Mantoloking Environmental Commission
Community Forum

Nutrient Removal BMPs for Barnegat Bay

April 28, 2011
Outline

• Overview of P retention processes
• Overview of N retention processes
  • Immobilization/Uptake
  • Denitrification
• UNH SSF Gravel Wetland Design
• UNH SSF Gravel Wetland Results
• Advanced Bioretention Design
• Advanced Bioretention Results
• NJDEP BMP Research Facility Design
Phosphorus Sources and Types

- Phosphorus has several forms with different pollutant loading implications.
- Runoff is dominated by:
  - **Organic P (OP)** comprising complex forms that are mostly dissolved. (ATP, nucleic acids, etc.)
  - **Ortho-phosphate**, an oxidized inorganic form that is dissolved. It is most bioavailable
  - **Particulate P**, which is adsorbed onto soil particles. It is mostly inert, and easily filtered by BMPs.
  - Some OP is eventually broken down into Ortho-Phosphate.
Phosphorus Transformation Overview

- Two processes to reduce Ortho-P:
  1. Sorption by reactive media.
  2. Microbial immobilization, then sorption as well as plant uptake.

- Both methods very effective if media has high sorption capacity.
- Plants essential to enhance performance of media.
- Reactions are fast, within minutes.
- However, most BMP media has low P sorption capacity.
- Most media saturated within ~5 years, so no more ortho-P retained.
- At that point, ortho-P will be discharged.
Nitrogen Sources and Types

- Nitrogen has many forms with differing pollutant implications.
- Runoff is dominated by:
  - **Organic N (ON)**, which comprises complex forms that are both particulate and dissolved. (proteins, amino acids, etc.)
  - Intermediate inorganic forms such as ammonia, &
  - **Nitrate**, an oxidized inorganic form that is dissolved.
- Much ON is eventually broken down into nitrate.
- Total N (TN) is basically sum of ON and nitrate.
Two methods to reduce nitrate:
1. Denitrification by anaerobic microbes.
2. Immobilization, then plant uptake and harvest. (Note that decay returns N as nitrate).

Both methods can be very effective if given enough time for reactions to occur.

However, retention time in typical BMPs too fast for much immobilization or denitrification.

Therefore, most nitrate ends up in groundwater and/or in surface outflow.

Either way, nitrate will be discharged.
During event, some ON is mineralized and nitrified into nitrate. Nitrate then immobilized by soil microbes that take up dissolved nitrate. Immobilization requires at least several hours of contact, complete by 24 hours. Once immobilized, microbes then release nitrate for uptake between events. In advanced bioretention systems, immobilization and uptake can remove 90% nitrate, and 70% total N. However, MUST harvest at least annually for optimal N retention to continue.
Denitrification (DNF) is the process by which nitrate is converted into N₂ gas.

- Requires at least 12 hours to approach completion.
- Requires an energy source, such as plant exudates from rhizodeposition.
- Requires that no oxygen is present (anoxic).
- BMPs that provide enough storage between events for long retention time can be very effective.
- Little ON removal since most runoff in anoxic setting.
The UNH Subsurface Gravel Wetland Design
Flow through gravel is a function of head, length, cross section area, and hydraulic conductivity.

If stone hydraulic conductivity too low, will result in more bypass flow.
The UNH Subsurface Gravel Wetland - Treatment Cells

Both Cells:
• Energy dissipation at inlets (inlet at surface)
• Holds 90% of WQV above ground
  \[ L:W > 0.5, \ L_{\text{min}} = 15 \text{ ft}, \ \text{drain time} \ 24 - 72 \text{ hours} \]
• 8-15 in. of wetland soil
• Graded filter course (if necessary), but NO geotextile
• Stone/coarse gravel (1/2-in or larger)
• Minimal infiltration to subsoil (requires bottom liner)

First Cell:
• Primary outlet is through the stone layer into second cell.
• Spillway to pass design flows to next cell.

Second Cell:
• Inflow underground from first treatment cell.
• Primary outlet is a vented pipe with invert below the soil surface.
• Spillway to pass design flow to stormwater conveyance system.

(Courtesy UNH, 2007)
The UNH Subsurface Gravel Wetland - Initial Planting

(Courtesy UNH, 2007)
UNH Subsurface Gravel Wetland Vegetation

Sagittaria, Cattail, Juncus, grasses, standing water

Bullrush (scirpus), aster, grasses, no standing water

Rush (juncus), cattail, grasses, open water

(Courtesy UNH, 2007)
The UNH Subsurface Gravel Wetland-Hydrology

- Note substantial reduction in peak flow (85%).
- Also, very considerable lag in discharge (~6 hours).
- Reduction in volume due to evapotranspiration since preceding event made more volume available prior to discharge.
The UNH Subsurface Gravel Wetland—Performance

- Very high removal of TSS, TPH and Zn, with no significant seasonal performance characteristics.
- High removal of nitrate, especially in summer. Do get some export due to plant senescence during winter.
- Less effective for P removal.

(Courtesy UNH, 2007)
The UNH Subsurface Gravel Wetland - Nitrate (and Ammonia)

- Very low median nitrate discharge concentration at ~0.03 mg/l.
- Approximately 90% reduction from inflow at ~0.30 mg/l.
- However, no data on ON loads or reductions. Expect fairly low ON reductions due to anaerobic setting.
Median discharge concentration of Ortho-P at ~0.070 mg/l.
Approximately 30% reduction from median inflow at ~0.100 mg/l.
However, no data on Organic P loads or reductions.
Advanced Bioretention Design
Flow through media is controlled by dual stage outlet.
Lower outlet throttled to provide ~3 hour retention time.
Upper outlet conveys high flows through media, adjustable to maintain flow response as media hydraulic conductivity declines.
This results in very little bypass flow.
Advanced Bioretention Media

- Media is a blend of sand, topsoil, water treatment residuals (WTRs), & refractory organic components.
- Media components are selected to provide the following:
  - High flow rates intercept more runoff and avoid potential clogging.
  - High efficiency in removing particulate pollutants and pathogens.
  - Very high efficiency in removing and retaining P, with P retention rates exceeding 90%, even after decades of stormwater loads.
  - Low leaching losses of nutrients compared to compost.
- Documented in the scientific literature, these findings are being replicated in large-scale experiments in WA, DE, MD, VA and NJ.
• After two years, conductivity rates range from 35cm (14 inches) to 130cm (52 inches) per hour.

• The individual replicates of most media treatments were also quite variable. This demonstrates inherent variability of natural systems.

• These high rates provide only very limited retention time for N removal processes.

• Therefore flows regulated to ensure similar responses and improve N retention.

Lucas and Greenway, 2011
Advanced Bioretention Outlet Design

- Lower outlet extends detention time for best N removal performance.
- Saturated zone provides for denitrification to occur between events.
- Upper outlet conveys peak flows in large events through the media.
- Elevations of both upper and lower outlets are adjustable, as is the aperture of the lower outlet. This provides adaptive management.
Plot of 25mm applied over 90 minute duration. Represents six month recurrence interval for Brisbane AU, so quite large.

- Outflow lasts for over 8 hours in outlet-regulated system. Average retention time is **150** minutes.
- However, even peak flows are treated, shown by the upper outlet flow.
- Compare to only 2 hours of flow in the no outlet free discharge system. Average retention time is **18** minutes.
Bioretention Nitrogen Processes

- Recall that nitrogen retention determined by processes of:
  1. Immobilization by microbes,
  2. Uptake by plants into roots and shoots,
  3. Denitrification, which also depends upon plants.
- As a result, N removal by uptake is a function of plant vigor, density, and time of year. Well-established plants will remove more N than plants that are immature.
- These N removal processes are promoted by increases in retention time, while denitrification is promoted by saturated conditions.
- In sandy soils where hydraulic conductivity can be as fast as media, it will drain too rapidly for effective N removal.
- Therefore, a geomembrane is needed to collect treated runoff for control by dual stage outlet to ensure adequate retention time.
Six month event results. Nitrate shown in solid, ON hatched.

Net Inflow represents projected uptake based on overall experiment.

At high concentrations, 62% nitrate & 66% TN retained with outlet.

TN reduced more than projected uptake, with high ON reduction.

Contrast with typical outlet, 19% nitrate & 27% TN retention.

At low concentrations, 86% nitrate retention, even at detection limit.

TN retention was only 35% since ON already at irreducible.

Outlet controlled system significantly better than free discharge system.

Lucas and Greenway, 2011
In 2009, 53-89% nitrate and 41-60% TN retention by outlet controlled systems.

In 2010, 82-94% nitrate and 66-78% TN retention by outlet controlled systems.

Improved performance due to smaller volume and more mature plants.

Nitrate close to or at detection limit, while organic N at irreducible.

Results further document how outlet controlled systems perform significantly better than typical free discharge systems.
After more than three decades of loads, the WTR systems were 99% effective for PO₄ retention, and over 90% effective for TP retention. P retention improved over time and after even more accumulated loads. Loads now equivalent to over 5 decades of runoff. Recent data finally shows slight decrease in retention (74% TP, 94% PO₄).
WSU Experimental Setup - Mesocosm Outlet
WSU Experimental Setup - Mesocosm Array
One advanced bioretention cell to be compared to several different types of SSF Wetlands.

To be Located at Georgian Court University, Lakewood, NJ
• One standard UNH cell to be compared to several different types of SSF Wetlands to be designed by NJDEP
• Intent is to optimize design and use of space and piping.
How We Can Do Better - Implementation
Implementing Advanced BMPs

• New Land Development:
  • Good Potential for Mainland Sites
  • But Limited Potential on Barrier Islands
  • Does Not Address Existing Problems

• Retrofit Existing Drainage Systems
  • Add BMPs to Upgrade Existing BMPs
  • Add BMPs to Existing Vacant Sites

• Construct Regional Measures
Retrofits and Upgrades

• Take Advantage of Opportunities:
  • Road and Drainage Improvements
  • Redevelopment Projects
  • Funding Programs

• Optimize Design Based Upon:
  • Available Space
  • Available Funding
  • Available O&M
• Four Cells comprise 4425 sq. ft. of treatment area.
• Source Area of 9.43 acres is equal to a 93:1 ratio.
• Source Impervious Area is 3.97 acres, or a 39:1 ratio.
• These high ratios are accomplished by a diversion to bypass peak flows.
• This reduces treated volume by only 11% in 1-year event.
• Therefore, system treats vast majority of runoff, even though undersized.
• Don’t let the Best be the Enemy of the Good!
Trench stores runoff and provides additional surface area for infiltration.
Trench also provides more root volume, promoting growth and ET.
Outlet controls discharge & allows systems to step down 5% slopes.
Planter is 1.3% of source impervious, with trench adding another 4.4%.
How We Can Do Better - Regionalization

- Implement Larger Scale BMPs:
  - Larger Drainage Areas with Multiple Property Owners and Jurisdictions
  - More Effective and Efficient
    - Construction, Performance, and Maintenance
  - Larger Funding Base
  - Requires Coordination and Cooperation
How We Can Do Better - Coordination

- Key is COMMUNICATION and COORDINATION between agencies and private sector.
  - NJDEP
  - Pinelands Commission
  - Counties/NJ DOTs
  - Municipalities
  - Conservation Districts

- Stormwater management requirements often conflict, with duplicate/overdesign of facilities.

- This results in inconsistent and/or inefficient adoption of new technologies.
How We Can Do Better-Summary

• Large, Complex Problem, but Can Be Solved.
• Extensive Network of Federal, State, County, and Municipal Stormwater Regulations and Programs need to be coordinated to expedite installations.
• Nonstructural BMPs Promising, but not enough.
• Current Structural BMP Performance Limited for Nitrogen Removal.
• Advanced Structural BMPs Available, but Need to Implement and Monitor As Soon As Possible to Verify Best Approach.
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