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Phosphorous Loading Algorithms for the South Nation River

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UPDATED PHOSPHORUS SOURCE ACCOUNTING METHODOLOGY FOR THE RURAL WATER QUALITY PROGRAM (2003)

The purpose of this document is to update The South Nation Conservation Authorities phosphorus loading algorithms used in the Rural Water Quality Program. The algorithms calculate phosphorus load reductions for a variety of Best Management Practices in farm management. The algorithms were updated by a review of the literature.

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1. MILKHOUSE WASHWATER

The purpose of the Milkhouse Washwater algorithm is to calculate the savings in phosphorus loading for proper disposal of milkhouse washwater. A description of milkhouse cleaning procedures is provided along with a breakdown of phosphorus loading for each wash cycle and water use characteristics for milking operations. The average phosphorus load per cow (Kg TP/cow/day) obtained from the literature is presented in Table 2. An attempt was made to only include studies in Table 2 that manage milkhouse wastes (including pipelines, equipment and bulk tank) separate from milkhouse and holding area manure, i.e. manure managed as a solid. Cleaning procedures and wastewater content are presented in Table 3. An estimation of the phosphorus load per cow for milking systems that manage manure with washwater is included at the end of the milkhouse summary.

Milkhouse Cleaning Procedure

Milkhouse washwater (or wastewater) generally refers to the wastewater generated from cleaning the milking equipment, pipeline, and bulk tank but may also include cleaning of the milk parlour floor, which may contain manure, bedding, and feed. Cleaning of the milking equipment and milk tanks usually involves four steps. (1) Prior to milking, a sanitizing step (usually sodium hypochlorite, NaOCL) ensures that bacteria are killed. (2) After milking, the pre-wash or rinse cycle uses lukewarm water to remove most of the milk residues. This cycle is typically high in Total Suspended Solids (TSS) and Biological Oxygen Demand (BOD) because of the milk proteins and fat. Jamieson et al. (2001) found 93% of the BOD in this cycle and an average concentration of 3132 mg/L from the pipeline rinse. Hayman (1989) found an average of 3237 mg/L BOD in the rinse cycle. Feeding the rinse cycle to calves is one way of reducing wastewater volume, TSS and BOD. (3) A hot chlorinated alkaline detergent (sodium hydroxide, NaOH, and/or sodium hypochlorite, NaOCL) is rinsed through to remove fats and oils. (4) The final cycle is an acid rinse (a mixture of phosphoric acid, H_3PO_4, and sulphuric acid, H_2SO_4) to remove minerals and prevent calcium build-up (OMAFRA, 1999, Malcolm et al., 1998).

Phosphorous from Detergent and Acid Wash Cycles

Hayman (1989) found that 93% of the total soluble reactive phosphorus (SRP) loading came from the detergent and acid wash cycle (detergent 7%, acid wash 86%). Similarly, 93% of the total phosphorus (TP) loading came from the detergent and acid rinse cycle (detergent 30%, acid wash 63%). Jamieson et al. (2001) found similar results of 86% of TP and 86% of SRP loading coming from the combined detergent and acid wash cycles (32%, 54% for TP and 3%, 83% for SRP, respectively)(Table 1). The majority of the phosphorus (P) in the acid wash cycle was found in the SRP form, while the P in the detergent precipitated due to the alkaline pH (Jamieson et al., 2001).

Table 1. Characteristics of milkhouse waste for individual wash cycles.

	Pipeline Wash			Bulk tank Wash			
	Rinse	Detergent	Acid	Rinse	Detergent	Rinse	Acid
BOD_5 (mg/L)	3132.0	53.0	<2	1090.0	84.0	94.0	50.0
TP (mg/L)	33.0	76.0	129.0	12.0	204.0	24.5	260.0
SRP (mg/L)	19.0	4.6	119.0	12.3	9.3	6.3	216.0
TSS (mg/L)	1703.0	149.0	33.0	380.0	160.0	130.0	85.0
pH.	6.6	10.9	2.7	7.3	11.5	9.4	2.2

Source: Jamieson et al. (2001).

Water Usage

Cuthbertson et al. (1994) performed a water use study on 308 Ontario farms. Water use in the milking parlour was an average of 14.2 L/cow/day. The water use broke down as follows: 76% for the milking equipment, 12% for the bulktank, 8% for the floor and other uses and 4% for the udder wash. Hayman (1989) found that nine farms with an average herd size of 43 generated 13.3 L/cow/day of milkhouse wastewater (not including water used to clean bulk tank or floor). He found no significant relationship between herd size and discharge volume but did find a significant regression between herd size and annual phosphorous loading. Gamroth and Moore (1995) performed a water use study on twelve Oregon dairy farms and found an average daily parlour water use of 25.9 L/cow/day. A survey of Dutch farms found 11.4-19 L/cow/day of wastewater generated from cleaning the milking equipment and parlours (Willers et al., 1999).

Milkhouse Washwater Phosphorus Loading excluding Manure

The results for the literature search on milkhouse washwater characteristics are presented in Table 2. The amount of TP produced per farm ranged from 11.5 to 280 Kg TP/yr, with an average of 46.7 Kg TP/yr. The farms ranged in size from 25 to 330 cows, with an average of 74 cows per farm. The amount of wastewater produced per cow ranged from 5.9 to 99 L/cow/day, with an average of 22.4 L/cow/day. Total phosphorous varied from 21.0 to 440.6 mg/L, with an average of 120.4 mg/L. Macgregor et al. (1982) and one farm in Sherman (1981) were considerably larger (310 and 330 cows, respectively) than the other reported farms. When these farms were removed from the analysis the average TP produced per farm is 32.8 Kg TP/yr (11.5 - 89.8 Kg TP/yr), average herd size was 57, average wastewater produced was 17.4 L/cow/day (5.9-70 L/cow/day) and the average TP concentration was 127.8 mg/L.

Milkhouse Washwater Phosphorus Loading including Manure

Milking facilities that incorporate manure disposal with milkhouse wastes will have considerably higher phosphorus loading then milkhouse wastes alone. Sweeten and Wolfe (1994) studied three dairy farms that managed wastes from holding (drip) shed, open lots or corrals, feeding lanes or bunks, and traffic lanes with milkhouse wastes, resulting in a combined liquid manure and milking facility wastewater system. The average concentration of phosphorus was 59 mg/L with an average water use of 149 L/cow/day for this combined milk sanitation and manure removal system. Average loading per cow was 3.4 +/- 2.7 Kg/yr. This is 5 times the loading determined for milkhouse systems that manage manure separately. USDA (1992) show a 3.5 times increase in phosphorus concentration from 134 mg/L for milkhouse, milking parlour, and holding area wastes that exclude manure to 483 mg/L for systems that include manure. A literature review by Chitikela and Ritter (1999) shows a phosphorus concentration of 30 mg/L for milkhouse wastes that exclude manure and 100 mg/L for systems that include manure. This represents a 3.3 times increase in phosphorus concentration when manure is managed with milking wastes. Their review shows a range of daily water use of 23, 40, 30-48 L/cow/day for systems that exclude manure and 3.8-22, 6.8-64, 45, 76-130 L/cow/day for cleaning operations that include manure. Milkhouse, milking parlour and holding area wastes that exclude manure produce 1.4 ft^3/day/1000# of wastes whereas systems that include manure produce 1.6 ft^3/day/1000# (USDA, 1992). The results from Chitikela and Ritter (1999) and USDA (1992) indicate that managing manure with milk sanitation increases water use by approximately 2, and 1.1 times over systems that exclude manure, respectively. An estimated 3 times increase in concentration and 1.5 times increase in water use in Table 2 would result in an estimated 4.4 Kg P/cow/yr load for cleaning operations that include manure disposal. This represents a 6.4 times increase. A conservative value for cleaning operations that include manure from floor washings, bedding, alleys, holding areas etc. is estimated at 2.76 Kg/cow/yr.
This is a 4 times increase over milk sanitation that mange manure separately (0.69 Kg P/cow/yr).

P controlled by Milkhouse Washwater (excluding manure)Projects = # cows * 0.69 Kg TP/cow/yr
P controlled by Milkhouse Washwater (including manure) Projects = #cows * 2.76 Kg TP/cow/yr

The effectiveness of various milkhouse waste treatments at reducing phosphorus pollution (flocculator, vegetated filter strips, constructed wetlands, lagoons, and ponds) is summarized in Appendix A.

Table 2. Summary of milkhouse wastewater characteristics. Wastewater and TP loading are expressed on a yearly basis per farm and per cow. TP = Total phosphorus and SRP = soluble reactive phosphorus.

Location	#cows	Wastewater (L/day)	Wastewater per cow (L/cow/day)	TP (mg/L)	SRP (mg/L)	TP (Kg/yr)	SRP (Kg/yr)	TP Kg/cow/yr	SRP Kg/cow/yr	Reference
Southwestern Ontario	35	373	10.7	136.6*	24.2*	18.6	3.3	0.53	0.09	Hayman, 1989
Southwestern Ontario	28	336	12.0	260.9*	95.4*	32.0	11.7	1.14	0.42	Hayman, 1989
Southwestern Ontario	48	545	11.4	224.7*	98.5*	44.7	19.6	0.93	0.41	Hayman, 1989
Southwestern Ontario	53	623	11.8	84.4*	36.9*	19.2	8.4	0.36	0.16	Hayman, 1989
Southwestern Ontario	50	296	5.9	440.6*	216.5*	47.6	23.4	0.95	0.47	Hayman, 1989
Southwestern Ontario	60	535	8.9	204.8*	68.6*	40.0	13.4	0.67	0.22	Hayman, 1989
Southwestern Ontario	35	553	15.8	163.5*	127.8*	33.0	25.8	0.94	0.74	Hayman, 1989
Southwestern Ontario	50	1640	32.8	77.7*	52.7*	46.5	31.6	0.93	0.63	Hayman, 1989
Central Nova Scotia	30	450	15.0			14.7	8.3	0.49	0.28	Jamieson et al., 2001
Univ. of Connecticut	100	2687	26.9	25.7		25.2		0.25		Newman et al., 2000
New Zealand			70.0	35.2	4.5			0.90	0.11	Warburton et al., 1981
New York state**	100	1533	15.3		57.6		32.2		0.32	Zall, 1972
Charlotte, Vermont	85	1158	13.6	81.5	54.6	34.4	23.1	0.40	0.27	Schwer and Clausen, 1989
New Zealand	310	23145-30684	74.6-99	25.0	4.9	211.2-280	41.4-54.9	0.68-0.9	0.13-0.17	Macgregor et al., 1982
Wayne county, Ohio	52	1136	21.8	47.2		19.6		0.38		Zimmerman, 1994
Wayne county, Ohio	52	1136	21.8	42.3		17.5		0.34		Zimmerman, 1998
Wayne county, Ohio	55	398	7.2	114.6		16.6		0.30		Zimmerman, 1998
North Carolina	25			145.0		26.0		1.04		Barker and Young, 1985
Bay of Quinte, Ontario	25					35.0		1.40		Draper, 1997
Unknown	25			97.8		17.0		0.68		USDA, 1992
Southern Ontario			20.0	60.0				0.44		GRCA, 1989
Sweden	30	345	11.5			11.5		0.38		Sundahl, 1985
New York State	60[a]		18.0	135.0		53.1		0.88		Sherman, 1981
New York State	125[a]		10.0	80.0		36.4		0.29		Sherman, 1981
New York State	63[a]		32.0	44.0		32.3		0.51		Sherman, 1981
New York State	45[b]		16.0	70.0		18.3		0.41		Sherman, 1981
New York State	85[b]		10.0	140.0		43.3		0.51		Sherman, 1981
New York State	330[c]		97.0	21.0		244.7		0.74		Sherman, 1981

Table 2 cont.

New York State	45 [b]		18.0	220.0		64.9		1.44		Sherman, 1981
New York State	44 [b]		22.0	255.0		89.8		2.04		Sherman, 1981
Ithaca, New York	125	1145	10.0	87.5		36.4		0.29		Bland et al., 1980
New York State	45	774	17.2	269		21.0		0.47		Robillard et al., 1982
New York State	85	901	10.6	174		48.5		0.57		Robillard et al., 1982
Unknown								0.75		Cornell University[d]
Central Nova Scotia	60	785	13.1	48.0	50.8	13.7	14.5	0.23	0.24	Jamieson et al., 2000a
Average	74	2108	22.4	120.4	68.7	46.7	20.3	0.69	0.32	
St. Dev.	70	5713	22.0	94.9	57.0	55.6	12.3	0.40	0.19	

* TP and SRP concentrations in Hayman (1989) are calculated from reported TP and SRP Kg/yr and wastewater (L/day).
** Average of 24 farms from 20 different counties
[a] Wastewater source= milking center
[b] Wastewater source= cleaning of milk pipelines
[c] Wastewater source= cowshed
[d] www.ansci.cornell.edu/prodairy/enviro/05milkwash.pdf

Table 3. Milkhouse cleaning procedure and wastewater content. N/I = not included, I = included, N/R = not reported

Location	Bulk Tank	Manure	Wastewater composition	Reference
Southwestern* Ontario	N/I	N/I	collected directly from pipeline cleaning, no bulk tank, floor or manure waste included	Hayman, 1989
Central Nova Scotia	I	N/I	collected at outlet of milkhouse drain; included pipeline and bult tank wastewater. Manure was managed separately as a solid.	Jamieson et al., 2001
University of Connecticut	I	N/R	wastewater included waters from rinsing the parlour floor, automatic rinsing of milking equipment and cleaning of the bulk tank.	Newman et al., 2000
New Zealand	N/R	I	wastewater included manure and urine from holding yards and milking machine washings.	Warburton et al., 1981
New York State**	N/R	I	Milkhouse and parlour waste included manure, feed, bedding and hoof dirt.	Zall, 1972
Charlotte, Vermont	N/R	N/R	Automatic pipeline washing system using a chlorinated detergent (.9% phosphate), bleach and an acid cleaner (12.5% phosphate)	Schwer and Clausen, 1989
New Zealand	N/R	N/R	All wash down wastewaters from the milking shed were passed through a coarse screen before being channelled to an underground pipe.	Macgregor et al., 1982
Wayne county, Ohio	I	N/R	Prior to each milking, a disinfectant solution was run through the pipelines and milking equipment machine (diluted sodium hypochlorite, bleach). After milking the lines and equipment were rinsed with plain water. Detergent contained polyphosphates and KOH. Acid wash mixture of sulfuric and phosphoric acid. Bulk tank used similar procedure. No milking parlour.	Zimmerman, 1994 Zimmerman, 1998
Southern Appalachia	I	N/R	Parlour is manually cleaned after each milking.	Barker and Young, 1984
Sweden	N/R	N/R	N/R	Sundahl, 1985
Ithaca, New York	I	N/I	Wastewater included milk units and pipeline, bulk tank, milkhouse and milk parlour floor washwater. Manure was removed from the parlour before the floor wash.	Bland et al., 1980
Central Nova Scotia	I	N/I	Wastewater is generated from cleaning of the pipeline and bulk tank. Manure, bedding and feed were excluded from the wastewater.	Jamieson et al., 2000

* Hayman (1989) reported the same milkhouse cleaning procedure and wastewater content for all 8 farms.

** Study looked at 24 farms from 20 different counties in New York State

2. STREAMBANK EROSION

The Illinois National Resources Conservation Service Rapid Assessment-Point Method (RAP-M) was chosen from 11 options as a method to estimate streambank erosion. The purpose of the RAP-M is to produce an estimate of the annual average rates of erosion by sampling small areas and expanding the results to illustrate the condition of the entire watershed. The procedure usually involves sampling steeply sloping (suspected erosion) sections of the watershed. If the watershed is 10 000 acres and around 6000 acres are steeply sloping, roughly 10% or 600 acres of steeply sloping channel should be measured to give a good estimate of erosion by the channel. The 600 acres to be sampled are divided into roughly four sites 150 acres in size. RAP-M then provides a technique to estimate the erosion in the four sites which is summed to provide an estimate of the erosion occurring in roughly 10% (600 acres) of the watershed. This estimate is then expanded to estimate the total erosion in the watershed. The manual emphasizes that RAP-M only provides estimates and is not a source of hard data. The full RAP-M method can be downloaded from www.il.nrcs.usda.gov in Technical Resources section where RAP-M can be located.

Briefly, the Rapid Assessment-Point Method (RAP-M) uses the following formula to calculate erosion (tons/yr):

L * H * Lat. Rec. Rate*Density/2000 = tons/yr

Where,

L = Length of channel sampled. Authors stress the importance of sampling both sides of the channel since each side might have different erosion rates. However, this may not be necessary for SNCA purposes.

H = Height of actively eroding slope and NOT the entire cut-bank. Although the top portion of a bank may be feeding material to the lower portions of the bank, only record the portion of the bank that is being eroded by channel flow. The RAP-M manual provides six figures for determining L and H measurements.

Lat. Rec. Rate = Lateral recession rate is not calculated, but is estimated from a chart derived from field observation and measurements in Lincoln, Nebraska. The chart includes lateral recession rates for five categories (i.e. for Moderate category of erosion, Lat. Rec. Rate = 0.06-0.2 ft/yr, avg. 0.13 ft/yr). Each category has a verbal (Figure 8) and photographic description (Photos 1-5). Illinois streams typically range from 0.05-0.5 ft/yr. Rates greater than 0.5 ft/yr usually occur in steep segments of the watershed and rates of 1 ft/yr are uncommon and not usually widespread.

Density= 95 pounds per cubic foot for loess and silty alluvium soils and 110 pounds per cubic foot for glacial till (reported by authors).

Site specific soil density and phosphorus content for the South Nation watershed soils should be used to calculate the amount of phosphorus associated with the sediment. A U.S. ton can be converted to a metric tonne by multiplying U.S. ton by 0.907.

3. MANURE STORAGE

The purpose of the Manure Storage algorithm is to calculate the phosphorus load savings for proper manure storage. This may include construction of a concrete basin to replace stacked dairy manure piles or berms, a settling basin, and a buffer strip to treat feedlot manure. Phosphorus savings are described for proper management of both dairy piles and feedlot manure. The feedlot manure algorithm is also partially used in the Clean Water algorithm (next section).

<u>Manure Characteristics</u>

The properties of fresh manure are greatly influenced by climate, season, diet, degree of confinement, animal age (stage of production/reproduction stage), and animal type. In addition, the amount of nutrients available at the time of land application depends on the amount of bedding and/or sediment included, method of collection and storage, and method and timing of land application.

Fresh manure characteristics for beef and dairy cows are presented in Tables 4 and 5, respectively. Frequently referenced "book" values include USDA (1992), MWPS (1985), ASAE (1984-2001) and studies by Gilbertson et al. (1979) and Overcash et al. (1983). It is difficult to trace the original sources for these book values. The USDA (1992) Agricultural Waste Management Field Handbook does not provide any sources for their data other than they are "reasonable values" and that both greater and lesser values can be expected experimentally. The data source for the Mid West Plan Service (MWPS-18, 1985) is the American Society of Agricultural Engineers (ASAE) committee S&E-412 report AW-D-1, revised 6-14-73. ASAE (2001) values are combined from a wide range of published and unpublished

Table 4. Beef manure characteristics (as excreted). All manure values are assumed to be fresh and from a 454 Kg animal. Daily manure production (Kg/day) is presented on a wet and dry basis (dry basis is calculated by multiplying wet by percent total solids). Percent total solids is on a wet basis. Percent TP composition and concentration of manure is presented on a wet and dry basis. The original source of data presented in a paper in the reference column is included in the source column. N/R = not reported, N/A = not available.

Source of manure	Animal weight (Kg)	Manure (wet) (Kg/cow/day)	Total solids %	Manure (dry) (Kg/cow/day)	% TP (wet)	% TP (dry)	TP (wet) g/Kg	TP (dry) (g/Kg)	TP (Kg/cow/day)	Reference	Original source
Fresh	454	26.83	11.6	3.11	0.17	1.49			0.0463	USDA, 1992	
Fresh	454	27.24	11.6	3.16	0.18	1.58			0.0499	MWPS 1985	ASAE revised 6-14-73
Fresh	454	26.33	14.7	3.87	0.16	1.08			0.0418	ASAE, 2001	
Fresh	454	23.61	15.0	3.54	0.13	0.88			0.0313	Miner et al., 2000	Overcash et al. 1983
Fresh	454				0.14				0.0318	Overcash et al., 1983	Avg. of 7 references
N/R	454	27.24			0.18				0.0495	GEIS, 1999	Gamroth and Moore, 1993
N/R	454	16.70	1.6	0.27	0.13				0.0225	Gilbertson et al., 1979	
N/R	N/R							9.6		Sharpley et al., 1998	Gilbertson et al., 1979
Fresh	N/R		23.5			0.57				Arrington and Pachek, 1980	
N/A	N/A						0.82			Barnett, 1994	Dupont et al., 1984
Fresh	N/R							6.7		Barnett, 1994	
N/A	N/A							8.4-11.5		Barnett, 1994	Peperzak et al., 1959
N/A	N/A				0.20					Dao, 1999	Ward, 1978
N/A	N/A								0.0440	Eghball and Power, 1994	Fedkiw, 1992
Fresh	N/A					1.10				Eghball and Power, 1994	Vivekanandan, 1990
Fresh	N/A					0.80				Kadlec and Knight, 1996	Reddy, 1981
N/R	454								0.0560	Madden and Dornbush, 1983	
Fresh	N/R							7.5		Masek et al., 2001	
N/R	454	25.20			0.23				0.0747	Taylor and Rickerl, 1998	
N/R	N/R		4.0-23			0.4-1.8	1.1			Tunney, 1977	Literature review
N/R	N/R		8.0				0.6			Tunney, 1977	Avg. of 33 irish farms

Table 5. Dairy manure characteristics (as excreted). All manure values are assumed to be fresh and from a 454 Kg animal. Daily manure production (Kg/cow/day) is presented on a wet and dry basis (dry basis is calculated by multiplying wet by percent total solids). Percent total solids of manureis on a wet basis. Percent TP composition and concentration of manure is presented on a wet and dry basis. The original source of data presented in a paper in the reference column is included in the source column. N/R = not reported, N/A = not available

Source of manure	Animal weight (Kg)	Manure (wet) (Kg/cow/day)	Total solids %	Manure (dry) (Kg/cow/day)	% TP (wet)	% TP (dry)	TP (wet) g/Kg	TP (dry) g/Kg	TP (Kg/cow/day)	Reference	Original source
Fresh	454	36.32	12.5	4.54	0.09	0.70			0.0318	USDA, 1992	
N/R	454	37.23	12.7	4.73	0.09	0.70			0.0332	MWPS, 1985	
Fresh	454	39.04	14.0	5.47	0.11	0.78			0.0427	ASAE, 2001	
N/R	454	37.23	12.7	4.73	0.07	0.55			0.0262	Gilbertson et al., 1979	
N/R	N/R							6.7		Sharpley et al., 1998	Gilbertson et al., 1979
Fresh + scraped daily	454				0.12				0.0499	Overcash et al., 1983	
Fresh	454		13.6							Safely et al., 1984	Overcash et al., 1983
Fresh	545-636		15.3							Safely et al., 1985	Avg. of 7 N.Carolina farms
Fresh	N/R		12.7							Safely et al., 1984	ASAE D384
Fresh	454								0.0330	CES, 1994	MWPS-1, 1983
N/R	454	40.41			0.11				0.0427	GEIS, 1999	Gamroth and Moore, 1993
Fresh	N/A						1.22			Barnett, 1994	Dupont et al., 1984
Fresh	N/R							9.3		Barnett, 1994	
Fresh	N/A							4.7		Barnett, 1994	McAuliffe and Peech, 1949
Fresh	N/A							2.6-6.4		Barnett, 1994	Peperzak et al., 1959
N/R	N/R							4.9		Ebeling et al., 2002	
Fresh	N/A					0.60				Kadlec and Knight, 1996	Reddy, 1981
N/R	454	32.50			0.10				0.0325	Taylor and Rickerl, 1998	

data. Gilbertson et al. (1979) is based on ASAE and MWPS values and original data. Overcash et al. (1983) beef data are an average of 13 studies from the literature. Additional references for fresh manure characteristics are presented in Tables 4 and 5. Manure values from OMAFRA's Nutrient Management Program (NMAN99) were not included in table 4 and 5 because the sampled manure was not fresh, but stored (solid beef manure 27.3 % dry matter and 0.17 % TP wet basis; solid dairy manure 20.1 % dry matter and 0.15 % TP wet basis). Manure characteristics (both manure and TP production) from ASAE (2001) are recommended for use in the manure storage algorithm because it represents the most current synthesis and probably the most extensive number of studies on manure characteristics (Table 6 and see Appendix B for full ASAE (2001) data).

Table 6. Phosphorous produced per day for various livestock per 454 Kg of body weight and per animal (calculated by multiplying column 2 by 3 and dividing by 454 Kg). Data marked "*" are from USDA (1992) all other data ASAE (2001). Average animal weights not provided in USDA (1992) were obtained from GRCA (1999) and are marked with "‡".

Type of Animal	Average Weight per Animal (kg)	Kg of Phosphorus produced per day per 454 kg (1,000 lb) of body weight	Kg of Phosphorus produced per day per animal (average weight x P factor/454 kg)
Dairy	640	0.043	0.061
Dairy Heifer*	408‡	0.018*	0.016
Veal	91	0.030	0.006
Beef	360	0.042	0.033
Beef Cow*	545‡	0.054*	0.065
Beef Cow*	204–340* (294‡)	0.045*	0.020 - 0.034 (0.029)
Beef Feeder (high forage diet)*	340–499* (408‡)	0.050*	0.037 - 0.055 (0.045)
Beef Feeder (high energy diet)*	340–499* (408‡)	0.043*	0.032 - 0.047 (0.039)
Swine	61	0.082	0.011
Dry sows*	136‡	0.027*	0.008
Boar*	136‡	0.023*	0.007
Feeder Pigs*	18-99* (55‡)	0.073*	0.003 - 0.016 (0.009)
Nursery pig*	0-18* (16‡)	0.114*	0 - 0.005 (0.004)
Layer	1.8	0.136	0.00054
Pullet*	0.68‡	0.109*	0.00016
Broiler	0.9	0.136	0.00026
Broiler breeder*	3.0‡	0.154*	0.001
Turkey	6.8	0.104	0.00156
Duck	1.4	0.245	0.00076
Lamb*	N/A	0.032*	N/A
Sheep	27	0.039	0.002
Goat	64	0.05	0.007
Rabbit*	1.0‡	0.006*	0.00002
Horse	450	0.032	0.032

Safely et al. (1984) reported 31% higher TP concentrations in their study of seven farms than values in ASAE (1984). Lindley et al., (1988) reported a mean P_2O_5 content 48% lower than the value given in MWPS (1985) for liquid dairy manure. Lindley et al., (1988) concluded that the deviation from published values appear to be related to housing-handling system and management. Powers et al. (1975) found the range of P concentrations reported in the literature to vary by 0.11 to 1.6%. Both USDA (1992) and ASAE (2001) warn that actual values will vary and site specific values are desired. MWPS (1985) reported that actual manure characteristics (all characteristics across different animal types) can easily vary by +/- 20% from their reported values. An average of five studies produced a value of 0.0458 Kg TP/ per 454Kg animal/ per day for fresh beef manure (Overcash et al., 1983, Gilbertson et al., 1979, Fedkiw, 1992, Madden and Dornbush, 1983, and Taylor and Rickerl, 1998). This average is 8.7% larger than the ASAE (2001) value of 0.0418 Kg TP/ per 454Kg animal/ per day. An average of four studies produced a value of 0.0354 Kg TP/ per 454Kg animal/ per day for fresh dairy manure (Overcash et al., 1983, Gilbertson et al., 1979, MWPS-1 1983, Taylor and Rickerl, 1998). This average is 17% lower than the corresponding ASAE (2001) value of 0.0427 Kg/ per 454 Kg animal /day.

The wet and dry TP concentrations and % TP from 11 studies were used to calculate three average beef manure TP production (Kg TP/ per 454Kg animal/ per day) values; one for each of the three different manure production values for USDA (1992), MWPS (1985), and ASAE (2001)(Table 4, columns 3 and 5). The calculated average beef values for TP production were 25, 43, and 39% lower than ASAE (2001), MWPS (1985), and USDA (1992) values, respectively. In a similar manner, the average TP production for 8 dairy values (Table 5) were 16, 3, and 2% lower for ASAE (2001), MWPS (1985) and USDA (1992) values, respectively. The ASAE (2001) beef and dairy manure values compare reasonably well with the literature with deviations ranging from 25% lower to 8.7% higher.

Phosphorus Runoff from Feedlot Manure

The previous report estimated that 4% of the total amount of phosphorus originally available in feedlot manure is leached out with runoff. Literature values for phosphorus loss from feedlot manure are higher than this previous estimate. Manure characteristics from dairy and beef feedlots are presented in Table 7. Arrington and Pachek (1980) reported phosphorus content to be 0.57% of fresh beef manure on a dry weight basis. Phosphorus content decreased to 0.38% on a dry weight basis for beef feedlot manure. This represents a 33% decrease in feedlot phosphorus. Gilbertson et al. (1979) determined the total phosphorus removed per ton of dry matter from a beef feedlot to be 1.3 g/Kg. The literature (Table 4) provides an average of 8.4 g/Kg phosphorus on a dry matter basis for fresh manure. A 1.3 g/Kg loss represents a 15% decrease in P content between fresh and feedlot manure. Sharpley and Moyer (2000)

Table 7. Manure characteristics for various storage methods. See Tables 4 and 5 for details

Animal	Manure source	Animal weight (Kg)	Manure (wet) (Kg/cow/day)	Total solids %	Manure (dry) (Kg/cowday)	% TP (wet)	% TP (dry)	TP (wet) g/Kg	TP (dry) g/Kg	TP (Kg/cow/day)	Reference
Dairy	Solid storage			18.0				0.88			MWPS, 1985
Dairy	Storage pits	454				0.07	0.78			0.0095	Overcash et al., 1983
Dairy	Scraped daily			22.3				1.83			Rieck-Hinz et al., 1996
Dairy	Scraped daily	545-636		16.8			0.84				Safely et al., 1984
Dairy	Removed daily	454		13.0	5.98		0.60			0.0359	Gilbertson et al., 1979
Dairy	Feedlot									0.0035	Overcash et al., 1983
Dairy	Barnyard	N/R		66.0			0.36				Arrington and Pachek, 1980
Dairy	Barnyard stockpile	N/R		95.7			0.33				Arrington and Pachek, 1980
Dairy	Stack					0.21		2.20			Forage Information System[a]
Beef	Stockpiled	N/R		48.6		0.30					Jones et al., 1995
Beef	Pits or storage tanks	454				0.13	1.10			0.0377	Overcash et al., 1983
Beef	Scraped	N/R					0.70				Eghball and Power, 1994
Beef	Scraped	454	12.71	56.0	7.12	0.25	0.45			0.0322	Miner at al., 2000
Beef	Stockpile*	N/R							2.1		Dao, 1999
Beef	Unpaved lot	454								0.0162	Gilbertson et al., 1979
Beef	Unpaved lot	N/R							1.3		Gilbertson et al., 1971
Beef	Unpaved lot	N/R							4.35		Eghball et al., 1997
Beef	Unpaved lot	N/R							0.9		Gilbertson et al., 1975
Beef	Paved/unpaved	**			4.68		0.40			0.0187	Manges et al., 1983
Beef	Open dirt lot	N/R		52.0				2.88			MWPS, 1985
Beef	Unsurfaced lot	454	7.95	55.0	4.37	0.80	1.45			0.0636	USDA, 1992
Beef	Feedlot	N/R							4		Robinson et al., 1995
Beef	Feedlot	N/R					0.54		5		Ward et al., 1978
Beef	Feedlot	454				0.32	0.65			0.0250	Overcash et al., 1983
Beef	Feedlot	N/R					0.65				Eghball and Power, 1994
Beef	Open lot	454		52.0	2.49		0.80			0.0199	Gilbertson et al., 1979
Beef	Open concrete lot			15.0				1.54			MWPS, 1985
Beef	Feedlot	N/R		83.3			0.38				Arrington and Pachek, 1980
Beef	Compost	N/R							5.2		Dao, 1999
Beef	Compost								4.19		Eghball and Gilley, 1999
Beef	Compost	N/R							5.32		Eghball et al., 1997

*Piled every 4-6 months

**Cattle weighed 600-800lb when they entered the plot and were 1050-1200 when slaughtered

[a] www.forages.css.orst.edu/Topics?Pastures/Fertilization/Manure.html

measured the release of phosphorus in dairy feedlot manure runoff using simulated rainfall experiments. The amount of dissolved organic phosphorus leached (g per Kg of material) was 0.375 g/Kg. The amount of dissolved inorganic phosphorus leached was 1.9 g/Kg. The total dissolved (inorganic + organic) phosphorus leached from five rainfall simulations was 2.3 g/Kg, or 58% of the total phosphorus available in dairy feedlot manure. Madden and Dornbush (1983) estimated that 8% of the total phosphorus production was removed by runoff from a 0.32 acre dairy confinement with 45 cows. This represents 2.5 Kg of phosphorus lost in runoff per cow per year. GEIS (1999) presented a table adapted from Moore and Gamroth (1993) on phosphorus retention for various storage systems compared to original P content in fresh manure (Table 8).

Table 8. Percentage of original phosphorus content retained in various storage systems[a]

	Dairy	Beef	Poultry	Swine	Sheep	Horse
Storage Method						
Daily spread	90		90		90	90
Dry + roof	90		90		90	90
Earthen	60	80		60		
Lagoon/flush	40	80	40	40		
Open lot	70	70		70	70	70
Pits + slats	95	95	95	95	95	
Scrape/storage tank	90	85				

[a] Adapted from Moore and Gamroth (1993).

Between 20-40% of phosphorus can be lost from open lots. Daily spreading, keeping manure dry (preventing runoff) and storage tanks are three storage methods that each result in only a 10% phosphorus loss. A comparison of feedlot manure values (Table 7) and fresh beef manure (Table 4) reveals a 35% loss when comparing % TP on a dry weight basis and a 62% loss of phosphorus when comparing P concentration (g/Kg) on a dry weight basis. The average % TP of dry weight was 1.07 for fresh manure (n=8) and 0.696 for feedlot manure (n=7). The P content on a dry weight basis for fresh manure was 8.4 g/Kg (n=3) and 3.11 g/Kg for feedlot manure (n=6). The range in TP loss from the literature for feedlot manure is 8 – 62%.

The value presented by Gamroth and Moore (1993) of a 30% loss of fresh manure TP content in feedlot runoff will be used to calculate phosphorus loading from feedlot runoff and reductions for Clean Water Diversion projects (next section).

The 4% P loss determined by the previous GRCA phosphorous algorithm report is perhaps an underestimation of phosphorus losses from open lots. The TP loss was calculated from results presented in Edwards et al. (1983) in which they found a paved feedlot with 56 beef cows lost on average 31 Kg of TP per year. The previous P loading algorithm report calculated a total of 920 Kg of TP produced per year in the fresh manure (from USDA, 1992, TP production of 0.045 Kg TP per 454 Kg cow per day). Therefore, a 31Kg runoff loss represents roughly 4% of the original amount. This % runoff loss value assumes that 920 Kg TP is originally available for potential loss, however, since the lot was scraped weekly the total amount of P originally available was probably much less than 920 Kg (this is the yearly total). A lower initial amount of TP available for runoff losses would result in higher loss rates when the 31Kg TP lost in runoff is kept.

The savings in P loading for the proper treatment of beef feedlot manure can be expressed as;

P controlled by proper Manure Storage of beef feedlot manure

= # of animals * days * phosphorus excreted * 0.30

The phosphorus excreted for beef cattle is 0.4177 Kg TP/cow/day (ASAE, 2001). Control measures for feedlot manure would include paving the lot and constructing low retention walls that would channel runoff into a settling basin. The solids may then be removed and stored with other solid wastes and the liquid waste may be treated by a number of methods including constructed wetlands or vegetated filter strips.

<u>Phosphorus Runoff from Dairy Pile Manure</u>

The previous manure storage algorithm estimated phosphorus pollution from feedlot manure leachate. However, the manure storage program offered by the SNCA is primarily designed to eliminate pollution from dairy manure piles frequently seen adjacent to the barn, and not from feedlot runoff. It would be erroneous to apply beef feedlot runoff information to calculate savings for the proper manure storage of dairy piles for the following reason, if not more. Phosphorus losses from feedlot manure would most likely be higher than piled manure because feedlot manure is spread out and more exposed to rainfall, resulting in more clean water contamination. When manure is concentrated in one place, such as a manure pile, less clean water will come into contact with it resulting in less contaminated clean water.

Only one source of dairy stockpile manure information was found in the literature (Table 7). Arrington and Pachek (1980) reported dairy barnyard stockpiled manure being 0.33% phosphorus on a dry weight basis. The literature provides an average of 0.66% phosphorus on a dry weight basis for fresh dairy manure (Table 5). This represents a 50% loss of phosphorus when manure is stockpiled. However, it must be kept in mind that foreign material (i.e. bedding) may change the chemistry of the manure if it is in sufficient quantities, either lowering or enriching the manure phosphorous content. Research conducted by Chris Kinsley and Anna Crolla (personal communication) at Alfred College found that 133.65 Kg of phosphorous leached from a dairy pile into a lagoon over a one year period. This represents 1.11 Kg/cow/yr, or 7.1% of a dairy cow annual 15.57 Kg phosphorous production (daily dairy cow phosphorus excretion, 0.0427 Kg TP/cow/day, ASAE (2001)). A literature search should be conducted to confirm this estimate.

The phosphorus loading savings for the proper treatment of dairy pile manure can be expressed as;

P controlled by proper Manure Storage of dairy pile manure

= # of animals * days * phosphorus excreted * 0.07

4. CLEAN WATER DIVERSION

The purpose of the Clean Water Diversion program is to divert clean water away from manure and thus reduce phosphorus loading through runoff. Some values of phosphorus feedlot runoff concentrations are presented in Table 9. Clean water inputs to a feedlot area includes runoff from the barn roof, the feedlot itself, wastewater disposal systems (i.e. milkhouse wastewater) and the upland drainage area. There is very little literature on clean water diversion used alone as a BMP. Brown et al. (1989) found that runoff concentrations were less variable than runoff from precipitation events. The phosphorus concentration appears to be buffered by the dense manure pack. Their research showed that the P load (Kg/yr) did not change per unit area when the size of the drainage area was reduced but that P load reductions were roughly proportional to the reduction in runoff volume.

In a situation where a roof has been constructed over the manure, the reduction in runoff is assumed to be 100%, and thus a 100% P load reduction. The P load reduction for installing a roof over a feedlot or

Table 9. Feedlot runoff characteristics for dairy and beef cows. N/R = not reported.

Animal	Beef source	Animal weight (Kg)	Total solids %	% TP of wet weight	% TP of dry weight	SRP (mg/L)	TP (mg/L)	TP production (Kg/cow/day)	Reference
Dairy	N/R	454	0.1	0.005					Gilbertson et al., 1979
Dairy	exercise area/open lot	454		0.004	1.4			0.00345	Overcash et al., 1983
Dairy	Stacked with bedding						190-280		Loehr, 1974
Dairy	paved barnyard						18.8 - 75.5		Croft, 1989
Dairy	paved barnyard					11.2-50.2			Croft, 1989
Dairy	Unpaved barnyard						10.7 - 25.1		Croft, 1989
Dairy	Unpaved barnyard					8.7-15.5			Croft, 1989
Dairy	Barnyard						7.0 - 30.0		Brown et al., 1989
Beef	N/R	454	0.1	0.01					Gilbertson et al., 1979
Beef	feedlot runoff						10-500*		Miner et al., 2000
N/R	feedlot						20-480		Kadlec and Knight, 1996
N/R	feedlot					5.0-26.0			Kadlec and Knight, 1996
Beef	feedlot						1-3**		Manges et al., 1983
Beef	feedlot						290-360		Loehr, 1974

* 300 mg/L typical

** runoff concentration from pasture with cows and not feedlot stockpiled dairy manure is considered to be the same for proper manure storage (see section 3 algorithms).

Roof construction over a feedlot is not always practical and berms might be used instead to divert clean water away from the manure. In this case, the P load reduction will be proportional to the reduction in clean water diverted from the feedlot.

P savings from Clean Water Diversion for feedlot manure (for dairy pile replace 0.30 with 0.07)

= # of animals * days * phosphorus excreted * 0.30 * (reduced feedlot runoff volume/ original feedlot runoff volume)

Calculating the original volume of clean water coming into contact with the manure involves determining the amount of surface runoff from upland areas entering the feedlot (Upland runoff (L/ha/yr) * Upland area impacting feedlotlot (ha)), the volume of water entering the feedlot from roof runoff (Precipitation (L/ha/yr) * Roof area (ha)) and liquid waste disposal, i.e. milkhouse wastewater, (Liquid waste disposal (L/yr)) and the amount of precipitation falling directly onto lot (Precipitation (L/ha/yr) * Feedlot area (ha)). Feedlot runoff is assumed to be 100% of precipitation for both paved and unpaved lots.

Original feedlot runoff volume (L/yr) = (Upland runoff (L/ha/yr) * Upland area impacting feedlotlot (ha)) + (Precipitation (L/ha/yr) * Roof area (ha)) + (Liquid waste disposal (L/yr)) + (Precipitation (L/ha/yr) * Feedlot area (ha))

A topographic study of the feedlot and upland area must be made to estimate the amount of upland water entering the feedlot. For example, if the feedlot is located in a depression, then a considerable amount of the upland runoff could be channelled into the lot. Alternately, if the lot is on high ground then upland runoff would be minor. If the lot is on an even plane with the upland area then the amount of upland runoff entering the lot would be proportional to the feedlot width.

The reduced feedlot runoff volume can be calculated in a similar manner to the equation above. For example, if all roof runoff was diverted through eavestroughs the roof term in the calculation for original feedlot runoff volume would be zero (Local Precipitation (L/ha/yr) * Roof area (ha) = 0).

If the farmer is willing to construct berms, then a simpler method to calculate the P load reduction would be to channel upland and roof runoff away from the feedlot and channel runoff produced in the feedlot from precipitation into a settling basin and/or vegetated filter strip.

5. LIVESTOCK ACCESS

Quantities of livestock manure directly deposited into streams are rarely calculated. Water quality studies on restricted livestock access tend to group phosphorus non-point sources (erosion, manure) and do not breakdown the phosphorus load reduction into its components (effect of buffer strips, reduced erosion and absence of direct manure discharge are not separated). Line et al. (2000) stated that the observed 75% reduction in weekly TP loads after exclusion was probably due to reduced erosion and filtering of sediment in runoff. Sheffield et al. (1997) reported a 98% reduction in TP loading (Kg/cm rain) and a 77% reduction in streambank loss when livestock were given the choice of an alternative water source. Owens et al. (1996) reported a 40% reduction in sediment loss from a 28.2 ha pasture when 17 cattle were excluded from the watercourse even with a 30% increase in average annual storm flow following the fencing. The decrease was believed to be related to less stream bank cutting by livestock rather than the effect of the buffer strip filtering out sediment from the grazing area.

The previous livestock access algorithm is based on a 1994 Soil Conservation Factsheet. The factsheet states that studies show cows spend an average of 5 minutes per day in the stream, releasing 200 Kg of manure per year. Using ASAE (2001) manure characteristics, this represents 0.32 Kg TP per cow per year. The 200 Kg amount excreted into the stream represents 2% of the total annual manure production per cow.

Studies have recorded cows spending 6.7 and 25.6 minutes or 0.77% of the observation period (5:30am-8pm) and 4.5% (7:30am-5pm), respectively (Sheffield et al., 1997, Miner et al., 1992). Clawson (1993) reported cows spend on average 4.7 minutes per day in a stream. In addition, cows spent an average 8.3 min and 12.7 min per day adjacent to the stream (Clawson, 1993, Sheffield et al., 1997). Gary et al. (1983) observed that cows spent roughly 5% of their day (33 minutes between 7a.m. to 6p.m.) in the channel and 21% of their day (139 minutes) within 25m of the channel. Miner et al (1992) noticed that there was very little cow activity during the hours of darkness. Gary et al. (1983) observed an average 8.6% of total daily defecations per cow occurring directly to the stream. Gary et al. (1983) collected manure from 3 metre wide strips on both sides of Trout Creek (1.28 Km) on three occasions to estimate the amount of manure that had the greatest potential to pollute the stream. The recovered manure in the 3 metre wide strips was 4.1, 5.3, and 5.8% of the total estimated manure production in the pasture. Gary et al. (1983) estimated that about 5% of the total manure produced by the cattle contribute to the pollution of the stream. From Gary et al. (1983) and the Soil Conservation Factsheet, an estimated 5% and 2% of daily manure production is discharged directly into a stream when there is no alternative water source for drinking, respectively. A 3% direct discharge will be used for the Livestock Access program. The phosphorus load savings from preventing direct manure discharge into streams is;

P savings from restricted Livestock Access = # of animals * days * phosphorus excreted * 0.03

For each beef cow this represents 0.46 Kg reduction in total phosphorus per year, assuming 365 days of access to the watercourse each year. The total reduction in phosphorus loading from livestock exclusion will be much higher due to associated decreases in streambank erosion and phosphorus removal by buffer strips. The algorithm assumes that the livestock has access to the stream all day. However, dairy cows might spend half their day in the barn being milked, so the number of days access to the watercourse may be multiplied by 0.5.

6. SEPTIC SYSTEMS

A septic system P loading algorithm was added to the Clean Water Program phosphorus accounting methodology in 1999. The current algorithms for direct and indirect septic system loading are:

P export from septic systems that discharge directly to ditch or stream = # systems*15.33Kg/system/yr
P export from septic systems with indirect discharge to ditch or stream = # systems*0.6 Kg/system/yr

A survey of the literature indicates that the "systems" in the equations should be replaced with per capita (ca). Some export coefficient values for septic systems from the literature are 0.24 Kg TP ca^{-1} $year^{-1}$, 0.6 Kg TP ca^{-1} $year^{-1}$ (1.0 high, 0.3 low), and 0.8 TP ca^{-1} $year^{-1}$ (Johnes, 1996, Reckhow and Simpson, 1980, Dillon et al., 1986, Vollenweider, 1968). These export coefficients are calculated from septic tank effluent concentrations ~7 - 19 mg/L TP and estimates of average daily water use per person, ~100 -190 L ca^{-1} day^{-1}. Direct discharge from a family of 4 with an export coefficient of 0.6 Kg TP ca^{-1} $year^{-1}$ results in a 2.4 Kg load of TP per year. The 15.33 Kg TP loading per system per year for direct loading is an improbably high value for household septic tank loading. The value of 0.6 Kg TP ca^{-1} $year^{-1}$ will be used to calculate septic system phosphorus loading.

The septic tank loading coefficients used in watershed phosphorus budgets mentioned above assume eventual 100% delivery of septic tank effluent to surface waters. This might be a reasonable assumption for lakeside cottages, however, it is unrealistic for homes that are set back from surface waters. In practice, soil attenuates much of the phosphorus load and slows the transport of the remaining phosphate to the point that it may take decades, centuries or millennia before septic tank effluent will have an impact on surface waters for homes that are not directly adjacent to freshwater.

Phosphorus migration through soil is retarded through mineral precipitation and sorption reactions (Wilhelm et al., 1994). Attenuation occurs through mineral precipitation in the unsaturated vadose zone resulting in phosphorus rich soils close to the infiltration pipes. Robertson et al. (1998) found 85% of the total P load from a school septic system was retained in the unsaturated vadose zone even after 44 years of operation (Langton, Ontario). The phosphate concentration was 300-500mg/Kg above the tile bed and increased sharply to 1000mg/Kg for 10cm below the tile bed but then returned to concentrations similar to above the tile bed. Mineral precipitation reactions may have the ability to permanently fix an unlimited amount of phosphorus (Robertson, 1995, Harman et al., 1996). The magnitude of phosphorus reaching the saturated groundwater zone is mainly controlled by attenuation through precipitation in the unsaturated vadose zone, however, once phosphate reaches the saturated groundwater zone there appears to be very little further attenuation (Robertson, 1995). The migration of phosphate in the groundwater depends on the sorption capacity of the soil, which is limited and reversible. Once the sorption capacity of the soil has been saturated, a steady-state stable concentration is established between sorption and desorption processes in the groundwater.

The portion of groundwater most affected by septic systems originates under the weeping bed, travels in the direction of the groundwater and is called a septic plume. The boundaries of the septic plume are determined by observing chloride or sodium concentrations that are substantially higher than background concentrations. An example of phosphate migration from the septic tank through the vadose and groundwater zone is presented in Figure 1. Phosphate plume concentrations are presented for a four person home at years 10, 14 and 17 of septic system operation in Cambridge, Ontario (Robertson, 1995). The tile bed is located over a carbonate rich, silt poor sand aquifer. The effluent residence time in the aerobic vadose zone was around 10 days. The plume core is characterized by Na^+ concentrations of 32-96 mg/L compared to 2-7 mg/L background concentrations. Phosphate effluent levels discharged from the septic tank ranged between 1.4 - 14.2 mg/L (average 6.3 mg/L). Phosphate plume concentrations under the tile bed between year 10 to 17 show a condition of near-steady state, with concentrations consistently in the range of 3-6 mg/L (average 4.6 mg/L). This represents ~25% attenuation of phosphate

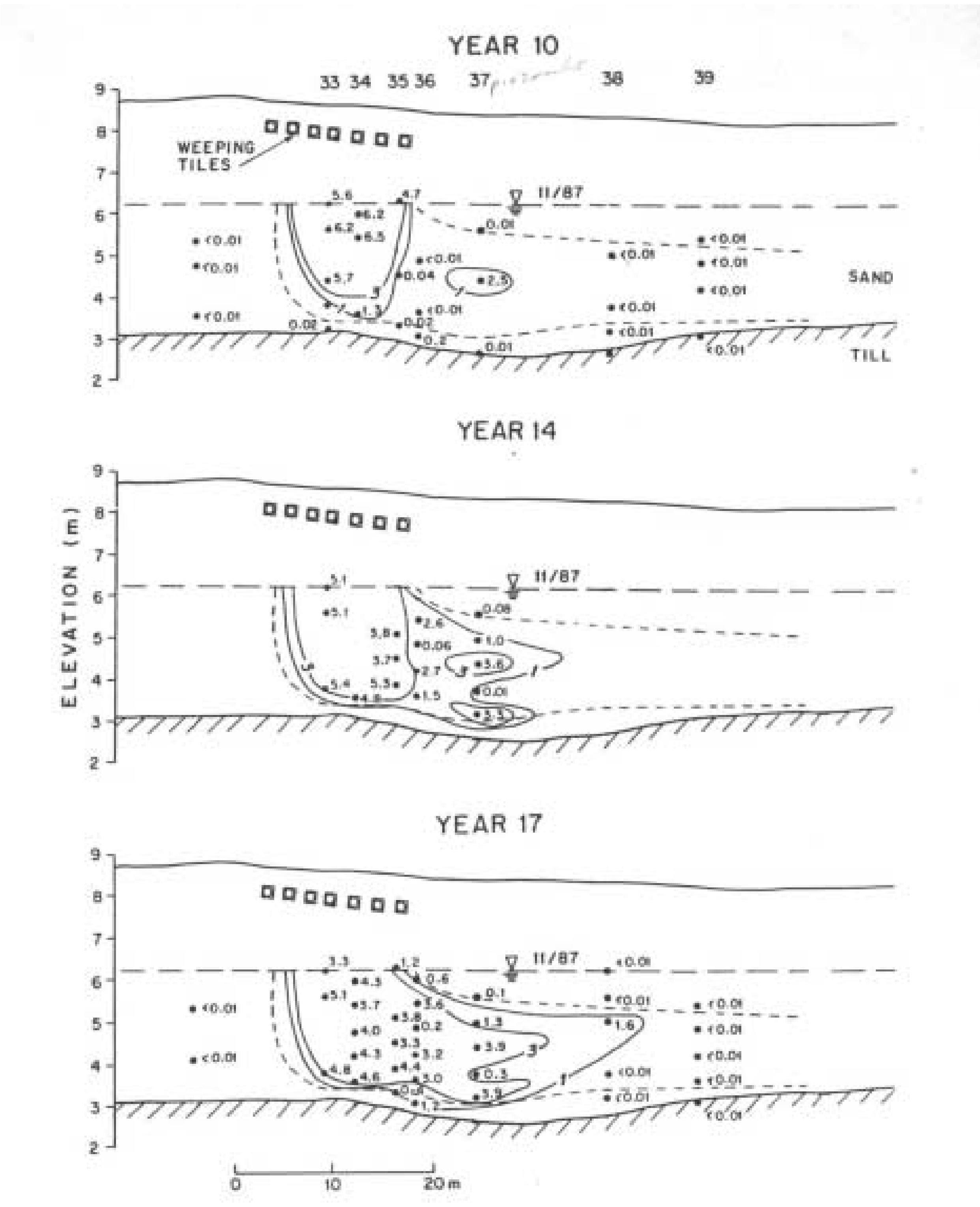

Figure 1. Phosphate distribution (mg/L) along the plume centerline during years 10 (1987) to 17 (1994) of system operation (dashed line denotes plume core based on Na+ levels of >40 mg/L). (Robertson, 1995).

through the vadose zone. Robertson (1995) suggests that precipitation with hydroxylapatite, variscite, and possibly strengite minerals could be responsible for the loss in phosphate mass in the vadose zone. Soil analysis revealed a 10 cm thick zone directly below the infiltration pipe that was enriched in TP (1500 ug/g) compared with values elsewhere in the vadose zone (~350 ug/g). Phosphate concentrations are lower in the distal end of the septic plume because sorption sites are unsaturated, but the phosphate concentration rises to steady-state values as the sorption sites approach saturation. Compare piezometer 37 in year 10 and 17. The phosphate plume is moving at 1m/yr, which is roughly 20 times slower than the groundwater velocity (Robertson, 1995). It appears that once phosphate enters the groundwater, the sorption process acts only to slow the migration but does little to attenuate it (Harman et al., 1996, Robertson, 1995, Robertson et al., 1998, Robertson and Harman, 1999, Wilhelm et al., 1994).

TP removal between the septic tank and a water source depends on the type of soil (proportion sand, silt and clay), soil drainage (frequency of saturation) soil structure (permeability) slope, oxygen, temperature and pH. Most studies are conducted on sand aquifers since this soil type poses the greatest threat. Generally, clay soils are less problematic because of greater TP attenuation capabilities and lower water permeability.

Estimates of TP attenuation in Ontario soils ranges from 1% to 99% (Dillon et al., 1996). Attenuation values derived in the field (water table P concentration directly under weeping bed/effluent value) for sandy aquifers from the literature range from 23 -99% (GWMAP, 1999, Harman et al., 1996, Robertson, 1995, Robertson et al., 1998, Robertson and Harman, 1999, Wilhelm et al., 1994, Robertson et al., 1991). However, some of these field calculations of attenuation may be overestimated if the system has not yet reached steady-state concentrations (young systems). Brandes et al. (1974), reported in Dillon et al. (1986), reports lab derived phosphorus retention coefficients below 0.5 for sand and 0.63 and 0.74 for silty sand and a 50% clay silts 50% sand mixture, respectively. In a review of ten septic systems, Robertson et al. (1998) report an 87% attenuation for a mixture silt and fine sand sediment type. Work by Viraraghavan and Warnock (1976), as reported in Cantor and Knox (1985), investigated the reduction of phosphate in soil around Ottawa, Ontario. The soil was sandy clay to a depth of 2 feet, followed by clay and less sand from depth 2 feet to 5 feet. At the 5 foot depth, the phosphate had been reduced by 25 to 50 percent, a “much lower value than reported in the literature”(Cantor and Knox, 1985). An attenuation factor of 0.40 (40 % TP attenuation in the unsaturated vadose zone) will be used in the septic loading algorithm for sandy soils with a grain size between 0.24-0.30 mm, and 0.7 (70 % TP attenuation) for soil that contains a mixture of sand with either limestone, silt, clay, or red mud (see Dillon et al., 1986).

Phosphorus migration for 7 household septic systems on a shallow sandy aquifers in Baxter, Minnesota ranged from <5 to 12 m for systems that ranged in age from <5 to 20 years (GWMAP, 1999). The longest phosphorus plume was 12 m (15 years old) with 4 of the plumes migrating 5m or less (system ages 5 to 20 years). Robertson et al. (1998) reported a range of phosphate plume lengths from 1 to 70m for 10 systems (homes, campgrounds, school) that ranged in age between 6 to 44 years. The plumes travelled at velocities that were 20-100 times slower than the groundwater. A fast phosphate plume velocity for a sandy aquifer is around 1m/yr (W.D Robertson, personal communication). A migration of 1 m/yr will be used in the phosphorus loading algorithm. Silty and clay soils would have much lower velocities (perhaps half to ten times slower) than sandy soils, therefore 1 m/yr represents a worst case scenario for phosphate mobility in South Nation groundwater.

It must be kept in mind that P load savings from septic system improvements will not have an immediate impact on reducing P loading to surface water, however, a phosphorus producer acquiring the credit will use it immediately. For a house 200m from surface water, the P load savings from any improvements made today will take roughly 200 years to be realized (assuming P migration of 1m/yr). Two hundred years is an estimate based on a worst case scenario 1 m/yr velocity. The actual time scale for a home 200m from surface water to impact it for silt and clay soils is probably around 400 – 2000 years (0.5 – 0.1 m/yr). A study of The East Branch reservoir (source of drinking water) in New York state concluded that only septic systems within 100 feet were included as potential phosphorus sources. The Muskoka Lakes Association assumes that cottages within 300m of surface waters will contribute phosphorous from septic systems.

Only repair or replacement of biologically failed systems (no P load attenuation) will produce a phosphorous savings that can be traded. A biologically failed septic system is one where the vadose zone is permanently saturated. In that case, the vadose zone will behave similar to groundwater and have a phosphorus attenuation factor of zero. This situation might arise if the septic system is undersized and receives excess waste volume. The excess waste volume would keep the vadose zone permanently saturated. Failure can also result from clogged soil pores from a biomat (undecomposed organic matter) that accumulates over time around the infiltration pipes. Surface ponding will be observed above the weeping bed and will result in biological failure only if the surface runoff directly discharges to surface waters. If the surface runoff eventually infiltrates the soil adjacent to the bed then we can assume that attenuation is still occurring in the unsaturated vadose zone and the system hasn't failed biologically, just operationally and therefore would not be included in the phosphorous trading program.

The P load savings for improved septic systems is as follows;

P savings = P loading (failed) – P loading (functional)

Where P loading (Failed or Functional) = 0.6 Kg TP ca^{-1} $year^{-1}$ * (#persons) * (1-A)

A = Attenuation in vadose zone (0-failed, 0.4-functional-sand, 0.7-functional-sand mixed with either silt, clay, or red mud)

An example in phosphorus load savings for a 4 person household with silty-sand soils and surface ponding runoff directly impacting a stream and/or a saturated vadose zone, the phosphorus load reduction will be calculated as;

P savings = P loading (failed) – P loading (functional)

= 0.6 Kg TP ca^{-1} $year^{-1}$ * (4) * (1-0) - 0.6 Kg TP ca^{-1} $year^{-1}$ * (4) * (1-0.7)

= 2.4 Kg TP/ yr – 0.72 Kg TP/yr

= 1.86 Kg TP/yr

7. CONSERVATION TILLAGE

Conservation tillage techniques leaves crop residue on the soil and produces very little soil disturbance compared to conventional techniques. The effect of no-till conservation technique on runoff, sediment loss, soluble P and TP loss is variable, however, it appears that runoff is generally decreased, soluble P loss generally increases and sediment and TP loss consistently decreases compared to conventional tillage.

Data was collected from the literature and four main topics are summarized in this section; runoff, soil, soluble phosphorus, and total phosphorus loss from conservation tillage compared to conventional techniques. All data is from surface runoff with the crop row oriented parallel to the field slope. Some studies were averaged across crop types, fertilization spreading methods, and years to produce single values for soil, soluble P, and TP in Tables 11, 12, and 13, respectively. For example, Kimmel et al. (2001) studied runoff from plots containing two crops (sorghum and soybean) with three fertilization methods (none, knife, and broadcast) over a two year period (1998 and 1999), resulting in twelve treatments. The results for the full range of original treatments are available in the attached excel file Tillage.xls.

Methods

The studies were either conducted using natural rainfall or simulated rainfall. The methods for these two types of experiments are presented after a brief additional description for two studies. Mostaghimi et al. (1988a) presented a study with two tillage treatments (no-till and conventional) each with three rye residue levels (0, 750, and 1500 Kg/ha), for a total of six treatments. For this study, a single value is presented comparing the results for the no-till (NT) at 0 Kg/ha and conventional tillage (CN) at 1500 Kg/ha because this is the most probable residue levels for traditional NT and CN methods. A comparison of NT and CN at 1500Kg/ha, or 0 Kg/ha, would have no practical significance in everyday farm practices. Results from Sharpley and Smith (1994) are referred to in the text of this section but not included in the tables 11, 12, and 13 because it is difficult to determine how they arrived at their numbers. Results are reported as a group for conventional tilled wheat (comprising five watersheds, E6, E7, E8, W3, and W4) and no-till wheat (two watersheds, E7and W4). The watersheds received different fertilizer applications (E6, E7 and E8, W3 and W4, received 12, 13 and 23 Kg P/ha, respectively) and varied in slope between on average 2.8% for watershed E and 8% for watershed W. It was difficult to determine how they arrived at the values reported in the text based on the data that they presented in tables and graphs.

The studies are divided into natural rainfall and simulated rainfall. Natural rainfall typically involved sampling all runoff events during the growing season. Kimmel et al. (2001) had two plots sized 4.65 m^2 (sorghum) and 58 m^2 (soybean) while in a study by Pesant et al. (1987) the plot was 45 m^2. In both studies, the total runoff was brought to a collection point and either sump pumped or stored in a tank. McDowell and McGregor (1984) had 88m^2 plots with the runoff passing through an H flume and the water collected with a wheel sampling device. Gaynor and Findlay (1995) had a plot size of 1006m^2 and collected water manually for all runoff events between January and September 1990. Johnson et al. (1979) sampled six small watersheds ranging in size from 0.55 - 1.75 ha. H flumes were installed at the outlet of each watershed, however due to sediment deposition above the H flumes they estimated that the reported soil losses would have been 10% higher for the conventional watersheds and 5% greater for the till-plant and ridge-plant watersheds. Chichester and Richardson (1992) monitored six small watersheds (3 conventional and 3 no-till) ranging in size from 4 - 8.4 ha. Each watershed had a concrete V-notch weir and automatic water samplers.

Simulated rainfall events were typically one-time events performed early in the growing season, just before or after planting. The plots sizes ranged from 1.3 m^2 to 180.2 m^2, with an average size of 73.3 m^2. McIsaac et al. (1995) and Andraski et al. (1985) applied rainfall for 1hr at a rate of 64 mm/hr and 73 - 136 mm/hr, respectively. McIsaac et al. (1987) applied rainfall at an intensity of 63 mm/hr until runoff was observed for approximately 20 minutes. Zhao et al. (2001) applied rainfall at an average rate of 68 mm/hr. The actual amount of rainfall applied to each plot varied from 67 to 93 mm, but these differences were not significantly different. Mostaghimi et al. (1988a, 1988b), Barisas et al. (1978), Seta et al. (1993) and Eghball and Gilley (2001) followed a similar technique of applying a "dry" run followed 24 hours later by a "wet" run which was followed 30 minutes later by a "very wet" run. The three run sequence of dry, wet, and very wet is a common method used to simulate different initial soil moisture conditions for erosion research in the United States. Intensity rates and rainfall durations for the dry run varied from 50-66mm/hr for 1-1.4hr, the wet run varied from 50-66mm/hr for 0.5-1hr, and the very wet run varied from 50-127mm/hr for 0.5hr for the different studies. Eghball and Gilley (2001) did not apply a very wet run. The runoff volume, soil, TP, and soluble P loss was expressed as the average of the three runs.

More weight is given to the natural rainfall studies that sample over the entire growing season or year and usually over much larger plot sizes up to entire watersheds. The simulated rainfall studies are usually conducted once during the spring around planting time and on smaller plots. Soil is most prone to erosion at this time because there is no plant cover to dissipate the energy of the rainfall. In addition, Egbhall and Gilley (2001) applied the rainfall simulator soon after manure, compost, and fertilizer were applied. This represents a worst case scenario for phosphorous loss in runoff. Averaging the results over an entire season would reduce the high phosphorus loss expected for rainfall experiments conducted in spring and soon after fertilizer application. An explanation of the abbreviations used in the text and tables is presented in Table 10.

Table 10. Description of methods and abbreviations presented in Tillage text and tables 11, 12, and 13.

	Tillage	Description
CN	Conventional	Methods that involve turning of the soil. May include moldboard plowing, chisel plow, chisel till, disking, harrowing and rototiller. Coventional tillage usually involves two or perhaps three of these tillage methods in the fall and/or spring, i.e. fall moldboard plow with two spring diskings. Conventional tillage decrease in level of soil disturbace from MP>Ch>disk. By definition CN leaves less than 10% of residue cover.
MP	Moldboard Plow	When combined with other tillage methods, it represents the most extensive disturbance of the soil.
till plant	Till plant	Disking for Johnson et al. (1979), not described in Barisas et al (1978)
ChP	Chisel plow	May include another tillage method, i.e. disking
ChT	Chisel till	May include another tillage method, i.e. disking
Disk	Disk	Single disking operation to 8cm depth in Eghball and Gilley (2001)
RT	Ridge till	Crop planted into ridges formed in the previous year. Ridges are usually reformed one month after planting. Reported residue coverage from literature is 59-93%.

Table 10 continued

Red. Till	Reduced till	Same as NT but two cultivations early in growing season to control weeds instead of herbicides.
NT	No till	No soil disturbance except planting and in some cases subsurface fertilizer application. Residue coverage greater than 90%.
CT	Conservation tillage	Conservation tillage methods include ridge-till, reduced-till and no-till

Runoff

Kimmel et al. (2001) reported significantly higher runoff from RT (8.4 x 10^5 L/ha) compared to NT (6.5 x 10^5 L/ha) and CN (4.3 x 10^5 L/ha) for sorghum 1998. Despite the higher runoff from NT, there was no significant difference between NT and CN. Some studies showed that was no significant differences in runoff between NT and CN (Chichester and Richardson 1992, Sharpley and Smith 1994, Zhao et al. 2001, and McIsaac et al. 1987). Runoff averaged 1.3 ML/ha annually for both NT and CN (Chichester and Richardson ,1992). Gaynor and Findlay (1995) found conservation tillage (RT and NT) increased surface runoff by 39% but reduced subsurface runoff by 20% compared to CN resulting in similar combined water losses for all three tillage treatments. Conservation treatments (Ridge planting and till planting) reduced runoff by an average 40% compared to CN (Johnson et al. 1979). A survey of the literature reveals runoff reduction values by NT of 25%, 64%, 67%, 75%, 83%, and 92% compared to CN (McDowell and McGregor, 1984, Pesant et al., 1987, Mostaghimi et al., 1988b, Kimmel et al., 2001, Seta et al., 1993, Mostaghimi et al., 1988a). Kimmel et al. (2001) reported a significant reduction in runoff from NT (0.1 x 10^5 L/ha) compared to RT (0.4 x 10^5 L/ha) and ChT (0.5 x 10^5 L/ha) for soybean-1999. RT was not significantly different from NT. Mostaghimi et al. (1988a) found that runoff and sediment loss decreased with increasing residue levels for both CN and NT, and that runoff from CN plots were around 12 times greater then NT plots.

The reduction in runoff from NT is generally attributed to greater infiltration rates due to less surface sealing and improved soil structure (Mostaghimi et al., 1988a, Seta et al., 1993). Pesant et al. (1987) attributed the reduced runoff and soil loss from NT due to the mulching effect of the residue.

Sediment loss

Although NT reduced soil loss by 54% averaged across soybean and sorghum 1998 and 1999, the only significant tillage main effect on soil loss was for soybean 1999. No till reduced soil loss by 82% from 97 Kg/ha in CN to 17 Kg/ha (Kimmel et al., 2001). Sharpley and Smith (1994) reported NT reducing sediment losses by 92% compared to CN. Mostaghimi et al. (1988a) concluded that the larger sediment loss from CN was due to larger runoff volumes and higher sediment concentrations. Zhao et al. (2001)

found that MP had 2 times the soil loss than RT. Since there was no difference in water loss, soil loss was due to increased sediment concentrations. MacIsaac et al. (1987) and Gaynor and Findlay (1995) found no significant differences in soil loss between CN and CT.

The overall decrease in soil loss for conversion to NT is 79%(+/-21) (Table 11). The decrease for the natural rainfall studies was 78%(+/-20) and 80%(+/-25) for the simulated rainfall studies. The reduced runoff from NT is generally attributed for the observed reduction in soil loss. Mostaghimi et al. (1988a) found that the greater sediment loss from CN was due to greater runoff volume and sediment concentrations than NT. Seta et al. (1993) attributed the reduction in sediment loss for NT to residue cover left on the soil. The residue protects the soil from the impact of raindrops. Zhao et al. (2001) attributed higher sediment concentrations in MP to lack of residue cover and increased soil disturbance.

Soluble Phosphorus

Andraski et al. (1995) reported soluble P losses of dissolved molybdate-reactive P (DMRP) for CT were similar to, or significantly lower than CN. I calculated a 38% reduction for NT compared to CN from the data they presented. This value is probably a slight overestimation since similar calculations resulted in a 86% reduction for TP losses when the authors reported a 81% reduction. Mostaghimi et al. (1988a) reported NT reducing soluble P losses by 91% despite having higher soluble P concentrations than CN. CN had higher losses probably because of higher runoff volume compared to NT. Seta et al. (1993) found that phosphate reduction was significant for NT treatment but not for chisel plow. Chichester and Richardson (1992) reported similar soluble P loss from NT and CN watersheds while Mostaghimi et al. (1988b) reported no significant effect of tillage system on ortho-phosphate losses. McIsaac et al. (1987) reported significantly greater soluble P loss for NT compared to CN. RT increased soluble P loss by 288% for manure (significant) and 46% (not significant) for urea (Zhao et al., 2001). Sharpley and Smith (1994) reported that conversion to NT wheat resulted in a decrease in sediment and particulate P but resulted in an average increase of 183% (308% and 58% increase for watershed E and W, respectively) compared to CN. Kimmel et al. (2001) reported 164% and 107% increase in soluble P loss for RT and NT, respectively, compared to chisel till for soybean 1998 (only RT was significantly greater from CN).

There is a large range in the effect of NT on soluble P loss from a 98% reduction to an approximately 1000% increase compared to CN soluble P losses (Table 12). The overall average increase in soluble P losses is 240%(+/- 385) with natural and simulation studies both increasing soluble P losses by 177%(+/-238) and 280%(+/-483), respectively.

Table 11. Percent soil loss reduction from conservation tillage treatments compared to conventional tillage. Asterisk "*" denotes CN tillage to which CT treatments are compared to and expressed as % reduced (positive) or increased (negative). Numbers in brackets are standard deviations. Range represents maximum and minimum soil loss values. Normal numbers are CN and bold numbers are CT. Tillage treatments are explained in Table 9. When more than one factor is included in date, crop or fertilizer column, then values presented are an average of treatments, i.e. Kimmel et al., 2001 NT soil loss reduction of 54% is an average of 12 treatments; 2 years X 2crops X 3 fertilizer methods.

Rain source	Sampling date	Crop	Fertilizer spreading method	MP	CN	till plant	ChP	ChT	Disk	RT	red. till	NT	Range (Kg/ha)	Reference
Natural	1998 17 June- 26 Aug. 1999 11 June- 5 Sept.	Soybean sorghum	Control, broad., knife					*		25 (33)		54 (25)	602-**299**	Kimmel et al., 2001
Natural	1984-1989 all runoff events, six watersheds three NT, three CN	Wheat, corn, sorghum rotation	side dress		*							90	1575-**160**	Chichester and Richardson, 1992
Natural	Jan. 1988- Sept. 1990. Both surface and subsurface	Corn	Subsurface	*	*					41		57	899-**391**	Gaynor and Findlay, 1995
Natural	1973-1975 growing season	Corn	Broadcast		*	62				89			31500-**3500**	Johnson et al., 1979
Natural	1975-1977 all rainstorm runoff	Corn grain and silage	Subsoil	*							93	96	20800-**765**	McDowell and McGregor, 1984
Natural	1974, 1975, 1976 May to Sept.	Corn	Broadcast	*								92	16800-**1300**	Pesant et al., 1987
Snowmelt runoff	Jan.-April 8, 1996 Feb.-March 27, 1997	Corn-soybean rotation	None	*			-250			-88			**280**-80	Hansen et al., 2000
Simulation	1event in April with 4 replicates	Corn	broadcast	*						52 (11)			728-**343**	Zhao et al., 2001
Simulation	1 event 3 replicates	Sorghum, wheat, corn	broadcast						*			74 (12)	14000-**1100** 1660-**580****	Eghball and Gilley, 2001
Simulation	N/R	Corn	Broadcast					*				40		McIsaac et al., 1987
Simulation	one event in spring	Rye residue	Broadcast		*							98	1442-**30*****	Mostaghimi et al., 1988a
Simulation	one event in spring	Rye residue	control, sub, broadcast		*							92	5034-**394**	Mostaghimi et al., 1988b
Simulation	one event but time of year is not given	Corn planting simulation	Broadcast		*		79					98	15500-**300**	Seta et al., 1993

* indicates conventional tillage to which CT is compared to.
** High and low range for range for 12 treatments, 4 fertilizer sources and 3 crops.
*** Average of three rye residues 0, 750, and 1500 Kg/ha for each tillage treatment.

Table 12. Soluble phosphorus reduction from conservation tillage treatments compared to conventional tillage. See Table 11 for details.

Rain source	sampling date	Fertilizer spreading method	MP	CN	till plant	ChP	ChT	Disk	RT	Red. till	NT	Range (Kg/ha)	reference
Natural	1998 17 June-26 Aug. 1999 11 June-5 Sept.	control, broadcast, knife					*		-478 (800)		-454 (792)	**0.349**-0.013 0.0023-**0.0001****	Kimmel et al., 2001
Natural	1984-1989 all runoff events, 6 watersheds 3 NT and 3 CN	side dress		*							-15	**0.76**-0.66	Chichester and Richardson, 1992
Natural	Jan.-Sept. 1990	subsurface	*	*					-137		-103	**2.53**-1.07	Gaynor and Findlay, 1995
Natural	1973-1975 growing season	broadcast		*	-111				-156			**0.23**-0.09	Johnson et al., 1979
Natural	1975-1977 all rainstorm runoff	subsoil	*							-150	-400	**1.0**-0.2	McDowell and McGregor, 1984
Natural	1974, 1975, 1976 May to Sept.	broadcast	*								85	0.27-**0.04**	Pesant et al., 1987
Snowmelt	1996 Jan.-April 8 1997 Feb.-March 27	none	*			-176			-266			**1.06**-0.29	Hansen et al., 2000
Simulation	1event in April, 1997	Broadcast Av. Manure and urea	*						-167 (171)			**0.4329**-0.0547	Zhao et al., 2001
Simulation	6 events over 4 yrs.	subsurface banding		*		60			15		38	2.13-**0.86** mg/m2	Andraski et al., 1985
Simulation	1 event	Broadcast (manure, compost chemical, control)						*			-1101 (1605)	**1.033**- 0.049 **0.369**- 0.126 **0.056**- 0.031	Eghball and Gilley, 2001
Simulation	two events each year 1982-1987	Broadcast (chemical)	*								-900	**0.09**-0.009	McIsaac et al., 1995
Simulation	one event but time of year is not given	surface applied (chemical)					*				-260		McIsaac et al., 1987
Simulation	one sim in spring	Broadcast (chemical)		*							95	0.506-**0.027**	Mostaghimi et al., 1988a
Simulation	one sim in spring	av. Broadcast, subsurface, none		*							28 (40)	0.243-**0.239** 0.115-**0.030^**	Mostaghimi et al., 1988b
Simulation	one sim event but time of year is not given	broadcast		*		43					56	0.7-**0.31**	Seta et al., 1993

Table 12 continued

Simulation	one sim event but time of year is not given	Broadcast		*	-80	-100		-100	-250		-200	**0.35**-0.1	Barisas et al., 1978

* indicates conventional tillage to which CT is compared to.

** highest loading (-2208%) 0.349-0.013, lowest loading(95%) 0.0023-0.0001

*** 1.033- 0.049 average for chemical, 0.369- 0.126 average for manure/compost, and 0.056- 0.031 average for control

^ High range broadcast 0.243-0.239, low range control 0.115-0.030

The increase in soluble P losses for NT is generally attributed to unincorporated phosphorus in fertilizer and leaching from crop residues. Two studies investigated the effect of P losses under different fertilizer spreading methods in addition to tillage. There were no significant differences in soluble P losses between control (no fertilizer), knifed (subsoil) or broadcast (surface application) fertilizer placement treatments for chisel till plots in sorghum 1998 and 1999 (Kimmel et al., 2001)(Figure 2). However, broadcast P in NT and RT resulted in significantly greater soluble P loss than either knife or control treatments (no difference between knife and control). This indicates that P application method makes no difference in chisel till plots but has a significant impact on soluble P losses in both NT and RT treatments. In Mostaghimi et al. (1988b) subsurface applied fertilizer resulted in a 39% and 35% reduction in phosphate losses and a 55% and 45% reduction in TP losses compared to surface application for NT and CN, respectively. Soluble P losses for surface and subsurface applied fertilizer plots for NT were 0.239 and 0.147 Kg/ha, respectively. Soluble P losses for surface and subsurface applied fertilizer plots for CN were 0.243 and 0.158 Kg/ha, respectively. Baker and Laflen (1982) reported similar dissolved P concentrations for unfertilized plots and fallow plots injected with liquid fertilizer. Mueller et al. (1984) found similar concentrations and losses of dissolved P for CN and CT when fertilizer was banded. Gaynor and Findlay (1995) remarked that soluble P loss was smallest for tillage treatments that mixed the fertilizer with the soil. The reverse was true of sediment bound P indicating that mixing of the soil and fertilizer increased sediment loss.

Barisas et al. (1978) found a positive correlation with of both phosphate loss and flow weighted concentration with the percent residue cover. Andraski et al. (1985) found a positive correlation between soluble reactive phosphorus and residue cover for one of five sampling periods, but overall the unincorporated residue did not appear to be a major source of dissolved P. McDowell and McGregor (1984) found that dissolved P concentrations were significantly greater in NT compared to CN. The increase was attributed to leaching from crop residues. Eghball and Gilley (2001) suggest that controlling dissolved P loss would require a reduction in runoff and incorporation of the phosphorus in fertilizer into the soil.

Total Phosphorus

Barisas et al. (1978) reported that conservation tillage practices (RT and NT) reduced total phosphorus losses by controlling erosion, however, only phosphate and available P data were reported. Kimmel et al. (2001) reported a main tillage effect in 1999 for soybean. NT significantly reduced TP loss by 76% compared to CN. Kimmel et al. (2001) saw no tillage effect in sorghum 1998, 1999 and soybean 1998. The low slope of their site reduced the soil erosion potential and thus minimized the influence of tillage

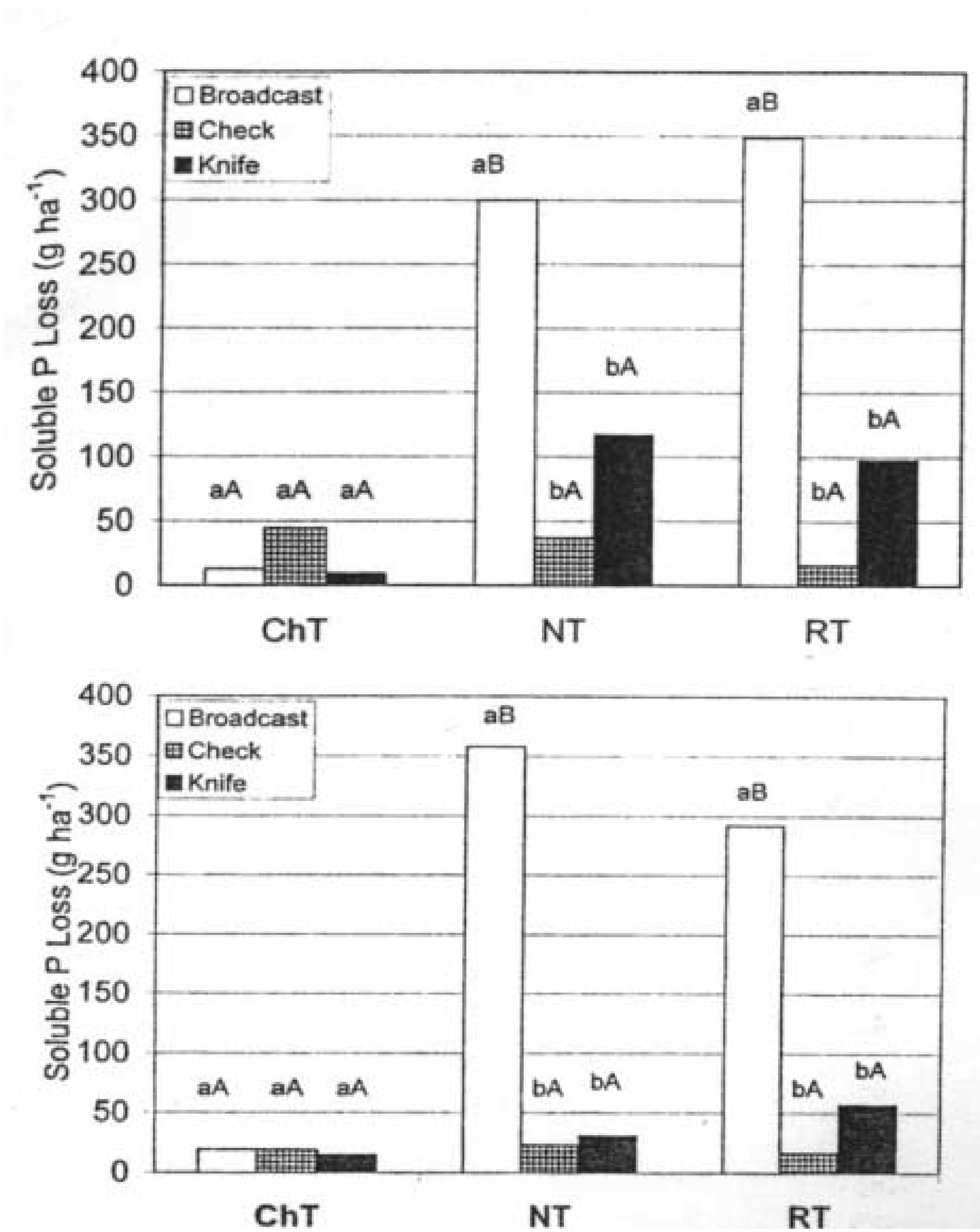

Figure 2. Effect of tillage and P placement on sorghum 1998 (top) and sorghum 1999 (bottom). Means with the same lower case letter within a tillage method are not significantly different at $P<0.1$. Means with the same upper case letter within a P application method are not significantly different at $P<0.1$. (Kimmel et al., 2001).

practices on sediment losses, and by association, TP losses. Zhao et al. (2001) found that RT significantly reduced TP loss by 55% compared to CN when urea was applied, however, RT significantly increased TP losses by 32% when manure was applied. The average for both fertilizer applications resulted in an overall 11% decrease in TP for the RT treatment (Table 13). McIsaac et al. (1987) recorded greater TP losses from NT compared to CN, but the differences were not significant probably because of the great variability of the two replicates. Sharpley and Smith (1994) found that NT reduced P loss by an average 70% compared to CN.

An average for all studies reveals a 46%(+/-60) reduction in TP loading for NT compared to CN (Table 13). No till in the natural rainfall and simulation studies reduced TP loss by 31%(+/-75) and 61%(+/-43), respectively. The study by Gaynor and Findlay (1995) had a large effect on the overall average of NT effectiveness in reducing TP loads. It is the only study that reported an increase in TP loading for NT (Table 13).

The peculiarity of the results in Gaynor and Findlay (1995) lies in the composition of the total phosphorus. Dissolved P accounted for 75 to 90% of the phosphorus transported from the three tillage treatments (MP, RT, and NT). Sediment bound P constituted 7-16% of the P loss. The major mechanism of loss of P for the three tillage methods was as soluble P from crop residue leaching. This is atypical for phosphorus runoff. Mostaghimi et al. (1988b) found that the sediment was the major source of P loss. Sediment bound P accounted for 56 and 87% of TP in NT and CN, respectively. NT reduced soil loss by 92% and TP by 91% compared to CN. Andraski et al (1985) and Barisas et al. (1978) reported that the sediment fraction was the major carrier of phosphorus for all tillage treatments. Andraski et al. (1985) concluded that CT reduced TP loss by controlling erosion. Barisas et al. (1978) reported that the loss of phosphate was small compared to P losses associated with the sediment. Gilliam et al. (1999) reports that around 75 – 90% of P transported in runoff in conventionally tilled land is associated with sediments and organic matter. Johnson et al. (1979) reports that 80-99% of the TP losses are associated with the sediment. Sediment bound P comprised 91% of TP for CN and 79% for NT in Pesant et al. (1987). McDowell and McGregor (1984) found more than 91% of the P losses from CN was sediment bound compared to 60% for NT.

Table 13. Total phosphorus reduction from conservation tillage treatments compared to conventional tillage. See Table 11 for details.

Rain source	N or sampling date	Fert spread	MP	CN	till plant	ChP	ChT	Disk	RT	red. till	NT	Range	reference
Natural	1998 17-June-26 Aug. 1999 11 June- 5 Sept.	Broadcast, knife, control					*		-14 (64)		20 (60)	0.664-**0.386**** 0.073-**0.0031**	Kimmel et al., 2001
Natural	1984-1989 all runoff events, six watersheds	side dress		*							47	1.5-**0.8**	Chichester and Richardson, 1992
Natural	Jan.-Sept. 1990	subsurface	*						-116		-92	**2.73**-1.27	Gaynor and Findlay, 1995
Natural	1973 growing season	broadcast		*	71				93			38.7-**2.8**	Johnson et al., 1979
Natural	1975-1977 all runoff	subsoil	*							85	84	15.6-**2.4**	McDowell and McGregor, 1984
Natural	1974, 1975, 1976 May to Sept.	broadcast	*								94	3.02-**0.19**	Pesant et al., 1987
Snowmelt runoff	Jan.-April 8, 1996 Feb.-March 27, 1997	none	*			-178			-227			**1.34**-0.41	Hansen et al., 2000
Simulation	1event on April 22-27, 1997 with 4 replicates	Broadcast (manure+urea)	*						11 (62)			0.572-**0.482**	Zhao et al., 2001
Simulation	1 event 3 replicates	broadcast (manure, compost, chemical, control)						*			39 (25)	2.716-**1.646**	Eghball and Gilley, 2001
Simulation	6 events over 4 years	subsurface banding		*		70			59		81	131.1-**18.1** mg/m2	Andraski et al., 1985
Simulation	one event but time of year is not given	surface applied (chemical)					*				-4		McIsaac et al., 1987
Simulation	one event in spring	Broadcast (chemical)		*							98	5.235-**0.097**	Mostaghimi et al., 1988a
Simulation	one event in spring	control, subsurface, broadcast		*							91 (3)	3.443-**0.322**	Mostaghimi et al., 1988b

* indicates conventional tillage to which CT is compared to.

** Highest loss from control treatment, lowest loss from Knife treatment. Knife is similar to no-till.

The typical composition and magnitude of TP losses with increasing residue cover is illustrated in figure 3 from Barisas et al. (1978).

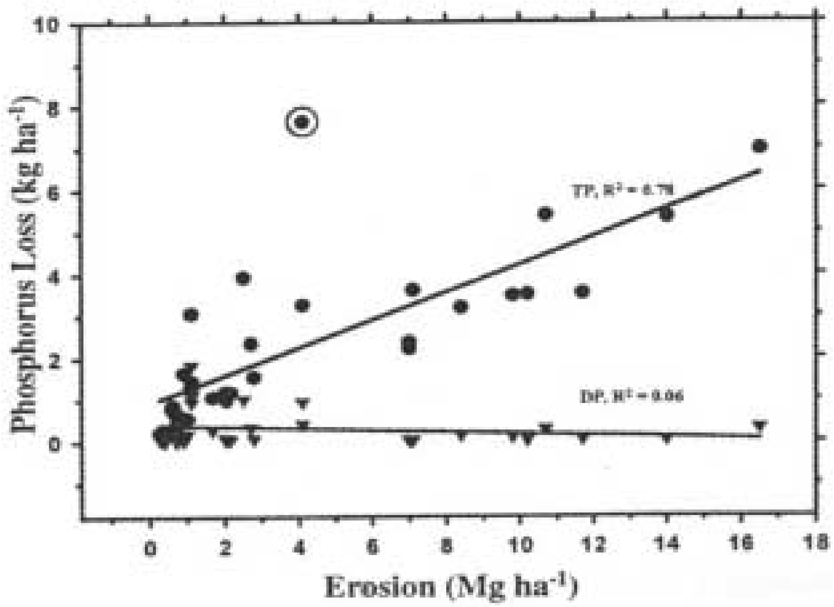

Figure 4. Total phosphorous (circles) and dissolved phosphorous (triangles) losses in runoff as related to soil erosion in rainfall simulation runoff studies. The circled value was not used in the regression analysis for TP (TP R^2= 0.78, DP R^2 = 0.06). (Eghball and Gilley, 2001).

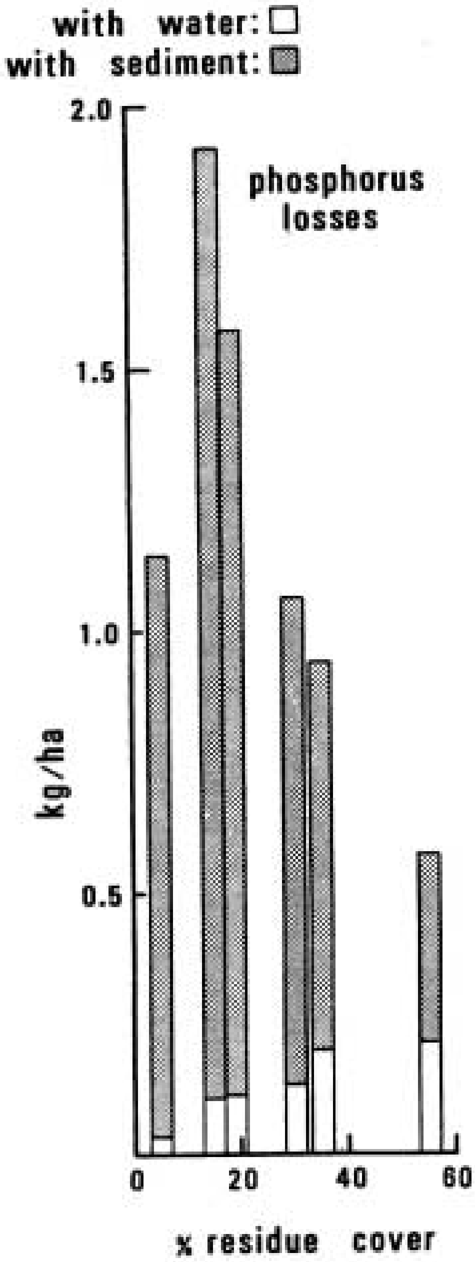

Figure 3. Effect of residue cover on total nutrient losses with sediment and water (phosphorous losses with sediment are as available P). (Barisas et al., 1978).

From left to right, the bars represent conventional till, till plant, chisel, disk, ridge till and coulter (coulter treatment is similar to no till). It can be seen that the soluble P fraction of the TP increases with increasing crop residue, however, the magnitude of the TP loss decreases with increasing crop residue. Barisas et al. (1978) concluded that conservation tillage methods were ineffective at reducing the loss of water soluble P, but were able to reduce TP loss by controlling erosion. Eghball and Gilley (2001) found a significant relationship between total and particulate losses (Figure 4). Dissolved P loss was mostly influenced by tillage method (disked and NT), runoff amount and P source (manure and compost). Sharpley (1995) also found a significant correlation between TP loss and soil erosion.

It appears that sediment bound P is the dominant fraction of TP for both CN and NT and that the reduction in TP seen in NT is mediated by the reduced soil erosion for NT compared to CN. When Gaynor and Findlay (1995) is removed from table TP, no-till reduced TP losses by 61% for all studies, natural and simulation studies (range of standard deviation +/- 34 - 42). A conservative 50% reduction in TP loss for NT compared to CN will be used in calculating P load reduction for conservation tillage. The previous P loading report estimates that each hectare of cropland contributes 1 Kg of phosphorus per year. No-till decreases the P load per hectare by 50% or 0.5 Kg per hectare.

P controlled by no-till = 0.5 Kg * hectares

8. BUFFER STRIPS

Buffer strips (BS) are areas of planted or naturally occurring vegetation that filter nutrients and sediments from agricultural runoff, commonly used to trap these contaminants before reaching surface waters. There have been numerous studies demonstrating the effectiveness of buffers of different types (i.e. grass versus vegetated) and widths, some of which are summarized in Table 14. Many factors can influence buffer performance such as the slope and soil type of the source area, whether the area has been tilled or not, and the intensity of rainfall events causing runoff. Areas of slope >12% are expected to exhibit high velocity concentrated flow (Agriculture Canada, 1995). Buffer strips are not very effective in trapping sediments and nutrients in situations of concentrated flow and therefore are most effectively used where the source area has a moderate slope that produces runoff in the form of sheet flow (Lee et al., 2000).

Research has concluded that buffer width is the most important factor influencing the amount of TP removed from runoff (Barfield et al., 1998; Lee et al., 2000; Dillaha et al., 1989; Magette et al., 1989; Schmitt et al., 1999; Nielsen and Hansen, 1993). Statistical analysis by Schmitt et al. (1999) showed that width had a significant effect on reducing concentrations for both grass and vegetated buffer strips. By increasing buffer width, infiltration capacity is also increased which reduces runoff and sediment transport (Barfield et al., 1989). Also, wider buffers are able to retain more small sediment particles (such as clay) since these particles tend to be carried further with runoff than larger ones (Lee et al., 2000). The ability of a buffer to decrease sediment transport, particularly of small particles, greatly affects the amount of TP that a buffer retains from the runoff because most of the TP eroded from croplands is bound to sediment. For example, Schmitt et al., (1999) found that 87% of TP in runoff is associated with the sediment phase and smaller particles, such as clay, have more bound phosphorous than larger ones (Magette et al., 1989). The % TP trapped increased 21% when a 7.1m buffer was widened to 16.3m in Lee et al. (2000). Percent TP trapped values (averaged from source areas of three different slopes) were 69% for a 4.6m buffer and 82% for a 9.1m buffer in Dillaha et al. (1989). Uusi-Kämppä et al. (2000). Summarized buffer research previously only available in Nordic languages showing that % TP trapped increased with buffer width.

Although buffer strips are effective in trapping sediment (and it's associated phosphorous) and TP from runoff, they generally are not as efficient in trapping dissolved phosphorous (DP). This has implications when deciding buffer width to filter tilled versus no-tilled land since the latter is expected to have a greater portion of phosphorous in the dissolved (soluble) form. Eghball et al. (2000) found that although buffers removed a similar amount of TP from no-till source plots and disked source plots (40% and 38% respectively), 47% of DP was removed from the no-till plots while only 21% DP was removed from the disked plots. These data reflect the fact that runoff from the disked land had more sediment-bound phosphorous than runoff from land that was not tilled, which in turn has a greater portion of DP. Lee et al. (2000) found that more intense rainfall created runoff with more small sized particles, such as clay. Their results showed that a wider buffer (16.3 m) consisting of switchgrass and woody plants trapped more of these clay particles (and the bound phosphorous) and DP than the thinner (7.1m) switchgrass only buffers. Schmitt et al. (1999) reported that DP and TP retention by buffer strips is consistent with the degree that phosphorous was originally partitioned in the runoff.

Some researchers found that DP values were sometimes higher in the outflow than in the runoff entering the buffer strip (i.e. Magette et al., 1989). It is suggested that phosphorous previously trapped is released from the buffer in these cases, making the BS a source of phosphorous (Barfield et al., 1989, Dillaha, 1989; Magette et al., 1989). Also, DP may increase with plant residue is left in the buffer (Uusi-Kämppä et al., 2000). Studies have noted that this problem can be partially alleviated by increasing buffer width, removing plant residue from the buffer, and harvesting or cutting the buffer vegetation (Uusi-Kämppä et al., 2000).

Comparisons of the effectiveness of vegetated buffers composed of grass, shrubs, and woody plants versus buffers consisting of grass alone have been done with conflicting results. For example, Lee et al. (2000) concluded that vegetated buffers containing larger, woody plants trapped 21% more TP than grass buffers due to the greater infiltration capacity provided by deep-rooted woody plants. In contrast, Schmitt et al. (1999) found that the vegetated buffer didn't perform much better than the grass buffer. It should be noted that phosphorous is incorporated by vegetation during the growing season and since trees and shrubs (woody vegetation) represent a greater total biomass than grass they would likely have a higher uptake of phosphorous (Uusi-Kämppä et al., 2000). Whether a buffer is vegetated or grass, studies agree that well developed (beyond their second growing season) buffers perform better and capture more TP due to their increased infiltration capacity and ability to retain sediment in situations of heavy erosion (large sedimentation) (Uusi-Kämppä et al., 2000; Schmitt et al., 1999).

When considering the values presented here one should keep in mind that in the literature, results of BS effectiveness in trapping TP are highly variable due to the numerous influential factors (i.e. runoff sediment characteristics, type of buffer, till situation, soil type) and the potential of buffers to act as a phosphorous source. Also, since the ratio of TP to DP in runoff will change depending on the amount of fine sediment particles in the runoff (depending on the soil type and tillage situation) the amount of TP trapped in the buffer will reflect the forms of phosphorous in the original runoff.

From the data presented in Table 14, average % TP retention values were created for three categories of buffer widths. Buffers of width 5m or less trap an average of 56% TP. Buffers between 6 and 10m trap an average of 67% TP, and buffers of 11m or greater widths trap an average of 74%. In view of the data, these values appear to be quite conservative. The previous Clean Water Program report estimated P loading from cropland at 1 Kg/ha/yr. It is recommended that buffer type and width be chosen depending on the slope, tillage situation, and soil type of the cropland where well developed buffers wider than 6m will likely prove to be highly effective in removing sediment, TP, and DP from runoff in most cases.

P controlled per year by buffer strip = 0.67 kg x hectares cropland buffered

PHOSPHOROUS ALGORITHM SUMMARY

The following tables provides a summary of the current and proposed new phosphorus loading algorithms used in the Rural Water Quality Program.

Table 15. Current phosphorus loading algorithms used in the Rural Water Quality Program.

Best Management Practice	Calculation Kg of P per year controlled
Milkhouse	# of cows x 1.26 kg/year
Manure Storage Facility	# of animals x animal phosphorus factor x days x 0.04
Clean Water Diversion	# of animals x animal phosphorus factor x days x 0.02
Livestock Access	# of animals x animal x phosphorus factor x days x 0.02
Septic systems	# systems x 15.33 Kg/system/yr (direct) #systems x 0.6 Kg/system/yr (indirect)
Conservation Cropping	0.75 kg x hectares
Cover Cropping	0.4 kg x hectares
Buffer Strip	0.7 kg x hectares
Fragile Land Retirement	0.7 kg x hectares
Nutrient Management	25 kg x hectares x 0.1

Table 16. Summary of the proposed new updated phosphorus loading algorithms presented in this report.

Best Management Practice	Calculation Kg of P per year controlled
Milkhouse	# of cows x 0.69 kg/year (excluding manure) # of cows x 2.76 kg/year (including manure)
Manure Storage Facility	# of animals x days x phosphorus excreted x 0.30 (feedlot manure) # of animals x days x phosphorus excreted x 0.07 (dairy pile manure)
Clean Water Diversion	# of animals x days x phosphorus excreted x phosphorous leached x (reduced feedlot runoff vol. / original feedlot runoff vol.) (phosphorous leached =0.30 for feedlot and 0.07 for dairy manure stockpile)
Livestock Access	# of animals x days x phosphorus excreted x 0.03 (multiply by 0.5 for animals with half day access to watercourse)
Septic systems	P savings = P loading (failed) – P loading (functional) Where P loading = 0.6 Kg TP ca^{-1} $year^{-1}$ * (#persons) * (1-A)
Conservation Cropping	0.50 kg/ha x hectares (no-till)
Cover Cropping	0.4 kg x hectares (not updated)
Buffer Strip	0.67 kg x hectares (for a 6-10 m buffer)
Fragile Land Retirement	0.7 kg x hectares (not updated)
Nutrient Management	25 kg x hectares x 0.1 (not updated)

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APPENDIX A

Milkhouse Washwater Treatment Efficiencies

Table 1. Reduction of Milkhouse washwater Phosphorus content using various treatments. VFS = vegetated filter strip, CW = constructed wetland. Columns with " indicates same as above. Phosphorus reduction expressed on a concentration and mass loading basis.

Location	Farm	Treatment	P form	Input (mg/L)	Output (mg/L)	% P reduction	Inflow g $m^{-2}d^{-1}$	outflow g $m^{-2}d^{-1}$	% P retention	References
Southwestern Quebec	1	Flocculator	TP	89.9	4.5	95				Malcolm et al., 1998
Southwestern Quebec	2	Flocculator	TP	84.4	0.5	99.4				Malcolm et al., 1998
Central Nova Scotia		Flocculator	TP	48	2.3	94.7				Jamieson et al., 2000a
"	"	"	SRP	50.8	1	96.5				Jamieson et al., 2000a
Central Nova Scotia		VFS (lawn)	SRP	50.7	0.1	99.8				Jamieson et al., 2001
Pictou County, N.S.	Eng.	VFS (no liner)	TP			38.2				Jamieson et al., 2000b
"	"	"	SRP	19.1	0.07*	15.6, 99.6*				Jamieson et al., 2000b
Charlotte, Vt		VFS (polyethylene lined)	TP	81.5	11.4, 6.6*	86, 92*	0.126	0.003, 0.012*	89	Schwer and Clausen, 1989
"		"	SRP	54.6	10.0, 5.6*	81, 90*	0.092	0.002, 0.006*	92	Schwer and Clausen, 1989
Carbondale, Illinois		VFS (lawn)	SRP	18.4, 31.4*	15.5, 0.3*	15.8, 99*				Yang et al., 1980
Carbondale, Illinois		VFS	SRP	16.7	15.5, 0.3*	7.2, 98.2*				Paterson et al., 1980
New Zealand		Pasture	TP	390-540 (Kg/ha)	380 (Kg/ha)	90				Macgregor et al., 1982
Frederick Co., Maryland	Cell 1	Two settling basins, two parallel wetland cells and one VFS	TP	57	62	-8				Cronk and Shiromhammadi, 1994****
Frederick Co., Maryland	Cell 2	"	TP	42	14	66.6				Cronk and Shiromhammadi, 1994
Frederick Co., Maryland	Cell 2	Settling basin and wetland cell	TP	200	190	5				Cronk et al., 1994

Table continued on next page

Table 1. Continued

Frederick Co., Maryland	Cell 1	Two settling basins, two parallel wetland cells and one VFS	TP	66		67			60	Cronk, 1995
"	Cell 2	"		36		44			47	Cronk, 1995
Frederick Co., Maryland	Cell 1	Two settling basins, two parallel wetland cells and one VFS	TP	70	30	57				Schaafsma et al., 2000****
"		"	SRP**	50	25	50				Schaafsma et al., 2000
Univ. of Connecticut		CW (polyethylene lined)	TP	25.7	14.1	45	0.188	0.06	68	Newman et al., 2000
Lagrange Co., Indiana	Cell1	CW (bentonite liner)	TP	56.1	24.4	56.5				Reaves et al., 1994
"	Cell 2	"	TP	74.7	22.5	69.9				Reaves et al., 1994
"	Cell 3	"	TP	62.2	22.6	63.7				Reaves et al., 1994
"	Cell1	"	SRP	116.1	33.3	71.3				Reaves et al., 1994
"	Cell 2	"	SRP	160.8	37.2	76.9				Reaves et al., 1994
"	Cell 3	"	SRP	137.2	35.2	74.3				Reaves et al., 1994
Oregon State Univ.		CW	TP	14.5	4.95	65.9				Skarda et al., 1994
"		"	SRP	4.86	1.78	63.4				Skarda et al.,1994
New South Wales	wetland 1	CW (synthetic liner)	TP	59.3	48.9	17.5	1.5		27.7	Geary and Moore, 1999
Wayne Co., Ohio	Cannon	CW		49.2	15	69.5				Zimmerman et al., 1994
"	Kauffman	CW		18.3	1.25	93.2				Zimmerman et al., 1994
Wayne Co., Ohio	Cannon	CW		42.48	21.11	50.3				Zimmerman, 1998
"	Kauffman	CW		48.5	0.44	99.0				Zimmerman, 1998
Wayne County Ohio	Kauffman	Pond		114.6	48.5	57.7				Zimmerman, 1998
Wisconsin		CW (3 cells in series)	TP	16.9	2.8	83.0				Holmes et al., 1995
Pictou Co., N.S.	Eureka	CW	TP	28.4	6.4	77.5				Rochon et al., 1999
"	"	"	SRP	27.3	5.65	79.3				Rochon et al., 1999
New Zealand		CW(butyl rubber)	TP				0.8	0.48	37	Tanner et al., 1995
"		"	TP				0.44	0.24	45	Tanner et al., 1995

Table continued on next page

Table 1 continued

"		"	TP				0.29	0.09	67	Tanner et al., 1995
"		"	TP				0.18	0.05	74	Tanner et al., 1995
New Zealand		CW(butyl rubber)	TP				1.22	0.94	19	Tanner et al., 1998
"		"	TP				0.86	0.7	15	Tanner et al., 1998
"		"	TP				0.57	0.39	39	Tanner et al., 1998
"		"	TP				0.43	0.26	35	Tanner et al., 1998
"		"	TP				0.26	0.15	38	Tanner et al., 1998
Erath Co., Texas	A	Anaerobic lagoon (2)	TP	85	39	54.1				Sweeten and Wolfe, 1994
"	B	Anaerobic lagoon (2)		54	55	-1.9				Sweeten and Wolfe, 1994
"	J	Anaerobic lagoon (2)		38	3	91.0				Sweeten and Wolfe, 1994
New Zealand		Anaerobic tank and aerobic trickling	TP	35.2	23.8	32.4				Warburton et al., 1981
Palmerston North , NZ		Facultative pond	TP	25.3	23.9	5.5				Mason, 1996
"		"	SRP	16.8	12.7	24.4				Mason, 1996
Ithaca, New York	Hatfield	Facultative pond	TP	123-146	16	87-89				Bland et al., 1980
"	Wright	Facultative pond	TP	81-95	9	89-91				Bland et al., 1980
"	Dow	Facultative pond	TP	39-49	7	82-86				Bland et al., 1980
Louisiana State Univ.		Water hyacinth	TP	39	26.1	33.1				Chen et al., 1995
"		Duckweed	TP	39	21.9	43.8				Chen et al., 1995
Pennsylvania		Aerobic lagoon	TP			30***				Krider, 1980
New York		Aerobic lagoon	TP			33***				Krider, 1980
Connecticut		Aerobic lagoon	TP			42***				Krider, 1980
Vermont		Aerobic lagoon	TP			47***				Krider, 1980

* Subsurface, all other values are for surface flow.

** Ortho-phosphate was a large percent of TP and exceeded TP at the VFS effluent when concentrations are very low. This may be because samples for the ortho-phosphate analysis were frozen and homogenized before analysis but samples for TP analysis were stored liquid; particulate phosphorous may have settled out before analysis.

*** Percent reduction is a comparison between inflow to lagoon and lagoon standing concentration, not lagoon outflow.

**** For all J.K. Cronk studies and Schaafsma et al., 2000, the % P reduction refers to the wetland cell referred to in farm name and not the efficiency of the whole system, i.e. settling basin, CW, and VFS.

APPENDIX B.

Excerpt from ASAE (2001)

Table 1 – Fresh manure production and characteristics per 1 000 kg live animal mass per day

Parameter	Units*		Animal Type[1]										
			Dairy	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
Total manure[4]	kg	mean[3]	86	58	62	84	40	41	51	64	85	47	110
		std. deviation	17	17	24	24	11	8.6	7.2	19	13	13	**
Urine	kg	mean	26	18	**	39	15	**	10	**	**	**	**
		std. deviation	4.3	4.2	**	4.8	3.6	**	0.74	**	**	**	**
Density	kg/m^3	mean	990	1 000	1 000	990	1 000	1 000	1 000	970	1 000	1 000	**
		std. deviation	63	75	**	24	64	**	93	39	**	**	**
Total solids	kg	mean	12	8.5	5.2	11	11	13	15	16	22	12	31
		std. deviation	2.7	2.6	2.1	6.3	3.5	1.0	4.4	4.3	1.4	3.4	15
Volatile solids	kg	mean	10	7.2	2.3	8.5	9.2	**	10	12	17	9.1	19
		std. deviation	0.79	0.57	**	0.66	0.31	**	3.7	0.84	1.2	1.3	**
Biochemical oxygen demand, 5-day	kg	mean	1.6	1.6	1.7	3.1	1.2	**	1.7	3.3	**	2.1	4.5
		std. deviation	0.48	0.75	**	0.72	0.47	**	0.23	0.91	**	0.46	**
Chemical oxygen demand	kg	mean	11	7.8	5.3	8.4	11	**	**	11	16	9.3	27
		std. deviation	2.4	2.7	**	3.7	2.5	**	**	2.7	1.8	1.2	**
pH		mean	7.0	7.0	8.1	7.5	**	**	7.2	6.9	**	**	**
		std. deviation	0.45	0.34	**	0.57	**	**	**	0.56	**	**	**
Total Kjeldahl nitrogen[1]	kg	mean	0.45	0.34	0.27	0.52	0.42	0.45	0.30	0.84	1.1	0.62	1.5
		std. deviation	0.096	0.073	0.045	0.21	0.11	0.12	0.063	0.22	0.24	0.13	0.54
Ammonia nitrogen	kg	mean	0.079	0.086	0.12	0.29	**	**	**	0.21	**	0.080	**
		std. deviation	0.083	0.052	0.016	0.10	**	**	**	0.18	**	0.018	**
Total phosphorus	kg	mean	0.094	0.092	0.066	0.18	0.087	0.11	0.071	0.30	0.30	0.23	0.54
		std. deviation	0.024	0.027	0.011	0.10	0.030	0.016	0.026	0.081	0.053	0.093	0.21
Orthophosphorus	kg	mean	0.061	0.030	**	0.12	0.032	**	0.019	0.092	**	**	0.25
		std. deviation	0.005 8	**	**	**	0.014	**	0.007 1	0.016	**	**	**
Potassium	kg	mean	0.29	0.21	0.28	0.29	0.32	0.31	0.25	0.30	0.40	0.24	0.71
		std. deviation	0.094	0.061	0.10	0.16	0.11	0.14	0.091	0.072	0.064	0.080	0.34
Calcium	kg	mean	0.16	0.14	0.059	0.33	0.28	**	0.29	1.3	0.41	0.63	**
		std. deviation	0.059	0.11	0.049	0.18	0.15	**	0.11	0.57	**	0.34	**
Magnesium	kg	mean	0.071	0.049	0.033	0.070	0.072	**	0.057	0.14	0.15	0.073	**
		std. deviation	0.016	0.015	0.023	0.035	0.047	**	0.016	0.042	**	0.007 1	**
Sulfur	kg	mean	0.051	0.045	**	0.076	0.055	**	0.044	0.14	0.085	**	**
		std. deviation	0.010	0.005 2	**	0.040	0.043	**	0.022	0.066	**	**	**
Sodium	kg	mean	0.052	0.030	0.086	0.067	0.078	**	0.036	0.10	0.15	0.066	**
		std. deviation	0.026	0.023	0.063	0.052	0.027	**	**	0.051	**	0.012	**
Chloride	kg	mean	0.13	**	**	0.26	0.089	**	**	0.56	**	**	**
		std. deviation	0.039	**	**	0.052	**	**	**	0.44	**	**	**
Iron	g	mean	12	7.8	0.33	16	8.1	**	16	60	**	75	**
		std. deviation	6.6	5.9	**	9.7	3.2	**	8.1	49	**	28	**
Manganese	g	mean	1.9	1.2	**	1.9	1.4	**	2.8	6.1	**	2.4	**
		std. deviation	0.75	0.51	**	0.74	1.5	**	2.1	2.2	**	0.33	**

Table 1 – Fresh manure production and characteristics per 1 000 kg live animal mass per day (continued)

Parameter	Units*		Animal Type†										
			Diary	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
Boron	g	mean	0.71	0.88	**	3.1	0.61	**	1.2	1.8	**	**	**
		std. deviation	0.35	0.064	**	0.95	0.30	**	0.48	1.7	**	**	**
Molybdenum	g	mean	0.074	0.042	**	0.028	0.25	**	0.083	0.30	**	**	**
		std. deviation	0.012	**	**	0.030	0.38	**	0.033	0.057	**	**	**
Zinc	g	mean	1.8	1.1	13	5.0	1.8	**	2.2	19	3.6	15	**
		std. deviation	0.65	0.43	**	2.5	1.0	**	2.1	33	**	12	**
Copper	g	mean	0.45	0.31	0.048	1.2	0.22	**	0.53	0.83	0.98	0.71	**
		std. deviation	0.14	0.12	**	0.84	0.066	**	0.39	0.84	**	0.10	**
Cadmium	g	mean	0.003 0	**	**	0.027	0.007 2	**	0.005 1	0.038	**	**	**
		std. deviation	**	**	**	0.028	**	**	**	0.032	**	**	**
Nickel	g	mean	0.28	**	**	**	**	**	0.62	0.25	**	**	**
		std. deviation	**	**	**	**	**	**	**	**	**	**	**
Lead	g	mean	**	**	**	0.084	0.084	**	**	0.74	**	**	**
		std. deviation	**	**	**	0.012	**	**	**	**	**	**	**
Total coliform bacteria	colonies#	mean	1 100	63	**	45	20	**	490	110	**	**	**
		std. deviation	2 800	59	**	33	26	**	490	100	**	**	**
Fecal coliform bacteria	colonies	mean	16	28	**	18	45	**	0.092	7.5	**	1.4	180
		std. deviation	28	27	**	12	27	**	0.029	2.0	**	**	180
Fecal streptococcus bacteria	colonies	mean	92	31	**	530	62	**	58	16	**	**	590
		std. deviation	140	45	**	290	73	**	59	7.2	**	**	**

*All values wet basis.

†Differences within species according to usage exist, but sufficient fresh manure data to list these differences was not found. Typical live animal masses for which manure values represent are: dairy, 640 kg; beef, 360 kg; veal, 91 kg; swine, 61 kg; sheep, 27 kg; goat, 64 kg; horse, 450 kg; layer, 1.8 kg; broiler, 0.9 kg; turkey, 6.8 kg; and duck, 1.4 kg.

‡Feces and urine as voided.

§Parameter means within each animal species are comprised of varying populations of data. Maximum numbers of data points for each species are: diary, 85; beef, 50; veal, 5; swine, 58; sheep, 39; goat, 3; horse, 31; layer, 74; broiler, 14; turkey, 18; and duck, 6.

‖All nutrients and metals values are given in elemental form.

#Mean bacteria colonies per 1 000 kg animal mass multiplied by 10^{10}. Colonies per 1 000 kg animal mass divided by kg total manure per 1 000 kg animal mass multiplied by density kg/m^3 equals colonies per m^3 of manure.

**Data not found.