

Animal Waste *and the* Land-Water Interface

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THE ROLE OF WETLANDS, PONDS, AND SHALLOW LAKES IN IMPROVING WATER QUALITY

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INTRODUCTION

Wetlands and shallow aquatic ecosystems (lakes and ponds) occur in almost all landscapes (Patten, 1990; Brinson, 1993; Whigham et al., 1993; Mitsch and Gosselink, 1993), and in many instances they have been shown to improve the quality of incoming water. Water quality improvement has been shown to occur at the landscape level where groups of aquatic and wetland ecosystems are hydrologically connected and at the level of individual systems. At the landscape level, one example of the influence that groups of wetlands and shallow aquatic ecosystems have on water quality comes from research on beaver (*Castor canadensis*). Naiman et al. (1994) have shown that beaver influence water quality over large areas of boreal landscapes and that the impacts are dynamic and long lasting. Beaver alter hydrologic patterns and create shallow impoundments and wetlands that provide conditions that are ideal for altering water quality, particularly through their influence on nitrogen and carbon dynamics (Cirmol and Driscoll, 1993). In some parts of the world (i.e., most countries in Central Europe), large portions of landscapes have been hydrologically modified to increase the number of shallow ponds, lakes, and associated wetlands for aquaculture and water quality management (Uhlmann and Recknagel, 1982; Kvet et al., 1990; Szumiec and Szumiec, 1993; Kub et al., 1994). At a smaller landscape scale, the quality of runoff from agricultural fields has been shown to improve when it passes through wetlands and shallow aquatic ecosystems before reaching streams and larger bodies of water (e.g., Karr and Schlosser, 1978; Schlosser and Karr, 1981; Peterjohn and Correll, 1984; Hill, 1991; Lowrance, 1992; Gilliam, 1994). Individually, wetland and shallow aquatic ecosystems have also been shown to improve water quality, and engineered systems have been used successfully to treat waste water (Godfrey et al., 1985; Carpenter et al., 1976; McNabb, 1976; Tourbier et al., 1976; Hammer, 1989).

It has been demonstrated that wetlands and shallow aquatic ecosystems can be used to treat animal wastes (e.g., Culley et al., 1990; Tanner et al., 1995a,b). The question is whether or not wetlands and shallow ponds and lakes can be used to treat animal wastes without degrading water quality in down-

stream aquatic and/or ground water systems. It has been shown, for example, that the addition of nutrients to shallow ponds and lakes can result in hypertrophic conditions, leading to severe degradation of water quality (Moss, 1988). Waste water inputs to natural wetlands have also been shown to result in undesirable changes such as the loss of biodiversity and deterioration of downstream water quality (Kadlec, 1983).

In this chapter the processes that control the movement of nitrogen (N) and phosphorus (P), two primary components of waste water, through wetlands and shallow aquatic ecosystems are discussed first, followed by a discussion of the potential limitations on the amounts of N and P that can be treated in wetlands and shallow aquatic ecosystems. The chapter concludes with the suggestion that, whenever possible, treatment of animal wastes should be effected in constructed wetland/pond systems and that natural ecosystems should be used only when they are associated with suitable constructed wetland/pond systems or under circumstances in which downstream water quality is not the subject of primary interest and/or where some form of aquaculture can be practiced.

NITROGEN AND PHOSPHORUS IN WETLANDS AND SHALLOW LAKES/PONDS

Considerable attention has been given to the issue of whether aquatic ecosystems, including wetlands and shallow lakes and ponds, are sources, sinks, or transformers of nutrients (Howard-Williams, 1985; Ryding and Rast, 1989; Mitsch and Gosselink, 1993). In most situations, it is not desirable to use shallow aquatic ecosystems to treat waste water unless the influent is pre-treated before it enters the pond/lake system (Ryding and Rast, 1989). In contrast, it has been shown that waste water can be effectively treated by many types of wetlands under a wide range of conditions (Godfrey et al., 1985). Richardson (1990) reviewed the literature on wetlands, and his conclusions are relevant today; those related to water quality are listed here.

1. Wetlands function as effective transformers of nitrogen (N) and phosphorus (P).
2. Wetlands maintain biogeochemical processes that are responsible for transforming and releasing significant quantities of dinitrogen.
3. Phosphorus is either adsorbed onto amorphous aluminum and iron in soil, stored in peat, or is taken up by microbes and plants in small quantities and recycled annually.
4. Wetland types differ in terms of the magnitude and form of N and P released to output waters.
5. N and P retention by wetlands varies among seasons, and each element has to be analyzed separately in terms of seasonal and annual retention patterns.

6. Wetlands can function as either sinks or sources for N and P, depending on wetland type, level of N and P loading into the wetland, the season of year, and whether or not the ecosystem is aggrading. Wetlands do not retain P as efficiently as terrestrial ecosystems.

While some of Richardson's (1990) conclusions are very specific, most are general statements that clearly suggest that it is necessary to consider each wetland separately before decisions are made about its ability to effectively treat waste water (e.g., animal wastes) that contain large amounts of nutrients, organic matter, and potentially harmful viruses and bacteria. There is little doubt, however, that almost every wetland transforms materials and at least changes the forms of N and P.

Most nitrogen enters wetlands and aquatic ecosystems through atmospheric or surface and sub-surface hydrologic inputs (Mitsch and Gosselink, 1993; Koerselman and Verhoeven, 1992), and the total loadings control whether the wetland will be nutrient poor (oligotrophic), nutrient rich (eutrophic), or intermediate (mesotrophic). Once nitrogen has entered a wetland, it can follow numerous pathways before it leaves in runoff or leaching, is returned to the atmosphere through denitrification or volatilization, or is stored in the wetland or transported from it in the form of biomass of plants and animals, or stored in litter and/or soil (Figure 1). Nitrogen cycling in ponds and shallow lakes follows the same pathways as shown in Figure 1 except that plankton and fila-

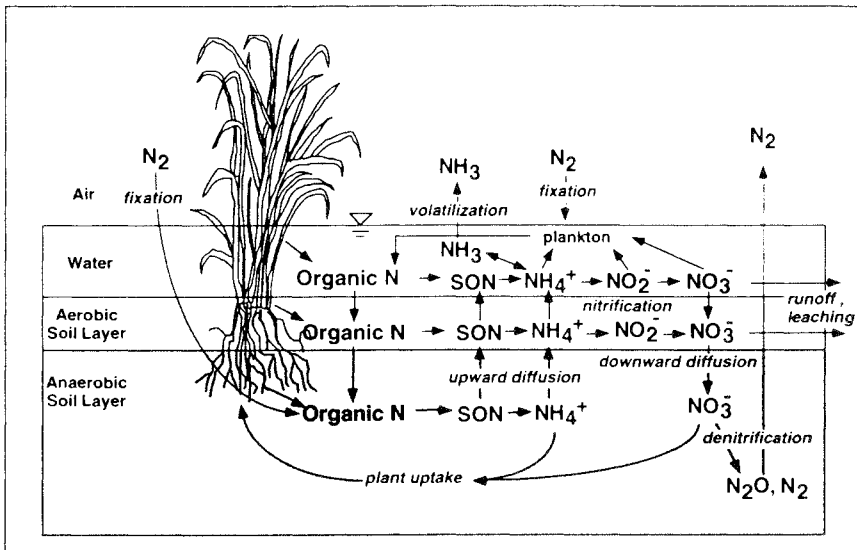


Figure 1. Nitrogen cycling in wetlands. SON = soluble organic nitrogen. (From Mitsch and Gosselink, 1993, with permission.)

mentous algae would be more important than macrophytes in nitrogen fixation and denitrification (Likens, 1975).

To be effective in treating animal wastes, wetlands and shallow aquatic ecosystems would have to provide long-term storage of more nitrogen than entered and/or have a high capacity to intercept nitrogen and return large amounts to the atmosphere as oxides of nitrogen. Wetlands that have high rates of denitrification have an oxidized surface soil-litter layer lying over a deeper layer of sediment that is anaerobic (Gambrell and Patrick, 1978), a continuous external (i.e., the addition of animal wastes) or internal (i.e. high ammonification rates) source of nitrate, and a source of carbon that is used as an energy source by microbes involved in transforming nitrogen.

Riparian forests are examples of wetland ecosystems that have a high capacity to remove nitrogen and return it to the atmosphere in various gaseous forms (e.g., Peterjohn and Correll, 1984; Gilliam, 1994). They occur at the boundary between terrestrial and aquatic ecosystems, they receive high inputs of nitrate from upslope agricultural fields, the soils often have an oxidized surficial layer and a deeper anaerobic zone, and the forests are highly productive and produce large amounts of organic matter.

Many wetlands, however, have lower denitrification rates than riparian forests because most of the nitrate forms and cycles internally and nitrate availability often limits denitrification rates (Verhoeven et al., 1994). Similar to riparian forests, denitrification rates increase in wetlands where nitrate inputs have increased (Koerselman and Verhoeven, 1992). Because animal wastes are high in both organic and inorganic forms of nitrogen, it can be expected that most wetlands would be able to remove nitrogen components associated with water quality. It needs to be emphasized, however, that other factors (e.g., soil acidity and temperature) are important, and most wetlands have a limited capacity to process nitrogen, as will be discussed in a later section of this chapter. Efficient nutrient cycling in shallow aquatic ecosystems can also improve water quality, but these systems often become eutrophic when waste water is added (Kub et al., 1994) because mechanisms for nutrient removal or long-term storage are not as great as those that occur in wetlands.

The number of pathways that phosphorus can cycle through (Figure 2) is less than those associated with nitrogen because there is not any significant atmospheric component to the phosphorus cycle. Once phosphorus enters a wetland or shallow aquatic ecosystem, it is transported through it or it is retained in the substrate or in the biomass. Within the substrate, the cycling of phosphorus is quite complex and depends on chemical conditions and the types and forms of sediments and minerals that they contain (Richardson, 1985; Richardson and Marshall, 1986; Barbanti et al., 1994). If a wetland or shallow pond/lake system receives and retains sediments, especially fine clays and silts that are high in phosphorus, then it is very likely that P will be removed from the water and water quality will be improved. Aquatic ecosystems with highly

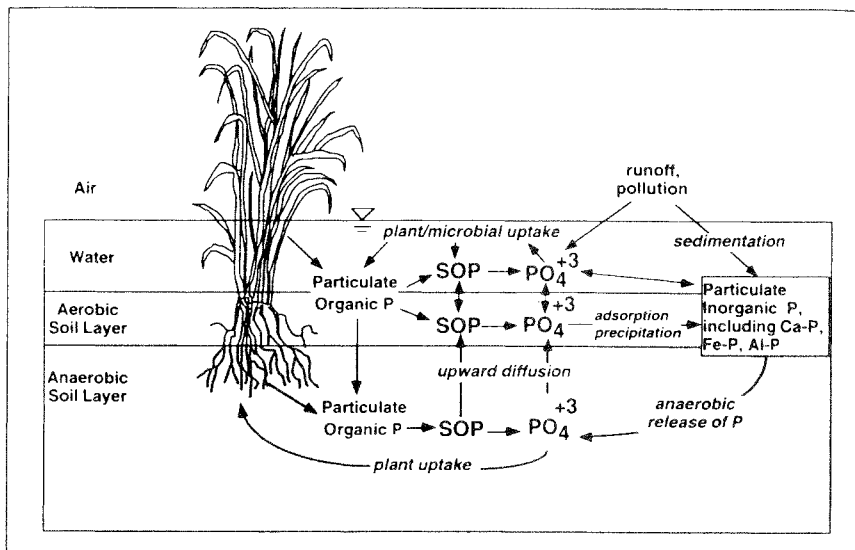


Figure 2. Phosphorus cycling in wetlands. SOP = soluble organic phosphorus. (From Mitsch and Gosselink, 1993, with permission.)

organic substrates (i.e., peat) can also efficiently remove phosphorus, but the absorption capacity is limited, the systems can ultimately become P saturated, and water quality improvement will cease. Phosphorus can effectively be stored in the substrates in shallow aquatic ecosystems, but it is often returned to the water column during periods of anoxia or when the substrates are disturbed by winds, bioturbation, etc.

LIMITATIONS ON THE ABILITY OF WETLANDS AND SHALLOW PONDS/LAKES TO IMPROVE WATER QUALITY

All aquatic ecosystems have the ability to change the quality of water but the levels of nutrients that are acceptable in a wetland or in downstream aquatic ecosystem is determined by social values and by legislation such as Section 303 of the Clean Water Act. In the US it is, in general, no longer acceptable to degrade water quality through the discharge of point sources of potential contaminants. Much of the current efforts to improve water quality in water of the US has, in fact, moved to efforts to effectively treat non-point source runoff (US EPA, 1986; Baker, 1992). Using existing wetlands and aquatic ecosystems to treat animal wastes would, therefore, be allowed only if the discharges had already been treated (e.g., see examples of pre-treatments in Ryding and Rast, 1989) or if it could be demonstrated that the natural systems would improve water quality while not deteriorating downstream aquatic ecosystems.

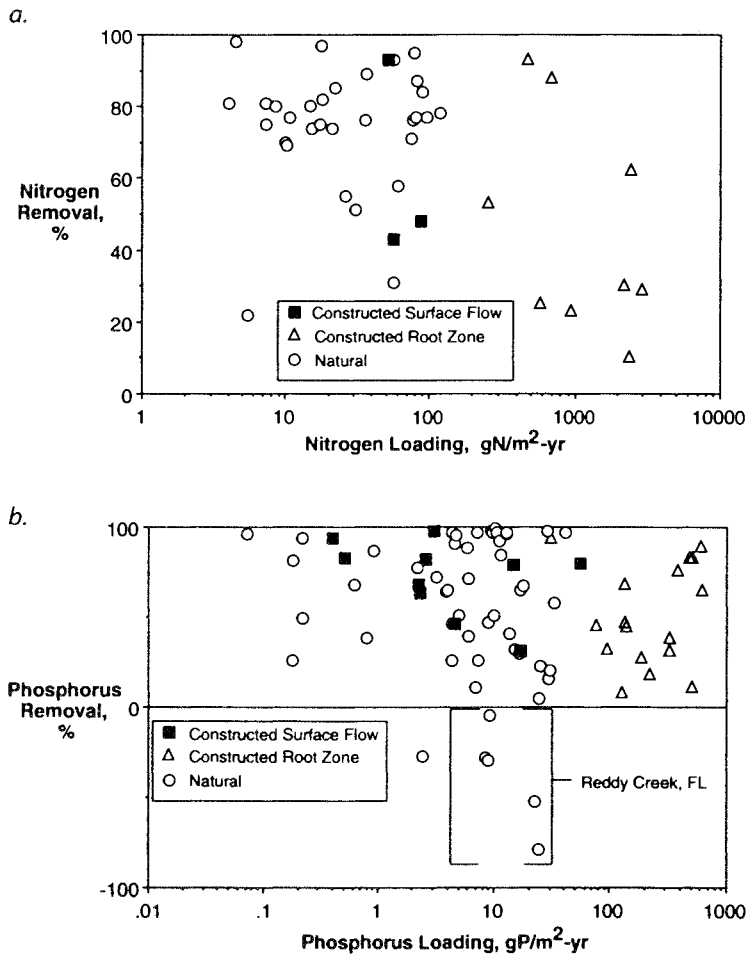


Figure 3. Nutrient retention in wetlands receiving wastewater or river water as a function of loading for a) nitrogen and b) phosphorus. (From Mitsch and Gosselink, J.G., 1993, with permission.)

What factors limit the ability of a wetland or shallow aquatic ecosystem to improve water quality in downstream areas? This issue has been addressed by a number of authors in recent years (e.g., Tourbier and Pierson, 1976; Ryding and Rast, 1989; Richardson, 1990; Verhoeven and Van der Toorn, 1990). Mitsch and Gosselink (1993) summarized a paper by Olson (1992) that provides useful guidance for managing wetlands for water quality improvement (Table 1). Olson's comments make it clear that no waste water should be discharged into a wetland (and by extension to shallow aquatic ponds and lakes) before its ability to improve water quality has been assessed, along with other functions.

Table 1. Questions that should be answered when consideration is being given to using a wetland or aquatic ecosystem for purposes of treating animal wastes.

Source: Olson, 1992, as summarized by Mitsch and Gosselink (1993).

Technical Considerations

1. Are other values associated with the wetland (e.g., wildlife habitat, recreational value, long-term storage of water) more important?
2. What nutrient loading rates are within the natural ability of the system to treat waste water?
3. How would the addition of animal wastes impact exiting ecological conditions within the wetland (e.g., would a diverse emergent vegetation be replaced by monotypic stands of cattail)?
4. What is the hydrology of the wetland? For example, wetlands that are hydrologically isolated from other aquatic ecosystems are likely to retain nutrients added in waste water and are likely to undergo significant biotic and substrate changes.

Institutional Considerations

1. Are there any conflicts among agencies in the use of the wetland for treating animal wastes?
 2. Will the use of the wetland for treating animal wastes result in positive benefits in functions and values?
 3. Are there any legal constraints (i.e., liabilities) associated with using the site for treating animal wastes?
 4. Are there local, state, and/or federal regulations that would need to be modified before the wetland could be used for treatment of animal wastes?
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In general, shallow aquatic ecosystems (ponds and lakes) have a limited ability to improve water quality (see Giussani and Callieri (1993), which describes many of the problems associated with lakes) and the addition of waste water to aquatic ecosystems most often results in eutrophication (Ryding and Rast, 1989). Once ponds and shallow lakes have reached a eutrophic stage, the condition can be reversed only when the nutrient loading is eliminated or greatly decreased, or by regulation of the types of organisms in the aquatic food web. Excellent examples of this condition can be found in the long-term patterns of water quality deterioration followed by recovery in the Great Lakes and in Lake Washington near Seattle.

Wetlands have a greater potential to treat waste water than ponds and shallow lakes, but they also have limited ability. Figure 3 shows that the ability of natural wetlands to remove N and P varies greatly and that the removal efficiency of both nutrients decreases as loading rates increase. While data compilations such as those shown in Figure 3 have limited value due to natural variability in ecosystems, they provide a cautionary note that should not be ignored.

In conclusion, there have been numerous studies that have demonstrated that wetlands, ponds, and shallow lakes can improve water quality. It has also been demonstrated that a limited number of aquatic ecosystems can be used to effectively process waste water. I believe that most wetland ecologists would support the use of constructed wetlands-pond systems rather than natural systems to treat waste water. It seems unlikely that natural aquatic systems can be

used to effectively treat animal wastes and a variety of engineered systems that use constructed wetlands have been developed that could be used for that purpose (e.g., see Table 17-1 in Mitsch and Gosselink, 1993).

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