State of the Practice: Enhanced Nutrient Removal in Stormwater Treatment

Since publication of Vermont's first Stormwater Management Manual (VSMM) in April of 2002, emphasis on nutrient removal has grown, and stormwater treatment technologies have evolved accordingly. Phosphorus and nitrogen are nutrients of particular concern in stormwater because excess concentrations of these nutrients in runoff cause algal blooms and subsequent low dissolved oxygen levels and fish kills. Best management practices (BMPs) have varying levels of documented nutrient removal capabilities. By utilizing nutrient-specific removal pathways, existing BMPs can be modified to achieve enhanced nutrient removal rates.

Phosphorus Removal Pathways

Phosphorus is present in stormwater as particulate phosphorus (attached to or a component of suspended solids) and dissolved phosphorus. Phosphorus is typically found as a negatively charged anion in the phosphate form (PO_4^{-3}), which can adhere to positively charged particles. Phosphorus can be removed from stormwater in the following ways:

- **Physical Removal:** The main removal mechanism for particulate phosphorus in runoff is settling. With a long enough residence time and flow path, even fine particles eventually fall from suspension and accumulate at the bottom of a BMP. This accumulated phosphorus can be removed during maintenance.
- **Plant Uptake:** Plants convert dissolved inorganic phosphorus to organic phosphorus as it becomes part of the plants' tissues. When the plant dies, bacterial decomposition converts the phosphorus back to the inorganic dissolved or particulate forms.
- **Adsorption:** Negatively charged phosphate can be removed by adsorption, which is the chemical binding of phosphate to positively charged soil particles.
- **Precipitation:** Negatively charged phosphate can react with positively charged dissolved iron, aluminum, manganese, or calcium to form phosphate minerals, which will precipitate from the water column.
- **Immobilization:** Plant-available inorganic phosphorus is consumed by microbes in the soil and is converted to organic phosphorus. Vegetation provides the energy to drive microbial immobilization. Thus, the presence of vegetation can greatly enhance phosphorus removal.

Enhanced Phosphorus Removal

Many existing BMPs are designed to remove particulate phosphorus through settling and/or filtering mechanisms. These BMPs can be enhanced to remove dissolved phosphorus using soil additives and vegetation. Additional particulate phosphorus removal can also be achieved using longer residence times.

Additives to the BMP Soil Media: There are four key additives that can be used for phosphorus removal:

- **Fly Ash—**Fly ash is a waste product from coal burning that has been shown in testing to have potentially high phosphorus removal rates. Optimal fly ash percentages vary by study, but values between 5-30% are documented to perform well. The use and eventual disposal of fly ash needs to be carefully considered as it is regulated as a waste and may have additional permit requirements governing its use.
- **Expanded Shale—**Expanded shale is made by firing shale at high temperatures. Expanded shale maintained high removal rates even when dosed with very dilute phosphorus solutions.
- **Iron Filings—**Iron filings are effective in removing both total and dissolved phosphorus. Studies in Minnesota show that iron filing additives are capable of providing decades of reliable service.
- **Water Treatment Residuals (WTRs)—**WTRs are waste products from the drinking water treatment process that contain aluminum hydroxides. Research has shown high removal rates even for phosphorus loading schemes equivalent to decades of runoff. The phosphorus sorption capacity of WTRs will vary depending on the treatment processes employed at the source facility.

Addition of Vegetation to the BMP: Plants provide uptake of phosphorus, converting orthophosphate ions to organic phosphorus as they become part of the plant tissues. Phosphorus is also removed or immobilized in the presence of microbes in the root system of plants. Since phosphorus may re-enter the system as the vegetation dies, care must be taken to remove dying or

decaying plants from the practice. All planting media should be tested for phosphorus content.

Longer Residence Time: Extending the time stormwater remains in a treatment practice increases the opportunity for particulate phosphorus to settle out of suspension. Longer residence times can be achieved by designing greater length-to-width ratios.

Table 1. Summary of BMPs that can be modified to enhance phosphorus removal

BMP	Enhancement Technique		
	Additives	Vegetation	Residence Time
Green Roofs	X	X	
Surface Constructed Wetlands	X	X	X
Subsurface Gravel Wetlands	X	X	X
Infiltration Practices			
Filter Practices	X	X	X
Level Spreader/Filter Strip		X	
Wet/Dry Basins		X	X

Nitrogen Removal Pathways

Nitrogen occurs in the form of ammonium, nitrite, nitrate, or dissolved/particulate organic nitrogen. In stormwater, nitrogen is mainly present as organic nitrogen and ammonium (NH_4^-). Under aerobic conditions and in the presence of nitfrifying bacteria, ammonia is oxidized to nitrite (NO_2^-), and then nitrate (NO_3^-). Nitrogen can be removed from stormwater in the following ways:

- **Assimilation**—Inorganic nitrogen (ammonium, nitrite, or nitrate) is taken up by plants and temporarily stored as organic nitrogen in the plants' biomass.
- **Adsorption—**Positive ammonium ions can be adsorbed onto negatively charged soil particles.
- **Denitrification—**Nitrate is transformed under anaerobic conditions and in the presence of an electron donor to nitrogen gas, which is released into the atmosphere.

Enhanced Nitrogen Removal

Existing BMPs can be altered to provide enhanced nitrogen removal by utilizing nutrient-specific removal pathways. Potential enhancements are discussed below and include adding an anaerobic zone, adding vegetation, and increasing residence time.

Anaerobic Zone: The addition of an anaerobic zone to a stormwater BMP may enhance permanent nitrogen removal to the atmosphere by promoting denitrification. Denitrification requires an electron donor, usually a carbon source for stormwater, and an anaerobic environment. Wood chips and newspaper are examples of carbon sources that have been shown to enhance the denitrification process. To create an anaerobic zone, research suggests maintaining a permanent volume of water in the bottom of the practice. This permanent internal storage may be created by constructing the practice in an area of low hydraulic conductivity or adding an impermeable liner. For systems with an underdrain, the addition of an upturned elbow will allow the formation of this permanent ponding depth. Permanent internal storage zones may also increase plant survival in dry periods.

Vegetation: Plants provide uptake of nitrogen into their root systems and store the nutrient as organic nitrogen in the plant tissues. Nitrogen uptake is greatest during the growing season. Nitrogen may leach back into the system when plants decompose, so care must be taken to remove dying or decaying plants from the practice.

Longer Residence Time: Extending the time stormwater remains in the treatment practice increases the opportunity for nitrogen uptake by plants and adsorption by soils. Longer residence times can be achieved by designing greater length-to-width ratios. A longer flow path will increase the contact time between the stormwater and the vegetation and soils (where the majority of removal takes place).

Table 2. Summary of BMPs that can be modified to enhance nitrogen removal

BMP	Enhancement Technique		
	Anaerobic Zone	Vegetation	Residence Time
Green Roofs		X	
Surface Constructed Wetlands	X	X	X
Subsurface Gravel Wetlands	X	X	X
Infiltration Practices	X		
Filter Practices	X	X	X
Level Spreader/Filter Strip		X	
Wet/Dry Basins	X	X	X

For More Information

The full *Enhanced Nutrient Removal Research* memo is available at:
http://www.vtwaterquality.org/stormwater/htm/sw_manualrevision.htm