Chapter 7
Manure Spills and Remediation Methods to Improve Water Quality

Shalamar D. Armstrong, Douglas R. Smith, Phillip R. Owens, Brad Joern, and Candiss Williams

Abstract Within the last 2 decades the transition in livestock production technology and intensity has resulted in an increase in annual livestock production and a drastic decrease in the number of livestock operations. Consequently, the susceptibility of current livestock operations to experience manure spills is far greater relative to livestock farms 20 years ago, due to increased herd size per farm. Therefore, manure spills in agricultural communities have become a pervasive issue and have led to the catastrophic contributions of nutrients and pathogens to surface and groundwaters, human health issues, and large fish kills. Furthermore, the current remediation methods for manure spills that reach surface waters focus on mitigating contaminants in the water column and give no attention to the manure-exposed ditch sediments that remain in the fluvial system and continue to impair the water column. Therefore, this chapter addresses the causes, environmental impacts, and current and alternative remediation methods for manure spills in agricultural streams. Geographic data suggest that the location of animal-feeding operations and the occurrence of manure spills were highly correlated with the location of tile-drained agriculture fields. In addition, at least 14% of reported manure spills were separately attributed to the failure in waste storage equipment and over-application of manure in the states of Iowa and Ontario, Canada. Evaluations of the downstream impacts of manure spills have reported ammonia, total phosphorus, and total N concentrations that were at least 28 times the average upstream concentrations before the spill occurred. Studies have also determined that the current manure spill remediation method results in soluble phosphorus and nitrogen concentrations significantly greater than the Environmental Protection Agency total phosphorus nutrient critical limit, 24 h after

S.D. Armstrong (✉), P.R. Owens, B. Joern, and C. Williams
Agronomy Department, Purdue University, 915 West State St., West Lafayette, IN 47907-2054, USA
e-mail: sarmstro@purdue.edu

S.D. Armstrong and D.R. Smith
USDA-ARS, National Soil Erosion Research Laboratory, 275 South Russell St., West Lafayette, IN 47907, USA

E. Lichtfouse (ed.), *Genetic Engineering, Biofertilisation, Soil Quality and Organic Farming,* Sustainable Agriculture Reviews 4,
DOI 10.1007/978-90-481-8741-6_7, © Springer Science+Business Media B.V. 2010

the plume of the spill has passed. However, supplemental treatment of manure exposed sediments resulted in at least a 50% decrease in the soluble phosphorus concentrations which was in compliance with the phosphorus nutrient criteria.

Keywords Manure spills • manure spill remediation methods • alum • ammonium • phosphorus • sediments

7.1 Introduction

Surface and groundwater degradation from agricultural losses of nitrogen and phosphorus are global environmental issues. Throughout the world, the consequence of nitrogen and phosphorus losses from agricultural fields to enriched waterways is realized in hypoxia zones such as the Gulf of Mexico (Alexander et al. 2008), the Black Sea (Tolmazin 1985), and the Baltic Sea (Rabalais et al., 1999). Thus, the US Environmental Protecting Agency has identified agricultural drainage, both surface and subsurface, as the primary source of nutrient losses to freshwater systems in the USA (USEPA 1995). Environmental studies have also found that manure spills are a major source of nutrient loading to agriculture streams and that the use of livestock manure in agricultural practices has contributed to 15% of the nitrogen loading in the Mississippi River drainage basin that discharges into the Gulf of Mexico (Hoorman et al. 2005; Ribaudo et al. 2003). Therefore, this chapter focuses on the causes, impacts, and current and alternative remediation methods of manure spills.

In the USA, between the years 1982 and 1997, the number of livestock per feeding operation increased by 10%, while the number of feeding operations decreased by 50% (Gollehon et al. 2001; Fig. 7.1). Between the years 1980 and 1995, the number of swine farms in the Netherlands decreased by 32%, while swine production increased or remained constant (van der Peet-Schwering et al. 1999). Similarly, in France there was a 25% increase in swine production between the years 1985 and 1995 and the province of Brittany accounted for 55% of swine production within a land area that was only 6% of the total agricultural land of France (Dourmada et al. 1999). This trend is a reflection of the industrialization of livestock production that has increased production efficiency, the quantity of manure produced daily, and the pressure applied on the related manure-management systems (Fig. 7.1). Consequently, the occurrence of manure spills in agricultural communities and the degradation of surface and groundwater have become more prevalent and have led to the contribution of nutrient and pathogen loading to source, surface and groundwaters globally (Burkholder et al. 1997; Mallin 2000; Hoorman et al. 2005). Therefore, nitrogen and phosphorus contamination of surface and groundwaters have been heavily associated with intensive livestock production, whether gradually through feedlot runoff events and leaching of waste lagoons, or catastrophically through animal waste spills. For example, animal feeding operations have contributed to the impairment of 50% of the lakes and 20% of the rivers in the USA (USEPA 2003).

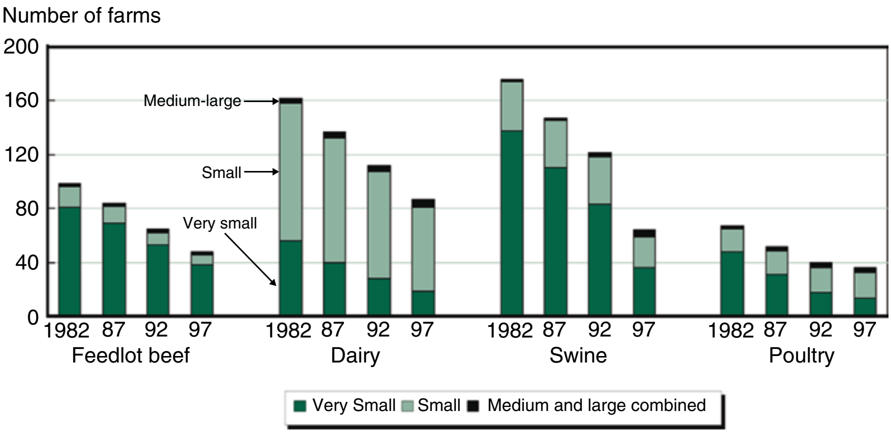

Fig. 7.1 The results of an assessment of confined animal farms by species and size within the years 1982–1997. The findings clearly illustrate the decline in very small and small livestock farms and the emergence of medium-to-large livestock operations (Gollehon et al. 2001)

Nitrogen and phosphorus losses from manure spills pose a significant threat to the health of humans and aquatic ecosystems. Manure spills have been found to result in nitrate contamination of groundwater and source water that leads to methemoglobinemia (Blue-baby syndrome) (Townsend et al. 2003). A survey of nutrient levels in the groundwater of the USA found that 9% of rural wells and 1% of community wells had concentrations of nitrate–N greater than the 10 mg L^{-1}, which is the maximum contaminant level for drinking water (Mueller et al. 1995). They also found that in areas near intensive livestock operations, wells were more likely to be contaminated above 10 mg L^{-1} nitrate–N. In addition, manure spills from livestock operations have led to contamination of surface water and source water by *Escherichia coli*, *Campylobacter*, and *Cryptosporidium* that resulted in widespread diarrhea, vomiting, fever, and even death (Guan and Holley 2003; Hoxie et al. 1997). Aquatic ecosystems that receive excessive loading of nitrogen and phosphorus could lead to eutrophic conditions, due to nitrogen and phosphorus being nutrient that contribute to eutrophication in freshwater ecosystems (Correll 1998), fish kills from toxic levels of NH_3 and NH_4 (Mallin 2000; De La Torre et al. 2004; Kater et al. 2006).

7.2 Causes of Manure Spills

In addition to the drastic increased herd size per farm, government and state regulations affect the susceptibility of animal-feeding operations to experience a manure spill. The most current regulation that affects confined animal-feeding operations manure-management systems is the ruling made by the Environmental Protection

Table 7.1 Chemical analysis of various animal wastes, suggesting that total phosphorus (TP) is most prominent in swine effluent (Hutchins et al. 2007). TN: total nitrogen

CAFO type	NH_4–N (mg L^{-1})	TN	TP
Beef feedlot (sl)	33	63	14
Dairy (pl)	84	185	30
Poultry (pl)	656	802	50
Poultry (sl)	289	407	23
Poultry (tl)	58	96	30
Swine sow (tl)	944	1,290	264
Swine finisher (tl)	1,630	2,430	324
Swine nursery (tl)	1,370	2,040	368

Secondary lagoon (sl), primary lagoon (pl), tertiary lagoon (tl)

Agency in 2003 (USEPA 2003). This regulation requires confined animal-feeding operations and large animal-feeding operations to develop and implement a nutrient-management plan in conjunction with applying for a National Pollution Discharge Elimination System permit. The permit specifies how manure is managed and disposed on each qualified livestock operation. However, the pressing issue is that permit holders' nutrient-management plans must comply with the agronomic nutrient requirement of the crops in the fields where manure is applied. Therefore, the volume of manure disposed is restricted to a rate that cannot exceed the nitrogen and phosphorus demand of the receiving agricultural field. For swine producers, phosphorus is the nutrient that results in the greatest limitations of manure application rate, since swine waste contains more phosphorus relative to the phosphorus demand of most crops (Table 7.1).

Contamination of surface water through manure violations often occurs on tile-drained fields where liquid manure is applied (Kinley et al. 2007). The function of tile drainage is to provide a pathway for excess water from poorly drained soils to be removed from agricultural fields. However, tile drainage has become a conduit for nutrients to surface waters when liquid manure is applied in excess (Kinley et al. 2007). This issue is most documented in the Midwestern USA and Canada where agricultural tile drainage is necessary for crop production (Fig. 7.2), and coincidentally, confined animal-feeding operations are prevalent. For example, in the southern portion of Ontario, Canada, over 70% of the agricultural fields are tile drained (Spaling and Smit 1995) and at least 20% of the total area is tile-drained cropland in Midwestern USA such as in Indiana, Ohio, Iowa, and Illinois (USDA 1987). Furthermore, studies have demonstrated that the application rate of manure is the driving factor of phosphorus and nitrogen loss after liquid manure is applied in the presence of tile drainage (Ball et al. 2007; Cook and Baker 2001). It has also been noted that fields that contain macropores and shallow water tables are more susceptible to manure violations after land application (Steenhuis et al. 1994; Stone and Wilson 2006). Macropores such as root channels, warm holes, and natural soil cracks allow liquid manure to bypass the soil matrix to be intercepted by the tile drain that facilitates transport to surface waters (Watson and Luxmoore 1986).

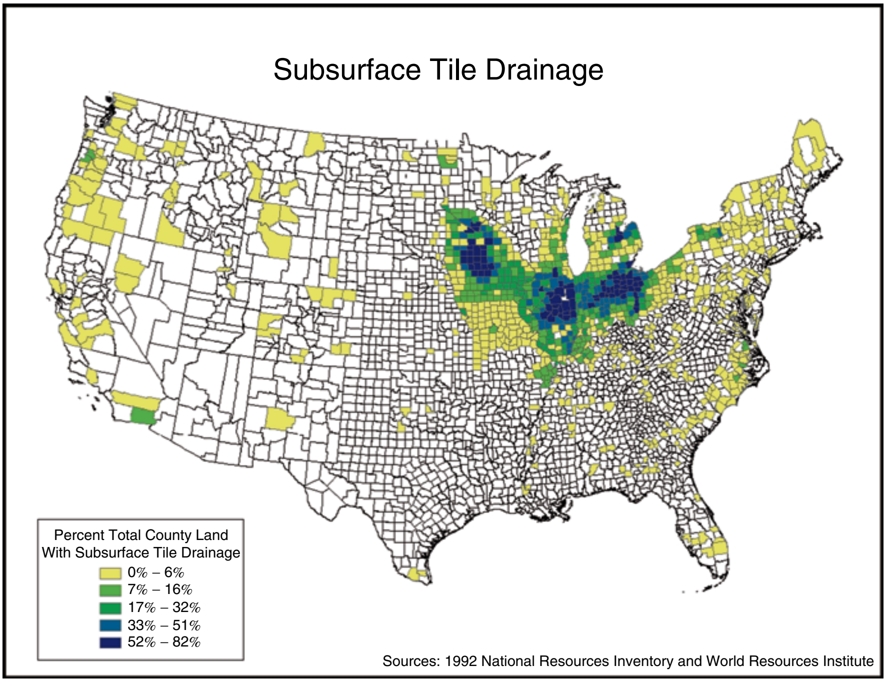

Fig. 7.2 The similarity in subsurface drainage density which is related to the density of swine density in the USA (Sugg 2007)

During a 1-year study Muller et al. (2003) monitored the concentrations of NO_3^-, NH_4^+, and pH in tile flow in an agricultural field. As a result of a manure application and preferential flow they observed a spike in the load of NH_4^+ (22.0 g NH_4–N), which resulted in a daily nitrogen load that was 65% greater than before the manure application.

Hoorman et al. (2005) investigated the factors that caused manure violations in the state of Ohio within a 4-year period. They found that between the years of 2000 and 2003 there were 98 manure spills reported. Heavy precipitation after land application of liquid waste accounted for 41 of the 98 manure violations, making it a primary cause of manure violations. The next contributing factor was manure storage mismanagement and equipment failure (e.g., ruptured pipes, holes, and failure of on-site manure transport equipment) that accounted for 33 of the 98 manure violations. According to Osterberg and Wallinga (2004), in Iowa, from 1992 to 2002, 304 manure spills were reported. Both manure storage overflow and equipment failure were responsible for 24% of the spills, runoff from animal feeding operations accounted for 18%, and over-application accounted for 14% (Fig. 7.3). In Southwest Ontario, Canada, 229 manure spills were reported between the years of 1988–1998. Spray irrigation application accounted for 40%, insufficient storage accounted for 16%, and equipment failure was the cause of 14% of the manure spills (Fig .7.3, Merkel 2004).

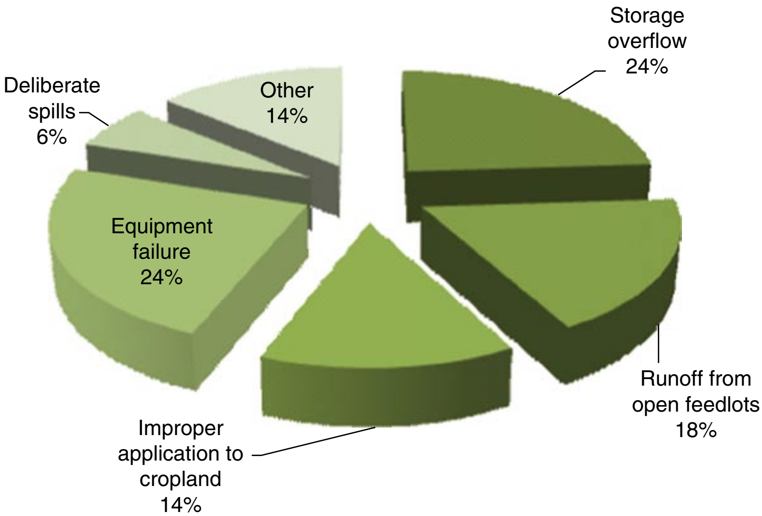

Fig. 7.3 The causes of major manure spill in Iowa, leading swine producing state, between the years 1992 and 2002 (Osterburg and Wallinga 2004)

In February 2008, a manure spill in Quebec, Canada resulted in the release of over 26,400 l of liquid cattle manure that drained into a nearby creek and contaminated a neighboring domestic well. This spill was caused by a broken valve on a pipe that was used to transport manure to a manure storage tank (Johnston 2008). Similarly in February of 2008, a 6 in. pipe on a cattle farm in Walkersville, MD resulted in approximately 21.8 million liters of manure to be pumped into Glade Creek and the contamination of the town's water supply, leaving citizens to boil their drinking water or purchase bottled water for 2 weeks. Bacteria counts in surface water and groundwater were 57 and 20 *E. coli* per 100 ml, and both were significantly higher than the drinking water standard of one bacteria colony forming units per 100 ml (Hauck 2008).

7.3 The Impact of Manure Spills

Unintentional manure spills in the past have impacted both aquatic ecological systems and human health (Novak et al. 2000; Mallin and Cahoon 2003; Mead 2004). Manure spills are large contributors of nutrients and pathogens, which are two of the top three water impairments in the USA, according the Environmental Protection Agency (USEPA 2000). As mentioned previously, the excess of nutrients and pathogens leads to elevated biochemical oxygen demand (BOD), fish kills, and accelerated eutrophication (USDA 1997; Frey et al. 2000) and manure spills can lead to catastrophic loading of these water contaminants. According to Indiana department of environmental management (1995), agricultural feedlots are one of the possible sources

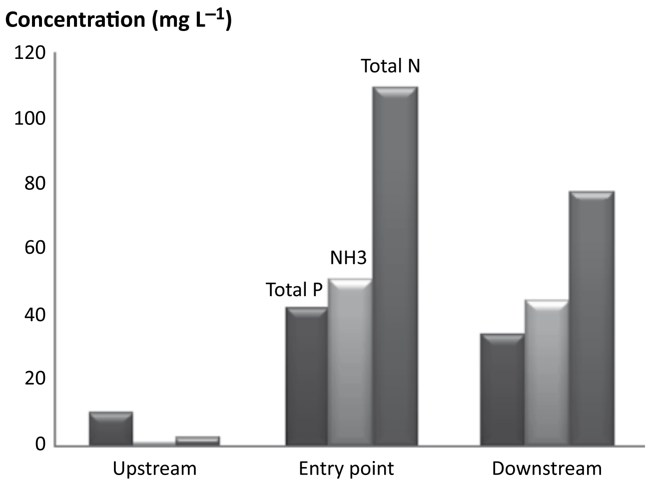

Fig. 7.4 Average concentration of total N, P, and ammonia from upstream, entry point, and downstream sampling location of 97 manure spills (Hoorman et al. 2005)

of *E. coli* contamination, which has been identified as being responsible for over 80% of 6,451 river miles in Indiana being declared unsafe for swimming or human contact. Hoorman et al. (2005) collected upstream, entry point, and downstream water samples during investigations of 97 manure spills (Fig. 7.4). The results of this study suggested that the downstream impacts of manure spills are catastrophic. The average downstream ammonia, total phosphorus, and total nitrogen concentrations after a manure spill were 49, 28, and 68 times greater than the average upstream concentrations, respectively (Fig. 7.4). Contamination of water with bacteria, such as *E. coli* and salmonella, are commonly associated with manure spills and when ingested, bodily illnesses such as hemorrhagic colitis, hemolytic uremic syndrome, and thrombotic thrombocytopaenic purpura may occur (Thu 2002). In addition, nitrate losses from manure spills pose a significant threat to the health of humans through the contamination of groundwater and drinking water (Townsend et al. 2003).

Nitrogen from a manure spill has an immediate impact on fish and benthic organisms through ammonia toxicity. Manure spills contribute excessive concentrations of nitrogen, and cations such as Ca^{2+} and Mg^{2+} that increase pH creating optimum conditions for ammonia toxicity (Poxton 2003). Studies have demonstrated that ammonia toxicity in fish and benthic organisms occur under alkaline conditions where the acid base reaction between OH^- and NH_4^+ produces toxic concentrations of NH_3 (Kater et al. 2006).

In addition, studies have indicated that at pH <8.3 both NH_4^+ and NH_3 contribute to toxicity (Scholten et al. 2005). Fish naturally excrete metabolic NH_3 concentrated waste from their blood through diffusion to the water column (Kater et al. 2006). However, this diffusion of waste will only occur when the concentration gradient of NH_3 is greater in the blood of the fish relative to the water column. Additionally, if the NH_3 concentration in water column becomes elevated enough, the concentration gradient could reverse, and NH_3 has the potential to be actively transported into the organism through an exchange with Na^+ on the gills of the fish (Kater et al. 2006). Therefore, after the occurrence of a catastrophic manure spill, the NH_3 excretion of fish is inhibited and toxic levels of NH_3 builds up within the fish, which ultimately leads to severe ammonia toxicity and high fish mortality.

Initial phosphorus loading from a manure spill and phosphorus desorption from manure-exposed sediments in streams and drainage ditches can lead to accelerated algal blooms and enhanced eutrophic conditions in receiving lakes, ponds, and reservoirs. Lakes and ponds receiving elevated phosphorus additions from manure spills could result in explosive algal blooms and the growth of other aquatic plants that eventually cover the water surface. After the death of the algae and aquatic plants, decomposition occurs through microorganisms that consume large fractions of dissolved oxygen (Scholten et al. 2005). This oxygen depletion ultimately leads to reduced oxygen supply for fish and benthic organisms, reduced growth of benthic organism, and fish kills. Moreover, carbon loading in fluvial systems can also result in oxygen depletion due to increased microbial activity and high oxygen consumption by microorganisms.

7.4 Current Manure Spill Remediation Methods

Currently, the recommended emergency response actions for manure spills that contaminate a drainage ditch or streams are (i) to contain and isolate the contaminated area using earthen or temporary dams, (ii) de-water the contained area using pumping equipment, and (iii) redistribute the recovered waste into an alternative storage system or to land-apply the waste in compliance with state regulations (IDEM 2002). However, the major inadequacy of the conventional spill remediation plan is the lack of attention given to the phosphorus-enriched ditch sediments that have been exposed to manure and remain in the fluvial system. Studies have demonstrated that phosphorus and nitrogen desorption from untreated contaminated sediments continue to impair the water column for weeks, after the spill has occurred.

For example, Burkholder et al. (1997) evaluated the impacts of a manure spill from a farm in Onslow, North Carolina, that released 97.5 million liters of swine manure into the surrounding drainage ditches. This spill resulted from heavy precipitation from a hurricane and faulty farm-operator management of manure storage. They found that the average total phosphorus concentration 2 days after the spill was 100 times greater than the total phosphorus average of 0.047 mg P $L^{-1}$from the previous 10 months (Table 7.2). Furthermore, with continual sampling of the water column at 5, 14, and 61 days after the spill they observed that total phosphorus concentrations were 7.6, 2.1, and 5.5 times greater than the previous 10-month average, respectively (Burkholder et al. 1997). A possible explanation for elevated total phosphorus concentrations days and weeks after the manure spill had occurred could be that sediment phosphorus concentrations exist in equilibrium with the

Table 7.2 The ability of sediments to act as a phosphorus source for up to 61 days after a manure spill has occurred due to sediment phosphorus desorption (Burkholder et al. 1997)

Time	Phosphorus concentration (mg P L^{-1})
Ten months before spill	0.047
Two days after spill	4.79
Five days after spill	0.36
Fourteen days after spill	0.106
Sixty-one days after spill	0.29

phosphorus concentration of the overlying water column within a fluvial system. Therefore, these elevated phosphorus concentrations observed days and weeks after the contamination plume had passed clearly indicate that the sediments became significant sources of phosphorus thereby releasing phosphorus into the water column. In other words, the sediments that contained elevated concentrations of phosphorus, release phosphorus to the subsequent flow with low phosphorus concentrations to maintain equilibrium with the water column.

Burkholder et al. (1997) also found that the density of fecal coliform bacteria at 5, 14, and 61 (7.0×10^2, 71.9×10^4, and 1.2×10^3 colony-forming units) days after the spill was greater than the state standard of 200 colony-forming units/100 ml. Therefore, this could be evidence that fecal coliform bacteria is surviving for days after the spill and is being redistributed back into the water column.

7.5 Alternative Sediment Amendments

Environmental and waste management scientists have provided vital findings that demonstrated the efficacy of aluminum sulfate (alum) as a treatment to reduce phosphorus availability in manure storage, after land application of manure, in ponds and wetlands, and in phosphorus-enriched sediments that have been contaminated by waste water treatment plants (Ann et al. 1999; Dao et al. 2001; Steinman et al. 2004; Choi and Moore 2008). There are two proposed mechanism in which alum reduces the availability of phosphorus in manure, soil solution, and sediment pore water. The first is shown in equation 7.1 where aluminum disassociates from SO_4^- in solution and forms a coprecipitate with PO_4^- (Moore and Miller 1994).

$$Al_2(SO_4)_3 \,.\, 14H_2O + 2H_3PO_4 \rightarrow 2AlPO_4 + 6H^+ + 3SO_4^{2-} + 14H_2O \qquad (7.1)$$

The second proposed mechanism involves the formation of amorphous aluminum oxide that adsorbs soluble phosphorus from solution (Peak et al. 2002; Hunger et al. 2004).

$$Al(OH)_3 + H_2PO_4 \rightarrow Al(OH)_3 - H_2PO_4 \qquad (7.2)$$

Moreover, as time after phosphorus adsorption to amorphous aluminum oxide increases the formation of minerals such as varisite ($AlPO_4 \cdot 2H_2O$) and wavellite [$Al_3(PO_4)_2(OH)_3 \cdot 5H_2O$)] may form and persist under acidic conditions.

Sims and Luka-McCafferty (2002) conducted a large-scale on-farm poultry litter study where alum was amended to poultry litter in 97 poultry houses for a 16-month period. They found that alum amendment at a rate 1.0 kg alum m^{-2} $flock^{-1}$ (approximately 0.09 kg alum per bird) decreased the dissolved phosphorus content in manure by 67%. Similar studies have also demonstrated that the addition of alum to poultry litter resulted in a reduction of phosphorus loss via runoff by as much as 52–87% using the following application rates 1:5 ratio of alum to poultry litter (Shreve et al. 1995); applications of 5%, 10%, 15% alum to poultry litter on a weight basis (Delaune et al. 2004); and 10% alum application by weight to poultry litter (Smith et al. 2004). Smith et al. (2005) investigated the effect of alum application on the phosphorus concentration and adsorption properties of sediments from tile-fed drainage ditches in an agricultural watershed in northeast Indiana. They determined that applying alum reduced the extractable phosphorus in sediments by 50–90% and the portioning index by 50% (Fig. 7.5). Haggard et al. (2004) evaluated the use of alum as a chemical amendment to sediments from streams that received a daily influx of phosphorus from a municipal waste water treatment plant's effluent discharge. Results from their study demonstrated that applying alum with $CaCO_3$ to phosphorus-enriched sediments resulted in a significant reduction in sediment labile phosphorus, equilibrium phosphorus concentrations, and a significantly increased in the phosphorus-buffering capacity of the sediments. The sediment equilibrium concentration is the concentration at which the net phosphorus adsorption and desorption of fluvial sediment is zero

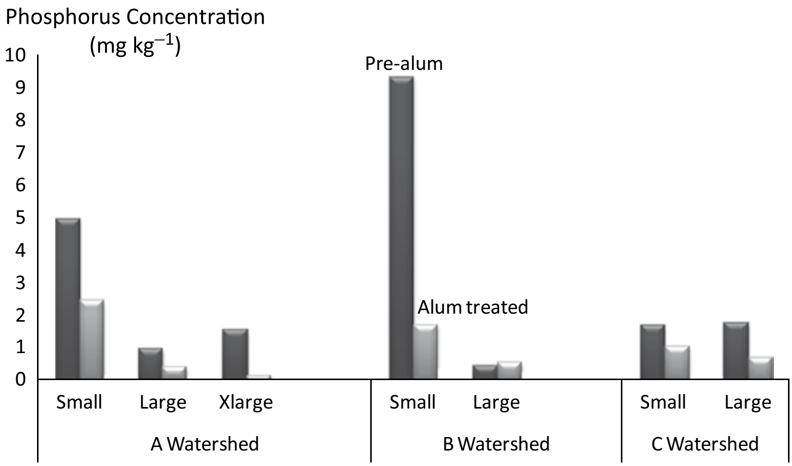

Fig. 7.5 The effect of alum application on the soluble phosphorus concentration of sediments collected from three watersheds within the St. Joseph River Watershed in North East Indiana (Smith et al. 2005)

(Taylor and Kunishi 1971) and the buffering capacity is a measure of the sediments ability to adsorb phosphorus per unit increase in phosphorus water concentration.

The efficacy of the current and an alternative manure spill remediation, where alum was used to reduce soluble phosphorus desorption from sediment following a manure spill were evaluated through a series of manure spills using fluvarium techniques. The manure spills were simulated for 24 h within a stream simulator using sandy and clayey stream bed sediments. The current manure spill remediation method was simulated by draining the contaminated water column, and uncontaminated water was circulated over alum treated and untreated sediments to simulate subsequent flow after the spill has occurred. Results from this study demonstrate that the current manure spill remediation method removes phosphorus from the contaminated water column, but does not adequately remediate manure exposed sediments that remain in the water column. Thus, sediments that received only the current manure spill remediation treatment desorbed soluble phosphorus in the water column to a maximum of 0.22 mg P L^{-1} which was significantly greater than the Environmental Protection Agency nutrient criteria for soluble phosphorus in that region. Furthermore, results suggested that a surface application of alum to clay and sandy sediments following a manure spill decreased phosphorus released from manure-exposed sediments by over 70% and mitigated the soluble phosphorus concentration in the water column below the Environmental Protection Agency nutrient criteria for phosphorus (Author's unpublished data).

Although the effectiveness of alum to reduce the availability of soluble phosphorus in sediments is well-known, the impact of alum on benthic organism is death. Steiman and Ogdahl (2008) studied the ecological effect of using alum as an amendment to reduce the phosphorus concentrations in Spring Lake, Michigan. The alum treatment was applied in 2006; data from an ecological assessment were collected eight months later, and were compared to a control (pretreatment) set of ecological data from the same lake recorded in 2003. In a laboratory experiment they found that the phosphorus flux from untreated sediments in 2003 was 43 times greater relative to sediments collected in 2006 after being treated with alum and that alum treatment reduced the mean pore water phosphorus and significantly reduced the extractable phosphorus. Additionally, they determined that the population of benthic invertebrates declined following alum applications, while Narf (1990) observed an increase in invertebrate density. Smeltzer et al. 1999 observed a decline in sediment invertebrate density 1 year after alum treatment, a recovery to the pretreated levels within 2 years, and a significant increase above pretreatment levels 10 years after the alum treatment.

7.6 Conclusion

Increased livestock production efficiency due to the emergence of new technology and confined animal-feeding operations has severely impacted the surface and source water of agricultural communities. Furthermore, it has been observed that greater herd sizes per livestock operation have led to enormous volumes of waste produced daily and excessive pressure on waste-management systems to maintain waste storage capacity. As a result, in Ohio, 41% of manure spills that occurred during a 3-year period were attributed to lagoon breaches and excessive precipitation. In Iowa, 48% of manure spills within a 10-year period were attributed to manure storage equipment failure and lagoon breaches, and in Ontario, Canada 40% of manure spills that occurred within a 10-year period were due to over-application of animal waste through spray irrigation.

Data have also suggested that the current remediation plan for manure spills is efficient in removing the nutrient contamination in the water column following a manure spill, but was not effective in remediating the sediment of the fluvial system. Due to astronomical loading of phosphorus and nitrogen during a manure spill benthic sediments initially act as sinks and are saturated. However, when subsequent flow enters the fluvial system after the plume of the spill has passed, the sediment acts as a phosphorus source to water column due to greater phosphorus and nitrogen in the sediment relative to the water column. Studies of the manure spills have demonstrated that the water column total phosphorus 3 months after the passing of the manure spill plume was five times greater than the 10-month average total phosphorus of the water column. Therefore, supplemental treatment is needed to remediate the entire fluvial system following a manure spill. The uses of alum on a small plot and watershed scale to reduce the vulnerability of soluble phosphorus have been effective in reducing phosphorus in runoff by as much as 50%. Moreover, data from a manure spill simulation experiment determined that with a molar application of alum the phosphorus desorption following a manure spill was reduced by at least 50%. Results from the studies in this chapter have raised the awareness of the impact associated with manure spills in agricultural streams and have presented novel, practical, and affordable solutions that can be used to remediate surface and source water following manure spills.

References

Alexander RB, Smith R, Schwartz G, Boyer E, Nolan J, Brakebill J (2008) Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi river basin. Environ Sci Technol 42:822–830

Ann Y, Reddy KR, Delfino JJ (1999) Influence of chemical amendments on phosphorus immobilization in soils from a constructed wetland. Ecol Eng 14:157–167

Ball Coelho B, Roy RC, Topp E, Lapen DR (2007) Tile water quality following liquid swine manure application into standing corn. J Environ Qual 36:580–587

Burkholder JM, Mallin MA, Glasgow HB, Larsen LM, McIver MR, Shank GC, Deamer-Melia N, Briley DS, Springer J, Touchette BW, Hannon EK (1997) Impacts to a coastal river and estuary from rupture of a large swine waste holding lagoon. J Environ Qual 26:1451–1466

Choi IH, Moore PA Jr (2008) Effects of liquid aluminum chloride additions to poultry litter on broiler performance, ammonia emissions, soluble phosphorus, total volatile fatty acids, and nitrogen contents of litter. Poult Sci 87:1955–1963

Cook MJ, Baker JL (2001) Bacteria and nutrient transport to tile lines shortly after application of large volumes of liquid swine manure. Trans ASAE 44:495–503

Correll DL (1998) The role of phosphorus in the eutrophication of receiving waters: a review. J Environ Qual 2:261–266

De La Torre A, Dminguez L, Gonzalez M, Aguayo S, Carballo M, Munoz MJ (2004) Impact from a cattle waste lagoon rupture on a downstream fish farm: a case study. Ecol Austr 14:135–139

DeLaune PB, Moore PA Jr, Carman DK, Shareply AN, Haggard BE, Daniel TC (2004) Development of a phosphorus index for pastures fertilized with poultry litter – factors affecting phosphorus runoff. J Environ Qual 33:2183–2191

Dao TH, Sikora LJ, Hamasaki A, Chaney RL (2001) Manure phosphorus extractability as affected by aluminum-and iron by-products and aerobic composting. J Environ Qual 30:1693–1698

Dourmada JY, Guingand N, Latimier P, Se`ve B (1999) Nitrogen and phosphorus consumption, utilisation and losses in pig production: France. Livest Prod Sci 58:199–211

Frey M, Hopper R, Fredregill A (2000) Spills and kills: manure pollution and America's livestock feedlots. Clean water network. Izaak walton league of America, and natural resources defense council

Guan TY, Holley RA (2003) Pathogen survival in swine manure environments and transmission of human enteric illness – a review. J Environ Qual 32:383–392

Gollehon N, Caswell M, Ribaudo M, Kellogg R, Lander C, Letson D (2001) Confined animal production and manure nutrients. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agriculture Information Bulletin No. 771

Haggard BE, Ekka SA, Matlock MD, Chaubey I (2004) Phosphate equilibrium between stream sediments and water: potential effect of chemical amendments. Am Soc Agric Eng 47:1113–1118

Hauck J (2008) Walkerville works to flush away *E. coli*-tainted water. http://gazette.net/stories/022108/walknew71843_32358.shtml

Hoorman JJ, Jonathan N Rausch, Martin J Shipitalo (2005) Ohio livestock manure violations. ASAE Meeting Presentation, Paper Number: 052060

Hoxie NJ, Davis JP, Vergeront JM, Nashold RD, Blair KA (1997) Cryptosporidiosis-associated mortality following a massive waterborne outbreak in Milwaukee, Wisconsin. Am J Public Health 87:2032–2035

Hunger S, Cho H, Sims JT, Sparks DL (2004) Direct speciation of phosphorus in alum-amended poultry litter: solid state 31P NMR investigation. Environ Sci Technol 38:674–681

Hutchins SR, White MV, Hudson FM, Fine DD (2007) Analysis of lagoon samples from different concentrated animal feeding operations for estrogens and estrogen conjugates. Environ Sci Technol 41:738–744

Indiana Department of Environmental Management (2002) Indiana confined feeding regulation program: guidance manual, p 22

Indiana Department of Environmental Management (1995) Office of Water Management, Indiana 305(b) Report, 1994–1995, p 9

Johnston D (2008) Drinking water near lachute contaminated by liquid manure from nearby farm. http://www.canada.com

Kater BJ, Dubbeldam K, Postma JF (2006) Ammonium toxicity at high pH in a marine bioassay using corophium colutator. Arch Environ Contam Toxicol 51:347–351

Kinley RD, Gordon RJ, Stratton GW, Patterson GT, Hoyle J (2007) Phosphorus losses through agricultural tile drainage in Nova Scotia. Can J Environ Qual 36:469–477

Mallin MA (2000) Impacts of industrial-scale swine and poultry production on rivers and estuaries. Am Sci 88:26–37

Mallin MA, Cahoon LB (2003) Industrialized animal production-a major source of nutrient and microbial pollution to aquatic ecosystems. Popul Eviron 24(5):369–385

Mead R (2004) Fish and invertebrate recolonization in a Missouri prairie stream after an acute pollution event. N Am J Fisher Manage 24:7–19

Merkel M (2004) Threatening Iowa's future: Iowa's failure to implement and enforce the clean water act for livestock operations. Washington, DC: Environmental Integrity Project; 2004:20. http://www.environmentalintegrity.org/pub194.cfm

Moore PA, Miller DM (1994) Decreasing phosphorus solubility in poultry litter with aluminum, calcium, and iron amendments. J Environ Qual 23:325–330
Mueller DK, Hamilton PA, Helsel DR, Hitt KJ, Ruddy BC (1995) Nutrients in ground water and surface water of the United States: an analysis of data through 1992. Water-Resour Invest Rep 95-4031. USGS, Reston, VA
Müller B, Reinhardt M, Gächter R (2003) High temporal resolution monitoring of inorganic nitrogen load in drainage waters. J Environ Monit 5:808–812
Narf RP (1990) Interactions of Chironomidae and Chaoboridae (Diptera) with aluminum sulfate treated lake sediments. Lake Reserv Manage 6:33–42
Novak JM, Watts DW, Hunt PG, Stone KC (2000) Phosphorus movement through a coastal plain soil after a decade of intensive swine manure application. J Environ Qual 29:1310–1315
Osterburg D, Wallinga D (2004) Addressing externalities from swine production to reduce public health and environmental impact. Am J Public Health 94:1703–1708
Peak D, Sims JT, Sparks DL (2002) Solid-state speciation of natural and alum-amended poultry litter using XANES spectroscopy. Environ Sci Technol 36:4253–4261
Poxton M (2003) Water quality. In: Lucus JS, Southgate PC (eds) Aquaculture: farming aquaculture animals and plants. Blackwell, Iowa, pp 47–73
Rabalais NN, Turner RE, Justic D, Dortch Q, Wiseman WJ (1999) Characterization of hypoxia: topic 1 report for the integrated assessment on hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Office, Silver Spring, MD. Decision Analysis Series no. 15
Ribaudo M, Gollehon N, Aillery M, Kaplan J, Johansson R, Agapoff J, Christensen L, Breneman V, Peters M (2003) Manure management for water quality: costs to animal feeding operations of applying manure nutrients to land. Agricultural Economic Report No. (AER824). Economic Research Service. US Department of Agriculture. Washington, DC
Scholten MCTh, Foekema EM, Van Dokkum HP, Kaag NHBM, Jak RG (2005) Eutrophication and the ecosystem. In: Eutrophication management and ecotoxicology. Springer, New York, pp 1–13
Shreve BR, Moore PA Jr, Daniel TC, Edwards DR (1995) Reduction of phosphorus in runoff from field applied poultry litter using chemical amendments. J Environ Qual 24:106–111
Sims JT, Luka-McCafferty NJ (2002) On-farm evaluation of aluminum sulfate (alum) as a poultry litter amendment: effects on litter properties. J Environ Qual 31:2066–2073
Smeltzer E, Kirn RA, Fiske S (1999) Long-term water quality and biological effects of alum treatment of Lake Morey, Vermont. Lake Reserv Manage 15:173–184
Smith DR, Haggard BE, Warnemuende EA, Huang C (2005) Sediment phosphorus dynamics for three tile fed drainage ditches in Northeast Indiana. Agric Water Manage 71:19–32
Smith DR, Moore PA Jr, Miles DM, Haggard BE, Daniel TC (2004) Decreasing phosphorus runoff losses from land-applied poultry litter with dietary modifications and alum addition. J Environ Qual 33:2210–2216
Spaling H, Smit H (1995) A conceptual model of cumulative environmental effects of agricultural drainage. Agric Ecosyst Environ 53:99–108
Steenhuis TS, Boll J, Shalit G, Selker JS, Merwin IA (1994) A simple equation to predict preferential flow solute concentration. J Environ Qual 23:1058–1064
Steinman AD, Ogdahl M (2008) Ecological effects after an alum treatment in Spring Lake. Mich J Environ Qual 37:22–29
Steinman AD, Rediske R, Reddy KR (2004) The reduction of internal phosphorus loading using alum in Spring Lake. Mich J Environ Qual 33:2040–2048
Stone WW, Wilson JT (2006) Preferential flow estimates to an agricultural tile drain with implications for glyphosate transport. J Environ Qual 32:1825–1835
Sugg Z (2007) Assessing U.S. farm drainage: can GIS lead to better estimates of subsurface drainage extent? World Resource Institute, Washington, D.C
Taylor AW, Kunishi HM (1971) Phosphate equilibria on stream sediment and soil in a watershed draining an agricultural region. J Agric Food Chem 19:827–831
Thu KM (2002) Public health concerns for neighbors of large-scale swine production operations. J Agric Safety Health 8:175–184

Tolmazin D (1985) Changing coastal oceanography of the black sea. 1: Northwestern shelf. Prog Oceanogr 15:217–276

Townsend A, Howarth RW, Bazzaz FA, Booth MS, Cleveland CC, Collinge SK, Dobson AP, Epstein PR, Holland EA, Keeney DR, Mallin MA, Rogers CA, Wayne P, Wolfe AH (2003) Human health effects of a changing global nitrogen cycle. Front Ecol Environ 1:240–246

USEPA (2003) National pollutant discharge elimination system permit regulation and effluent limitations guidelines and standards for concentrated animal feeding operations: final rule. Fed Regist 69:7175–7274, Feb

USEPA (2000) Water quality conditions in the United States: a profile from the 2000 national water quality inventory. http://www.epa.gov/305b/2000report/factsheet.pdf

USDA (1997) Agricultural waste management field handbook. Part 651, National Engineering Handbook. Published in 1992, with revisions through 1997. Washington, D.C.: USDA-NRCS. http://www.ftw.nrcs.usda.gov/awmfh.html

USEPA (1995) National water quality inventory. Report to Congress. U.S. Government Printing Office, Washington, D.C.

USDA (1987) Farm drainage in the United States: history, status, and prospects. In: Pavelis GA (ed) USDA-ARS Miscellaneous Publication Number 1455, Washington, DC

van der Peet-Schwering CMC, Jongbloed AW, Aarnink AJA (1999) Nitrogen and phosphorus consumption, utilisation and losses in pig production: The Netherlands. Livest Prod Sci 58:213–224

Watson KW, Luxmoore RJ (1986) Estimating macroporosity in a forest watershed by use of a tension infiltrometer. Soil Sci Soc Am J 50:578–582