exported from farms, watersheds, and counties, as well as the destinations of the shipments, are scarce. Often, litter is transported from a poultry farmer to a neighboring farmer within the same watershed or county, or to a farmer from another county within the Potomac headwaters region. To correctly account for litter exports in this model, it is essential to know the destination of poultry litter sales.

Although data are scarce, some sources give a sense of the scale of litter exports and their destinations. Rather than trying to precisely estimate litter exports, these available data are used to help understand the role that litter exports can play in alleviating the nutrient surplus in the Potomac headwaters.

The first set of data comes from a 1994 survey of Potomac headwaters poultry producers (Basden et al., 1995). The survey results paint a mixed picture of the use of poultry litter in the region: about one-half of surveyed poultry farmers use over 50% of their own poultry litter on their farms, while the other half of surveyed farmers use less than 50% of their own litter. Table 5 shows a more detailed breakdown of these results.

Table 5: On-farm use of poultry litter (1994)

Percent of litter used on-farm	Percent of producers
0%	14%
1-25%	16%
26-50%	18%
51-75%	7%
76-100%	44%
Total	100%

Notes: Data from Basden et al., 1995.

For the nutrient uptake capacity analysis, only a portion of the litter sent off-farm is considered to be exported: the portion that leaves the watershed (for the Lost River watershed calculation), the county (for the county calculations), or the Potomac headwaters region (for the five-county regional calculation). The same poultry producer survey provides data describing the destination of litter sent off-farm; Table 6 summarizes these data. The first two columns describe the litter sold that stays within the watershed, and the third and fourth columns describe the litter sold that is exported from the Potomac headwaters region. No data are given for the county scale. The data in Table 6 suggest that most sold litter stays within the watershed in which it is generated, while only a small percentage actually leaves the Potomac headwaters region.

Table 6: Destination of poultry litter that is sold (1994)

Percent of sold litter that stays in your watershed	Percent of producers	Percent of sold litter that is exported from the Potomac headwaters	Percent of producers
0%	19%	0%	63%
1-25%	3%	1-25%	3%
26-50%	17%	26-50%	13%
51-75%	6%	51-75%	5%
76-100%	55%	76-100%	16%
Total	100%	Total	100%

Notes: Data from Basden et al., 1995.

A second data source for estimating litter exports is a telephone hotline, established in 1996 by the Potomac Interagency Water Quality Office in Moorefield, that links farmers who have litter surpluses with prospective buyers. The West Virginia University Extension Service reports that this service has been responsible for the movement of 6,000 tons of poultry litter to counties in West Virginia and to neighboring states (Basden, 1997b). About 1,000 of these 6,000 tons were purchased in Hampshire, Hardy, and Mineral Counties, three of the five counties in the Potomac headwaters region (Basden, 1997b). Therefore, 5,000 tons, rather than the total of 6,000 tons, is a more appropriate estimate of exports from the region as a whole. On the other hand, the 6,000-ton total is likely to underestimate the actual amount of litter sales, because the hotline does not track shipments after the initial contact is made between sellers and buyers. About 140,000 tons of litter are generated in the region each year

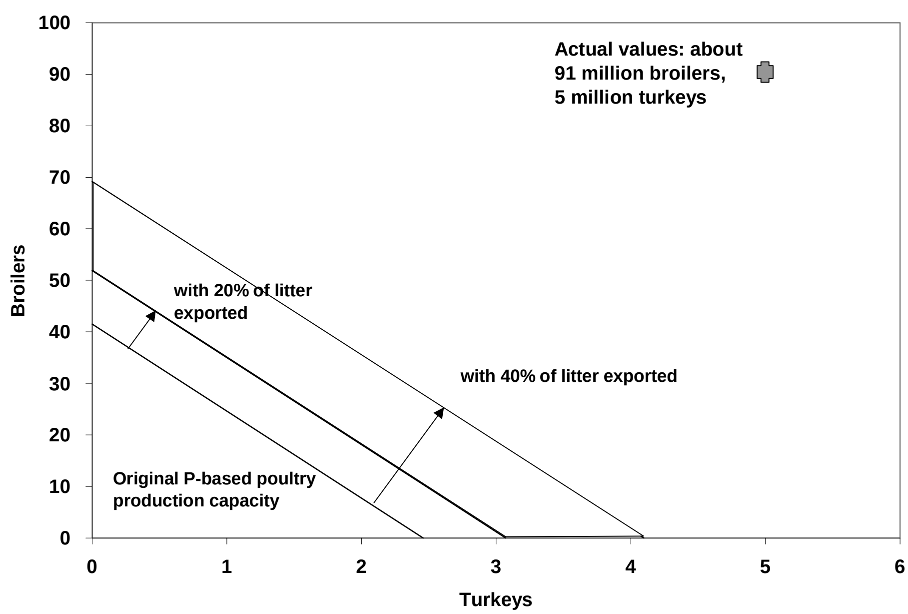
(Basden, 1997a). If the 5,000 ton estimate were accurate, this would suggest exports of about 4% of total production. But if the 5,000 ton figure is an underestimate, litter exports would then be greater than 4% of total production.

A recent total maximum daily load (TMDL) report for the Lost River watershed provides a third data source for estimating litter exports (USEPA, 1998). The report, citing a West Virginia Soil Conservation Agency (WVSCA) memo from June, 1998, reports that WVSCA expects about 5,000 tons of poultry litter per year to be transported out of the Lost River watershed to private facilities after an unspecified poultry sales operation is in full swing. This figure corresponds to exports of 19% of all broiler, turkey, and breeder litter generated in the Lost River watershed.[14]

To investigate the effect of litter exports on each area's poultry production capacities, two assumptions are considered. With the first assumption, 20% of broiler litter generated in each study area is exported from that area. The 20% figure is about five times higher than that documented by the litter hotline, and roughly equal to the figure used in the TMDL report. The second assumption considers the implications of exporting twice this amount: 40% of all broiler litter that is generated. This figure probably goes beyond what can reasonably be expected to take place in the near future, but it allows an investigation into what litter exports at this scale would mean in terms of establishing a balance between nutrient generation and use.

Figure 17 demonstrates the effect of poultry litter exports on the P-based poultry production capacity for the entire Potomac headwaters region (see Appendix B for a sample calculation). As illustrated by this graph, even with 40% of litter exported, the P-based poultry production capacity is still significantly exceeded.

Figure 17: Potomac headwaters P-based poultry production capacity after litter exports (million/year)



Many poultry farmers already export litter. Increasing the volume of litter exports is one solution for approaching a closer balance between nutrient generation and use. But, as illustrated in Figure 17, significantly more than 40% of litter would need to be exported in order to balance P generation and uptake over the long term.

5. CONCLUSIONS AND RECOMMENDATIONS

This analysis begins to address the need to plan for a long-term nutrient balance, given the quantity of nutrients generated by the concentrated poultry industry in the Potomac headwaters. The model results suggest a number of conclusions, which are listed below with recommendations.

Conclusion 1: Nutrient generation by poultry exceeds or roughly equals the nutrient uptake capacities of the region's major poultry-producing areas.

While clear differences are found among the areas in the region, the major poultry-producing areas—Grant, Hardy, and Pendleton Counties and the Lost River watershed within Hardy County—show common results. Conservative calculations show that N uptake capacities are significantly exceeded in Hardy and Pendleton Counties and in the Lost River watershed. In these areas, excess N is being generated; if land applied, this excess N will end up either in surface water, groundwater, or the atmosphere. In Grant County and in the Potomac headwaters region as a whole, N generation by poultry roughly equals the N uptake capacities.

Similar calculations show that P uptake capacities are significantly exceeded in all of the major poultry producing areas and in the region as a whole. This imbalance suggests that soil P levels are likely to increase year after year if most poultry litter is applied to agricultural land within the area in which it is generated. In the short term this may be beneficial. But for a balance to be achieved in the long term, P applications in these areas will need to be significantly less than the amount of P generated by poultry in these areas.

Recommendation: Efforts that address nutrient generation and use should focus on those areas that are most strikingly out of balance.

Hardy County and particularly the Lost River watershed within Hardy County require the most immediate attention. Pendleton and Grant Counties also show significant need for assistance. These areas generally correspond to the high priority areas identified for assistance by the NRCS and other cooperating agencies through the Potomac Headwaters Land Treatment Watershed Project. Through this project, many farmers have signed long-term contracts and have begun to receive technical assistance, grants, and loans to improve their management of poultry litter. Future efforts in these regions must focus on the remaining growers, especially those who use the least proper management practices, and on the proper distribution of litter throughout the watersheds.

Recommendation: To minimize N losses and ensure a long-term P balance, pasture and crop management practices must improve over time.

The relative N and P content of poultry litter does not generally match the nutrient needs of plants; therefore, when litter is applied to satisfy N needs, P is generally over-applied. Field data show that some soils in these areas already contain high and very high levels of P. Eventually, litter applications on pasture and cropland should be limited to meet P requirements and should be guided by the P index. Additional N applications, presumably from commercial fertilizers, would be required. Recommendations for litter application rates will eventually need to be based on these new conditions.

On pasture, rotational grazing, in which fields are fenced into smaller areas and livestock are rotated through these areas, shows promise as a management technique that can rejuvenate pasture plants and improve production while applying fewer nutrients. This technique may prove to be valuable if litter applications on pasture are limited to meet P requirements. Rotational grazing and other improved pasture management practices should be more vigorously promoted in the region. The U.S. Fish and Wildlife Service's Partners for Wildlife Program should be expanded and fully utilized as called for in the President's Clean Water Action Plan.

Conclusion 2: Litter exports can play an important role in approaching a nutrient balance.

Considerable quantities of poultry litter are already being exported out of the region. The analysis demonstrates that exports of 20 to 40% of generated litter from the region as a whole—an ambitious goal for the future—would be an important step toward balancing nutrient generation with uptake. Litter exports, while not the only long-term solution, clearly can play an important role in approaching a nutrient balance.

Recommendation: Agencies should continue to promote poultry litter exports.

Poultry litter is a nutrient-rich resource that is in demand in areas outside the region. If economic barriers to long-distance transport can be overcome, exports can be increased. Agencies have already begun programs to promote litter exports.

For example, the Potomac Interagency Water Quality Office in Moorefield established a telephone hotline in 1996 that links farmers who have litter surpluses with prospective buyers. This hotline has helped facilitate the export of thousands of tons of poultry litter from the region.

Although they are not currently given, state subsidies toward transportation costs of exporting poultry litter should be considered, especially if the exports will significantly improve the nutrient balance and prevent the need for other costly government programs.

Support for existing programs must be sustained, and promising new opportunities must be identified and funded. Once programs show significant potential, they must go beyond demonstration projects and be implemented fully.

Recommendation: Particular emphasis should be placed on composting, which can create local jobs and place more money in farmers' pockets.

Because composted litter contains more nutrients per unit weight compared with raw litter, it may prove to be a more economical alternative for export. The NRCS and other partners have established a poultry litter composting demonstration project in Fisher. If large quantities of poultry litter were converted from a waste material into a valuable product through composting, local jobs would be created.

Conclusion 3: Litter exports alone will not balance P generation and uptake in the long term.

Based on conservative calculations, P generation by poultry alone in the region is four times the P uptake capacity. In the Lost River watershed, generation and uptake are most significantly out of balance: Generation by poultry totals eleven times the uptake capacity. Even if 40% of the region's litter were exported, the P in the remaining litter would still greatly exceed the P uptake capacity. P generation is so far out of balance in the region's major poultry producing areas that expanded litter exports alone will not be sufficient to balance P generation and uptake in the long term.

Recommendation: Alternative methods for balancing nutrient generation and uptake must also be promoted.

Poultry litter is sometimes used as cattle feed; this alternative use can help to balance flows in the region because litter fed to cattle is not returned directly to agricultural land. Research may demonstrate the feasibility of incinerating poultry litter, processing litter into wood products, or using litter as a component of new road surfacing products.

Shifting the region's crop mix or implementing new management practices could increase P uptake on farmland. In woodlands with P-deficient soil, litter applications can promote tree growth, sequester carbon, and reduce atmospheric concentrations of carbon dioxide, a greenhouse gas. Also, feed additives, genetically engineered feed, or new feed formulations could minimize the P content of poultry litter; poultry integrators should conduct research into these alternatives.

While these options may prove to play a role in achieving a long-term nutrient balance, each also has its own problems and uncertainties. Research must continue so that a realistic mix of methods can be found that will balance nutrient generation and uptake.

Conclusion 4: More comprehensive data and more detailed assessments will be useful in the future.

An upper-bound analysis such as this one outlines general patterns and allows agencies to identify broad needs for initiatives. Over time, however, more detailed information will be needed and more detailed evaluations should be conducted.

Recommendation: Collect more data.

Better data are required to refine the nutrient uptake and poultry production capacities presented in this report. Particularly helpful would be accurate and current data for poultry and cattle production by county and watershed, the percentage of cattle raised in confinement, the portion of pasture accessible to manure spreaders, the disposition of N in litter applied to pasture and cropland, the current average soil P levels found in each study area, commercial fertilizer use, sludge spread by septage haulers, and deer consumption of pasture plants.

Recommendation: Conduct more detailed evaluations.

More detailed evaluations can focus on particular areas within the region, or on particular nutrient cycles and pathways. For example, a more detailed evaluation of the Lost River watershed could help to set goals for litter exports from the watershed or to generate new crop or pasture management recommendations that take current soil P levels into account. A more detailed model of N cycles and losses on pasture could help to refine the calculation of N uptake capacities and could help to refine litter application recommendations.

Most fundamentally, the analysis suggests that we have a choice: To achieve a long-term nutrient balance, either agencies and farmers can continue to improve their efforts to curb the poultry industry's environmental effects, or the scale of poultry production in the region must ultimately be limited.

The poultry industry has developed into the region's most economically important industry. Hundreds of farmers raise millions of birds each year; jobs are provided not only for these farmers but also for others whose businesses are linked to the industry. The significant capital investments made by farmers require many profitable years of production to pay off. Clearly, rather than reducing the current scale of the poultry industry, the most realistic option is to continue to improve nutrient management practices, increase litter exports, and promote alternative litter uses.

Efforts currently under way by agencies and farmers to address the environmental problems associated with concentrated poultry production are an extremely valuable first step. These activities are important; over time, they should help to minimize excess N applications and improve water quality by minimizing N losses. But it is unclear now whether these efforts will be sufficient in the long term, especially in terms of preventing future P losses.

Preserving the long-term prospects for this industry requires addressing its long-term environmental impacts.

REFERENCES

Ator, Scott W., J.D. Blomquist, J.W. Brakebill, J.M. Denis, M.J. Ferrari, C.V. Miller, and H. Zappia. 1998. *Water Quality in the Potomac River Basin: Maryland, Pennsylvania, Virginia, West Virginia and the District of Columbia, 1992-96*. U.S. Geological Survey Circular 1166.

Basden, Thomas, A. Walker, and C. Ritz. 1995. *West Virginia Poultry Production Survey: A Report on Implementation of Water Quality Improvement Practices in the Five Eastern Panhandle Poultry Producing Counties*. Requested by The West Virginia Poultry Water Quality Advisory Committee.

Basden, Tom. 1997a. *West Virginia's Potomac Headwaters Water Quality Project*. Moorefield, WV: Potomac Interagency Water Quality Project Office.

___________. 1997b. Poultry Litter Movers and Shakers. *West Virginia Farming and Forestry*. 2(7). December 1.

Bhumbla, Devinder K. Personal communication. Professor, West Virginia University. Telephone conversation, May 5, 1998.

Bhumbla, D.K., R. Heaslip, and E. Rayburn. Undated. Phosphorus Index for Nutrient Management. Prepared for WV Farm Bureau, WV Department of Agriculture, WV University Extension Service, WV State Soil Conservation Agency, NRCS, WV Poultry Water Quality Advisory Committee, and WV University College of Agriculture and Forestry.

Bucklew, Chad. Personal communication. NRCS. Meeting, June 11, 1998.

Fritsch, David A. and A.R. Collins. 1993. The economic feasibility of poultry litter composting facilities in eastern West Virginia. *Agricultural and Resource Economics Review*. 22(2):199-209.

Gillies, W. Neil. 1998. Water quality studies in a watershed dominated by integrated poultry agriculture. *Proceedings, West Virginia Nonpoint Source Conference*. October 1-3, 1998. Charleston, West Virginia. Pp. 64-81.

Haid, Ken and A. Walker. 1995. *Poultry Mortality for Broiler, Breeder, Pullet, and Turkey Operations in the Potomac Valley Soil Conservation District*. Potomac Interagency Water Quality Office. November 8.

Joost, Richard E. 1996. Nutrient cycling in forage systems. *Nutrient Cycling in Forage Systems*. Proceedings of a symposium held March 7-8, 1996 in Columbia, MO.

Lander, Charles H., D. Moffitt, and K. Alt. 1998. Nutrients available from livestock manure relative to crop growth requirements. U.S. Department of Agriculture, Natural Resources Conservation Service. Resource Assessment and Strategic Planning Working Paper 98-1. February.

Mathes, Melvin V. 1996. Streamwater Quality in the Headwaters of the South Branch Potomac River Basin, West Virginia, 1994-95, and the Lost River Basin, West Virginia, 1995. U.S. Geological Survey Administrative Report. Prepared for the U.S. Department of Agriculture and the Natural Resources Conservation Service.

Natural Resources Conservation Service (NRCS). 1998a. *Potomac Water Quality Effort*. Fact sheet from Morgantown office. February.

___________. 1998b. *The Potomac: Protecting the Nation's River*.

Potomac Valley Soil Conservation District (PVSCD), West Virginia Soil Conservation Agency, and USDA Natural Resources Conservation Service. 1996. *Potomac Headwaters Land Treatment Watershed Project Environmental Assessment: Hardy, Hampshire, Mineral, Grant, and Pendleton Counties, West Virginia*. June.

Rayburn, E.B. Unpublished manuscript. The Livestock Aspect of Nutrient Cycling in Pasture Systems. West Virginia University Cooperative Extension Service.

___________. Personal communication. Extension Agronomist, West Virginia University Extension Service. Telephone conversation, January 11, 1999.

Reese, Peg. Personal communication. Public Affairs and Marketing Specialist, NRCS. E-mail, February 3, 1999.

Scholefield, D., D.R. Lockyer, D.C. Whitehead, and K.C. Tyson. 1991. A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle. *Plant and Soil*. 132:165-77.

Sharpley, A., J.J. Meisinger, A. Breeuwsma, J.T. Sims, T.C. Daniel, and J.S. Schepers. 1998. Impacts of animal manure management on ground and surface water quality. In J.L. Hatfield and B.A. Stewart, eds. *Animal Waste Utilization: Effective Use of Manure as a Soil Resource*. Chelsea, Michigan: Ann Arbor Press.

Smith, Linda S. 1992. Potential Water Quality Problems Associated with Poultry Production in the Potomac Drainage of West Virginia. U.S. Fish and Wildlife Service, West Virginia Field Office, Special Project Report 94-05. September.

Soil Conservation Service (SCS). 1989. *Soil Survey of Grant and Hardy Counties, West Virginia*.

U.S. Department of Agriculture (USDA). 1998. West Virginia 1997 Poultry Production and Value. NASS. April 29.

U.S. Department of Commerce. 1994. *1992 Census of Agriculture, Volume 1, Geographic Area Series, Part 48, West Virginia State and County Data.* Washington, DC: U.S. Government Printing Office.

U.S. Environmental Protection Agency Region III (USEPA). 1998. *Fecal Coliform TMDL Development for Lost River, Hardy County, West Virginia.* September.

U.S. Environmental Protection Agency Region III (USEPA) and West Virginia Division of Environmental Protection (WVDEP). 1998a. *Fecal Coliform Total Maximum Daily Load South Fork South Branch Potomac River, West Virginia.* February 20.

___________. 1998b. *Fecal Coliform Total Maximum Daily Load Anderson Run, West Virginia.* February 20.

___________. 1998c. *Fecal Coliform Total Maximum Daily Load South Branch Potomac River including Lunice Creek, Mill Creek, and North Fork, West Virginia.* February 20.

West Virginia Department of Agriculture (WVDA). 1997. West Virginia Agricultural Statistics 1997. Bulletin No. 28. Office of West Virginia Agricultural Statistics in cooperation with U.S. Department of Agriculture, National Agricultural Statistics Service.

West Virginia Division of Environmental Protection (WVDEP). 1998. Letter to author dated October 30, 1998 from Office of Water Resources.

West Virginia University (WVU) Extension Service. 1998. Spreadsheet based on drive–by containing estimated number of broiler houses by county and watershed.

APPENDIX A: DETAILED DATA TABLES

Table A-1: Nutrient content of field crops

Crop	N	P	Unit
Hay: alfalfa	50	4.7	pounds/ton
Hay: other	26	4.5	pounds/ton
Corn: grain	0.80	0.15	pounds/bushel
Corn: silage	7.1	1.1	pounds/ton
Wheat	1.0	0.20	pounds/bushel
Oats	0.59	0.11	pounds/bushel
Barley	0.90	0.18	pounds/bushel
Rye	1.1	0.18	pounds/bushel
Soybeans	3.6	0.36	pounds/bushel

Notes: Data from Lander et al., 1998. Hay other than alfalfa assumed to be small grain hay.

Table A-2: Field crop production, 1995-1996 average (thousand)

County	Hay: alfalfa (tons, dry)	Hay: other (tons, dry)	Corn: grain (bushels)	Corn: silage (tons, green)	Wheat (bushels)	Oats (bushels)	Barley (bushels)	Rye (bushels)	Soybeans (bushels)
Potomac headwaters	14	171	675	84	61	34	20[c]	6[c]	17[c]
Grant Co.	3	25	49	9	1[c]	4[c]	D	D	D
Hampshire Co.	2[b]	53[b]	101	9	18	16[a]	4[c]	<1[c]	D
Hardy Co.	3	35	386	38	20[c]	6[c]	14[c]	6[c]	17[c]
Mineral Co.	2	22	76	4	3[c]	8[c]	2[c]	D	D
Pendleton Co.	4	35	63	24	18[a]	D	D	D	D

Notes: Data are 1995-96 averages from WVDA, 1997 except: "a" based on 1995 only (1996 data unavailable), "b" based on 1996 only (1995 data unavailable), and "c" based on 1992 data from U.S. Department of Commerce, 1994 (1995 and 1996 data unavailable). D: Production data not published in 1996, 1995, or 1992.

Table A-3: Lost River watershed and Hardy County land use assumptions

Land use	Lost River watershed (acres)	Hardy County (acres)	Lost River as percentage of Hardy County
Cropland	8,350	22,626	37%
Pasture	15,000	47,770	31%

Notes: Lost River watershed cropland is sum of "cropland" and "hayland" from PVSCD et al., 1996. Lost River watershed pasture is taken directly from PVSCD et al., 1996. Hardy County cropland is calculated as "total cropland" minus "cropland used only for pasture and grazing" from U.S. Department of Commerce, 1994. Hardy County pasture is calculated as sum of "cropland used only for pasture and grazing" and "pastureland and rangeland other than cropland and woodland pastured" from U.S. Department of Commerce, 1994.

Table A-4: Pasture acreage, 1992 (thousand acres)

County	Total pasture	Accessible pasture
Potomac headwaters	215	161
Grant Co.	41	31
Hampshire Co.	37	28
Hardy Co.	48	36
Mineral Co.	23	18
Pendleton Co.	66	50
Lost River watershed	15	11

Notes: Total pasture for Potomac headwaters and counties from U.S. Department of Commerce, 1994. Total pasture is the sum of two categories: "cropland used only for pasture or grazing" and "pastureland and rangeland other than cropland and woodland pastured." Lost River watershed total pasture data from PVSCD, 1996. Accessible portion based on assumption that 75% of total pasture is accessible.

Table A-5: Nutrient uptake capacities (thousand pounds/year)

Area	N	P
Potomac headwaters	12,683	1,509
Grant Co.	1,984	230
Hampshire Co.	2,923	362
Hardy Co.	3,271	388
Mineral Co.	1,470	176
Pendleton Co.	3,035	353
Lost River watershed	1,164	138

Notes: Field crop results are from Table 1. Pasture results are from Table 2. Post-application N losses are assumed to be 30% for field crops and 60% for pasture; post-application P losses are assumed to be 5% for field crops and pasture.

Table A-6: Derivation of actual broiler and turkey production and cattle inventories

	Broilers		Turkeys		Cattle
Area	No. houses	Production (million/year)	No. houses	Production (million/year)	inventory (thousand)
Potomac headwaters	473	91	155	4.5	81
Grant Co.	107	21	5	0.1	14
Hampshire Co.	21	4	0	0.0	17
Hardy Co.	236	45	61	1.8	22
Mineral Co.	14	3	0	0.0	7
Pendleton Co.	95	18	89	2.6	21
Lost River watershed	96	18	47	1.4	5

Notes: Broiler and turkey houses from WVU Extension Service, 1998. Broiler production calculated by dividing total 1997 production of 90.8 million among the five counties in proportion to the number of broiler houses. Turkey production calculated by dividing total 1997 production of 4.5 million among the five counties in proportion to the number of turkey houses. Cattle inventories from WVDA, 1997 except for Lost River watershed, calculated based on ratio of number of cattle feedlots in Lost River watershed compared with Hardy County from WVU Extension Service, 1998.

Table A-7: Assumptions used in nutrient generation calculations

Variable	Broilers	Turkeys	Cattle
Manure production (ton manure/animal unit/year)	15	8	12
N content of manure (pounds N/ton manure)	27	30	11
P content of manure (pounds P/ton manure)	7.8	12	3.8
N losses in storage and handling	40%	47%	70%
P losses in storage and handling	15%	15%	15%
Average weight (pounds/animal)	2.2	15	1,000
Production cycles per year	6	2	1

Notes: All data from Lander et al., 1998. N and P contents of manure are as excreted.

Table A-8: N and P production by broilers and turkeys (thousand pounds/year)

	N		P	
Area	**Broilers**	**Turkeys**	**Broilers**	**Turkeys**
Potomac headwaters	8,015	4,420	3,301	2,762
Grant Co.	1,813	143	747	89
Hampshire Co.	356	0	147	0
Hardy Co.	3,999	1,740	1,647	1,087
Mineral Co.	237	0	98	0
Pendleton Co.	1,610	2,538	663	1,586
Lost River watershed	1,627	1,340	670	838

Notes: Populations from Table A-6. Other nutrient generation assumptions from Table A-7. N and P production are after storage and handling losses, not as excreted.

Table A-9: Detailed sludge data

Area	Land applications (dry tons)	N content (pounds/dry ton)	P content (pounds/dry ton)
Potomac headwaters	14,029	N/A	N/A
Grant Co.	246	102	52
Hampshire Co.	50	14	36
Hardy Co.	2,023	67	29
Mineral Co.	11,711	3	1
Pendleton Co.	N/A	N/A	N/A

Notes: Based on WVDEP, 1998. Sludge sources are listed in Table 3. Data do not include six septic services or the U.S. Navy site in Sugar Grove. Land applications are average for 1996 and 1997. N content is organic N. N and P content not given for Potomac headwaters region or Pendleton County. N and P content for Hardy County calculated as weighted average of data for Wampler Foods, Inc. and Hester Industries.

APPENDIX B: SAMPLE CALCULATIONS

Nutrient uptake capacity on cropland (for P)

Nutrient uptake by field crops are calculated by multiplying nutrient content (Table A-1) by production (Table A-2) for N and P for each crop. To calculate the nutrient uptake capacity on cropland, post-application losses are then accounted for. Post-application losses are assumed to be 5% for P. For example, the portion of the P uptake capacity in Grant County attributed to alfalfa hay is calculated as follows (some numbers may not match exactly due to rounding):

P uptake by alfalfa hay = (4.72 lb P / ton alfalfa hay) * (3,398 tons alfalfa hay produced) = 16,039 lb N

P uptake capacity attributed to alfalfa hay = 16,039 lb N / (1 – 0.05) = 16,883 lb N

N content of a calf and cow

The N content of a calf and cow is based on equations presented by Rayburn (unpublished manuscript). These equations estimate protein content based on the empty body weight of the animal. N content is directly related to protein content. For example, the N content of a 500-pound calf is calculated as follows (some numbers may not match exactly due to rounding):

Live weight of calf = 500 lb = 227 kg

Shrunk weight (after 12-24 hour fast) = 90% of live weight = 205 kg

Empty body weight (EBW) = 92% of shrunk weight = 188 kg

Protein = $-2.418 + (0.235 * \text{EBW}) – (0.00013 * \text{EBW}^2) = 37$ kg

Nitrogen = Protein / 6.25 = 6 kg = 13 lb

P content of a calf and cow

The P content of a calf and cow is also based on equations presented by Rayburn (unpublished manuscript). These equations estimate protein and ash content based on the empty body weight of the animal. P content is directly related to the sum of protein and ash content. For example, the P content of a 500-pound calf is calculated as follows (some numbers may not match exactly due to rounding):

Live weight of calf = 500 lb = 227 kg

Shrunk weight (after 12-24 hour fast) = 90% of live weight = 205 kg

Empty body weight (EBW) = 92% of shrunk weight = 188 kg

Protein = $-2.418 + (0.235 * \text{EBW}) – (0.00013 * \text{EBW}^2) = 37$ kg

Ash = $-0.632 + (0.057 * \text{EBW}) – (0.00003 * \text{EBW}^2) = 9$ kg

Phosphorus = (Protein + Ash) * 0.0332 = (37 kg + 9 kg) * 0.0332 = 1.5 kg = 3.4 lb

Nutrient uptake capacity on pasture (for N)

The nutrient uptake capacity on pasture is based on the removal of calves and cows from accessible pasture, plus unavoidable losses. It is assumed that all accessible pasture is used in cow-calf production systems that support, on average, one cow-calf unit on every two acres of pasture. It is also assumed that calves are exported from the system once per year at an average weight of 500 pounds, and that cows are culled once every six years at an average weight of 1,200 pounds. Post-application N losses include volatilization, denitrification, and leaching of the original applied N as well as N deposited on pasture by grazing livestock as urine and feces. In total, these losses are assumed to total 60% of applied N. The N uptake capacity on pasture in Grant County is calculated as follows (some numbers may not match exactly due to rounding):

N removed by calf = (13 lb N/calf) / (2 acres/calf) * (1 calf removed/1 year) = 6.5 lb N/acre/year

N removed by cow = (27 lb N/cow) / (2 acres/cow) * (1 cow removed/6 years) = 2.3 lb N/acre/year

Total N removal = 30,584 acres * (6.5 lb N/acre/year + 2.3 lb N/acre/year) = 269,499 lb N/year

N uptake capacity on pasture = 269,499 lb N/year / (1 – 0.6) = 673,749 lb N/year

Nutrient generation by broilers (for N)

Nutrient generation by broilers is based on estimates of annual broiler production and a series of estimates related to manure characteristics, the production systems, and the animals themselves. It is assumed that broilers produce 15 tons of manure per animal unit (AU) per year, and that this manure contains 27 pounds N per ton. It is assumed that the average weight of a broiler, over its entire life, is 2.2 pounds, and that, on average, poultry farmers have 6 production cycles per year. Finally, it is assumed that during storage and handling of the manure, 40% of N is lost. The following equations illustrate the calculation of N generation by broilers for Grant County (some numbers may not match exactly due to rounding).

Avg. broiler inventory = Total annual production / Production cycles per year / Broilers/AU
= 20,540,381 broilers/year / 6 cycles/year / 455 broilers/AU
= 7,524 AU

Manure generated = Avg. broiler inventory * Manure production/AU
= 7,524 AU *15 tons manure/AU/year
= 112,634 tons manure/year

Total N generated = Manure generated * N content of manure
= 112,634 tons manure/year * 27 lb N/ton manure
= 3,021,957 lb N/year

N generated after losses = Total N generated * (1 – N storage and handling losses)
= 3,021,957 lb N/year * (1 – 0.4)
= 1,813,174 lb N/year

Poultry production capacities (for N)

Two poultry production capacities are calculated for each study area: one based on the N uptake capacity and one based on the P uptake capacity. Each poultry production capacity represents a line (see Figures 7 through 13). The poultry production capacities are also based on a series of estimates related to manure characteristics, the production systems, and the animals themselves for both broilers and turkeys.

It is assumed that broilers produce 15 tons of manure per animal unit (AU) per year, and that this manure contains 27 pounds N per ton. It is assumed that the average weight of a broiler, over its entire life, is 2.2 pounds, and that, on average, farmers have 6 broiler production cycles per year. Finally, it is assumed that during storage and handling of the manure, 40% of the N is lost.

It is assumed that turkeys produce 8 tons of manure per AU per year, and that this manure contains 30 pounds N per ton. It is assumed that the average weight of a turkey, over its entire life, is 15 pounds, and that, on average, farmers have 2 turkey production cycles per year. Finally, it is assumed that during storage and handling of the manure, 47% of the N is lost.

The following equations illustrate the calculation of the x-intercept (maximum broiler production if no turkeys) and y-intercept (maximum turkey production if no broilers) of the line that corresponds to the N-based poultry production capacity for Grant County (some numbers may not match exactly due to rounding).

Calculating the x-intercept (maximum broiler production if the entire N uptake capacity were satisfied by broilers):

N requirement after storage and handling losses = N uptake capacity / (1 – storage and handling losses)
= 1,983,598 lb N/year / (1 – 0.4)
= 3,305,997 lb N/year

Maximum mass of broiler manure = N requirement after storage and handling losses / N content of broiler manure
= 3,305,997 lb N/year / 27 lb N/ton manure
= 123,220 ton manure

Maximum avg. broiler inventory (AU) = Maximum mass of broiler manure / manure production/AU
= 123,220 ton manure / 15 tons manure/AU/year
= 8,231 AU/year

Maximum avg. broiler inventory = Maximum inventory in AU / Broilers/AU
= 8,231 AU/year * 455 broilers/AU
= 3,745,169 broilers/year

Maximum broiler production = Maximum avg. broiler inventory * Production cycles per year
= 3,745,169 broilers/year * 6 cycles/year
= 22,471,015 broilers/year (this is the x-intercept)

Calculating the y-intercept (maximum turkey production if the entire N uptake capacity were satisfied by turkeys):

N requirement after storage and handling losses = N uptake capacity / (1 – storage and handling losses)
= 1,983,598 lb N/year / (1 – 0.47)
= 3,742,639 lb N/year

Maximum mass of turkey manure = N requirement after storage and handling losses / N content of turkey manure
= 3,742,639 lb N/year / 30 lb N/ton manure
= 123,275 ton manure

Maximum avg. turkey inventory (AU) = Maximum mass of turkey manure / manure production/AU
= 123,275 ton manure / 8 tons manure/AU/year
= 15,070 AU/year

Maximum avg. turkey inventory = Maximum inventory in AU / Turkeys/AU
= 15,070 AU/year * 67 turkeys/AU
= 1,009,712 turkeys/year

Maximum turkey production = Maximum avg. turkey inventory * Production cycles per year
= 1,009,712 turkeys /year * 2 cycles/year
= 2,019,425 turkeys/year (this is the y-intercept)

Accounting for cattle manure (for P)

Because nutrients cycled through pastured cattle are already included in the pasture nutrient uptake calculation, this calculation accounts for nutrients generated by confined cattle only. Two assumptions are proposed for the percentage of all cattle that are raised in confinement: 10% and 40%. Calculations are performed separately for each of these percentages. The following equations illustrate the calculations for accounting for P in cattle manure for the Potomac headwaters region as a whole, assuming that 10% of all cattle are confined.

The P uptake capacity for the Potomac headwaters region was calculated to be 1,509,272 pounds P per year. The following estimates are also used in this calculation: There are an estimated 81,000 cattle in the region. cattle produce 12 tons of manure per animal unit, and this manure contains 4 pounds P per ton.

Manure generated by confined cattle = Total cattle population * Percent confined * Manure production/AU * Cattle/AU
= 81,000 cattle * 0.10 * 12 tons/AU/year * 1 cattle/AU
= 93,150 ton manure/year

P generated by confined cattle = Manure generated by confined cattle * P content of manure
= 93,150 ton manure/year * 4 lb P/ton manure
= 353,039 lb P

P generated after storage and handling losses = P generated by confined cattle * (1 – Storage and handling losses)
= 353,039 lb P * (1 – 0.15)
= 300,083 lb P

Modified P uptake capacity = Original P uptake capacity – P generated by confined cattle after losses
= 1,509,272 lb P - 300,083 lb P
= 1,209,190 lb P

The calculation for poultry production capacity is then performed based on the modified P uptake capacity.

Accounting for sludge (for P)

The P uptake capacity for the Potomac headwaters region was calculated to be 1,509,272 pounds P per year. Sludge applications in the region were estimated to be 81,571 pounds P per year.

Modified P uptake capacity = Original P uptake capacity – P in applied sludge

= 1,509,272 lb P – 81,571 lb P

= 1,427,701 lb P

The calculation for poultry production capacity is then performed based on the modified P uptake capacity.

Accounting for poultry litter exports (for P)

Two assumptions are proposed for the percentage litter exported: 20% and 40%. Calculations are performed separately for each of these percentages. The following equations illustrate the calculations for accounting for P in exported litter for the Potomac headwaters region as a whole, assuming that 20% of litter is exported (some numbers may not match exactly due to rounding). The P uptake capacity for the Potomac headwaters region was calculated to be 1,509,272 pounds P per year.

Modified P uptake capacity = Original P uptake capacity / (1 – Percent of litter exported)

= 1,509,272 lb P / (1 – 0.20)

= 1,886,591 lb P

The calculation for poultry production capacity is then performed based on the modified P uptake capacity.

APPENDIX C: COMMENTS AND RESPONSES

In November, 1998, a review draft of this report was sent to about thirty people across the state. Extremely helpful comments and suggestions were received from many of these reviewers. The final report has been significantly revised to incorporate many of the suggestions provided by these reviewers. Because of the changes made between the review draft and the final report, some of the comments listed below refer to assumptions and wordings that no longer appear in the final report. In particular, the review draft used the terminology "nutrient carrying capacity" and "poultry carrying capacity" to refer to what are now called "nutrient uptake capacity" and "poultry production capacity." Also, some commenters refer to page numbers in the review draft; many of these page numbers have changed in the final report.

Below, the following reviewers' comments are listed together with responses:

- Tom Basden, Extension Specialist, West Virginia University Extension Service;
- Professor William Bryan, West Virginia University;
- Gus Douglass, Commissioner, West Virginia Department of Agriculture;
- Neil Gillies, Science Director, Cacapon Institute;
- William Hartman, State Conservationist, Natural Resources Conservation Service;
- Laidley Eli McCoy, Potesta & Associates, Inc., for the West Virginia Farm Bureau and the West Virginia Poultry Association;
- Dan Ramsey, Biologist, U.S. Fish and Wildlife Service;
- Ed Rayburn, Extension Agronomist, West Virginia University Extension Service; and
- Dave Workman, West Virginia University Extension Service.

Tom Basden

Comment	Response
A study like this is a complex undertaking and models are hard to construct without large amounts of accurate data. I feel that the evaluation of environmental impacts on an ecosystem needs to be done within a time frame. A soil system has a buffering capacity that allows it to absorb nutrients before nutrients such as phosphorus (P) begin to leach. The models you presented may have been more relevant if you had started a scenario in 1990 and then extrapolated out to the year 2020. My understanding of your model is that you assume that we have reached critical P levels in the soil and any additional applications greater than crop removal will impact the water quality of the Potomac drainage. I do not feel that this reflects our current conditions in the area. Many of the soils sampled in the Potomac Headwaters area have been shown to be low in P and other essential plant nutrients, so additions of animal manures are needed to raise the soil nutrient levels into the optimum range and to improve the soil quality. If the farmers manage the manures for the nitrogen content to minimize loss of this nutrient into the environment and continue to build up P, I feel that this is a sustainable practice until P levels reach a critical level.	The draft report did not mean to suggest that the soil's P buffering capacity has already been exceeded or that we have already reached critical P levels in the soil. The final report more clearly states that, while some soils in the regions test high and very high for soil P, many soils are still far from their buffering capacity and that manure applications on these soils will help to raise soil P levels and improve soil quality. However, the model does not depend on the ability of the region's soils to retain nutrients. In the long term, if nutrients are over-applied, soil P levels will eventually reach high enough levels such that P should only be applied to satisfy current crop needs plus unavoidable losses. The model takes this long-term view and is not meant to suggest that current exceedances of the P uptake capacity imply an immediate environmental threat.
In your conclusions you state that "we are already accepting significant environmental compromises". I feel we will have a potential environmental impact in the watershed if applied nutrients exceed their retention capacity in the soils, but we have not reached this situation in regards to phosphorus.	This statement has been reworded.

Studies that look at the long term sustainability of animal production systems are needed. I hope that this study is followed up with a more detailed evaluation as we begin to better understand the different nutrient carrying capacities of the soils in the region and better measure the export of litter from this watershed.	The upper-bound analysis presented in this report is meant to be a first step. The conclusions of the report identify data needs and suggest that more detailed evaluations are necessary in the future.

William Bryan

Comment	Response
You have probably thought about the words 'Nutrient Carrying Capacity". It does not sound well to me, perhaps because we use it to describe animal carrying capacity. I thought of Sustainable Nutrient Application, but that sounds unwieldy.	The term "nutrient carrying capacity" has been replaced with "nutrient uptake capacity," and the term "poultry carrying capacity" has been replaced with "poultry production capacity."
Have you taken into account that not all crops will be removed from the area, many will be fed back to cattle to return as nutrients?	Nutrients cycled through pastured cattle are not included in the model because they do not represent an input to or an output from the model. In a refinement to the nutrient generation model in Section 4, the analysis considers nutrients generated by confined cattle. See Figures 3 and 14, which help to clarify the inputs to and outputs from the model.
Also it seems that there is a fundamental difference between N & P, because P does not cycle through the air.	The report takes this difference into account through the different estimates of storage and handling losses and post-application losses.
Also litter application may be more limited by its P content than N content & additional N may be applied to provide 'enough' for a particular crop.	While this statement is true, the intent of the analysis is not to suggest N or P sources or application rates for individual fields. Rather, the analysis assesses long-term, average nutrient uptake and generation patterns without consideration for whether or not nutrient applications at these rates are economical or feasible from a farmer's perspective.

Gus Douglass

Comment	Response
Regarding the graphs on pages 17-20 concerning broilers and turkeys in particular counties and watersheds: Figure 6: 91 million broilers, 5 million turkeys -- Total Potomac Headwaters. Figure 9: 45 million broilers, 1.8 million turkeys -- Hardy County. Figure 12: 18 million broilers, 1.4 million turkeys -- Lost River Watershed. In Figures 9-12, the broilers and turkeys may have been counted twice because Lost River is in Hardy County. If that is true, the numbers should read in Figure 9 .4 million turkeys and 27 million broilers, and in Figure 12 (Lost River) 18 million broilers and 1.4 million turkeys. Another scenario is that you only count Hardy County.	Broiler and turkey production levels in each county and in the Lost River watershed were calculated by dividing WV's 1997 production according to the number of broiler and turkey houses in that county or watershed. It is true that the 18 million broilers and 1.4 million turkeys estimated for the Lost River watershed are included in the Hardy County figures. This is intended, as for the figures for other counties, to represent all of the broilers and turkeys in Hardy County, and does not represent double counting.
Questions about pulling the 500-pound calf and not taking into consideration of pulling cull cows and others.	The final report has been modified to include cull cows in addition to feeder calves.
We must be very cautious about using assumptions. This is why we feel that long-term data collection is necessary before reports of this magnitude should be published.	Assumptions in this analysis were carefully chosen so that they overestimate the nutrient uptake capacities and poultry production capacities. Long-term data collection is extremely important and will help to fine-tune the results of this analysis.
There is a later report stating that *pfiesteria* may not be the contributing factor to lesions in fish. It may be another type of bacteria that is causing this problem.	While there is certainly some debate about the cause of fish lesions, some researchers have linked them to *pfiesteria*.

Neil Gillies

Comment	Response
Phosphorus was spelled wrong.	The spelling has been changed.
2nd paragraph page 5. Link between fish kills and nutrient enrichment in our area not at all clear, maybe not even reasonable.	The draft did not mean to suggest a local link between fish kills and nutrient enrichment. However, algae growth, an indicator of excess nutrients, has been found locally (Smith, 1992). The final report has been reworded to clarify this issue.
Fourth paragraph on page 5. Nutrients will be lost from septic fields whether they are failing or not - it is an area of waste concentration. Also the effluent statement should include sewage treatment plants. During the current period of drought, the Wampler effluent stream seems to be the major source of nutrients to the South Branch (not quantified by load yet, will have that soon).	This paragraph has been reworded.
Spread throughout the document are discussions of cattle manure and feed production. Cattle in these watersheds mostly feed on hay and pasture and silage, produced from fields largely fertilized using poultry litter. I have trouble seeing cattle manure, in most cases, as representing nutrient import to the system. It probably, primarily, represents recycling of nutrients imported as poultry feed (and N from the sky).	Nutrients cycled through pastured cattle are not included in the model because they do not represent an input to or an output from the model. In a refinement to the nutrient generation model in Section 4, the analysis considers nutrients generated by confined cattle. See Figures 3 and 14, which help to clarify the inputs to and outputs from the model.
Also, why consider cattle in feedlots any differently than cattle in fields if the nutrients supporting their growth is generated from poultry byproducts? Is	See response to previous question.

manure dropped in a field any different than manure dropped in a feedlot then spread in a field?	
Any reason why egg and chick producers not mentioned in report? No data?	Egg and chick producers are not mentioned because their populations are small compared with broilers and turkeys. Statewide, 91 million broilers and 5 million turkeys were produced in 1997, compared with 1 million chickens other than broilers (USDA, 1998). Broilers therefore represent 94%, and turkeys represent 5%, of the total number of birds produced statewide in 1997. Because most poultry production is concentrated in the Potomac headwaters region, these statistics also describe the situation found there.
If those folks are doing a pretty good job the way things are, is there really a large excess of nutrients? Or, are the implemented nutrient management plans allowing considerable excess of litter to be placed on the ground?	The model looks at nutrient flows at broad geographic scales and does not assess nutrient management plans on individual farms. The model results suggests that, at these broad scales, nutrient generation exceeds or roughly equals the uptake capacities in the major poultry-producing regions. These results therefore suggest that, at least in the long term, an excess of nutrients is being produced.

William Hartman

Comment	Response
What has been presented is a simplistic model which attempts to predict and account for transportation and fate of nutrients in a very complex ecosystem. Your premise that calculated nutrient levels in excess of plant growth needs is the threshold above which environmental compromises might occur is neither substantiated nor confirmed by water quality data in the watershed.	Although it is simplified, the model includes all major nutrient flows. A broad, aggregated model such as this abstracts from the complexities found in the ecosystem and identifies the key nutrient stocks and flows that are most relevant to the questions being answered. The threshold used in the model follows from a simple mass balance. In the long term, once soil nutrient levels, on average, are not deficient, excess nutrient applications will reach either surface water, groundwater, or the atmosphere (N only), or will build up to higher levels in the soil and will therefore be even more likely to reach waterbodies or the atmosphere in the future. Recent water quality data show increased N concentrations in rivers that run through agricultural portions of the Lost River watershed (Gillies, 1998).
The draft document is based upon numerous assumptions and calculations including nutrient contents of livestock manure, nutrient uptake by pasture plants, nutrients generated by poultry, some losses due to denitrification, litter export levels, percent of cattle confinement, percent of pasture available and production data for Lost River Watershed. Deducting a definitive conclusion from a series of assumptions and data sets which incompletely describe the complex ecosystem is not a technically sound approach.	The assumptions are based on existing data and are chosen conservatively to provide upper bounds for the nutrient uptake capacities and associated poultry production capacities. The existing data are sufficiently robust to support this type of analysis.
The assumptions made can only lead one to predict, through this simplistic analysis, that the nutrients available exceed agricultural crop and plant growth needs. Exceeding crop and plant needs does not necessarily lead to the conclusion that the watershed nutrient carrying capacity is exceeded.	There are certainly other ways to define a nutrient uptake capacity. This report proposes a definition that is meaningful and useful for answering important questions, clearly defines the term, and uses it consistently. In the report, nutrient uptake capacities are defined as the total N or P uptake on an area's farmland each year, plus unavoidable losses, such that there is no long-term buildup of soil nutrients and minimal nutrient loss to surface water, groundwater, and the atmosphere. With this definition, if available nutrients exceed agricultural crop and plant growth needs (plus unavoidable losses plus nutrient harvested through pastured livestock), then the nutrient carrying capacity is exceeded.
Atmospheric loss of nitrogen reduces nutrient loading of agriculture lands.	Atmospheric N losses are included in the model as a component of the storage and handling losses and as a component of post-application losses. In the final report, post-application losses on pasture have been increased to account for additional atmospheric losses that occur when livestock urinate and defecate.
The soils in the watershed have a high potential to retain phosphorous and nitrogen in various forms.	Portions of the report have been reworded to emphasize this fact. However, the report's broad conclusion does not depend on the ability of the region's soils to retain nutrients. In the long term, if nutrients are over-applied, soil nutrient levels will eventually reach high enough levels such that nutrients should only be applied to satisfy current crop needs plus unavoidable losses.
Watershed crop yields and soil analyses do not indicate any adverse influence of land application of litter and manures.	The report does not suggest any current adverse influence. While excess N is likely to be lost and not to adversely affect crop yields or soils, these losses would show up as algal blooms and other effects that we do see in the watershed. Regarding P, some soil P levels already measure high or very high.
Your model and analysis doesn't account for the intense work on the part of producers and agencies to manage the watersheds' agriculturally related nutrients through nutrient management plans and improved animal waste management.	The important work done by producers and agencies is recognized more explicitly in the final report. Note that, when nutrient management plans are properly implemented, nutrient losses are lowered, resulting in decreased nutrient uptake capacities and poultry production capacities. Because the intent of the model is to calculate conservative upper bounds for these values, the conservative loss estimates used in the model are justified.
Water quality data does not indicate that the actual nutrient carrying capacity of the watershed has been approached let alone exceeded.	Water quality data show increased N concentrations in rivers that run through agricultural portions of the Lost River watershed (Gillies, 1998). For N, the report suggests that, in the major poultry-producing counties, N generated by

	poultry exceeds or roughly equals the N uptake capacities. The report does not suggest that the P uptake capacities have already been exceeded. It suggests that over the long term, if soil P levels continue to rise through application of manure generated at current poultry production levels, the P uptake capacity will be exceeded. The analysis is designed to identify long-term prospects for achieving a nutrient balance and not to predict whether nutrient excesses should currently be detected.
Furthermore, the model in its current simplistic form defies any attempt to calibrate it in the natural ecosystem, and it is unlikely that it could be truly validated in the natural system in any meaningful way that would lend credibility to the model and its underlying assumptions.	The model considers nutrient uptake and generation at large geographic scales: watershed, county, and region. A broad, aggregated model such as this abstracts from the complexities found in the ecosystem and identifies the key nutrient stocks and flows that are most relevant to the questions being answered. Several conservative estimates are used to arrive at upper-bound results. Therefore, calibration would not be appropriate. Instead, the model should be assessed based on whether or not the estimates are conservative and whether or not the simplifying assumptions are justified.
It is an overstatement, not substantiated by facts and scientific analysis, when you conclude (on page 27),"These calculations demonstrate that we are already accepting significant environmental compromises by exceeding the carrying capacities in the Potomac headwaters."	This statement has been reworded.
The assumption of nutrient export only through calves is not valid. Calves, steers, cows, bulls and other livestock are exported at live weights for slaughter outside the watershed.	The final report has been modified to include cull cows in addition to feeder calves. A simplifying assumption in the model is that all accessible pasture is used in cow-calf production, because this is the predominant pasture system used in the region. Therefore, steers, bulls, and other livestock are not accounted for in the model.
The analysis does not consider the actual export of N and P in the form of poultry products, beef, milk, fruit and hay or grain outside the watershed and this is profound and significant in that a very small percentage of the products are recycled within the Potomac Headwaters.	The model is unaffected by the destination of the harvested nutrients. See Figures 3 and 14, which help to clarify the inputs to and outputs from the model. Nutrients in beef, hay, and grain are included as outputs from the model. Nutrients in milk and fruit are not included because they are small compared with meat and field crops. Regarding poultry products: Nutrients in imported feed are transformed into poultry products—which are not included in the model—and into poultry manure and nutrient losses, both of which are considered in the model. Adding poultry products and imported feed to the model would result in a net cancellation.
Carrying capacities in the watershed for N & P are also related to natural N & P as well as non-agricultural sources and transport. These are not fully evaluated in the model.	One major non-agricultural sources of N and P--sludge--is evaluated in the model. Other non-agricultural sources, such as atmospheric deposition, are not included. If they were included, they would tend to decrease the poultry production capacities because fewer nutrients would be left to be supplied by agricultural sources. Therefore, these omissions help to calculate conservative, upper-bound poultry production capacities.
The scaling of the graphs would lead the reader to conclude that there exists a continuum in the model between the number of broilers and turkeys which truly describes the carrying capacity of an area, above which is a single point describing the over availability of N or P. There is also an assumption that this continuum is linear, and as we know in most natural systems, this is not true. Scaled equally and correctly considering the turkeys to be relatively insignificant in impact, you essentially have a nearly vertical line to the right of which all of the rest of the universe would be described.	The relationship in the graphs between broiler and turkey production levels is, in fact, linear. Consider the N-based poultry production capacity line. It is assumed that each broiler and each turkey produces a certain average mass of N per year (NB for broilers and NT for turkeys). The N produced by broilers and turkeys together totals the N-based poultry production capacity (NPPC). If the number of broilers is B and the number of turkeys is T, the following linear equation results: (B * NB) + (T * NT) = NPPC.
The model you prepared may be useful in evaluating the relative benefits of various alternatives to reduce the nutrient loading in the watershed. Used this way the model may become a useful tool to develop strategies to assist rural communities and landusers with conserving their natural resources and maintaining a viable agricultural economy and healthy ecosystem. Thank you for the opportunity to review the document. I hope you utilize it as a relative index to evaluate alternatives and not as a definitive model that has determined the threshold carrying capacities for nutrients.	The model may indeed be useful for the purpose you describe.

Laidley Eli McCoy

Comment	Response
The purpose of the report as stated is an attempt to answer the question, "Is the current scale of the region's poultry industry sustainable in the long term." However, it seems the purpose of the report is more to determine if the area can assimilate the nutrients produced by the industry over the long term, given the current known level of nutrient management. The fact is that the poultry industry is sustainable, based upon market conditions, etc. The question is, can the area stand the current level of poultry production, using current nutrient management practices, without causing environmental harm in the form of	There are many valid ways to frame the analysis that attempt to answer similar questions. We do not assume beforehand that the poultry industry is sustainable, and instead use the results of this analysis to help answer this question. The purpose of the report has been restated as answering the question: Given the quantity of nutrients generated by the concentrated poultry industry in the Potomac headwaters of West Virginia, how can we ensure a long-term nutrient balance?

build-up of nutrients in the soils, surface water and groundwater.	
No matter how you decide to ultimately state the purpose of the report, you may want to consider qualifying your statements by indicating that they are based on the current information on nutrient handling practices. Other factors to be considered over the long term include increasing litter exports, the mandated inclusion of phytase in feeds to reduce phosphates, and the genetic engineering of crops to improve feed conversions that will lessen nutrient levels in manures.	Poultry litter exports are included in the analysis. It is true that phytase in feeds and genetic engineering of crops may eventually reduce P levels in manure. These options are clearly stated in the final report.
It took several readings of various parts of the report to understand the author's approach to the issue under discussion, and even then, it was not very clear. Some thought needs to be given to making the approach to the subject clearer, or perhaps switching the approach. It may be more comprehensible if the report started with the sources of nutrients generated in the watershed, then proceeded on to the various ways the nutrients are consumed, lost, or exported, and ended with the surplus of nutrients.	It is true that the order in which the report proceeds—from nutrient uptake through nutrient generation—may be unintuitive. But the model used for the analysis calculates the amount of nutrients that can be generated without exceeding uptake. Therefore, uptake must be calculated first.
You may want to consider revising the paper so that it is presented in the third tense, rather than the first tense.	The report has been changed to incorporate this comment.
Much of the report uses the term "carrying capacity" in a way that is confusing and may be in error. Carrying capacity is truly a value, K, representing the number of individual organisms an area or ecosystem can support, taking into account the most limiting conditions. Section 4 of the report provides information on the poultry carrying capacity of the watershed, based on the limiting conditions of nitrogen and phosphorus and is the section that comes closest to fitting our understanding of the term. Even this is somewhat dubious as: 1) the nutrient levels in the soils and/or water will not have a limiting effect on the poultry population; and 2) the natural poultry carrying capacity of the ecosystem has been artificially elevated through selective breeding, feeding, artificial shelter, artificial light cycles and disease control. References to the carrying capacity of the soils and water throughout the rest of the report may be more accurately stated as the "nutrient assimilative capacity" of the watershed	The term "nutrient carrying capacity" has been replaced with "nutrient uptake capacity," and the term "poultry carrying capacity" has been replaced with "poultry production capacity."
Much of the document refers to the generation of poultry litter and its associated nutrient content. Are the nutrient values used actually those of poultry excrement, while the volumes are those of poultry litter? As you know, much of the volume of poultry litter is bedding material that does not have the nutrient content of poultry excrement. This would significantly elevate the estimated nutrient production in the area.	The nutrient content and manure generation figures all refer to poultry excrement or manure, and not to poultry litter. There are no references to volumes.
The second paragraph on page 5 insinuates that streams in the area are low in dissolved oxygen and have algal blooms and fish kills as a result of nutrient enrichment. However, we are unaware of any documentation of these types of occurrences. These streams are only listed by the West Virginia Division of Environmental Protection (DEP) as having use impairment based on fecal coliform levels, and when the actual data are reviewed, the violations are not numerous enough to justify the 303(d) list according to the DEP listing criteria.	The draft did not mean to suggest a local link between fish kills and nutrient enrichment. However, algae growth, an indicator of excess nutrients, has been found locally (Smith, 1992). The final report has been reworded to clarify this issue.
The third paragraph on page 5 states that some litter is pelletized and used as cattle feed. While that is true, it is not the primary way that litter is fed to cattle in this area. Composted litter is more often fed in feed rations with silage or ground corn or as free choice, accounting for a very large volume of litter usage in the area.	The report has been changed to incorporate this comment.
This paragraph also states that most of this litter is applied locally to agricultural land. We do not believe that there is documentation to support this statement. It is more likely to be a perception and should not be presented as fact.	A poultry producer survey (Basden et al., 1995) suggests that most of the region's litter is applied on the farm on which it is generated. Of the remainder that is used off-farm, the survey suggests that most stays within the same watershed. More detailed and recent data would certainly be welcome.
This paragraph also states that it is not important how the litter is used, only if it stays in the watershed. We disagree. The balance of nutrients in the watershed is greatly affected by the way the litter is used. If the litter is used as cattle feed or land applied at proper agronomic rates, it limits the imports of feed and fertilizer.	The report has been changed to incorporate this comment.
The last paragraph on page 5 includes mortality as a source of nutrients in the area. It is our understanding that dead birds from the farms of integrators, such as Wampler, are rendered or composted.	Whether dead birds are rendered or composted, they still constitute a nutrient source. Omitting poultry mortality from the analysis results in more conservative upper-bound poultry production capacities because nutrients in composted mortality, when applied to agricultural land, use up a portion of the nutrient uptake capacities.
On page 7, the first partial paragraph states, " ...or by limiting the scale of poultry or livestock production." This statement is inflammatory and is likely to generate a hasty, hostile response to this report on the part of the industry, rather than a carefully considered evaluation. Although it is true that this may be an option, it should only be considered as a last resort after other avenues, such as full implementation of best management practices, additional litter exports, digesting, etc. have been exhausted. The farmer would tell you that	As you state in this comment, limiting the scale of poultry or livestock production is one option among those considered in this analysis for achieving a long-term balance between nutrient generation and uptake. This phrase therefore remains in the report.

limiting production would result in the eventual loss of the farm, which will only bring about urbanization, which is fraught with its own environmental concerns.	
In the third paragraph on this page, there is a discussion of unavoidable losses. Although you reference runoff as a loss, do you have a quantification of the amount of nitrogen and phosphorus that leaves the watershed in the surface water? It would seem that this would be a significant source of loss and one that could be quantified.	Quantifying the amount of N and P runoff losses that leave the watershed would require a much more comprehensive model that not only accounts for nutrient losses, but also tracks the nutrients as they enter and travel through the rivers. Therefore, they are not estimated.
Your report states that seven (7) pounds of nitrogen are removed per acre. However, West Virginia University has advised that a minimum of 50 pounds of nitrogen should be applied per acre for pasture land application. Why the conflict between these numbers? Surely the university is not advocating nutrient overloading of the soil.	Compared with the review draft, the final report takes additional N pasture losses into account. The final model suggests that a total of 22 pounds of N are removed and unavoidably lost per acre of pasture. This figure is still below the recommended minimum of 50 pounds per acre. One difference between the calculation in the report and the Extension Service recommendations is that in the report, nutrients in hay cut from pasture are accounted for separately in the field crop calculation. The N content of hay varies considerably; according to the data used in this report, alfalfa hay removes about 145 pounds N per acre and other hay removes about 50 pounds N per acre. Hay cut from pasture can explain the discrepancy between the application rates implied by this analysis and those recommended by the Extension Service.
Also with regard to losses, if not already considered, you may want to include the following as additional unavoidable losses: (a) Volatilization of poultry nutrients in the actual poultry house; (b) Additional volatilization when the litter is removed from the house and put into storage areas; (c) Additional volatilization when the litter is spread; (d) More when the cow digests the grass and exhausts to the air; and (e) More when the cow defecates and the material is deposited on the ground.	Points (a) and (b) are included in storage and handling losses. Point (c) is included in post-application losses. Point (d) refers to N losses when cows exhaust to the air; little or no N is lost directly when cows exhaust to the air. Point (e) is an internal cycle in the pasture nutrient cycle and doesn't enter into the calculation; however, additional N losses when cattle defecate have been included in the final analysis.
On page 8, you state that the model used is intentionally simplified. Considering that this is an important issue to the industry and economy of the area, is it appropriate to keep it simple? What about the value of having real data on the nutrient levels in the soils and their ability to assimilate more or the current quality of surface and groundwater? What about the economic benefits of certain currently proposed nutrient handling alternatives, such as digesting or composting? What about the beneficial aspects, in terms of production and erosion control, of bringing P-deficient soils up to optimal fertility?	Although it is simplified, the model includes all major nutrient flows. A broad, aggregated model such as this abstracts from the complexities found in the ecosystem and identifies the key nutrient stocks and flows that are most relevant to the questions being answered. The nutrient retention capability of the soils is important in the short term, but less so in the long term, which is the time scale investigated by this model. The economic benefits of alternative litter use strategies, while possibly significant, do not fall within the scope of this analysis. However, the report's conclusions stress the possible economic benefits of digesting and composting and the need to promote these alternative strategies. The final report also stresses more clearly the benefits of bringing P-deficient soils up to optimal fertility.
On page 9, second paragraph, you refer to stable levels of N and P in the soil. Do you define "stable" as not changing over time? If so, what about those soils that are currently nutrient deficient? You may want to consider defining the level of N and P that are considered fertile for land use and setting this as the baseline that should be maintained.	The final report emphasizes more strongly the fact that poultry and cattle manure are beneficial for increasing soil P levels in soils that are low in P. However, this model focuses on the long term implications of repeated poultry litter applications. It suggests that over the long term, if soil P levels continue to rise, the nutrient uptake capacity will be exceeded by nutrients in manure generated at current poultry production levels. The analysis is designed to identify long-term prospects for achieving a nutrient balance.
The statement on page 10, third paragraph, regarding the application and uptake of P and its associated footnote do not seem to have solid support. When Bhumbla stated that 20% of recent soil tests are classified as very high, how many tests was he referring to and where were they taken? What about the other 80 percent of samples? Can this data be extrapolated across the region, or even individual counties?	This statement was meant to illustrate that, already, a significant portion of soil test results from the region show very high soil P levels. However, the analysis is equally valid whether or not region's farmland is already uniformly saturated with P. The analysis suggests that over the long term, if soil P levels continue to rise, the nutrient uptake capacity will be exceeded by nutrients in manure generated at current poultry production levels. The analysis is designed to identify long-term prospects for achieving a nutrient balance and not to model whether the nutrient uptake capacities are currently being exceeded.
On page 10, paragraph 4, you talk about uptake by crop fields and list six categories. Other considerations in this part of the calculation should perhaps include: (a.) Hay fields that are used as first or second cutting hay and then grazed; (b.) The nutrients removed by second and third cuttings; (c.) Double cropping of fields. Fields are often planted to rye after corn has been removed; (d.) Fields that use rye as a cover crop, then grazed, silage, hayed or taken off as grain; (e.) Barley fields; and (f.) Soybean crops; used as a double crop with rye and barley, or stand-alone.	Nutrient uptake by field crops is based on production data from the WV agricultural statistics (WVDA, 1997) and the U.S. census of agriculture (U.S. Department of Commerce, 1994). Acreage data are not used. Therefore, the uptake figures account for second and third cuttings of hay, double cropping of fields, and cover crops, as long as production of these crops are included in the statistics. Rye, barley, and soybeans have been included in the final analysis. These result in a 2% increase in N uptake and a 1% increase in P uptake by field crops.
Page 11, Table 1 and 2 do not cover all the crops grown in the area. Potential significant omissions are those of rye and barley.	See response to previous comment.
It appears that on page 11, when you discuss nutrient removal from pasture land that you have not taken into account the additional losses of nutrients to the atmosphere that would occur each time the material cycles the livestock and is re-deposited.	Post-application N losses on pasture have been significantly increased to account for these atmospheric losses, as well as for the additional N that is leached from urine and feces.
Additionally, it appears that the only livestock taken into account are the harvested livestock. There are other types of culled livestock, including those that are sold (for reasons other than harvesting) to farmers outside the watershed.	The final report has been modified to include cull cows in addition to feeder calves.

Page 12, paragraph 1 assumes that only 75% of pasture land is utilized. In fact, livestock travel throughout the pasture land distributing nutrients. Additionally, field equipment has a broadcast radius that allows it to reach areas that it cannot transverse, increasing the utilization of the fields, including steep slopes.	The 75% assumption refers to the pasture accessible by manure spreaders, not livestock. Based on conversations with local experts, 75% is a conservative upper bound of the percentage of pasture acreage that is accessible for manure spreading.
An additional consideration that should possibly be taken into account in this calculation is the impact of deer. Large numbers of deer graze these fields from dusk until dawn, removing nutrients to be deposited in the forest or harvested by hunters.	Deer consume nutrients that originate in wooded areas as well as on farmland. They also deposit manure in wooded areas and on farmland. There is no reason to believe that, as a first-order approximation, deer result in a significant transfer of nutrients from farmland to forests. However, deer can cause additional N losses on pasture when N in their urine and feces that is deposited on pasture volatilizes, denitrifies, or leaches. Also, a portion of the N contained in deer that grazed on pasture and that are harvested by hunters would also add to the N uptake capacity on pasture. With appropriate data, deer could be added to the model as a refinement.
The discussion of nutrient loss and cycling beginning on page 12 could perhaps benefit from the insight of soil scientist or agronomist.	A more specific comment would be necessary to generate a specific response.
On page 16, you discuss the use of P as the limiting factor because the P "carrying capacity" is the lower number. However, since the point of the report is to look at long-term environmental degradation, might it be more appropriate to use N as the limiting factor due to its known environmental and human health impacts?	The point of this report is to consider the question: Given the quantity of nutrients generated by the concentrated poultry industry in the Potomac headwaters of West Virginia, how can we ensure a long-term nutrient balance? An overabundance of P, in addition to N, can have significant environmental effects. The report considers both.
In our general comments, we discuss the use of the term carrying capacity. If you intend to retain the use of this term in Section 4, we would suggest that the graphs be modified to show the N and P lines as soil nutrient assimilative capacities, with the dots labeled as the carrying capacities.	The term "nutrient carrying capacity" has been replaced with "nutrient uptake capacity," and the term "poultry carrying capacity" has been replaced with "poultry production capacity."
Considering the potential use of this report and its audience, we would suggest that more emphasis be placed on the lack of current, reliable data. This would appropriately qualify the report and may serve as an incentive for the generation of more reliable data on the part of the industry.	The need for more data is discussed in the conclusion of the report.

Dan Ramsey

Comment	Response
Technical language will make the report difficult to understand by ordinary citizens.	Sections of the report have been reworded so that it will be more accessible to non-technical readers. Also, the final report includes a new summary that brings out the main points in non-technical language.
The definitions of carrying capacity are confusing. It is confusing to use two types of carrying capacities (nutrient and poultry), especially when the term "carrying capacity" may already be defined to mean something entirely different in a field's technical jargon.	The term "nutrient carrying capacity" has been replaced with "nutrient uptake capacity," and the term "poultry carrying capacity" has been replaced with "poultry production capacity."
In Figures 4 and 5, where does the estimate of confined cattle come from?	Confined cattle have been removed from these figures.
It would be easier to follow if the endnotes were converted to footnotes.	There are pros and cons of using endnotes and footnotes; endnotes are retained in the final report.

Ed Rayburn

Comment	Response
There is one place noted where I think there are better numbers then those you chose, the P content of "other hays". Using your numbers will result in a higher poultry carrying capacity than the numbers I would use.	Both the N and P content of other hays have been revised. The draft averaged values for small grain hay, other tame hay, wild hay, and grass silage found in Lander et al. (1998). The final report simply uses the figure for small grain hay.
In the short term, a practical nutrient management model should include the use of poultry and livestock manure for increasing the P content of soils that are low in P. Based on preliminary calculations, this may take 10-20 years at the current rate of litter production, more if forest lands are included. Research has shown that where soils are low in P, trees respond to P fertilization. Thus using poultry litter in woodlands could increase carbon sequestration and reduce greenhouse gasses. Of course this management option needs to be based on not exceeding safe levels of P in the soil.	The final report emphasizes more strongly the fact that poultry and cattle manure is beneficial for increasing soil P levels in soils that are low in P. It also mentions the possibility of using litter to fertilize forested areas. To date, litter is not used to fertilize forested areas. An interesting extension of this report would be to consider how the fertilization of forested areas would increase the nutrient uptake capacities of the region.
You mentioned that geographic scale is important when viewing ecological problems. This is very true and one that needs to be addressed at a national level relative to sustainable agriculture. The issue is not as simple as the carrying capacity of relatively small, defined watersheds. Long term, sustainable agriculture requires that nutrients in the food consumed by livestock and people be returned to land that will be producing future crops. Crop and livestock production cannot be separated on a geographical scale that precludes the transport of manure and offal back to the fields where the feed was produced.	It is true that geographic scale is important, and that perhaps the most fundamental solution to balancing nutrient flows would be to ensure that crop and livestock production are not separated on a geographic scale that precludes the transport of manure and offal back to the fields where the feed was produced. This report attempts to clarify some issues related to this very question in relation to concentrated livestock production: what portion of nutrient generation can be returned to the area in which the nutrients are generated, and what role can litter exports play in approaching a nutrient balance?
Also, sewage sludge cannot include heavy metals or chemicals that may contaminate soils or crops grown to feed livestock and people.	While this statement is true, it is not fundamental to the nutrient analysis and is not included in the final draft.

Given your long term scenario, with a large input of P through imported feed, to keep the P in balance an equal amount of P needs to be exported, once the soil P is brought up to a safe agronomic/ecological level and "safe" losses are accounted for. This P export can be in crops or litter sold out of the area.	The model does not explicitly track whether harvested crops and hay are used locally or exported. This addition to the model would provide a more complete picture of all of the nutrient inputs and outputs to and from the region, but is not essential for the current analysis.
If litter is sold outside the area, it needs to be used in an environmentally safe manner. Otherwise the problem is just shifted to a different watershed.	While this statement is true, it is not fundamental to the nutrient analysis and is not included in the final draft.
We must also remember that using litter incorrectly in an urban environment can cause as much ecological risk per square mile as in an agricultural area. This has been shown by USGS research in the lower Potomac watershed in Virginia and Maryland.	Again, while this statement is true, it is tangential to the nutrient analysis and is not included in the final draft.
For the short term litter and manure can be used to increase the P in soils agronomically low in P with little environmental risk.	The final report emphasizes more strongly the fact that poultry and cattle manure are beneficial for increasing soil P levels in soils that are low in P.
More N can be used on pastures than what is taken off in the calf without increasing environmental risk.	Two changes were made in the final report that relate to N use on pastures. First, the harvest of cull cows, in addition to feeder calves, has been included. Second, N post-application losses are significantly increased to account for losses as livestock urinate and defecate on pasture.
P removal in "other hay" is probably lower than the number you are using now.	Both the N and P content of other hays have been revised. The draft averaged values for small grain hay, other tame hay, wild hay, and grass silage found in Lander et al. (1998). The final report simply uses the figure for small grain hay.
The sale of cull cows will increase P removal from pastures by about 1/3 over using only the calf removal rate.	The final report has been modified to include cull cows in addition to feeder calves.
It is unlikely that P will leach from most of the soils in the watershed.	This clarification has been included in the final report. Nevertheless, if P is repeatedly applied at rates that exceed uptake, even these soils will become saturated and will be more likely to leach P. It is this eventuality that the report addresses. In addition, the post-application P loss rate has been reduced from 10% to 5%.
I hope it will not be used to justify some level of livestock production/stocking rate in the watershed. The issue is not that simple. There are ecologically safe management practices for using the litter and economically viable ways for moving it to areas that can use it safely.	As discussed in the report conclusions, there are a number of changes that could be made to approach a long-term nutrient balance. While one potential solution would be to limit livestock production/stocking rates, many other options are also available. These options include increasing litter exports, shifting the crop mix, applying litter in wooded areas, and other possible solutions.

Dave Workman

Comment	Response
Who is the intended audience? It may be difficult for non-scientific readers to follow some parts of the report.	Sections of the report have been reworded so that it will be more accessible to non-technical readers. Also, the final report includes a new summary that brings out the main points in non-technical language.
Pfiesteria has nothing to do with what happens in WV because it only occurs in brackish water.	The report does not mean to imply that *pfiesteria* occurs in WV. It implies only that *pfiesteria* has been linked to high nutrient levels in the Chesapeake Bay. Rivers that originate in the Potomac headwaters eventually feed into the Chesapeake Bay.
Soil test results from the WV Soil Test Lab show that many soils test in the low and medium category for phosphorus.	The report does not mean to imply that all soils in the region test high or very high for P. The final report emphasizes the benefit of raising soil P levels in deficient soils.
The TMDL report cited in the draft report is very flawed. For example, the wildlife figures are gross underestimates.	The assumptions drawn from the TMDL report are not related to the wildlife figures. They are taken directly from a WVSCA memo, referenced in the TMDL report, that suggests the amount of poultry litter expected to be transported out of the Lost River watershed in the future. I also draw from the report estimates of the number of poultry houses in the watershed, and litter production per house.
There are areas in the region that have never had poultry litter applied to them.	This assertion is likely to be true, but it does not affect the model. The model looks at broad areas--a watershed, counties, and the 5-county region--and does not depend on the particular situation found on individual fields.
Almost all poultry farms have viable nutrient management plans in place.	More and more farmers in the region are implementing nutrient management plans. When these plans are properly implemented, nutrient losses are lowered. Note that, when nutrient management plans are properly implemented, nutrient losses are lowered, resulting in decreased nutrient uptake capacities and poultry production capacities. Because the intent of the model is to calculate upper bounds for these values, the loss estimates used in the model are conservative and justified.

ENDNOTES

[1] The P index identifies fields that are potential sources of P pollution to surface waters, and can be used to assess management strategies that minimize losses.

[2] Poultry litter use on forested land is currently being investigated by government agencies but, at present, litter is not applied in these areas.

[3] As poultry litter is applied year after year, soil P levels are rising, and we will eventually reach the point where, on average, soil P levels are high enough that P applications, on average, should be limited to that which is harvested and removed from the field and unavoidably lost. In Grant, Hampshire, and Hardy Counties, roughly 20% of recent soil P tests are already classified as very high due to repeated applications of litter (Bhumbla, personal communication). The West Virginia University Extension Service recommends that no additional P be applied on these soils until soil P levels decline.

Estimates vary on how long it may take for fields with low soil P levels to reach high soil P levels with repeated applications of poultry litter. One estimate suggests that this situation may be encountered in fifteen to twenty years (Rayburn, personal communication).

[4] N losses after field-application include volatilization, denitrification, leaching, and runoff. Data presented by Sharpley et al. (1998) provide an indication of some typical N losses after field application of manure. Figure 5 in this publication suggests that about 5% of applied N is lost through volatilization and denitrification, and about 20% is lost through leaching when dry dairy manure is applied at a rate of 550 pounds N per acre to forage crops of winter barley and summer sudangrass. Table 5 in this publication surveys N losses in surface runoff after the application of poultry litter. After application to non-fallow ground, N losses through runoff range from 0.3% for fescue to 10.7% for C. Bermuda grass. This high value of 10.7% results from a heavy application of about 1,200 pounds N per acre. Almost all values for N losses through runoff are in the 3-5% range. The total post-application loss rate of 30% is calculated as the sum of 5% (volatilization and denitrification), 20% (leaching), and 5% (runoff).

[5] P losses after field-application include losses through runoff and, if soil P levels are high enough, through leaching. According to Table 5 in Sharpley et al. (1998), P losses in surface runoff after poultry litter is applied to non-fallow land vary from about 2% to 3%. It is unlikely that P will leach in most soils found in the Potomac headwaters region. Still, post-application P losses are conservatively estimated to be 5%, which is higher than the 2% to 3% loss rates suggested for runoff alone.

[6] In this mountainous region, where about two-thirds of the land area is sloped at greater than 15% (SCS, 1989), pasture is generally located on the more hilly agricultural land. The pasture calculation is based on accessible pasture, defined as pasture that is flat enough to allow manure spreaders or other fertilizing equipment to operate. Based on conversations with local experts, a conservative assumption is used: 75% of the pasture in all study areas is assumed to be accessible.

[7] Post-application P losses on pasture are likely to be smaller than losses on cropland, because year-round soil cover is likely to minimize soil erosion. Still, P losses on pasture are conservatively estimated to equal those on cropland: 5% of applied P.

[8] Many sources provide data on manure production rates and the nutrient content of manure. Data used in this report are based on manure characteristics in a recent NRCS publication (Lander et al., 1998), which in turn bases its data on a survey of recent standard sources (*Livestock Waste Facilities Handbook* from MidWest Plan Service, *Agricultural Waste Management Handbook* from NRCS, and livestock manure characterization values from a North Carolina State University database).

Storage and handling losses, taken from the same NRCS report (Lander et al., 1998), include N volatilization, as well as N and P losses through rainfall and erosion if litter is not adequately protected from precipitation. These losses are included in the model, with the assumption that some amount of storage and handling losses is simply unavoidable as litter is collected and stored for future field applications.

Because manure production data are based on animal units (AUs), defined as 1,000-pound animal-equivalents, average animal weights are needed. Again, estimates of animal weights are based on Lander et al. (1998). The final assumption, production cycles per year, is necessary for converting average broiler and turkey inventories into annual production.

Although farmers apply litter—not manure—on their fields as fertilizer, this model is based on manure data. The manure data used are "as excreted," and therefore account for the full quantity of N and P produced by the birds. Between the time that the manure is excreted and the litter is applied on the field, a number of transformations take place: some nutrients are lost during storage and handling, the manure is mixed with bedding material, and evaporation takes place. N and P losses in storage and handling are explicitly accounted for, and any additional nutrients in the bedding material are ignored. There is no need to account for evaporation, because evaporation does not add or subtract N or P.

[9] In 1997, the five counties of the Potomac headwaters supported an inventory of 18,700 sheep and lambs (WVDA, 1997). In 1996, Hampshire County alone supported 1,200 hogs (WVDA, 1997). When these livestock are confined, farmers may collect their manure and apply it as fertilizer. Nutrients in this manure actually "uses up" a portion of the nutrient uptake capacities.

[10] Statewide, 91 million broilers and 5 million turkeys were produced in 1997, compared with 1 million chickens other than broilers (USDA, 1998). Broilers therefore represent 94%, and turkeys represent 5%, of the total number of birds produced statewide in 1997. Because most poultry production is concentrated in the Potomac headwaters region, these statistics also describe the situation found there.

[11] The term "cattle" is used to include both beef cattle and milk cows. In 1997, 81 thousand cattle and milk cows were raised in the Potomac headwaters region. Of these, only 700 were milk cows (WVDA, 1997). Beef cattle therefore represent about 99% of all cattle and milk cows in the region.

[12] As detailed in the section that describes the calculation of pasture nutrient uptake capacities, all N eaten by pastured cattle is not cycled; some is lost through urine and feces. These N losses are accounted for in the pasture nutrient uptake capacity calculation.

[13] Many cattle are confined for a portion of the year. The "percentage raised in confinement" therefore represents the average percentage of the year during which the region's cattle are confined.

[14] The TMDL analysis uses a figure of 14 tons of poultry litter exports per day, or 5,110 tons per year. Total litter generation in the Lost River watershed is calculated to be 26,400 tons per year from the following figures in the TMDL report: number of broiler houses (104), litter production per broiler house (165 tons per year), number of breeder houses (42), litter production per breeder house (100 tons per year), number of turkey houses (42), and litter production per turkey house (120 tons per year). Exports as a percentage of generation are calculated by dividing 5,110 tons by 26,400 tons.