SELECTED BMP EFFICIENCIES

WRENCHED FROM EMPIRICAL STUDIES

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INTRODUCTION

Despite years of research on BMP effects on water quality, a current, empirically based compilation of BMP nutrient reduction efficiencies does not exist. The Maryland Department of the Environment requested that the Interstate Commission on the Potomac River Basin (ICPRB) prepare a list of BMP nutrient reduction efficiency estimates based on water quality studies reviewed in an earlier ICPRB report[1].

The following report summarizes studies of BMP efficiencies. Frequently efficiencies calculated from results of studies conducted for purposes other than efficiency estimation are cited. For some BMPs which have not been adequately studied inductive reasoning is applied to the existing data to produce crude efficiency estimates.

The sparsity of studies, the local variation in site conditions, and the simplified conceptual models used to describe some BMPS contribute to the uncertainty around all the efficiency estimates. Nevertheless, estimates based on some data are better than estimates based on none.

These efficiency estimates will be of value in formulating and checking BMP representations in the Monocacy Nonpoint Source Model and in the Chesapeake Bay Watershed Model Phase 2. Individual components of such numerical models have to be "scaled" so that their predictions are consistent with observation. This paper is intended to provide reference points for the internal scaling process. The BMP efficiency estimates may also be used in certain economic assessments, independent of the watershed models.

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[1]Casman, E. and P. Pacheco. 1989. *Parameters and Concepts for Modeling Tillage Practices, Animal Waste Management Systems, and Vegetated Filter Strips*, ICPRB Report No. 89-6, Rockville, MD.

DEFINING BMP EFFICIENCY.

When discussing point sources (such as sewage treatment plants), efficiency is defined as one minus the ratio of the effluent load to the influent load,

$$1 - OUT/IN$$

and can be thought of as the fraction of the load removed by the treatment process. The same general approach will be taken with nonpoint sources in this report. Consider "IN" to be the pre-BMP load and "OUT", the post-BMP load. For example, if the conventional practice results in an annual total nitrogen loss of 100 kg/ha and the BMP results in an annual loss of 30 kg/ha, the TN reduction efficiency of the BMP is 1 - 30/100 or 0.70. Total nitrogen loss is reduced by the BMP by 70%.

In the discussion of BMP efficiencies for water quality management it is important to identify the destination of the nutrients. Some BMPs designed to reduce runoff and runoff associated nutrients shunt surface flows to subsurface flows. Reporting such a BMP's effect in terms of surface runoff pollution alone results in good removal efficiencies; however, it omits the pollution of the ground water, which may outweigh surface water pollution.

Typically BMP efficiencies for surface runoff improvement are evaluated at the edge of the field or the outlet of the structure, and have no connection to the dilution capacity of the receiving water. To be consistent, in this study ground water nutrient removal efficiencies will be evaluated in terms of what escapes the root zone, i.e., the mobile nutrients that are not available for plant uptake. This approach sidesteps the issues of the dilution capacity of aquifers and their contribution to baseflow pollution. An attempt will be made to estimate total as well as surface and subsurface efficiencies, where possible.

DIFFICULTIES OF ESTIMATING EFFICIENCIES FROM THE LITERATURE.

There are several serious obstacles frustrating the evaluation of BMP efficiencies from published experimental studies. Many of these obstacles are related to the studies' experimental designs. The designs, though appropriate for their intended purposes, are not often suitable for extracting BMP efficiencies that represent the impact of the BMP on ground and surface water quality.

For the purpose of this discussion, the problems interfering with the determination of BMP efficiencies from studies with other objectives can be divided into spatial, temporal, methodological, and conceptual categories.

SPATIAL: The literature contains small plot studies as well as larger watershed studies, the results of which are not always compatible. We see studies contrasting similar sites, dissimilar sites, and studies of the same site with different treatments. Because of the sensitivity of BMP effectiveness to local conditions, the transferability of quantitative conclusions to unmonitored sites can be tenuous.

TEMPORAL: We see studies of single events, selected events, whole year, and multiple years. Studies focusing on the short term may misrepresent annual behavior. Studies are often too brief to capture the effects of meteorologic and other natural sources of variability on BMP efficiency.

METHODOLOGICAL: We see studies of selected dissolved nutrient species, total filtered nutrient species, and/or total unfiltered nutrient species. Often key constituents for efficiency calculations are lacking. Sampling protocols are inconsistent between studies, with everything from occasional grabs to weighted composites. Different sampling equipment may give inconsistent results. For instance, estimates of ground water nutrient losses have different biases depending on whether samples were taken from wells, lysimeters, or tile drain outlets. Typically rainfall simulator studies are conducted for single crop stages at rainfall intensities representing the 2, 25 or 100 year storm. Snapshot characterizations such as these give considerably different efficiencies than long term natural rainfall studies over all stages of crop development.

CONCEPTUAL: Some studies do not include the pre-BMP observations needed in order to calculate efficiencies. Studies usually examine surface water or ground water, but rarely both.

The net result is a body of literature that gives unclear, contradictory, fragmentary, and/or difficult to generalize perceptions about BMP efficiency. It should be noted that most of the authors cited in this paper were not trying to demonstrate BMP efficiencies and shouldn't be condemned for the crimes I am about to commit with their data.

This is not meant so much as a disclaimer, as to alert the reader that the state of the empirical literature on BMP efficiencies is not advanced at this time. Even so, some important insights for modeling can be gained from this analysis.

DOCUMENT ORGANIZATION

Three broad categories of BMP will be discussed. First, recent studies of BMPs for field crops will be reviewed, with greatest emphasis on tillage practices. Studies of surface runoff quality will be presented followed by studies of ground water quality as affected by tillage. An attempt will be made to unify them. To the extent possible, other related BMPs (Nutrient Management, Fertilizer Placement, Fertilizer Timing) will be included.

For lack of appropriate studies, animal waste management will be treated more conceptually in order to establish some upper bounds for the efficiencies of manure storage, clean water protection, and nutrient management in the livestock operation context.

Vegetated filter strips will be handled in a manner similar to that of the section on tillage practices.

This paper is written for two audiences, modelers and managers. Modelers will be interested in the details of the text, such as monthly efficiencies, separate surface water and ground water efficiencies, and efficiencies for various nutrient species. Managers will be more interested in the annual efficiencies reported for surface and ground water combined, which are summarized in the last table, because these measure the performance of the BMP.

CONSERVATION TILLAGE

An obstacle to determining conservation tillage efficiencies independent of the installation site is the BMP's sensitivity to site-specific influences. Soil properties; surface slope; the previous crop; the amount of residue removed; placement, type, quantity, and timing of fertilizer; harvesting practice; variety of crop; planter style; orientation of contour; and meteorology can all dramatically change the efficiency of a tillage practice. An attempt to overcome the site-specificity problem will be made in the summary sections, where all the efficiency estimates will be compiled for the extraction of common characteristics.

Though many tillage studies are in the literature, there are not enough to definitively characterize the complexity of conservation tillage and related options. Even some of the better studied tillage variations are not adequately described in terms of efficiency. This is because many of the authors were addressing the problem of nutrient loss in terms of the economics of crop production, i.e., how much N and P was available for crop uptake, and not water pollution concerns.

Many studies, including most rainfall simulator studies, focus on single rainfall events, missing the contribution of the source over time as the crop develops and is harvested. Many of the comparative tillage studies characterize the pollution coming off a field during the seedbed stage (planting to emergence) because this is a window when the field is vulnerable to the forces of large storms. If the bulk of the year's nutrient loss usually occurs during seedbed, it is appropriate to discuss BMP efficiency in terms of this window; if not, the efficiency may represent a relatively insignificant movement of mass on an annual average basis.

Many of the studies did not include replications, so the meaning of their results in the context of the expected natural variability could not be tested statistically.

TILLAGE EFFECTS ON SURFACE WATER QUALITY

Studies of tillage effects on water quality usually report surface water nutrient losses, ground water nutrient losses, or both. Likewise, nutrient reduction efficiencies can be calculated for the surface, subsurface, or for the sum of the two. The reader will notice that focusing on either ground or surface water losses misrepresents the total system losses (important to the water quality manager). However surface or subsurface efficiencies may be useful to modelers.

Positive efficiencies provide the fraction of nutrient load reduced by the action of the BMP, whereas negative efficiencies indicate the fraction of the load added by the BMP. (For example, read an efficiency of +.21 as a 21% reduction, and an efficiency of -2.77 as a gain of 277% over loads from conventional practices.) Negative efficiencies are calculated by the same formula as the positive efficiencies.

It is easy to accept that the runoff from a BMP could be more nutrient rich than the runoff from the conventional practice. One presumes that excess nutrient loss in runoff is compensated for by reduced amounts of nutrients entering the subsurface, so no violation of the principle of conservation of mass is required.

Negative efficiencies for surface and ground water losses combined (when inputs to the base case and BMP are equal, which is not always the case) are more problematic, and are probably due to sampling errors and/or inadequate study time horizons.

Here begins the listing of various conservation tillage practice efficiencies derived from surface water quality measurements. In most cases these data were reported as mass losses in their original papers, and efficiencies were calculated by me. The individual studies are collated and summarized at the end of the Surface Loss Section.

Angle et al. (1983, 1984) contrasted surface water runoff sediment and nutrient losses from conventional and no-till corn fields in the Maryland Coastal Plain Physiographic Province. The soil was a Manor loam with 6 to 7% slope.

Prior to planting, the conventionally tilled watershed was contour plowed, disc harrowed, and cultipacked. The corn was planted in April and harvested in October. The no-till watershed was planted using no-tillage procedures. Both watersheds received surface applied fertilizer, however the fertilizer was plowed under on the conventional tillage plot.

Summarizing 31 storm events over 3 years, the no-till efficiencies for storms averaged within months are presented in Table 1. (Efficiencies are calculated as 1 minus the ratio of the no-till load and the conventional till load.) Though the paper contained results from all months except September and December, because of the wide variability of individual storms, only months represented by at least 3 storms are reported here. (This decision eliminates only four data over the 3-year study, one storm each in January, February, October, and November.) A longer period of record would greatly improve confidence in these monthly efficiencies.

These results compare no-tillage to contour conventional tillage. The efficiencies may have been greater if they could have been calculated relative to parallel-to-slope tillage. (This is an example of a study whose control is itself a BMP and not the control needed for calculating the efficiency as defined in the Introduction.)

Ortho-P and soluble P were the only two parameters which did not demonstrate a statistically significant tillage effect for the 3-year summed export. That is, on an annual basis, dissolved phosphorus species in runoff were neither reduced nor increased by no-tillage, though all N species and particulate P in runoff were significantly reduced.

The no-till corn field produced more runoff and nutrients in April than the conventionally tilled field, but less suspended sediment, suggesting two mechanisms: enhanced infiltration of plowed fields and increased nutrient availability of broadcast fertilized no-till fields.

Efficiencies are not constant over months. Seasonal differences are most apparent during field preparation activities.

Nutrient removal efficiencies did not track sediment removal efficiencies well on a monthly basis.

Though efficiencies are negative in April, because the heaviest rainfall occurred at other times (only 3 April storms were recorded), April does not exert a noticeable influence on the yearly efficiencies. (This should be kept in mind when reading the results of simulator studies conducted during seedbed crop stage that follow. The most vulnerable season is not necessarily the controlling season in terms of total losses.) This is contrasted to sediment loss, where one or two rainfall events contributed the bulk of the yearly total sediment loss each year.

Table 1. Monthly Nutrient Reduction Efficiencies for No-tillage

	runoff	suspended sediment	ammonium-N	nitrate-N	total N
MAR	.72	.72	.99	.84	.88
APR	-.34	.59	-6.67	-.71	-1.67
MAY	.91	.99	.81	.63	.84
JUN	.81	.80	.99	.85	.84
JUL	.47	.98	-[1]	.94	.91
AUG	-	-	-	-	-
YEAR[2]	.82**[3]	.87**	.93**	.87**	.88**

	ortho-P	soluble P	total P	number[4]
MAR	-.70	-.17	.70	3
APR	-5.04	-6.63	-.90	3
MAY	.80	.92	.80	7
JUN	.66	-.07	.97	9
JUL	-	.51	.78	3
AUG	-	-	-	3
YEAR	.22	.13	.90**	32

[1] "-" means no runoff from no-till plot
[2] all storms, including months not listed above
[3] ** means there was a significant difference between 3-year sums at $p \leq 0.05$ for tillage pairs
[4] number of storms used to estimate efficiency

Ross et al. (1987) contrasted runoff quality from several tillage plots using simulated rainfall. Efficiencies calculated on the basis of the losses from the sum of two days of simulator tests are reported.

The rainfall was applied at a rate of 4-5 cm for 60 minutes, followed after 24 hours by two 30 minute applications separated by half and hour. The second day application totaled 5 cm. Each set of tests was run on a different soil. The test date and soil type are listed with each table.

Table 2. No-till Efficiencies during Seedbed Crop Stage for Corn on Goldsboro Fine Sandy Loam, 2% Slope, May 15-16, 1985

TSS	NH4	NO3	TKN	T N
.98	.62	.70	.85	.83

T P	o-P	filtered TKN	filtered T P	RUNOFF
.88	-	.57	.72	.76

Table 3. No-till Efficiencies for Corn with a Developed Canopy on Tetotum Fine Sandy Loam, 6% Slope, August 6-7, 1986

TSS	NH4	NO3	TKN	T N
.82	.80	-6.74	.70	.57

T P	o-P	filtered TKN	filtered T P	RUNOFF
.82	-.68	.53	.91	.62

Table 4. No-till Efficiencies for Soybeans during Seedbed on Slagle Fine Sandy Loam, 5% Slope, June 19-20, 1985

TSS	NH4	NO3	TKN	T N
.99	.89	.63	.80	.80

T P	o-P	filtered TKN	filtered T P	RUNOFF
.92	-	.66	.45	.53

Table 5. No-till Efficiencies for Soybeans with a Developed Canopy on Suffolk Loamy Sand, 2% Slope, July 26-27, 1985

TSS	NH4	NO3	TKN	T N
.92	-1.66	.43	.39	.39

T P	o-P	filtered TKN	filtered T P	RUNOFF
.78	-	-.19	-.61	.13

Table 6. Chisel Till Efficiencies for Soybeans during Seedbed on Suffolk Loamy Sand, 2% Slope, July 26-27, 1985

TSS	NH4	NO3	TKN	T N
.28	.38	.39	.36	.36

T P	o-P	filtered TKN	filtered T P	RUNOFF
.39	-	-.01	-.02	.19

Table 7. No-till Efficiencies for Soybeans with a Developed Canopy on Caroline Fine Sandy Loam, 6% Slope, August 11-12, 1986

TSS	NH4	NO3	TKN	T N
.996	.66	.29	.92	.88

T P	o-P	filtered TKN	filtered T P	RUNOFF
.97	-2.91	.74	.55	.75

In this study no-till efficiencies for TN in runoff, ignoring soil, crop, and date, ranged from 0.40 to 0.90, and the efficiencies for TP in runoff ranged from 0.80 to 0.97

The May corn results seem to be consistent with Angle et al.'s May results.

Laflen and Tabatabai (1984) examined tillage effects on two soils with simulated storms in early June (before canopy closure). They studied two crops in four rotations, continuous corn, continuous soybeans, corn followed by soybeans, and soybeans followed by corn. The two soils were a 5% slope Clarion sandy loam and an 11% slope Monona silt loam. They collected time weighted composite runoff samples over a 30 minute period.

The interesting part of this table is the asterixes, which tell you for which parameters and which soils no-till nutrient losses resembled those from chisel till, but were distinct from conventional tillage; for which soils and parameters the losses from the two conservation tillages were distinct from each other as well as from conventional tillage; and for which parameters and soils there was no differences among the three tillages. This is important in large models where tillage practices are often lumped together.

Table 8. Conservation Tillage Efficiencies for Nutrients in Runoff From Two Soils During Seedbed

	Clarion	Monona
dissolved ammonium		
chisel	-2.17	-1.58
no-till	-7.00**	-7.86**
dissolved nitrate		
chisel	0	-1.57
no-till	-6.70**	-5.24**
dissolved phosphate		
chisel	-1.22	-0.98
no-till	-8.89**	-4.67**
total N		
chisel	0.42*	0.27
no-till	0.56*	0.69**
total P		
chisel	0.38*	0.29**
no-till	0.55*	0.71**

Single asterixes indicate significant difference from conventional tillage at $p \leq 0.05$. Double asterixes indicate that in addition to being different from conventional tillage, chisel and no-till were also significantly different from one another at $p \leq 0.05$.

During seedbed, for this half-hour single storm simulation, chisel and conventional tillage were indistinguishable on the basis of dissolved ammonium, dissolved nitrate, and dissolved phosphate in runoff on either soil.

On the less erodible Clarion soil no-till and chisel tillage reduced total nitrogen losses relative to conventional tillage, but on the highly erodible soil chisel and conventional tillage lost the same amount of total nitrogen. On the less erodible Clarion soil, no-till retained the same amount of sediment bound nutrients as did chisel tillage, and lost more dissolved nutrients.

On the highly erodible Monona soil there was always a difference between chisel and no-till. No-till retained more sediment bound nutrients than chisel tillage, and lost more dissolved nutrients.

The authors concluded that soil type is the most influential factor in runoff pollution during seedbed crop stage; more important than rotation, tillage, or type of standing row crop. During seedbed dissolved nutrient losses from the steeper, finer textured Monona soils were 3 times that from the Clarion soils, and particulate nutrients were 20 times greater.

There were 6 (no-till) and 88 (conventional) times more particulate N than dissolved N in runoff from the Clarion soil, and 13 (no-till) and 330 (conventional) times more particulate N from the Monona soils during seedbed.
Rotation effects were evident during seedbed on the Clarion soil, but not on the more erodible Monona soil. The authors attributed the greater resistance to erosion during seedbed for rotations with corn as the first crop to the greater amount of residue remaining after corn harvest. The erodible soil was not significantly protected, however. These results should not be generalized to unsampled growth stages.

NUTRIENT MANAGEMENT

A decade ago Reckhow et al. (1980) wrote a critical literature review of agricultural nonpoint pollution. Though much of their data is not in a form amenable to efficiency calculation, they made several observations about farm practices that are relevant to this discussion:

(1) The type of fertilizer (chemical or manure) used is not as important to nutrient flux as the time of application.

(2) Incorporation of fertilizer after application reduces export by runoff.

(3) The type of crop (non-row versus row crops) also influences

nutrient loss to runoff. Though median loss values reported were not statistically distinguishable, the highest reported loss from non-row crops was ten times smaller than the highest loss from row crops.

(4) Excessive or insufficient fertilization can increase nutrient losses to runoff.

Some examples of annual efficiencies for the BMP nutrient management can be extracted from their report. The studies were all from the 1970's and little detail was given. Median values for annual nutrient load per unit area were reported.

Table 9. Efficiencies of Selected Nutrient Management Alternatives For Conventionally Tilled Corn for Runoff Total N and P

	Total N	Total P
Base Case: recommended spring application of N and P on conventional corn	0	0
recommended winter application of N and P on conventional corn (two studies)	-1.36 -2.61	-1.67 -3.20
80% of recommended fertilizer applied in spring	.15	-0.27
corn without fertilizer (two studies)	-0.17 -0.02	-0.63 -0.60
contour conventional corn with half recommended N and P	-1.55	-0.35
contour conventional corn with 260% recommended N and 160% recommended P	-3.14	-1.27

The efficiencies in Table 9, derived from Reckhow et al.'s median TN and TP loads, compare different fertilization options to conventional tillage corn fertilized in spring with the proper amount of fertilizer. Tillage effects were not analyzed. The practices compared to the base case are, with one exception, not BMPs, as can be seen from the negative efficiencies.

Though these are not hard numbers (because of the age of the studies and questions about methodology), it is clear that timing and quantity of fertilizer have important runoff quality consequences.

Whitaker et al. (1978) also examined the effects of nutrient management alternatives on nitrate and ammonium in runoff. The alternatives included fall fertilization at plowing versus spring fertilization by plowing or disking immediately before planting.

Corn was planted parallel to slope on a slowly permeable clay pan silt loam soil with 3% slope. The advantage of fall plowing in such a soil is not having to wait for the field to dry out in spring before plowing. This permits earlier planting and increases the crop's ability to withstand late summer drought. The disadvantage is that it makes fields more vulnerable to erosion during the winter.

Soluble nitrate and ammonium concentrations were measured with ion sensitive electrodes. The sampling protocol was not explained, but flow weighted composite samples were not the rule in 1978. Considering spring plow conventional till as the base case, relative runoff retention efficiency for nitrate plus ammonium N are reported by groups of months in Table 10.

Table 10. Efficiencies of Fall Plow Conventional Tillage and No-Tillage Relative to Spring Plow Conventional Tillage in Terms of Dissolved Mineralized Nitrogen Loss to Runoff

	fall plow	no-till
fall plow to spring plow (November through March)	-4.67	-0.17
spring plow to planting (April and May)	0.43	0.88
planting to sidedress (June)	-0.39	-2.12
sidedress to fall plow (July through October)	0.66	-0.08
2 year average	-0.27	0.04

The real water quality issues in spring versus fall plowing concern particulate N loss and N losses to ground water, which unfortunately were not measured.

Whitaker et al. (1978) also fertilized no-till and conventional till corn with increasing amounts of nitrogen fertilizer. In Table 11 no-till efficiencies are expressed relative to conventional tillage for each fertilizer level, so the no-tillage efficiencies can be examined independent of the fertilizer level.

These results suggest that the ability of no-tillage to reduce nitrate and ammonium runoff losses results from sediment reduction at high fertilizer levels. Over-fertilized conventionally tilled corn lost more dissolved mineralized nitrogen in runoff than over-fertilized no-till corn. Dissolved nitrogen species losses are somewhat enhanced by no-tillage, but these are dwarfed by sediment N retention.

Table 11. No-till Efficiencies for Runoff Pollutant Removal at Several Fertilizer Levels

Fertilizer kg/ha N	dissolved nitrate + ammonium	sediment bound TKN	dissolved + particulate N species[2]
14.6	0.00	0.83	0.63
97.5	-.51	0.91	0.41
211.8	-.34	0.89	0.53
219.8[1]	-.23	0.90	0.42
249.9	0.43	0.82	0.56
364.3	0.03	0.90	0.36

[1]Considered to be the optimum N level. Precipitation supplied an additional 5 kg/ha N
[2]Not equivalent to TN because missing dissolved organic N and particulate NO3.

But more interesting is the uniformity of runoff TN efficiencies over the range of fertilizer levels (last column). The ratio of the total losses remained fairly constant regardless of the fertilizer level. *The no-till efficiency (with fertilizer effects removed) was about .40 to .60 whether the fertilizer N application was 7% or 166% of recommendation.*

NUTRIENT MANAGEMENT: SPLIT APPLICATION WITH BANDING

Another part of Whitaker et al.'s (1978) study concerned banding and split application of fertilizer. Banding at side-dress decreased dissolved nitrogen losses in runoff by 50% at 2 fertilizer levels, 212 and 364 kg/ha.

NUTRIENT MANAGEMENT: FERTILIZER REDUCTION

The data from Table 11 can be reworked to give nutrient management efficiencies without a tillage factor, showing the effect of deviating from 100% of the recommended fertilizer application for either no-till or conventional tillage. The efficiency is calculated as one minus the ratio of the sum of runoff N losses from the test fertilizer level plot divided by the sum of the runoff N losses from the 100% recommendation plot. Tillage treatments are handled separately.

Table 12. Nutrient Management Efficiencies for N in Runoff by Tillage

fertilizer level	no-till	conventional
7%	.42	.25
44%	-.13	.15
96%	.06	.23
100%	0	0
114%	-.25	-1.68
166%	-.88	-1.38

Here is how these data look graphed. A linear regression on this data (R^2 = .69) gives an equation for predicting TN removal efficiency for runoff, E_r, from fertilization level (percent of recommendation), L:

$$E_r = 0.3274 - 0.00367\ L$$

Increasing fertilizer level by ten percentage points decreases runoff TN removal efficiency by about 0.04, according to this equation. More data are needed before definitive statements of this type can be made.

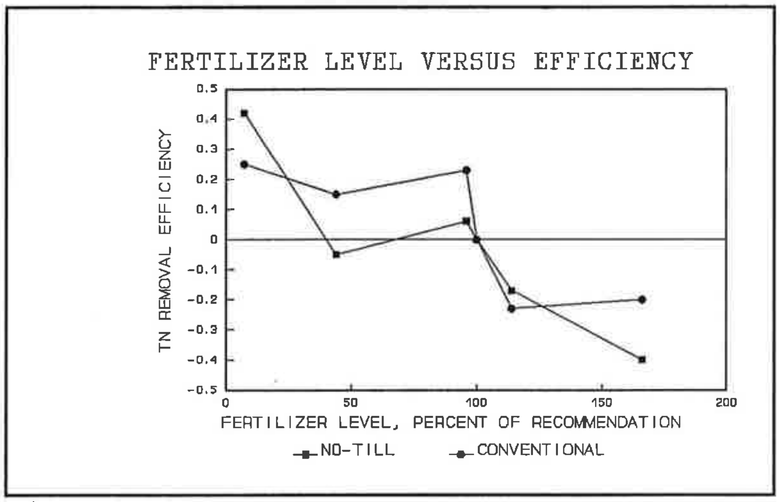

Figure 1

In this case, under fertilization did not seem to increase N in runoff, as had been concluded by Reckhow et al. Over fertilization was associated with increased N loss in runoff. A tillage factor could exist.

BANDING

Subsurface banding of fertilizer is reported to reduce both dissolved N in runoff (Whitaker et al., 1978) and total P in runoff (Andraski et al., 1985) by half.

Andraski et al. (1985) studied the effects of subsurface banding on P losses in runoff for conventional tillage, no-tillage, chisel tillage and till-plant systems. Their efficiency estimates are based on three years of simulator studies composed of three tests per growing season (June, July, and September). Corn plants were removed before rainfall was applied. Because of these experimental peculiarities, the numbers in Table 13 are neither growing season nor annual efficiencies.

The efficiencies are reported relative to conventional tillage and represent the effect of the combined BMP of conservation tillage with subsurface banding. Efficiencies for reducing total algal available P (dissolved plus particulate[2]) and total P in runoff are given.

Table 13. Runoff P Reduction Efficiencies for the Combined BMP of Conservation Tillage and Subsurface Banding

	total algal available P	total P
no-till	0.63	0.81
chisel till	0.58	0.70
till-plant	0.27	0.59

TERRACES AND WINTER COVER

Langdale et al. (1985) studied phosphorus losses in runoff from contour conventional till corn (winter fallow), contour conventional corn on terraces with a rye winter cover, and contour conventional wheat and soybeans on a Cecil sandy loam of 7% slope.

Runoff phosphorus removal efficiencies for this combined BMP (relative to contour conventional till corn without terraces or winter cover) can be found in Table 14.

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[2]that which desorbs from the sediment

Table 14. Phosphorus Removal Efficiency of Terracing Plus Winter Cover

	dissolved phosphate	total phosphorus
Base case: contour conventional corn, winter fallow	0	0
conventional corn on terraces with winter rye cover	average annual efficiency	
	-.07	0.66
	winter efficiency	
	-.37	-.91
	summer efficiency	
	0.30	0.98

The rye cover contribution to the BMP scenario can be surmised from the winter efficiency entries. A rye cover crop did not enhance phosphorus retention on terraced fields. To the contrary, it increased phosphorus loss in runoff, probably due to the fertilization of rye at planting that did not occur on the fallow field.

Terracing plus winter cover greatly reduced total phosphorus losses in runoff (efficiency = 0.66) on an annual basis.

Dissolved phosphorus losses to surface runoff were reduced by terracing during the warmer months but increased during the winter. The net result was a slight (7%) annual increase in dissolved phosphorus loss in runoff relative to losses from a corn field left fallow in the winter.

Brinsfield et al. (1988) recommended planting a winter cover crop of cereal grains (rye, wheat, barley, or oats, presumably without fertilization) to remove dissolved nitrogen from the soil. They observed that for cereals planted immediately after corn harvest (September 13), cereal nitrogen uptake ranged from 33% to 82% of the applied N fertilizer. For cereals planted a month later (October 13, the typical cereal grain planting date for grain production on Maryland's Eastern Shore) 7 to 19% of the nitrogen in the soil pool was taken up.

These high nitrogen uptake figures are probably related to drought conditions in the summer preceding cover crop planting. The drought had severely decreased corn yields and left a large soil N pool. Cereal cover crops' growth response is dependent on the amount of available soluble nitrogen in the root zone (Widdowson et al., 1982). In a normal year, N uptake by the cover crop would probably have been less. Reports of 4 to 6% N uptake by cover crops are not uncommon See the "Synthesis" section for a derived efficiency estimate for winter cover based on these data.

SURFACE LOSS BY TILLAGE PRACTICE OVERVIEW

The Bay watershed model makes no distinction between reduced tillage and no-tillage. Depending on the vulnerability of the soil, this may or may not be true. Runoff TN and TP losses from highly erodible soils are not identical for these two forms of conservation tillage. On less erodible soils the losses are similar.

Lumping crop type, soil variability, and conservation tillage specifics (as does the Bay model), the following efficiencies were reported for no-tillage. Studies are identified by their first author. Multiple entries under the same author indicate different experimental conditions within the same general category.

Table 15. March Conservation Till Efficiencies for Runoff

	Angle
TSS	0.72
NH4	0.99
NO3	0.84
TN	0.88
oP	-.70
dis.P	-.17
TP	0.70

Table 16. April Conservation Till Efficiencies for Runoff

	Angle
TSS	0.59
NH4	-6.67
NO3	-.71
TN	-1.67
oP	-5.04
dis.P	-6.63
TP	-.90

Table 17. May Conservation Till Efficiencies for Runoff

	Angle	Ross
TSS	0.99	0.98
NH4	0.81	0.62
NO3	0.63	0.70
TN	0.84	0.83
oP	0.80	-
dis.P	0.92	0.91
TP	0.80	0.88

Table 18. June Conservation Till Efficiencies for Runoff

	Angle	Ross	Laflen	Laflen	Laflen	Laflen
TSS	0.80	0.99				
NH4	0.99	0.89	-.88	-.89	-.68	-.61
NO3	0.85	0.63	-.87	-.84	0.00	-.61
TN	0.84	0.80	0.56	0.69	0.42	0.27
oP	0.66	-				
dis.P	-.07	0.45	-.90	-.82	-.55	-.49
TP	0.97	0.92	0.55	0.71	0.38	0.29

Table 19. July Conservation Till Efficiencies for Runoff

	Angle	Ross	Ross
TSS	0.98	0.92	0.28
NH4	-	-1.66	0.38
NO3	0.94	0.43	0.39
TN	0.91	0.39	0.36
oP	-	-	-
dis.P	-.51	-.61	0
TP	0.78	0.78	0.39

Table 20. August Conservation Till Efficiencies for Runoff

	Ross	Ross
TSS	0.82	0.996
NH4	0.80	0.66
NO3	-6.74	0.29
TN	0.57	0.88
oP	-.68	-2.91
dis.P	0.91	0.55
TP	0.82	0.97

Table 21. Full Year Conservation Till Efficiencies for Runoff

	Angle	Langdale	Andraski	Andraski	Andraski
TSS	0.87				
NH4	0.92				
NO3	0.87				
TN	0.88				
oP	0.22				
dis.P	0.13	-.07			
TP	0.90	0.66	0.81	0.70	0.60

The reader will note that only five studies went into these estimates. Though efficiencies for runoff nutrients are in most cases not well characterized, some clear patterns emerge. Poor winter efficiencies are compensated for by good crop season efficiencies, giving no-tillage overall good removal efficiencies for pollutants carried by runoff.

TN and TP in runoff are reduced annually by 60 to 90% by conservation tillage (Table 21). The dissolved species may be increased, but they are insignificant compared to the total losses.

SUBSURFACE LOSSES

The important issues in this section are how much N and P are lost via subsurface routes relative to surface routes and is this loss influenced by BMPs.

House et al. (1984) found 14 and 15% of fertilizer N in leachate under no-till and conventional till sorghum. For soybeans, 37 and 46% of the fertilizer N was leached from no-till and conventional till plots, respectively.

This does not support the contention that tillage influences N loss, but does indicate a difference in N loss between sorghum and soybeans.

Kanwar et al. (1987) cited studies indicating that on the average 20 to 40% of applied N fertilizers are lost to subsurface waters regardless of tillage.

Schwab et al. (1980) analyzed tile drainage water from conventional till corn, oats, soybeans, alfalfa, and bare soil in rotation on a poorly drained silty clay soil. They reported an average annual 0.3% loss of dissolved phosphorus to leachate, 1.6% loss to particulate P in runoff, and 0.5% loss to dissolved P in runoff, for a total P loss of 2.4%. In their 10 year study, they reported that 20% of the N fertilizer was lost as leachate nitrate and 9% as runoff nitrate.

Kanwar et al. (1987) studied the effect of tillage and split fertilizer application on nitrate loss through ground water on corn grown on silt loam with 2% slope. Six plots were established, 2 each for no-till and conventional till continuous corn, each receiving 175 kg/ha N fertilizer at planting, and 2 plots of no-till corn receiving 25 kg/ha at planting, 50 kg/ha in June and 50 kg/ha in July. Results for the average growing season subsurface nitrate loss were reported for 3 years.

In the first year of the study, all three plots demonstrated the same nitrate losses, however in the third year, ground water N loss was greater for no-till. Nutrient management (split and reduced fertilizer application) improved NO3 conservation. No difference in yield was observed.

Table 22. Growing Season Efficiencies for Subsurface NO3 Losses from Corn by Tillage and Nutrient Management

Conventional Till	0
No-till	-.30
No-till with 70% N and split application	0.14

Since significant N leaching is expected to occur during winter and early spring, these ratios should only be used for the period May through October.

No-tillage increased N subsurface loss after the first year. No-tillage with fertilizer management reduced subsurface loss after the first year. In general, the effect of tillage or conservation methods will not be felt in the first year of implementation because of influences from the previous year's cropping practice. Also it takes 1 to 3 years to establish the soil profile typical of no-tillage which is responsible for the enhanced infiltration rates of no-tillage fields (Casman, 1989).

N application reduction is not equal to subsurface N loss reduction for no-tillage. A 30% reduction in fertilizer produced a 15% reduction in subsurface N loss.

Tyler and Thomas (1977) found that leachate losses were higher under no-till than under conventional till corn. N losses were especially large during the month following fertilizer application, and during the months, January and March.
The soil was a well drained silt loam formed from phosphatic limestone. Prior to the study the site had been under bluegrass sod for 50 years. Leachate was collected by lysimeters.

Table 23. Monthly Ground Water Nitrate Reduction Efficiencies for No-tillage Corn

	1st Year	2nd Year	3rd Year
JAN		0.20	0.22
FEB		0.80	0
MAR		0.44	-.39
APR		-.26	-.71
MAY		0.41	-1.38
(fertilizer applied in mid May)			
JUN		-2.68	-1.93
JUL		-1.40	0
AUG		no flow	0.73
SEP		no flow	0.79
OCT		no flow	
NOV	0	-8.00	
DEC	1.00	0.86	
ALL MONTHS			-.28

Most of the N loss occurred the month after fertilization on both plots. Winter subsurface N loss (Nov-Mar) was 45% of total N loss for no-till corn and 60% of total N loss for conventional till corn. No-till corn lost about 20% of applied fertilizer to subsurface drainage where conventional till corn lost about 15% of applied N.

STUDIES OF SURFACE AND SUBSURFACE LOSSES

Alberts and Spomer (1985) measured ammonium, nitrate and phosphate in runoff and leachate from corn grown on deep loess, contrasting contour conventional tillage to contour till-plant systems. Samples were taken monthly for ten years. Subsurface losses of nitrate exceeded surface losses by a factor of 10. Surface and subsurface ammonia losses were generally of the same magnitude, as were dissolved phosphate losses.

Table 24. Ten Year Average Dissolved Nutrient Reduction Efficiencies in Corn Field Runoff and Leachate Comparing Contour Till-Plant to Contour Conventional Till

	Nitrate	Ammonium	Phosphate
Surface	-0.55	-0.39	-1.50
Subsurface	-2.31	-0.05	0
Total	-2.08	-0.27	-1.15

They reported that 16% of the fertilizer N appeared as ground water nitrate under till-plant corn, and 5% leached into ground water below conventional till corn. One percent appeared as runoff nitrate for both tillage treatments. Ground water ammonium accounted for 0.1% of the applied N for either tillage, and ammonium in runoff was about 0.2%. Particulate and organic species were not measured.

The quantity of leachate P from conventional and till-plant corn was about the same, 0.1% of the amount of fertilizer P applied annually. Three tenths of a percent and 0.7% of the annually applied P fertilizer were lost as dissolved P in runoff from conventional and till-plant corn, respectively. (Particulate P in runoff, usually the largest P fraction in runoff, was not measured.)

Ellis et al. (1985) give one of the few reports of nutrient losses from cropland which include both runoff and drainage water nutrient losses. They sampled 19 events over 3 years (not a lot of storms) on plots which grew corn for the first two years and beans the third. Subsurface samples were from tile drainage.

Chisel plowing with 50-60% corn residue left was contrasted to conventional tillage on tile drained, somewhat poorly drained Londo loam plots with 1% slope.

Table 25. Pollutant Reduction Efficiencies for Chisel Till Corn and Soybeans

	surface	subsurface	losses summed
sediment	0.69	0.32	0.61
total P	0.50	-.07	0.32
nitrate	0.20	0.38	0.35
TKN	0.49	-.04	0.35
TN	0.35	0.36	0.36

This points out how measuring surface and subsurface losses separately can lead to different conclusions than when they are considered together.

Surface losses are reduced with chisel tillage relative to conventional tillage for all parameters. Tile drainage water from chisel tilled corn carried roughly the same amount of total P and TKN as drainage water from conventional tilled corn, but less nitrate.

Overall chisel tillage resulted in total nutrient savings of about 35%. N and P savings were about the same when totalling surface and subsurface losses, though surface effects were more important for P than N.
For either tillage ground water N losses exceeded surface losses. Conventional tillage ground water nitrate losses were 5.7 times

greater than surface losses. Total nitrogen losses to ground water were 3.3 times greater than total nitrogen losses in surface water. Chisel tillage nitrate and TN subsurface losses were 4.4 and 3.3 times the surface losses.

Kitur et al. (1984) examined the nitrogen balance under conventional and no-tillage fields with isotopic tracer techniques. Two levels of N fertilizer were used, N deficient (84 kg/ha) and high N (168 kg/ha). After 3 years 71-75% of the fertilizer was accounted for in the harvested grain, stover, or soil. Neither tillage nor fertilization rate had a large effect on the size of the lost fraction (denitrified, runoff, or leached N) which was indistinguishable by t-test for the two tillages and two fertilizer levels. This is contrary to many other studies which report various tillage effects in total N losses.

Such tracer studies are probably more accurate in estimating nutrient losses than studies relying on water quality sampling because the tracer studies do not have the problem of gathering ground and surface water for analysis. The soil and plant matter don't flow away, and they don't have to be sampled in the rain.

Colbourn (1985) studied denitrification losses under winter wheat for no-till and conventional tillage. He estimated that the crop took up about half of the N fertilizer, a quarter was retained in the soil, and the rest was lost to air, runoff, or leaching.

SUBSURFACE AND SURFACE LOSS OVERVIEW

The study of surface losses alone is not sufficient to characterize conservation tillage efficiencies. The enigmatic scatter observed in surface nitrogen loss efficiencies becomes trivial against the background of the large ground water losses.

Table 26. Summary of Conservation Tillage Efficiencies from Studies with a Subsurface Loss Component

	Alberts	House	House	Ellis	Kanwar	Tyler
SUBSURFACE						
NO3	-2.31			0.38	-.30	-.28
NH4	-.05					
PO4	0					
TN		0.07	0.20	0.36		
TP				-.07		
SURFACE						
NO3	-.55			0.20		
NH4	-.33					
PO4	-1.50					
TN				0.35		
TP				0.50		

Table 27. Summary of Conservation Tillage Efficiencies Calculated on the Basis of Sum of Surface and Subsurface Losses

	Ellis	Kitur	Alberts
TP	0.32		
NO3	0.35		-2.08
TKN	0.35		
TN	0.36	0	
NH4			-0.27
PO4			-1.15

Unfortunately the only study found with runoff and leachate TN and TP measurements seems to hold the minority opinion of conservation tillage. Most of the other studies indicated greater subsurface losses with conservation tillage than with conventional tillage.

From these data it looks like conservation tillage alone cannot be relied upon to consistently reduce N and P delivery to surface and subsurface waters. However, nutrient management in conjunction with conservation tillage can be expected to reduce nutrient loss.

Conservation tillage has agronomic benefits other than nutrient loss reduction, primarily, erosion control and soil improvement. Decisions on which tillage to employ should be based on considerations in addition to potential for nutrient loss reduction.

Nutrient management is a composite of several practices including various degrees of reduced fertilizer application, split application, subsurface banding, and spring (and not fall) fertilization.

Several reports already discussed quantified nutrient loss relative to the amount of fertilizer applied. Table 28 contains a summary of these reports. (All conservation tillages are listed under low-till, and high-till stands for conventional tillage.) These are not efficiencies. However, efficiencies could be calculated from pairs of observations. This presentation of data eliminates the site-specific swings in actual load and focuses attention on tillage differences. This presentation of data (rather than efficiencies derived from data) is included here to make some important points about nutrient management.

Table 28. Percentage of Fertilizer Recovered from Runoff and Leachate

author	ground water NO3 low-till	ground water NO3 high-till	runoff nitrate low-till	runoff nitrate high-till
Alberts	16%	5%	1%	1%
House (sorghum)	14%	15%		
House (soy)	37%	46%		
Kanwar	(20% to	40%)		
Schwab		20%		9%
Tyler	20%	15%		
Average	22%	22%		5%
Median	18%	15%		

	ground water NH4 low-till	ground water NH4 high-till	runoff ammonium low-till	runoff ammonium high-till
Alberts	0.1%	0.1%	0.2%	0.2%

	dissolved ground water PO4 low-till	dissolved ground water PO4 high-till	dissolved runoff phosphate low-till	dissolved runoff phosphate high-till	particulate runoff phosphate low-till	particulate runoff phosphate high-till
Alberts	0.1%	0.1%	0.3%	0.7%		
Schwab		0.3%		0.5%		1.6%

Two observations about these data stand out:

(1) There doesn't seem to be a consistent tillage difference in ground water nitrate losses (half the studies showed increased NO3 loss and the other half didn't). For large watershed models the implication is that ground water N losses from no-tillage should be moderately greater (3 to 5% of the applied N) than those from conventional tillage.

(2) The percent of applied N lost to ground or surface water appears to be generally independent of level of fertilization. This suggests a simple check on fertilizer reduction scenarios in water quality modeling, that is, annual total N losses should be around 20-40% of the applied N. (This of course does not apply to cases of severe under-fertilization where canopy development may be impaired.)

This observation leads to the conclusion that the efficiency for the BMP of nutrient management depends on the pre-BMP degree of over-fertilization, and that this efficiency is roughly equal to the percent fertilizer reduction recommended by the nutrient management plan. For example, if the crop needs 100 kg of TN but is getting 160 kg, the pre-BMP TN loss is .20 x 160 = 32 kg, the post-BMP loss is .20 x 100 = 20 kg, and the efficiency is 1 - 20/32 = .375, which is the same as the percent fertilizer reduction: (160-100)/160 = .375.

SYNTHESIS

Several studies reported BMP effects in terms of surface loss alone, proposing general rules. One goal of this report is to deliver BMP efficiencies in terms of total system (surface plus subsurface) losses. An attempt will now be made to combine the BMP rules for surface water effects with some observation of nutrient loss partitioning by tillage to come up with crude estimates of total system efficiencies.

If one knew with certainty the partitioning of nutrient loss between the surface and subsurface for a particular tillage practice, one could infer the effect of the BMP on surface and subsurface losses by applying the rules to the affected component.

Only one of the studies cited so far (Ellis et al., 1985) measured TN and TP annual losses from the surface and subsurface. The two-year nutrient export from conventional and chisel tilled fields were (in kg/ha):

	Conventional		Chisel	
	Runoff	Tile Flow	Runoff	Tile Flow
TP	0.96	0.42	0.48	0.45
TN	10.98	36.89	7.34	23.67

This is far from a definitive partition, but is better than nothing. It would be preferable to have many such studies so that ranges of expected efficiencies could be estimated.

To calculate the total system TP reduction for chisel tillage from Ellis's data, sum the losses from each tillage and apply the efficiency formula: 1 - (.48 + .45)/(.96 + .42) = 0.33. Likewise the total system TN loss efficiency for chisel tillage is
1 - (7.34 + 23.67)/(10.98 + 36.89) = 0.35.

With subsurface banding, a 50% reduction in runoff TN and TP are anticipated (Whitaker et al. 1977, and Andraski et al., 1985). Banding injects the fertilizer several inches below the soil surface. TN applied in this manner is shunted from the surface to subsurface loss pathway. Neglecting volatilization losses, the anticipated 50% decrease in runoff N (0.50 x 7.34 = 3.67) is balanced by an equivalent increase of subsurface N loss (3.67 + 23.67 = 31.01), resulting in a combined banding plus chisel efficiency of 0.35, the same as the efficiency without banding. Therefore the efficiency of banding for total system TN removal is zero (0.35 - 0.35 = 0).

Applying the same logic to TP, a 50% reduction of runoff TP decreases surface loss to 0.24. Unlike TN, TP would probably be largely immobilized in the soil, and the efficiency of chisel plus banding would be 1 - (.24 + .45)/(.96 + .42) or 0.50. The difference between this efficiency and the pre-BMP efficiency gives a TP removal efficiency for banding of 0.15.

Langdale et al. (1985) observed a 65% reduction of runoff TP with terracing and winter cover for conventional tillage. If terracing reduces runoff TP by 65%, then, borrowing Ellis's conventional tillage data, the total TP removal efficiency is
1 - (.42 + (1-.65).96)/(.42 + .96) = 0.45. Applying the same formula to Ellis's chisel till data results in a TP reduction efficiency of 1 - (.45 + (1 - .65).48)/(.45 + .48) = 0.34.

Though no studies of runoff TN reduction by terracing were found, it is reasonable to assume that N is mainly shunted from surface water to subsurface water (as in the banding discussion). If this is true, then the TN removal efficiency from terraces is also zero.

Winter cover crop nutrient removal efficiency is dependent on whether the cover crop is fertilized at planting and on the date of planting.

Abundant fall growth is essential if substantial amounts of nitrate are to be assimilated before the winter recharge period begins. Cover crops planted in Carroll County (located on Maryland's northern border) are usually killed by frost at a height of 4 inches (personal communication, Jack Sanders, Carroll County District Conservationist). However cover crops on Maryland's Eastern Shore are more successful.

If one assumed that annually 20% of the applied fertilizer nitrogen is lost in runoff and ground water, and that planting a cover crop without additional fertilizer tied up 10% of the fertilizer in plant tissue (the low end of Brinsfield et al.'s observations), all one would need to approximate an efficiency for cover crops would be an estimate of what portion of that 10% would have been lost to runoff or leachate and what would have stayed in the soil pool without a cover crop. That information is not available. If the whole 10% would have been lost, then the resultant efficiency for winter cover would be 1 - 10/20 or 50%. If the cover crop could not become established, or if it was fertilized at planting, the efficiency is zero.

Some multi-year studies aimed specifically at measuring N and P losses from fields with cover crops are needed.

ANIMAL WASTE STORAGE

Much has been written about manure storage structure efficiencies, most of it from the point of view of how much manurial N and P a farmer might hope to reclaim as fertilizer if he had a storage facility. The water quality modeler is more interested in treatment efficiencies calculated on the basis of the amounts of manure entering streams and ground water before and after BMP installation.

There are several reasons the manure storage efficiency ratings encountered in agronomic handbooks do not translate into treatment efficiencies similar to those calculated for conservation tillage.

(1) A storage structure may promote proper or improper timing of fertilizer application, depending on its capacity, and this, of course, will affect nutrient losses.

> Manure storage capacity is typically measured by the number of days the herd's manure can be stored before the structure is filled. For instance, a structure with 90 days' capacity is filled and must be emptied 4 times a year. Depending on the

fields available to the farmer and the crop rotations, up to 3 of these 4 loads of manure (3/4 of the annual production) could be wasted (not applied to the fields on which the major summer crops are grown).

(2) The presence of a properly sized storage structure does not guarantee water quality protection.

Structures which retain solids from runoff and release liquids essentially change nonpoint sources into point sources. Also structures which are not emptied on schedule could force the farmer into spreading manure during times when the fields are likely to produce excessive runoff pollution.

(3) There are important features to manure management other than manure storage, such as nutrient management, efforts to prevent clean water from being contaminated (diversions, guttering, spring development), parlor water disposal practices, and pasture management. A farm's impact on water quality is determined by total farm operation.

This last observation is the most important in terms of estimating efficiencies. The efficiency attributed to a single element (such as storage) should not be used to represent the whole.

The best way to evaluate manure management efficiencies is with well planned, long term, before and after, on-site studies. I know of no completed empirical studies that can give this information at this time, though several are now in progress[3].

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[3] Notably, within the Chesapeake Bay Watershed, the Owl Run Watershed Study by VPI&SU with the Virginia Department of Conservation and Recreation, the Piney Creek Study by the SCS and Maryland Department of the Environment, the Double Pipe Creek RCWP study, and the Conestoga Creek Watershed Study by the USGS and Pennsylvania Department of Environmental Resources.

Some of the fragmentary results relevant to this discussion are listed below.

Hensler et al. (1970) reported that as much as 20% of the N and 12% of the P in manure applied to tilled frozen soil was lost, mostly during a single runoff event which occurred a few hours after the manure was applied.

Reckhow et al. (1980) estimated that from 2 to 10% of manure generated in feedlots is lost to surface runoff.

Westerman and Overcash (1980) measured nutrients in open dairy lot runoff. They found that 12% of the applied P appeared in runoff. They also observed that high intensity storms were responsible for most pollutant transport even though these storms were responsible for only 20% of the total precipitation.

In the absence of complete descriptions of the effects of storage on a farms nutrient budget, efficiencies can only be estimated from simplified conceptual constructs or modeling.

The type of livestock determines the appropriate manure management elements. To illustrate this, two very distinct animal waste management situations, dairy and poultry farming, are discussed. Both types of livestock are confined much of the time. When constructing storage efficiency estimates for other animals, it would be important to factor in the time spent unconfined on pasture.

DAIRY

Dairy waste usually has two components, manure with or without bedding and milking parlor wash water. The latter is distinct from manure in that in addition to dung and urine it contains detergent, disinfectants, milk solids and fat, and large volumes of water.

From a water quality point of view, manure management for a dairy is more than the construction of manure storage structures. It includes sizing the structure to minimize water pollution, proper disposal of parlor water, diverting clean water sources away from sources of contamination, and fertilizing fields with the proper amount of manure at the proper time.

Conceptually, manure N is lost at four points during the collection and disposal process: collection, storage, application, and weathering. Relative to fresh manure (with volatile losses already deducted), collection N losses can be from 20 to 60%; total containment storage losses from 5 to 15%; and application losses from 15 to 60% (Casman, 1989). Total P losses are not as well characterized.

Further nutrient losses once manure is applied to fields, are dependent on field conditions and meteorology. Appropriating the results of Kitur et al. (1984), Alberts and Spomer (1985), and Schwab et al. (1980), tentative values for field losses to ground and surface water are 20 to 30% of N and 1 or 2 percent of the applied P.

Adding the low end of ranges for nitrogen losses we get pre-field estimates of N and P losses:

	TN	TP
collection	20%	20%
storage	5%	0%
application	15%	15%
	40%	35%

This represents the expected N loss from manure handling for a dairy with 365 days of storage (neglecting parlor water). A 40% loss from manure handling means that 60% remains, of which 20% is lost from the field as runoff or leachate after application (60% x 20% = 12%), meaning about 12% + 40% = 52% of the generated N manure is lost to ground or surface water with the BMP of storage. Analogously, total annual manurial TP loss is roughly (1%)(65%) + 35% = 36% of the manurial TP generated annually.

For the sake of this exercise, assume that the amount of manure available in the spring (60% of the TN and 65% of the TP generated) exactly meets the requirement of the crop to be grown.

To calculate efficiencies for storage consistent with those listed for conservation tillage in previous sections, the annual TN and TP losses for a farm with storage must be compared to losses from the pre-BMP practice.

Without storage the manure would be collected, stacked in heaps, and spread roughly weekly, even during the winter. If the stacks are sheltered, the losses can be minimal, but if they are exposed to the elements, more nutrient loss is expected.

When the major crop[4] is in the field (6 months), manure is spread on some idle field. In the dead of winter (2 months) about half of the applied manure is washed off. That is, 50% of 2 months of manure (1/6 of the 80% collected) or (.50)(.167)(80%) = 7% of the TN or TP enters ground or surface water in winter. Assuming a 5% stack loss rate for the 80% collected manure (.05 x 80% = 4%), the loss from weathering of stacks is about 4%. Taken all together, an estimate for pre-growing-season nutrient loss would be

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[4]The term "major crop" is used here to mean the grain crop grown from spring to fall. It is assumed to have large nitrogen requirements. Corn is a good example. The term "major field" refers to the field on which the major crop is grown.

	TN	TP
collection	20%	20%
winter loss	7%	7%
stack loss	4%	4%
application	15%	15%
	46%	46%

Calculating the post-application losses requires more leaps of faith. As before, only half of the collected manure (.5 x 54% = 27%) could be put on the major field, so commercial fertilizer to meet the crop need must be applied (*i.e.*, 60% - 27% = 33% TN and 65% - 27% = 38% TP). That brings the total N and P application to the all fields to an equivalent of 54% + 33% = 87% TN and 54% + 38% = 92% TP. This results in a growing season loss .20 x 87% = 17.4% TN and .01 x 92% = 0.9% TP. Added to the pre-field losses the total annual losses are 46% + 17% = 63% for TN and 46% + 1% = 47% for TP.

Recall that the total farm nitrogen loss with one-year manure storage was estimated to be 52% and the total annual P loss to be 36%. The total farm loss estimates are sensitive to the length of winter, loss estimates, and other assumptions, and the distinction between 52% and 63% loss may not be significant. Therefore the efficiencies calculated from these losses (1 - 52/63 = .17 for TN) and (1 - 36/47 = .23) should be taken as order of magnitude estimates, not exact values. Even so, they do show that the nitrogen reduction expected from 1-year storage is far from 100% (the Phase I Bay Model assumption).

A storage structure with 180-days capacity will give even less nutrient reduction relative to weekly spreading because the manure stored during the growing season must be dumped in the fall. If one adds a winter loss factor of 7% to the pre-field loss estimates for 365-day storage to represent the effect of fall clean-out, the resultant BMP efficiencies for 180-day storage are 1 - 60/63 = 5% for TN and 1 - 43/47 = 8% for TP.

This conceptual framework is too crude to provide estimates for storage structures of smaller capacity.

Despite the limitations and errors of the method, the calculations highlight an important point. The largest nutrient savings attributable to manure storage will be related to the amount of manure that can be substituted for fertilizer.

In general about half the excreted manure is lost with or without storage. Full-year storage results in about a 20% nutrient reduction, half-year storage efficiencies are in the 5-10% range.

A more elaborate modeling study came up with similar conclusions. Crowder and Young (1985) modeled a variety of field scenarios with CREAMS. They found that 1-year manure storage did not result in water quality improvement unless it was coupled with nutrient management BMPs.

Parlor water usually contains less than 1% of the manure excreted daily, though this can represent significant amounts of N and P. Parlor water is handled separately from scraped manure. It is usually discharged to lagoons or treated by vegetated filter strips. Untreated parlor water discharge can have serious detrimental effects on streams. But conversely, parlor water treated by infiltration may move large amounts of dissolved nutrients into ground water (see the section on vegetated filter strips, below).

CLEAN WATER PROTECTION FOR DAIRIES

As mentioned above, the best performance of 1-year storage structures corresponds to the loss of about than half the nitrogen generated. This half can be managed by other BMPs. For instance, "collection" losses represent manure that is left around the farmstead to be washed off by rain. Therefore the upper bound on the set of BMPs designed to prevent contamination of clean water with manure (roof guttering, diversions, etc.) would approach the collection loss, or 20% to 60%.

Assuming a collection loss of 20% of the generated manure and a total farm loss of 50%, the efficiency of complete clean water protection BMPs would be 1 - 30/50 = 0.40. This is an upper bound for a herd kept constantly indoors.

This means clean water protection BMPs could theoretically result in as much as a 40% reduction of nutrients leaving a dairy farm. It is not likely that these BMPs can economically or routinely be installed to operate at their upper bound of efficiency. It would not be unreasonable to reduce this efficiency in proportion to the fraction of manured area that can be shielded from clean water runoff. A very thorough clean water protection program might be able to treat half the manured areas, for a BMP efficiency of 20%. This is the efficiency for "partial implementation of clean water protection" which will appear later in this discussion. Each farm, of course, presents a unique situation, and it is likely that 20% is an optimistic efficiency.

FERTILIZER MANAGEMENT FOR DAIRY FARMS

An obvious nutrient management BMP falling out of the assumption that 20% of the N applied to a field ends up in ground or surface water is reducing the amount of manure applied to the field. Simplistically, if 20% of whatever is applied contaminates water, reducing the amount applied will reduce the amount of contamination proportionately. (This assumes fertilizer is not reduced to the point of causing crop failure, which would increase nutrient losses.)

In the case of weekly spreading, if the fertilizer N were reduced by 15% (assuming 15% over-fertilization), the farm-wide efficiency of nutrient management for TN would be 0.03 (that is, (.54 + .33)(.85)(.2) + .46 = 61% and 1 - 61/63 = 0.03). The change in TP loss would be undetectable (again, (.54 + .38)(.85)(.01) + .46 = .47 and 1 - 47/47 = 0).

A 25% reduction (now assuming 25% over-fertilization as the pre-BMP condition) would have a nitrogen reduction efficiency of about 0.06 because (.54 + .33)(.75)(.2) + .46 = .59 and 1 - 59/63 = .06. TP reduction efficiency for a 25% fertilizer reduction still would be zero, because (.54 + .38)(.75)(.01) + .46 = .47 and 1 - 47/47.

For the combination of BMPs of 365-day manure storage plus 15% N reduction, the efficiency for TN relative to weekly spreading is 0.21 (that is, (.60)(.85)(.2) + .40 = .50 and 1 - 50/63 = .21). For 1-year storage plus 15% P reduction, the efficiency for TP relative to weekly spreading is 0.23 (because (.65)(.85)(.01) + .35 = .36 and 1 - 36/47 = .23).

The combination of partial clean water protection, 365-day storage, and 15% N application reduction produces TN and TP efficiencies of 0.41 and 0.43, respectively.

It is interesting to note that Hession et al. (1989), using the agricultural water quality model, AGNPS, to simulate the effects of dairy farm BMP implementation on a small watershed in Virginia, concluded that the combination of storage and a 50% fertilizer reduction program resulted in TN and TP efficiencies of 0.45 and 0.46, respectively.

POULTRY

Most chickens are raised in houses. For most of the year there is little or no feedlot type runoff from large chicken farms, whether or not they have manure storage sheds. Poultry manure from houses can be exposed to the elements when the manure pack is "crusted" or when the house is cleaned out.

Without a storage shed, manure from a chicken house cleaning is typically left exposed to the elements for from 0 to 6 months per year, with an average exposure of 2 weeks. (Frequently manure is spread immediately on a field without intermediate stacking.)

The storage BMP for chicken operations consists of a shed that is used only at clean-out to store manure before spreading. The shed is used when the fields cannot accept manure spreading, so the sheds do not contain manure most of the year. In years with mild winters the sheds might not be used at all.

The main source of water pollution from poultry operations is gross over-application of manure on fields. Typically poultry farmers of the DelMarVa peninsula apply 2 to 4 times the recommended amount of manure, based on manure N. Manure P is applied at even higher rates. Thus nutrient management is the most important BMP for this area.

For the years when the manure shed is not used for storage, obviously, the efficiency of that BMP is zero. For the other years, assuming a 2 week annual exposure time for stacks of manure, a 4% collection loss, a 1% stack loss[5], and a 20% loss of manure spread on fields, the nutrient loss from chicken manure on a farm without storage would be 24% of the manure nutrients generated.

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[5]Poultry manure is dryer than dairy manure, so stacking and collection losses are smaller.

collection loss	0.04	
stack loss	0.0096	i.e, (1 - 0.04) * 0.01
field loss	0.19008	(1 - 0.0496) * 0.20
	0.23968	

For a farm with a storage shed the farm loss is the collection loss, 0.04, plus the field loss, .96 * .20 = .192, which sums to .232. Thus the nutrient reduction efficiency attributable to a manure storage shed on a chicken farm is 1 - .232/.23968, or 3%.

OVERVIEW OF ANIMAL WASTE STORAGE

The nutrient reduction attributable to dairy waste storage alone is roughly from 5 to 20% for TN and TP, depending on the structure's capacity. Waste storage without nutrient management and clean water protection programs does not meet the Bay-wide 40% nutrient reduction goal.

Clean water protection BMPs could typically have up to a 20% efficiency for TN and TP.

A dairy installing 1-year storage and implementing clean water protection and nutrient management could achieve the nutrient reduction goal.

Storage structures for poultry farms will not significantly reduce nutrient losses.

Storage facilities of the capacities now commonly installed in the Chesapeake Bay watershed (180 days or smaller) provide significantly less water quality benefit than full year storage.

Animal waste scenarios should be modeled to include the group of BMPs comprising manure management.

GRASSED WATERWAYS AND VEGETATED FILTER STRIPS

Vegetated filter strips (VFS) are areas of planted or indigenous vegetation used for erosion protection and to filter sediment and pollutants from agricultural runoff. In contrast grassed waterways are installed primarily to stablize watercourses so they can resist gullying and erosion from intermittent flows. The efficiency of a VFS is calculated relative to the influent load. This implies that in the absence of the strip the waste would be discharged directly to a stream or ditch.

Some of the older studies illustrate that an important pollutant removal mechanism for VFSs is solids retention.

Kreis et al. (1972) analyzed the effect of passing runoff from a beef feedlot through a combination of ponds and waterways. The runoff was held in detention ponds for several days before being discharged to a 2 mile long grassed waterway. Once the solids were reduced in the holding ponds, pumping the effluent from the ponds through the grassed waterway had no significant effect on concentrations of total P, total organic N, and nitrate N in surface flows. Average ammonium nitrogen concentrations were slightly reduced, though this was not statistically demonstrable.)

Hayes and Hairston (1983) evaluated the efficiency of vegetative filters (85 ft. x 8.5 ft., 2.4% slope) over 16 months to determine the effective duration of sediment control. Solids trapping efficiency varied from 20% to 80% and showed considerable variability. The best sediment trapping efficiencies were observed when the hydraulic loading rates were quite small at the beginning of the experiment. The average efficiency over 18 storms was 53% and the median was 56%. Solids filtering efficiency generally drops from near 80% to roughly 50% within a single season.

Dillaha et al. (1988) studied the effectiveness of vegetated filter strips for treating feedlot runoff. Filter lengths were 30 and 15 feet. Three slopes were tested: (1) 11% with no cross slope, (2) 16% with no cross slope, and (3) 5% with 4% cross slope. Simulated rainfall was delivered to a feedlot-like surface uphill from the strips at a rate approaching the typical 2 year storm for the test area.

Flow in the strips with a cross slope component confined itself to a 1 foot channel, while flow in the other strips was uniform and distributed across the width of the strips.

Average efficiencies for removing pollutants were calculated relative to the amount of pollutant leaving the feedlot as runoff. Ground water pollution was not monitored.

This study does not adequately capture the change of filter efficiency over time. The two test runs were separated by 7 days. Average results are reported below.

These efficiencies are for the first two weeks after installation of a VFS. They are also for steep, eroded landscapes. Efficiencies are also specific for filter length.

Sediment reduction from the cross slope flow strip was much less than from the uniform flow strips, even though the uniform flow strips had much steeper slopes. This is because the channelized flow of the cross slope strip was deeper and swifter and therefore less well treated.

Filters with concentrated flow were 40 to 60% less effective for sediment removal, 70 to 95% less effective for P removal, and 60 to 70% less effective for N removal.

Table 29. Sediment and Nutrient Removal Efficiencies for Vegetated Filter Strips of Various Slopes and Lengths

Slope %	Length feet	TSS	NH4	NO3	TKN	TN
11	30	.95	.69	.04	.80	.70
11	15	.87	.34	-.36	.64	.61
16	30	.88	-.35	.17	.72	.71
16	15	.76	-.21	.03	.69	.67
5x4	30	.58	-.11	-1.58	.09	.07
5x4	15	.31	.01	-.82	.01	0
average over all runs		.72	.06	-.38	.49	.46

Slope %	Length feet	TP	PO4	total filtered TKN	total filtered P	Runoff
11	30	.80	.30	.67	.35	.25
11	15	.63	-.20	.51	.33	-.06
16	30	.57	-.51			.01
16	15	.52	-1.08			.16
5x4	30	.19	.31			-.01
5x4	15	.02	-.03			.08
average over 2 weeks		.46	-.25	.59	.34	.07

With all filters, N removal effectiveness decreased as sediment and nutrients collected in the filters. The best removals usually occurred in the first three runs. Sediment removal on the 15 ft. 16% slope filter decreased from 90% in the first simulation to 77, 66, 74, 41, and 53% in the second to sixth simulations, and the full suite of simulations represented only 2 weeks of feedlot time.

The authors commented that:

> A large amount of nutrients was not trapped by the filters.

Vegetative filter strips are ineffective for sediment and nutrient removal under concentrated flow conditions.

Most on-farm filter strips are ineffective because runoff tends to concentrate in natural drainageways before it reaches the filter strip.

The effectiveness of a VFS decreases with time as sediment accumulates within it unless the vegetation can grow as fast as it is being buried.

Phosphorus in runoff from feedlots is not removed as effectively by VFSs as is sediment.

The VFSs were not effective in removing soluble phosphorus from the simulated feedlot runoff.

Magette et al. (1987a,b) examined the effectiveness of two lengths of filter strips in reducing nutrient and sediment losses from tilled fertilized plots.

Like the previous study, the test took 2 weeks and consisted of 3 simulated rainstorms. Slopes were 3, 4, and 5% and filter lengths were 15 and 30 feet. The experimental plots were located on sandy loam in the Maryland coastal plain. Unlike the previous study, ground water nitrogen losses were measured.

These results are only for the experiment runs and not for annual totals. All simulations occurred within a 2 month period during the growing season. Filter performance would be expected to vary seasonally because of changes in infiltration, evaporation, and other meteorologically related factors, such as freezing and thawing.
Subsurface losses of nitrogen far outweighed surface losses and did

not seem to be related to filter length. Surface losses accounted for 5 to 25% of the total nitrogen losses. (Subsurface P was not measured.)

Infiltration into VFSs can be considered a nutrient removal mechanism only to the extent that the nutrients are absorbed by plants or become trapped in or bound to the soil. The nutrients that are not immobilized are simply delivered to the receiving water by a subsurface route rather than by a surface one.

The authors observed that:

Repeated waste disposal on soil reduced its cation exchange capacity, so a soil's ability to trap P would be expected to diminish over time.

The performance of vegetated filter strips in reducing nutrient losses from agricultural lands is highly variable.

Vegetated filter strips are more effective in removing suspended solids from runoff than in removing nutrients.

The performance of vegetated filter strips diminishes as the volume of wastewater to be treated increases.

The effectiveness of vegetated filter strips is highly dependent on the condition of the filter itself.

Subsurface leaching losses can be an important component of inorganic N movement from agricultural areas. When these losses are considered together with surface losses, the relationship between VFS length and nitrogen removal becomes lost.

Table 30. Pollutant Removal Efficiencies From VFSs with No Cross Slope Component

slope	length	TSS Runoff	TN Runoff	TN Leachate	TP Runoff	TN Removal: leachate plus runoff
3%	30 ft	.82	.41	.87	.42	.83
4%	30 ft	.82	.48	-	.25	-
5%	30 ft	.86	.51	.03	.52	.11
3%	15 ft	.65	-.15	-.10	.22	-.20
4%	15 ft	.66	-.06	-	.27	-
5%	15 ft	.72	-.17	.39	.41	.36
average efficiency over all conditions		.76	.17	.30	.35	.28

The 76% reduction in sediment did not correspond to a similar reduction in runoff N or P. The filters were generally somewhat effective in reducing surface losses of both nutrients and solids. Overall ninety-five percent of the total nitrogen loss left the root zone and exited the watershed in subsurface flow.

Schwer and Clausen (1989) studied the ability of an 85 foot long (almost 3 times the length of the longest strip in the previous study) vegetated filter strip to treat milking parlor waste water. They measured nutrients leaving surface and ground water over a period of two years.

The filter strip's loam soil was graded to a 2% slope and seeded with a mixture of fescue, rye, and bluegrass. Ground water was collected at the foot of the slope in drain tiles buried parallel to the width at a depth of 1 to 3 ft (not a particularly good design because it only collected shallow, nearly horizontal flow). Parlor waste containing about 80 mg/l TP and 50 mg/l TKN was discharged twice a day to the strip at a rate of 2.94 cm/week. Annual areal mass loading was 0.86 kg/m^2 TSS, 0.13 kg/m^2 TP, and

0.08 kg/m^2 TKN.

Surface and subsurface solids and nutrient losses were monitored for two years. Nitrate was not included in the list of parameters analyzed (total solids, total dissolved solids, total suspended solids, volatile suspended solids, total P, ortho-P, total Kjeldahl N, and ammonia-N). Therefore no estimate of total nitrogen losses can be made.

A water balance analysis of the plot left 20% of the water inputs unaccounted for. This probably was ground water loss under the strip. The authors assumed the unaccounted for water had the same chemical characteristics as the ground water collected at the monitoring station at the foot of the strip. The accuracy of these assumptions could greatly affect the efficiencies presented below.

From the first part of Table 31 one can see that 4 times as much TP left through subsurface drainage as through surface, and 5 times as much TKN moved with subsurface flows. (This is not in line with the previous study.)

Table 31. Input-Output Breakdown of Vegetated Filter Strip Performance and Overall Pollutant Removal Efficiencies

	Input	Output Surface	Output Subsurface	Overall Removal Rate
	kg/m^2 per year			
TSS	0.855	0.009	0.029	0.95
TP	0.126	0.003	0.012	0.89
o-P	0.092	0.002	0.006	0.92
TKN	0.085	0.001	0.005	0.92
NH4	0.008	<0.001	0.001	0.78

The strip retained 95% solids, 89% P and 92% TKN. Retention was greatest during the growing season and poorest during snowmelt periods. Nutrient losses in subsurface outputs were greater than in surface runoff, accounting for 76% of TSS, 80% of TP and 77% of TKN losses.

The authors noted that despite the high percentage reductions in pollutants, the quality of effluent from the filter strip was not highly polished. The mean total P concentration in surface water leaving the strip was 11.35 mg/l, and average TKN was 8.13 mg/l.

Table 32. Seasonal Efficiency of a Vegetated Filter Strip (Surface Plus Subsurface Nutrient Removal)

	TP	TKN
Snowmelt	0.35	0.57
Winter	0.95	0.94
Growing	0.96	0.98
Spring,Fall	0.96	0.94

Seasonally, surface runoff concentrations did not vary except for total P, which was lower during the growing season than during the winter or spring-fall periods. Subsurface output concentration of total P and TKN were greater during snowmelt than during any other period.

Fifty-six percent of the annual TSS and TP exports and 61% of TKN exports were measured during snowmelt periods even though snowmelt accounted for only 12% of the duration of the study.

Uptake of P and N by vegetation was not a primary removal mechanism. Approximately 2.5% of input P and 15% of input N was removed by the vegetation.

Comparing these results with other studies, the authors concluded that hydraulic loading rate strongly influenced P and N retention.

As hydraulic loading rate increased, the percent mass retention declined.

Grassed waterways are not considered to be a nutrient removal BMP. Their purpose is to stabilize ditches and reduce gullying. However, to the extent that the grasses take up the nutrients flowing through them (2-3% of TP and 15% of TN, to borrow Schwer and Clausen's results), upper bound nutrient removal efficiencies can be assigned. Flow in grassed waterways is always channelized, and, drawing from Dillaha et al.'s experience with concentrated flow, under these conditions nutrient removal efficiencies will approach zero. Furthermore, in the long term, the sediment bound nutrients filtered out by the grasses tend wash back into the water and therefore should not be credited as removed.

VEGETATED FILTER STRIP OVERVIEW

VFSs are much better suited to sediment removal from runoff than nutrient removal. Total suspended sediment is reduced by 65 to 95% in a well functioning VFS.

When the flow submerges the vegetation in the filter strip, no filtration is achieved. This can occur even with properly sized filter strips and average sized storms if secondary drainage patterns develop.

Several factors influencing VFS efficiency have been identified, including filter length, depth of flow, slope, cross slope, soil type, influent characteristics, clogging of filter with repeated use, and hydraulic loading rate. The end result of all these influences is a literature reporting wide ranges of efficiency for this BMP.

Runoff TSS removals from 31 to 95% were encountered. TN removals ranged from -.17 to .71 and TP removals from .02 to .80. Reports of subsurface TN removal efficiency ranged from -.10 to .87, and when surface and subsurface losses were summed the total TN removal efficiencies ranged from -.20 to .92.

One reason the ranges are so broad is an inconsistency in how pre-BMP inputs were defined in Magette's and Clausen's studies. Magette et al. considered as input the nutrients leaving a plot of land to which fertilizer and manure had been applied. Surface and subsurface inputs were measured separately. For subsurface input (before the vegetated filter strip) they took samples at the edge of the manured plot. Therefore separate reduction efficiencies for the surface and subsurface could be calculated, analogous to the tillage efficiencies in Part I. Schwer and Clausen applied their parlor water directly to their vegetated filter strip and calculated efficiencies relative to what was applied to the strip. (The resultant efficiencies are not analogous to those reported in Part 1.) In order to make the efficiencies from the two studies comparable, Magette would have had to have defined inputs as the nutrients placed on the manured plot, and not as the nutrients that left the plot and entered the VFS.

Another reason for the efficiency spread is the design of the strips. Results were reported for strips from 15 feet to two miles long, possessing slopes from 2 to 16%. Magette et al. write that they chose the 15 and 30 foot lengths because those dimensions bracketed lengths generally being required by agricultural cost sharing programs. When determining which studies have most relevance for the Chesapeake Bay watershed, this should be kept in mind.

With all the variation in experimental design and results, it is clear that no single efficiency should be used to characterize VFS performance. Average values have little meaning, because they are really not expected values. However, if cornered into estimating VFS nutrient reduction efficiencies, I'd say, on the basis of Dillaha and Magette's work, that about 30% of the TN is retained by a filter (surface plus subsurface retention).

Limiting the discussion to surface flows, about 45% of the TN and TP from surface runoff is retained.

The average TN removal efficiency from the subsurface reported by Magette et al. was 30%. Only one estimate of subsurface P loss was found (Schwer and Clausen), 90%, and it was calculated in a manner incompatible with the other studies. It is likely that subsurface P retention exceeds subsurface N retention because large amounts of P can be immobilized in the soil (see Schwab, Table 28), but 90% retention is probably too high and 30% retention is probably too low.

SUMMARY

CONSERVATION TILLAGE

When discussing conservation tillage nutrient reduction efficiency, it is important to include subsurface losses because from 5 to 20 times more nutrients are lost via the subsurface route than from surface runoff.

From Table 26 it appears that subsurface nitrate losses are increased by conservation tillage (efficiencies from -70 to +.38 were reported, averaging -.21, with three out of four studies reporting negative efficiencies). Total nitrogen losses are reduced by as little as 7 or as much as 36% (averaging 29% reduction).

About 15 to 20% of applied fertilizer N is lost to ground water under conventional tillage (Table 28). An additional 3 to 5% is lost under conservation tillage.

Only one study that measured surface and subsurface total phosphorus losses from conservation tillage was found. Surface TP was reduced by half and subsurface TP increased by 9% with chisel tillage, for a total removal of 32%. So it seems that surface TP loss dominated subsurface losses. A second study tracked phosphate only. It reported equal ground water phosphate losses from conservation and conventional tillage, but double the dissolved phosphate in runoff from conventional till fields. Unfortunately, particulate P in runoff was not monitored. Runoff phosphate losses were 3 times ground water losses for conservation tillage and 7 times greater for conventional tillage. As nitrate does not behave like total nitrogen, it is likely that phosphate does not travel like total phosphorus. More phosphorus studies are needed.

From these data it looks like conservation tillage can reduce total N and P loss from fields by up to 35%.

When discussing surface nutrient losses separately from subsurface losses, a seasonal component is evident. Efficiencies for the same parameter vary dramatically by month (Tables 15 through 21). Fertilizer application and freezing weather are two factors which enhance nutrient losses from conservation tillage fields.

NUTRIENT MANAGEMENT

Nutrient management has different efficiencies for farms with and without livestock. See the next section for nutrient management efficiencies for dairy farms.

For farms without livestock, it appears that fertilizer N reduction effects are proportional to the amount of fertilizer applied, with around 20% of the fertilizer reaching ground and surface water from fields regardless of tillage or fertilization level. This is a good check for modelers to use for determining if their representations of nutrient losses hit ballpark targets.

In some, but not all cases, ground water N loss from conservation tillage will exceed that from conventional tillage. The magnitude of the difference is determined by local conditions such as soil properties and field history. For a large lumped parameter model of an agricultural watershed where the majority but not all of the soils are well drained, it would be reasonable to expect ground water nitrogen losses from conservation tillage to represent 23 to 25% of the applied fertilizer.

It is likely, but less well documented that P loss is also proportional to application rate.

Most nutrient management studies only addressed surface runoff nutrient losses. Two studies claimed that banding reduced surface N and P runoff losses by 50%. This is more encouraging for P management than for N, because most nitrogen losses occur via the subsurface route.

The gross effect of fall fertilization on annual nutrient losses in runoff is to multiply losses observed from spring-only fertilization by a factor of 1.5 to 2.

ANIMAL WASTE MANAGEMENT

The nutrient reduction efficiency attributable to dairy waste storage alone is small. About half the manure generated annually on a dairy farm is lost to ground or surface water. Full-year storage results in about a 20% TN and TP loss reduction, but half-year storage and smaller capacities result in N and P losses in the 5 to 10% range.

Raising cows on concrete with complete clean water protection could result in up to 40% efficiency, but on the relatively small scale of most dairy farms, could not be economically justified. Rigorous implementation of clean water protection BMPs on a typical dairy farm might better be credited with an efficiency not to exceed 20%.

If the fields are being fertilized at a level 15% over the crop needs, implementing nutrient management (fertilizer reduction) without storage would result in a 5% TN reduction efficiency and roughly zero TP reduction. These disappointing efficiencies follow from the fact that most of the nutrient losses from dairy farms are not associated with field losses, but with surface runoff from places where animals congregate or places associated with manure handling. The net effect is that field loss reductions are dwarfed in comparison to the other losses in the efficiency calculations.

Coupled with 365-day storage, the TN and TP reduction efficiencies increase to 20%.

The combination of partial clean water protection, 365-day manure storage and 15% fertilizer application reduction produces TN and TP efficiencies of about 40%.

VEGETATED FILTER STRIPS

The high nutrient and sediment removal rates reported for vegetated filter strips in the early literature did not account for several factors commonly associated with filter failure: namely the development of natural drainageways in the filter which drastically narrow the effective width of the filter, and the clogging of the filter over time.

Only a couple of percent of the influent nutrients to a filter strip become plant tissue. The rest is temporarily immobilized due to the roughness of the strip, and can slowly leach out over time. This is probably the explanation for the negative efficiencies (nutrients leaving the strip in excess of nutrients entering the strip) reported for many nutrient species.

Ground water nutrient losses from strips are significant.

A ballpark estimate of VFS efficiency for TN removal is 0.30. Greater efficiencies, though reported for some short term or runoff quality studies, are not justified in large watershed modeling (where one would expect a mixture of successful and unsuccessful strip installations). TP removal however can approach 90% (observed for an 85 ft. long, graded 2% slope strip). For large watershed modeling, it would not be unrealistic to halve this number to account for the VFSs in the basin with concentrated flow or with designs less conducive to rapid infiltration, whose TP removal efficiencies would approach zero. More work on ground water phosphorus losses from VFSs is needed.

Studies sponsored by the Bay Program warn against relying on VFSs for agricultural waste water treatment. Even a study showing higher efficiencies commented that effluent from a VFS is not polished and would still be considered a source of water pollution.

Table 33 gives some annual nutrient reduction efficiencies for TN and TP. This table is for the convenience of water quality managers. Modelers should go back to the text to extract the more detailed (partitioned to ground or surface water, monthly, or chemical species specific) efficiencies appropriate for their work.

TN and TP reduction efficiencies in this table are equal in many cases. Sometimes this is supported by experimental findings, in other cases, there was simply not enough information to justify separate estimates.

Remember that efficiencies are not the same as export. Furthermore, the efficiencies of several BMPs cannot be added to represent the effects of implementing them on the same farm because changes in one activity may affect the nutrient flux of others.

Table 33. Annual Nutrient Reduction Efficiencies for Ground and Surface Water Losses Combined

	TN	TP
Conservation tillage	35%	35%
Banding*	0%	15%
Winter Cover TN efficiency without fertilization,* TP efficiency with fall fertilization (empirical)	0-50%	0%
Terraces*	0%	40%
Dairy*		
1-year manure storage	17%	23%
180-day manure storage	5%	8%
clean water protection (depending on extent of program)	≤20%	≤20%
15-25% fertilizer reduction with no other BMPS	5%	0%
1-year storage and 15% fertilizer application reduction	20%	20%
1-year storage, clean water protection, and 15% fertilizer application reduction	40%	40%
Poultry*		
Manure shed	0-3%	0-3%
Vegetated Filter Strips	30%	30-90%
Grassed Waterways*	0-2%	0-15%
Fertilizer Reduction* (farms without livestock)	Roughly the same as the percent change in fertilizer application	

* synthetic or conceptual estimate

LIST OF BMPS

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