Problem Solving in Stormwater Wetland Ponds
It's All in the Muck

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Wetland treatment ponds can produce excellent water quality and can function as an important part of your sustainable landscape. These new innovative systems are far different than typical stormwater detention basins, because they function as dynamic ecological treatment systems. Unlike stormwater bioretention systems (LAM May 2006) which are designed primarily for small storm events, wetland pond systems can be effective biological treatment systems for both small and large storm events.

Traditional detention basins hold stormwater only long enough to reduce the peak discharge rate of runoff to the predevelopment discharge rate. The wetland detention pond was the next generation of systems and they typically hold stormwater for two to five days to allow for settlement of suspended solids. Research studies over the last ten years have provided a much better understanding of why these systems frequently fail to adequately treat the stormwater. The lessons learned from this research can now being used to design wetland treatment ponds that overcome the inherent problems found in the older wetland detention ponds. These three types of basins are defined as:

1. **<u>Traditional Detention Basins</u>** – are basins that merely detain the runoff peak discharge rate sufficient to reduce the discharge rate to predevelopment conditions, but provide no water quality treatment.

2. **<u>Typical Wetland Detention Ponds</u>** – are basins that detain the peak discharge rate, detain the runoff waters for a several days sufficient to allow for partial settlement of suspended solids, maintain a normal water pool, and use marshes that provides for limited biological treatment.

3. **<u>Innovative Wetland Treatment Ponds</u>** – are basins that maintain a normal water pool, use extensive wetland marshes and aeration for biological treatment, but in addition use flocculants for settlement of colloidal particles, detain all of the runoff waters from large storm events for an extended period of time, and minimize thermal stratification to prevent resuspension of sediments and pollutants.

EPA completed a recent survey of stormwater best management practices and found that traditional detention basins and the older wetland detention ponds were largely ineffective in controlling the physical and chemical impacts on downstream waters[2]. Generally, EPA found that the wetland detention pond systems were being substantially undersized and occupied too

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[2] EPA. 2002. Consideration in the Design of Treatment Best Management Practices (BMPs) to Improve Water Quality. EPA-600-R-03-103.

Belvedere Lake, Central Park, NYC

small a portion of new construction sites to be hydrologically effective. In addition, they found that the suspended solids were not being properly settled, because the ponds lacked a means to eliminate turbulent scouring velocities, means to sufficiently still the waters during a storm event, and means to use flocculation agents [3].

EPA found that bioretention systems were found to generally achieve the downstream water quality parameters. Wetland detention ponds were far less effective. Bioretention systems achieve higher reductions in total suspended solids, total phosphorus, soluble phosphorus, nitrates, and metals, than wetland detention ponds. So, why is there such a disparity in performance? And, how can we design stormwater treatment ponds to work as well as bioretention systems?

We must be able to create excellent biological treatment in the ponds. Innovative wetland treatment ponds must be designed to deal with the physical onslaught of runoff, still the turbid waters for sufficient time to settle even the smallest suspended particles, and prevent resuspension of the pond bottom muck by subsequent runoff events.

Biologically, the ponds must have vigorous growth of primarily rhizomatous perennials that create a thick root mat, because the primary biological and chemical treatment processes occur in the microbes that lace the roots. The plants and microbes work together best in a thick organic rich muck to assimilate metals and nutrients, to release nitrogen by denitrification[4], and by adsorbing metals and phosphorus on organic and clay particles. The plants oxidize an area immediately around the roots and thereby enable microbes to assimilate the pollutants. The microbes feed on decomposed plants and organics matter in the settled sediments; the food source requires incorporating thoroughly decomposed organic material

[3] Flocculation agents include "Floc Logs" by Applied Polymer, Inc., "Floc Clear" by Rocklin Products, Inc., and "Storm-Klear Gel-Floc" by Natural Site Solutions, Inc.
[4] Denitrification is the process of reduction of nitrogen oxides (usually nitrate and nitrate) to molecular nitrogen or nitrogen oxides with a lower oxidation state of nitrogen by bacterial activity.

into the topsoil mix for new wetland pond systems and can be jump started by incorporating granular glucose sugar. So success really depends upon the muck. The plants are also important by continuing to build organic matter in the muck and by stabilizing the muck.

The degree of treatment in wetland ponds is dependent upon the pollutant concentration in the pond waters, the amount of time to assimilate the pollutants into the muck, and the abundance of microbes. The abundance of the microbes is dependent upon extent of the decayed food source, the extent of time with soil temperatures above 38^{o} F, and the extent of oxidized root channels in the muck.

Biological treatment is achieved by creating robust plant and animal life in the ponds. The plants and organisms will bioaccumulate[5] the pollutants. The plants and organisms need rich muck that will promote biological interchange[6] and biodegradation[7]. Extended aeration[8] can be used to promote biological activity and to provide sufficient dissolved oxygen in the water for aquatic life. Settlement[9] of particles can be improved by extending the detention time and by using flocculation[10] agents.
The following chart illustrates common downstream water quality parameters, standards and control mechanisms that we can use to create the biological treatment.

Water Quality Strategies for Achieving Downstream Standards

Water Quality Parameters	**Water Quality Standards**	**Potential Water Quality Treatment Mechanisms**
Dissolved oxygen[a]	< 5 mg/l	Extended aeration
Fecal coliform[b]	< 200 counts/100 ml	Extended aeration & biodegradation in the muck
Nitrogen	< 5 mg/l	Bioaccumulation of nitrogen in vascular plants & organic detritus through biodegradation in the muck
Phosphorous	< 5 mg/l	Bioaccumulation of phosphorus in vascular plants & organic detritus through biodegradation in the muck
Turbidity[c]	< 50 NTU	Extended detention time, increased storage volume & flocculation adding clay and organics to the muck
Toxic Metals[d]	1 to 50 ug/l	Bioaccumulation & biodegradation in the muck

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[5] Bioaccumulation is the process of accumulation of water and nutrients into biological mass in flora and fauna.
[5] Biological interchange is the interchange of elements between organic and inorganic states in soil through the action of living organisms. It results from biological decomposition of organic compounds with the liberation of inorganic materials (mineralization) and the utilization inorganic materials with synthesis of microbial tissue (immobilization).
[7] Biodegradation is the process of breaking down of natural or synthetic organic materials by microorganisms in soils, natural bodies of water, or treatment systems.
[8] Extended aeration is the process of aerating water to maintain at least 5 ppm of oxygen; this usually involves forced aeration for at least 12 hours per day.
[9] Settlement is the process where suspended particles in water settle by gravity according to Stokes' law. Micron sized particles tend to state in suspension or settle extremely slowly.
[9] Flocculation is the coagulation of colloidal particles due to the ions in solution. Clays and humus remain flocculated due to the presence of doubly and triply charged ions; opposite of dispersion.
[10] City of Austin. 1997. "Wet Pond Design Supplement". Section 1.6.6C of Environmental Criteria Manual, City of Austin, Texas Drainage Utility.

Pesticides	0.0002 to 0.1 ug/l	Bioaccumulation & biodegradation in the muck
Organic Chemicals[e]	0.001 to 10 ug/l	Bioaccumulation & biodegradation in the muck

[a] Dissolved oxygen – a minimum level is needed to maintain aquatic life of waters.
[b] Fecal coliform – is an indicator of bacteria from digestive system of warm blooded animals.
[c] Turbidity – is an optical measure of amount of suspended colloidial clay and organic materials in water.
[d] Arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, nickel, mercury, silver, & zinc.
[e] Organic chemicals include naturally occurring and synthetic carbon based compounds.

Problems with Wetland Detention Ponds

Recent studies have focused on the reasons why typical wetland detention ponds fail to function properly. These studies documented a variety of fundamental physical and biological problems that we need to address in the design of new systems. The basic problems are as follows:

Physical Problems:

1. **Ponds Fail to Maintain Permanent Pools –** Wet detention ponds and wetland detention ponds frequently fail to maintain a permanent pool; the basins dry up so much that the plantings fail. This has been a significant problem in semi-arid landscapes and during dry periods in humid landscapes. The City of Austin, for example, requires installation of a 12-inch thick compacted clay liner to reduce seepage and prevent ponds from drying up in the summers[11]. I always design ponds with a 12-inch liner to reduce seepage and allow larger surface areas of marsh and muck. Reducing the seepage allows us to increase the evapotranspiration in the water balance and still maintain a permanent pool.

2. **Ponds Are Not Designed For Adequate Settlement of Suspended Solids –** The primary physical role of a pond is to provide settlement of suspended solids. Most states require 80 to 85% removal of total suspended solids; however the vast majority of basins fail this standard. Detention times of 2 to 5 days are simply insufficient to settle fine particles. Recent studies indicate that average detention times should be at least thirty days[12]. The City of Austin has shown excellent results with thirty day average detention times. Increased detention times also increasing the time for biological assimilation of pollutants.

3. **Longer Detention Times May Not be Enough in Some Regions** - Many regions have soils that have highly clayey or silty subsoils that erode and make the streams turbid; in these regions 60% or more of the suspended solids can be fine silt or clay (less than 7 microns in diameter) and required substantially greater detention times. Researchers have found that long detention times as much as 70 days have allowed

[11] Borden, Robert C. 2001. Performance Evaluation of Regional Wet Detention Ponds and a Wetland for Urban Nonpoint Source Control. North Carolina Water Resources Research Institute, Report No. 335.
[12] City of Austin. "Wet Pond Design Supplement". Section 1.6.6C of Environmental Criteria Manual, City of Austin, Texas Drainage Utility.

greater settling of suspended sediments, increased nutrient uptake by algal and have improve the nutrient removal efficiency of the ponds[13].

4. **Basin Need to Use Flocculating Agents to Enhance Settlement –** Studies in the eastern piedmont region have shown that >60% of suspended solids in suburban runoff have diameter of less than 6 microns (6 millionth of an inch). These fine silt and clay particles stay in suspension much like the pigment in paint. Water in many wetlands ponds stay continually turbid. It is difficult to effectively remove this size of particles without use of a flocculating agent. EPA has found that the use of flocculating agents will improve the
removal of suspended solid by 20% or more, removal of nitrogen by as much as 40%, removal of phosphorus by as much as 70%, and removal of metals by as much as 60%.[14]

   Anionic polyacrylamide chemicals[15] are preferred because they aggregate the suspended particles, once aggregated the particles act as heavier particles, and rapidly settle into the bottom sediment. Anionic polyacrylamide chemicals have been approved by EPA as a safe flocculants to enhance settlement of colloidal clay and organic particles. The use of these new polymer techniques may revolutionize how we protect the water quality of the receiving streams. The new polymers are extremely powerful flocculating agents that will allow us to treat, flocculate, and trap the colloidal particles in less than one minute. Polyacrylamide chemicals are commercially available from a number of distributors. One approach is to purchase them already embedded into "polymer gel blocks". The polymer gel blocks are then installed in the stormwater pipes just upstream of the settling basin. The flowing water activates and releases some of the chemical into the stormwater to start the process. One word of caution is that the polymer gel blocks only last for about 3 to 4 months, so you should still enlarge the pond volume.

5. **Ponds Are Not Designed For Adequate Storage Volume –** Larger storm events tend to scour previously deposits sediments in the basins. Storm surges of less polluted waters can dynamically exchange adsorbed constituents from the bottom sediments and transport them out of the pond and into downstream waters. One approach to minimize this problem is to design the basins to detain the runoff volume from substantially larger storm events. In semi-arid and humid warm climates these storm surges frequently occurs in the summer due to large convective rainstorm events. However, in the semi-arid and humid cold climates it also occurs as the spring melt waters scours the bottom sediments below the ice covered pond. Currently, I am designing basins using a minimum of 50 year frequency or larger rainstorms. This involves significantly increasing the surface

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[14] EPA. 2002. Consideration in the Design of Treatment Best Management Practices (BMPs) to Improve Water Quality. EPA-600-R-03-103.

[15] Anionic polyacrylamide is group of chemicals approved by EPA as ecologically safe for use in water as flocculants to settle small suspended particles; faster and more power acting than calcium sulfate or alum.

area of the ponds, since the depth of the flood pool needs to low enough to avoid excess submergence of the aquatic plants. Using this approach the pond design will need to store the entire runoff volume from these large events and allow any suspended sediments and pollutants to resettle.

6. **Ponds Are Not Design to Adequately Reduce Velocities –** All of the stormwater needs to be retained in the pond acting as a stilling basin where the velocity of the water stopped so that the suspended solids can settle. This can be done by utilizing two ponds with the first pond serving as the stilling basin. It has been my experience that forebays build into the main pond simply do not adequately still the water and do not provide sufficient storage time to settle the colloidal clays and organic particles. In lieu of forebays, I have constructed wetland floodplains upstream from the ponds to serve to settle these fine particles prior to entry into the wetland pond. Another approach to reduce velocities is to install a series of submerged fences that are covered with open weave jute fabric. The fences are constructed in the open water portions of the wetland ponds, about 1 foot below the normal pool elevation, and orientated perpendicular to the storm flows.

7. **Ponds Are Not Designed to Properly Control Outflows –** The traditional approach is to install a large outlet pipe and due to the high velocities block the swirling waters with a non-vortex unit. Of course this traditional approach is all wrong. The normal discharge from wetland detention ponds should be very slow and the water should be drawn from the surface of the stilled waters in the pond. A floating skimmer intake device[16] achieves this intent and when installed correctly will stop discharging once the pond returns to the normal pool elevation. Floating skimmers typically discharge through 2-inch to 5-inch diameter outlet pipes. Additionally, I like to provide post-treatment of the pond outflow and have found it effective to connect the outlet pipe into an aluminum pipe having ½-inch orifices about every 3 to 5 feet. The aluminum pipe lays on the surface and acts as a level spreader. During smaller outflow events the level spreader simply allows for infiltration of the stormwater. During larger outflow events the stormwater runs overland flow to the stream channel. The size of the intake and the length of the level spreader pipe will reduce the overflow to just a trickle.

8. **Ponds Fail to Prevent Thermal Stratification and to Maintain Sufficient Dissolved Oxygen** – The surface of ponds will heat during the warmer periods of the year while the bottom waters will remain cooler and become anoxic. In the fall these thermal layers will "turn over" and will resuspend bottom sediments and contaminants[17]. The use of aeration and mixing of the waters can significantly reduce the thermal stratification and at the same time increase the dissolved oxygen in the waters. The use of a solar or conventional powered fountain or aerator increases the oxygen

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[16] Floating skimmer intake devices such as those manufactured by J. W. Faircloth & Son, Inc.; www.fairclothskimmer.com

[17] Borden, Robert C., et al. 1997. Evaluation of Wet Ponds for Protection of Public Water Supplies. University of North Carolina Water Resources Research Institute, Report No. 311.

concentration of the waters, improves biological activity, prevents stagnation, and significantly reduces the breeding of mosquitoes.

9. **<u>Ponds Fail to Provide Pre-Treatment of Influent Waters</u> –** The success of wetland ponds can be markedly improved in humid regions by flow through a series of wetland floodplains or bioswales prior to entry into the wetland pond. I have been designing wetland floodplains to slow velocities, settle suspended solids, and infiltrate nutrients prior to entry into the aquatic marshes in the ponds. Others have found this approach to be effective in dealing with highly concentrated spring melt waters prior to entry into the wetland ponds[18]. Post treatment has also been effective in Colorado, where the pond waters are discharged through a series of floodplain wetlands each separated by step-down weirs.[19] Whether wetland biofilters are used up front or at the end of the treatment train, they significantly enhance biological treatment.

<u>Biological Problems</u>:

10. **<u>Basins Fail to Adequately Remove Pollutants</u> –** Wet detention basins typically only remove about 30% of the nitrogen inflowing the pond[20]. The City of Austin has reported higher rates of nutrient removal which has been attributed long detention times and robust growth of surface and benthic algae, emergent plants, and submerged plants. Other researchers have shown that the abundance of native aquatic macrophyte species, especially rooted emergents to be important[21]

11. **<u>Ponds Fail to Foster Growth of Macro-Invertebrate Organisms</u> –** It is essential that the wetland ponds achieve an abundant community of macro-invertebrate sediment species such as snails, midgets, damselflies, dragonflies, skimmers, backswimmers, and various diving and crawling beetles. A diverse community of these sediment species is indicative of healthy organic muck. As landscape architects, we tend to focus first on the diversity of the plant species. However, a rich flora community does not mean there is a rich fauna community. Pond muck is the common factor in successful flora and fauna diversity and population, as well as, successful bioaccumulation and biodegradation. So, it is important to focus on all three as key indicators or measures of success.

    Dragonfly species serve as a usual indicator for healthy fresh water ponds. The adult dragonfly begins its life cycle in the pond muck. The juvenile larvae burrows in the muck or is found in the shoreline emergent plants. Few stormwater ponds foster

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[18] Oberts, Gary. 1994. Performance of Stormwater Ponds and Wetlands in Winter. Watershed Protection Techniques 1(2): 64–68.
[19] Urbonas, B., et al. 1994. Joint Pond-Wetland System in Colorado, USA. Report of Denver Urban Drainage and Flood Control District.
[20] Borden, Robert C. 2001. Performance evaluation of regional wet detention ponds and a wetland for urban nonpoint source control. Water Resources Research Institute of University of North Carolina, Report No. 335.
[21] Mallin, Michael A., et al. 2000. Pollutant Removal Efficacy of Three Wet Detention Ponds. Journal of Environmental Quality 31:654–660.

an abundant population of dragonfly. The restoration of Belvedere Lake (Turtle Pond) in Central Park was delayed due to concerns of the projects impact on the diversity of dragonfly species. After rebuilding the lake and expanding the marsh borders, the population dramatically increased and the dragonfly species were featured on the Central Park Conservancy's restoration poster.

Central Park Conservancy's Post Project Poster Promoting Diversity of Dragonfly Species

Creation of the Mucky Topsoil

One of the key issues is how to specify and how to construct suitable mucky topsoil for the aquatic marsh. Muck is an organic rich sediment that is normally soft when moist and aqueous when wet. The installation of mucky topsoil normally causes over compaction when moist and mess when wet. Although not impossible, it is normally difficult to work with heavy equipment. The alternative approach is to use a structural topsoil that combines decomposed organic matter with medium sand. A structural topsoil will produce similar results and is much easier to mix, work, and install with heavy equipment. As fine clay and silt is deposited into the pond, a layer of the finer material will build over top of the installed topsoil material.

Mucky Topsoil

A mucky soil is the preferred soil material for aquatic planting in stormwater ponds. A mucky soil consists of greater than 50% organic humus in which the plant residues have been altered beyond recognition, and less than 50% mineral soil. The mineral portion of the soil usually consists of silt, silt loam, and loam textures (0 to 50% sand, 75 to 100% silt, and 0 to 25% clay). Mucky topsoil is difficult to install with heavy equipment. Therefore, it is usually used on small installation, but should be avoided in larger installation when the soil material is going to be placed and graded using heavy equipment. It is recommended that a structural topsoil be used on larger installations.

Structural Topsoil
Structural topsoil mixes have been developed that remain porous when compacted. They use a high portion of narrowly graded sand or stone as the load bearing structure in the soil. The following structural topsoil is suitable for aquatic planting in a stormwater pond.

Chemical Properties: The acidity range of the mineral portion of the topsoil shall be pH 5.0 to 6.0 inclusive. Organic matter shall be added in a ratio of one part of organic matter with one to two parts of mineral soil on a volume basis and thoroughly mixed prior to delivery to the job site. Organic matter shall consist of approved leaf composted and shall consist of natural leaves composed for at least 9 months, with piles aerated at least bimonthly. The resultant leaf humus shall be of uniform quality, free of toxins, any debris or undesirable material. The acidity range shall be pH 5.0 to 7.5 inclusive. The electrical conductivity shall be less than 5,000 micro-mohs/cm. The leaf compost shall be screened and shall pass through a one-half inch screen.

Mechanical Analysis of Mineral Soil Material: Sieve Analysis (USDA size scale) shall consist of the following:

Material	Size Range	Acceptable Range
Medium Gravel & Larger	> 5.00 mm	0%
Fine Gravel	5.00 to 2.00 mm	< 3%
Very Coarse Sand	2.00 to 1.00 mm	< 3%
Coarse Sand	1.00 to 0.50 mm	< 10%
Medium Sand	0.50 to 0.25 mm	70 to 90%
Fine Sand	0.25 to 0.10 mm	< 3%
Very Fine Sand	0.10 to 0.05 mm	< 3%
Silt & Clay	< 0.05 mm	5 to 10%

Mineral soils that meet this sieve analysis must be screened to remove larger diameter particles (gravels and coarse sands) and screened to remove smaller diameter particles (fine sand and very fine sand). The screening produces a narrowly graded material that is 70 to 90% medium sand.

Marsh as Safety Buffer
When marsh fringes were installed in some of the lakes in Central Park, we found that the marshes indirectly kept dogs from swimming in the ponds. It had become difficult for the police to prevent people from releasing their dogs in the lakes. The dogs would get stuck in the muck and when they finally got back out of the lake they would shake mud over their masters. People learned quickly and stopped releasing their dogs into the lakes. In a similar fashion, people have great difficulty getting through the muck in the marshes. A person sinks down to the bottom of the muck with their first step into the marsh. It simply stops intrusions into the marsh without the use of signs or fences. Even the structural topsoil described above will not carry loads when wet.

Challenge to Landscape Architects

Wetland treatment ponds are biological systems that if designed properly can achieve a similar level of water quality treatment as bioretention systems. It may be preferable to incorporate both wetland treatment ponds and bioretention systems into a site design. During larger storm events the excess runoff that can not be handled by bioretention systems can flow into wetland treatment ponds.

The challenge to landscape architects is for us to better understand how wetland treatment ponds function, how to measure success, and to learn new methods in the design of innovative wetland treatment ponds that solve the design problems discussed in this article.