Surface Water Best Management Practice | Managing Runoff Quality

Constructed Wetlands:

A How to Guide for Nurseries

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Contents

Nutrients & Water

Essential Components of Nursery Production

Fertilizers and pesticides help nursery growers produce quality plants in a relatively short time period. Excess nutrients and pesticides can exit nursery production areas in runoff and enter surface waters or leach into groundwater.

Nutrient enrichment of surface waters can degrade onsite water quality and lead to algal blooms. Recirculated onsite water can become phytotoxic from increasing concentrations of chemicals and overall water quality can degrade from undesired chemical reactions (precipitation or dissolution). Algal blooms can negatively impact water quality leading to potential harmful impacts to both aquatic organisms and humans.

Nutrient Costs: Economic and Environmental

Economic Case for Nutrient Conservation

Over the past few years, fertilizer costs have risen along with petroleum costs, dramatically increasing nursery production costs. The increase in resource costs for growing specialty crops makes it critical to efficiently apply nutrients and water at the right time and in the amount needed by the crops. Also, recycling and reusing the nutrients whether in the form of composted organic matter or from captured runoff is a way to further increase efficiency.

Phosphorus Reserves and the Future

Geologists studying world phosphorus reserves calculate that our phosphorus resources are likely to run out before petroleum reserves[1]. Over 83% of the world's phosphorus mines are located in Morocco, China, the United States, and South Africa. It is likely that within 40 years the easily accessible and extractable phosphorus reserves in the U.S. will be depleted.

In the future, agricultural practices and fertilizer use will be dramatically different simply because the phosphorus we take for granted today may not be available in the form (or price) that make it easy to use. Phosphorus costs may become so high that it is more economically feasible to capture and reuse phosphorus leached from containers and agricultural waste materials than to simply apply phosphorus in the form of a fertilizer.

Environmental and Resource Conservation

So what can you do to reduce production costs and also protect the environment? A group of researchers funded by a Floriculture and Nursery Research Initiative grant and advised by the United States Department of Agriculture developed a whole-systems approach to environmental resource management, and developed an online resource available for download free at:

http://tinyurl.com/sustainable-nursery.

This resource is intended to help you use production inputs such as irrigation, nutrients, and pesticides as efficiently as possible. Once you have optimized how you apply water and nutrients, then you could consider how you treat any runoff, whether the water leaves your property as runoff or if it can be recycled, cleaned, and reused.

Constructed Wetlands

Centuries ago in Europe and in the early 1900s in the US, natural wetlands were viewed as wastewater treatment plants: wastewater entered the wetland, and voila! — clean water exited from the other end. Fast-forward to the 1950s with the birth of constructed wetlands — engineered systems designed and constructed to treat wastewater with vegetation, soils, and associated microbial populations that take advantage of the same biological and physicochemical processes that occur in natural wetlands.

Since their origin in Germany, constructed wetlands have been studied and implemented around the world. They have been used for decades, mostly for the treatment of domestic or municipal sewage, which largely focused on reducing nutrients, suspended solids, heavy metals and pathogens. Success in cleansing municipal and industrial point-source discharges led to the widespread use of constructed wetlands to treat many other types of wastewater, including industrial and agricultural wastewaters, acid mine drainage, landfill leachate, and stormwater runoff (suspended solids, organics, oil and grease, and heavy metals).

[1]Vaccari. David A. 2009. Phosphorus: A Looming Crisis. *Scientific American*. 300, 54-59. doi:10.1038/scientificamerican0609-54

For the nursery and greenhouse industry, constructed wetlands offer producers a relatively inexpensive approach for treating runoff containing nutrients, pesticides, and other organic contaminants; thus, allowing compliance with increasingly stringent environmental regulations regarding the discharge of nonpoint-source pollutants.

Three types of constructed wetland systems exist: surface-flow (free-water surface), subsurface-flow (horizontal or vertical flow), and floating wetlands (floating vegetated mat systems). Surface-flow and subsurface-flow constructed wetlands are commonly used to treat agricultural wastewater. This publication primarily addresses design considerations for surface-flow constructed wetlands, because the authors' research characterized the fate of nutrients from production runoff in surface-flow constructed wetlands.

Nutrient Cycling in Constructed Wetlands

Nitrogen and phosphorus cycle through wetlands in a variety of ways: the simplified nutrient cycling scheme (Figure 1) depicts various pathways by which both nitrogen and phosphorus are moved and transformed within a constructed wetland. Nitrate-N can be absorbed by plants in both the ammoniacal (NH_3-N) and nitrate (NO_3-N) forms. Nitrogen can also be denitrified by anaerobic bacteria to gaseous forms (N_2, NO, and N_2O); it can also be released from plants as ammonia-gas (NH_3).

Phosphorus is cycled through wetlands in both organic and inorganic forms. Some phosphorus is absorbed by plants, and then through natural cycling, the plant material decays and the phosphorus, now bound organically in plant tissues, is released back into the water column. Other phosphorus (usually in PO_4 form) may precipitate out of the water column through sedimentation processes. The main phosphorus removal mechanism in constructed wetlands is through phosphorus binding (sorption) to clay (Fe and Al sites) in sediments. Some phosphorus bound to clay may be available for plant uptake. Phosphorus can also desorb from soil particles and be re-suspended in the water column. Phosphorus can be exported from wetlands via various internal loading (plant decay, phosphorus desorption, sediment suspension) pathways.

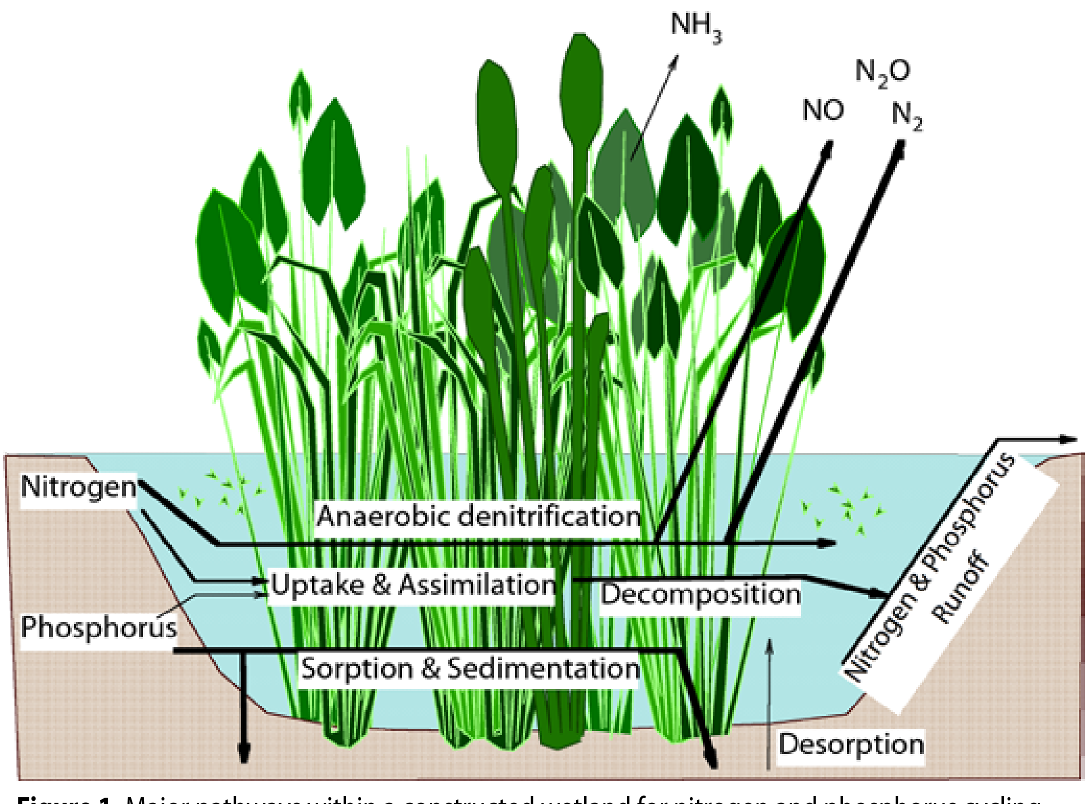


Figure 1. Major pathways within a constructed wetland for nitrogen and phosphorus cycling. Thicker lines represent a larger "sink" or transformation pathways, while thinner lines represent less prominent nutrient removal, storage, or release mechanisms.

Nursery Case Study

Monrovia® - Cairo, GA

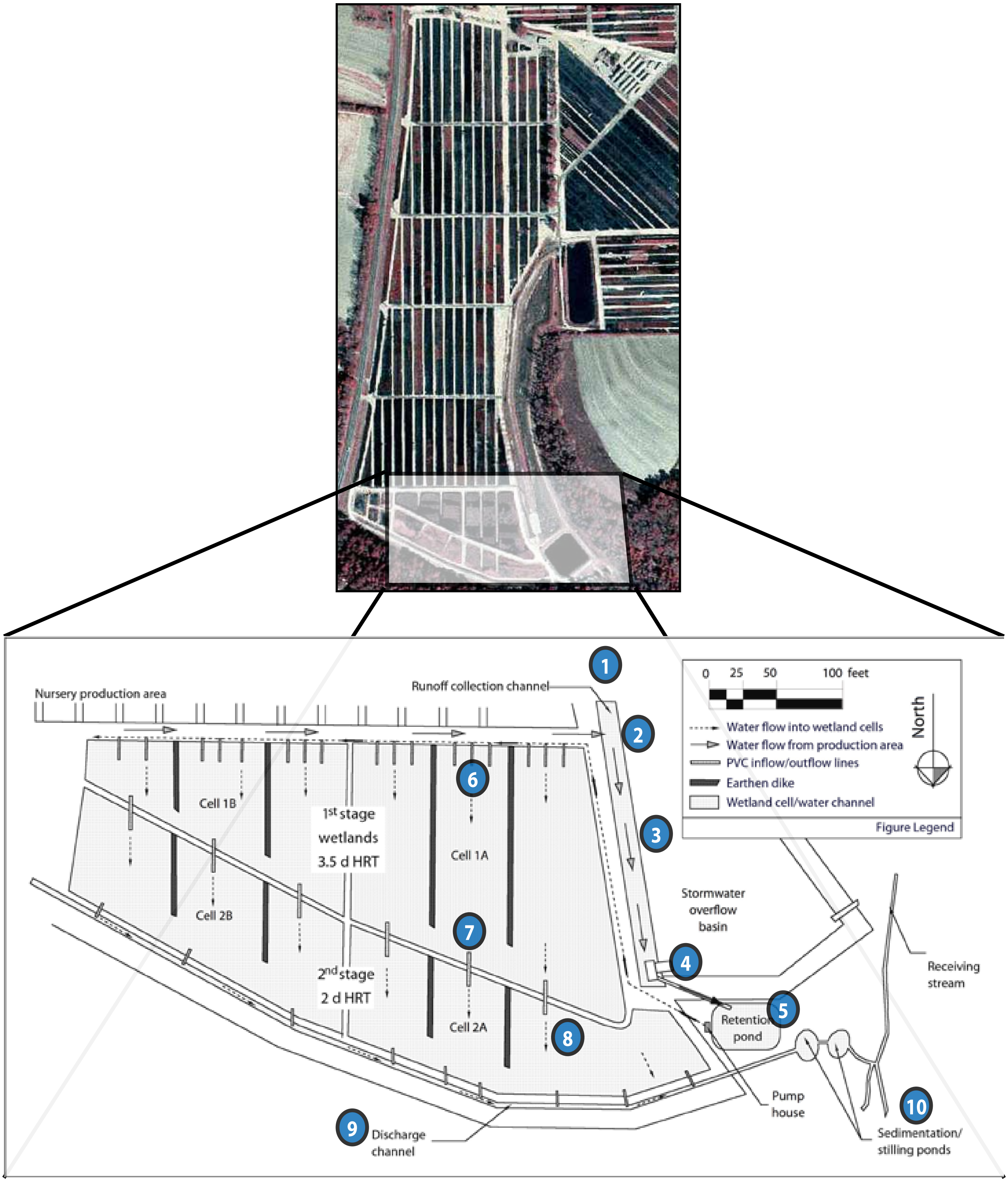
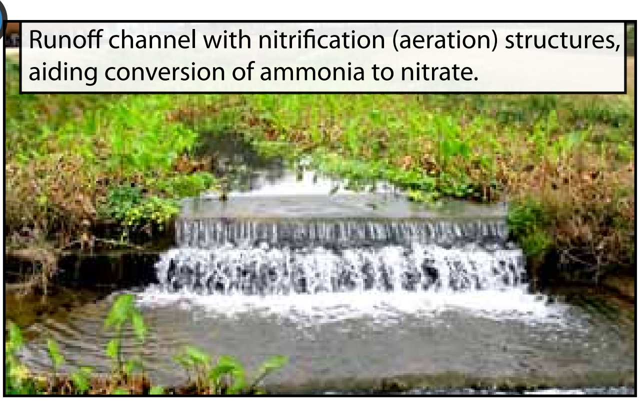


Figure 2. 9.3-acre surface-flow constructed wetland at Monrovia® Growers Nursery. Numbers correspond to the various stages pictured and described on p. 5.

1

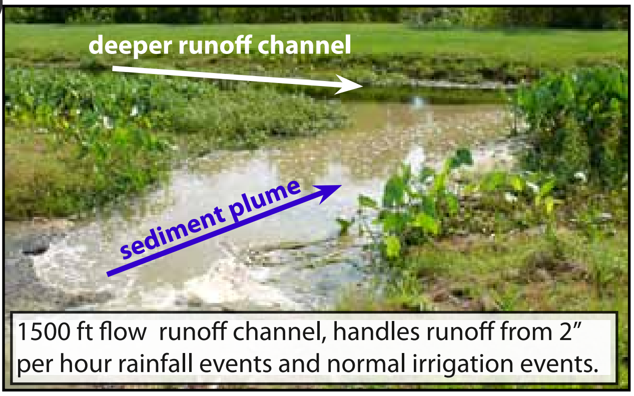


Runoff channel with nitrification (aeration) structures, aiding conversion of ammonia to nitrate.

2

Runoff collection channels from nursery beds flow into the main flow/runoff collection channel.

3

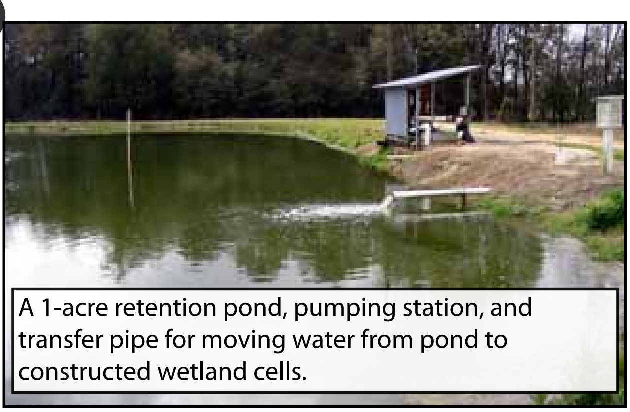


1500 ft flow runoff channel, handles runoff from 2" per hour rainfall events and normal irrigation events.

4

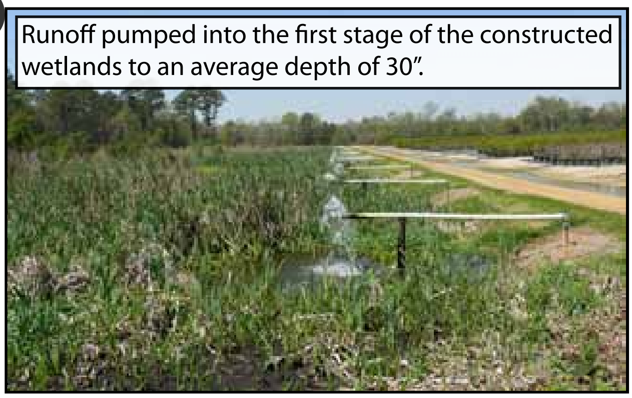
500 ft, concrete flow control channel permits capture of first $^1/_2$" of a rainfall event before overflow begins into stormwater overflow basin.

5



A 1-acre retention pond, pumping station, and transfer pipe for moving water from pond to constructed wetland cells.

6

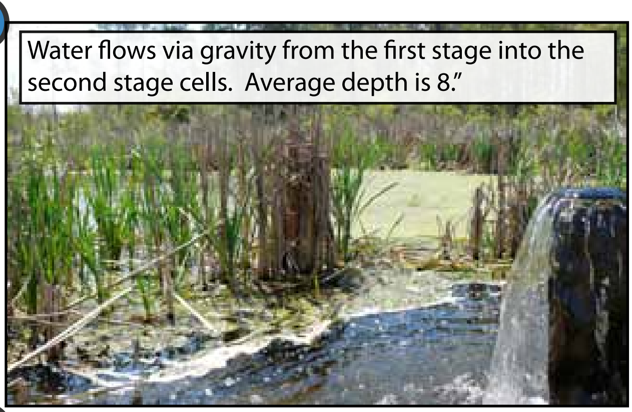


Runoff pumped into the first stage of the constructed wetlands to an average depth of 30".

7

First stage vegetation initially established in bands, but colonization of new plant species occurs rapidly.

8



Water flows via gravity from the first stage into the second stage cells. Average depth is 8."

9

Discharge channel from second stage of the wetland cells leads to stilling ponds.

10

Stilling pond (recently dredged) removes sediment that settles out of the water column before the water is released off-site

In 2002, we began monitoring a surface-flow wetland receiving runoff from nursery production. Monrovia Growers® in Cairo, GA installed a 9.3 acre surface-flow constructed wetland (Figure 2) in 1997. The constructed wetland receives runoff from ~120 acres of nursery production. Water from the production area flows down a series of collection channels 1-4 and into a holding pond 5. From the holding pond, water is pumped into the upper end of the wetland system 6 and flows by gravity 7-9 until it enters a series of stilling ponds 10 before its final release into a nearby stream. Typical daily flow through the wetlands ranges from 423,000 to 1,200,000 gallons.

Terminology to clarify the following discussion about constructed wetlands:

- Effluent - the water running out of the constructed wetland.
- Influent - the water flowing into the constructed wetland.
- Hydraulic Retention Time (HRT) - the amount of time it takes for water to travel from wetland inflow 6 to outflow 9. The wetland has a HRT of 3.5 days in the 1st Stage and a total HRT of 5.5 days.
- Load - the concentration (in ppm) of a nutrient (nitrogen or phosphorus) multiplied by the volume of water that nutrient is in - basically the amount of nutrient in the water flowing into (influent) a wetland.
- Removal efficiency is expressed as a percent and represents the efficiency by which a nutrient is removed using wetland processes. It is calculated by dividing the effluent nutrient concentration by the influent nutrient concentration and multiplying the answer by 100.

Nitrogen Lessons

- Nitrogen remediation in the surface- flow wetland was cyclical and changed predictably by season (Figure 3).
- Periods with highest nitrogen remediation efficiency occurred when water temperatures were warmest (Figure 4) and at times when nursery irrigation and fertilization rates were at their peak.
- Removal efficiency declined during winter, but nutrient loading from nursery bed runoff was also lower.

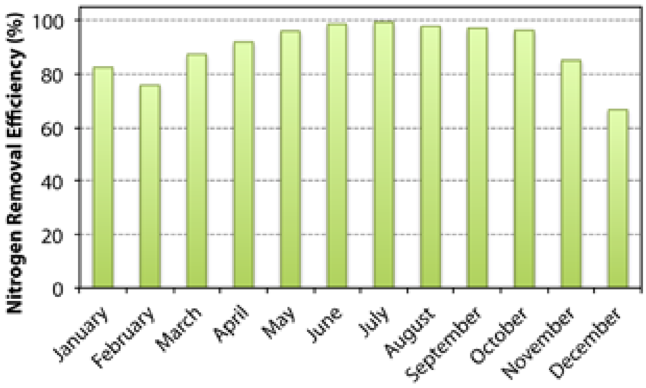


Figure 3. Average nitrogen removal efficiency in a surface-flow constructed wetland system over 5-years.

- Nitrogen removal rates closely mimicked loading rates (Figure 5). This means that for almost every unit of N loaded into the wetland system one unit of nitrogen was removed (1:1 black line).

Peak nitrogen removal efficiency occured during peak nitrogen loading. Constructed wetlands are designed to manage peak loads.

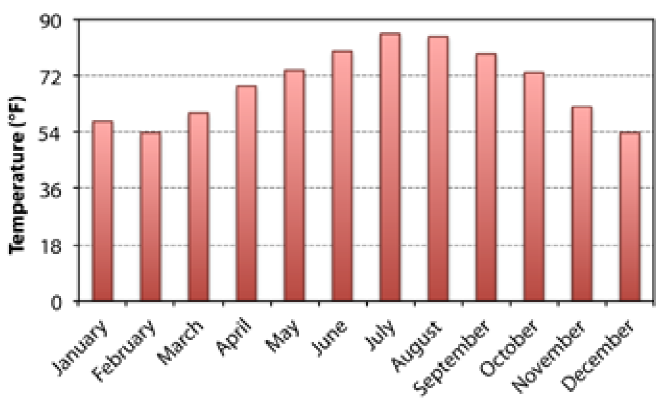


Figure 4. Average water temperature measured in a surface-flow constructed wetland over 5-years.

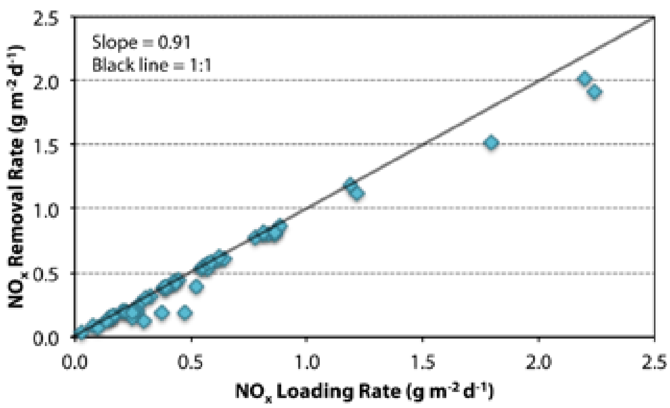


Figure 5. Nitrogen loading rate vs. removal rate - for every N unit loaded almost every unit of N is removed.

Phosphorus Lessons

- Phosphorus loading and removal were highly variable in the constructed wetland.
- Phosphorus influent loading tended to be highest during the spring (Figure 6).
- Phosphorus loading from nursery sources declined dramatically from 2004 to 2005 as Monrovia® growers reduced phosphorus fertilization rates.
- Reduced phosphorus fertilization rates dramatically lessened phosphorus loss from containers, *reducing phosphorus waste and fertilization costs*.
- As phosphorus influent load declined phosphorus removal efficiency in the constructed wetland declined (Figure 7).
- The wetlands "assimilated" phosphorus for short periods of time (usually when plants were actively growing - blue bars), but mainly exported phosphorus as the phosphorus influent loading rate decreased (green bars, Figure 6).

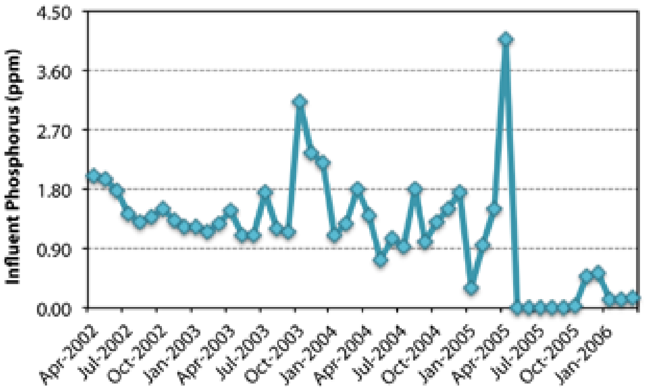


Figure 6. Influent phosphorus concentration in a surface-flow constructed wetland system over 5-years.

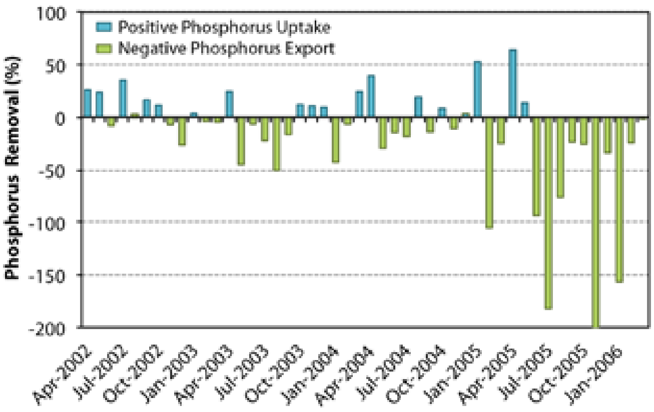


Figure 7. Phosphorus removal efficiency in a surface-flow constructed wetland system.

- Phosphorus removal in wetlands is mainly due to binding to sediment particles. As phosphorus binding to sediment nears a "saturation" point, phosphorus release from soil can occur.

No clear phosphorus assimilation patterns could be characterized.
Phosphorus cannot be consistently removed by surface-flow constructed wetlands.

We needed to develop an alternative treatment plan for phosphorus removal- so we took the problem back to the laboratory for additional study.

Natural floating islands formed within the first stage of the constructed wetland cell.

In the fall, smooth beggarstick (*Bidens laevis*) blooms throughout the second stage constructed wetland cells

Phosphorus Remediation in Small-scale Subsurface-Flow Constructed Wetlands

Phosphorus Binding to Clay Aggregate: Laboratory Trials

- Clay aggregate can be used to treat phosphorus rich water because minerals within clay can bind phosphorus, removing it from runoff.
- We evaluated multiple clay aggregate for their capacity to bind phosphorus to find an aggregate best suited to nursery production conditions and remediation needs.
- Two promising clay aggregates were chosen from laboratory experiments and further evaluated in *subsurface-flow constructed wetlands*. We wanted to find a clay aggregate that had:
  - › Great phosphorus binding longevity when used in subsurface-flow constructed wetlands, and
  - › A high binding capacity, so large amounts of phosphorus can be removed during treatment.
- The clay aggregates chosen were:
  - › Calcined clay (a palygorskite bentonite clay, industrial product) and
  - › Crushed brick (a building by-product)

A

B

Pilot-scale experiment to determine the effect of calcined clay and brick lined subsurface-flow wetland treatment cells that were either planted or unplanted. (A) May and (B) September 2007.

Use clay-based substrates to fill subsurface-flow constructed wetlands to bind phosphorus from runoff.

Phosphorus Binding: Field Trials

- Each clay aggregate filled a 50-gallon tank to mimic subsurface-flow constructed wetland conditions; each tank was either planted or not-planted to determine if vegetation improved nutrient removal efficiency and longevity.
- Subsurface-flow treatments averaged more than 80% phosphorus removal efficiency (Figure 8) - the red line represents 80% removal efficiency.
- All clay treatments had similar phosphorus removal efficiency until the non-vegetated (not planted) brick subsurface-flow treatments became phosphorus saturated (Figure 8).

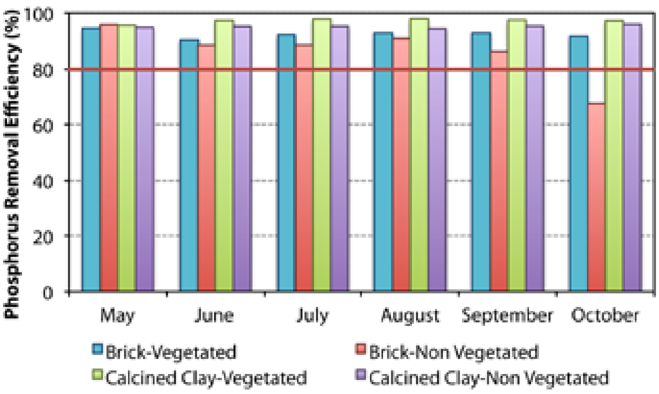


Figure 8. Phosphorus removal efficiency in subsurface-flow constructed wetland cells filled with clay aggregates.

Planting subsurface flow wetlands enhances phosphorus removal and increases clay substrate longevity.

Phosphorus Saturation Point

- Eventually, phosphorus binds to all available sites within the clay aggregate, and phosphorus removal efficiency decreased as the clay became phosphorus saturated (Figure 8, October: Brick-Non Vegetated).
- When clay binding sites fill, no additional phosphorus can be bound and phosphorus will begin to desorb (Figure 9).
- The red line in Figure 9 represents effluent phosphorus concentration in the Brick-Non Vegetated tanks.
  - › Phosphorus began to desorb from the brick in Sept. and dramatic phosphorus release from brick occurred in October.

Brick binds ≈ 100 mg P / kg substrate.

Calcined clay binds ≈ 300 mg P / kg substrate.

Calcined clay aggregates bind phosphorus effectively for 6 to 12 months depending on phosphorus loading rates.

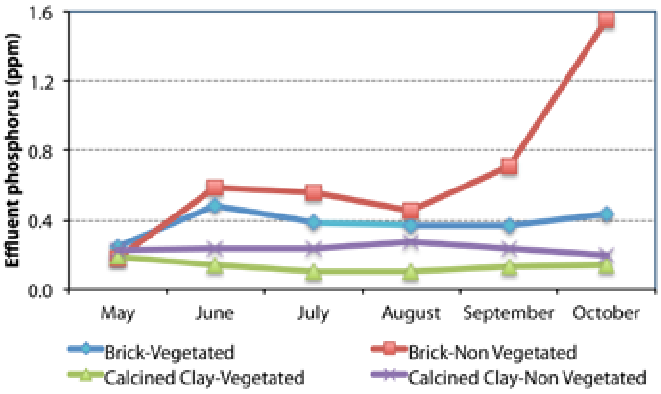


Figure 8. Effluent phosphorus concentrations from subsurface-flow constructed wetland cells filled with clay aggregates.

- pH can influence phosphorus binding and precipitation in constructed wetlands.
  - › pH 4.0 - 6.5: Aluminum and iron precipite with phosphorus
  - › pH 7.5 - 8.5: Calcium and magnesium precipitate with phosphorus
  - › Calcined Clay pH ≈ 6.5 - 7.5 - *sorption* likely driving phosphorus removal
  - › Brick pH ≈ 7.5 - 9.0 - *precipitation* likely driving most phosphorus removal
- Nutrient remediation in constructed wetlands is complex and requires a "mixed" approach using:
  - › Surface-flow constructed wetland cells to remediate nitrogen, and
  - › Subsurface-flow constructed wetland cells filled with clay aggregate to remediate phosphorus.
- Constructed wetland nutrient remediation efficiency can vary with climate. But plant choice and treatment time can be adjusted to achieve desired nutrient limits. Table 1 lists the nutrient remediation efficiency of constructed wetlands established in various clamatic conditions.

Implement routine effluent sampling to monitor phosphorus levels; replace clay aggregate when phosphorus concentrations in effluent increase above predetermined limits.

Table 1. Surface- and subsurface-flow constructed wetland nutrient remediation efficiency in various climatic conditions.

Wetland Type	Location	Age (years)	HRT (day)	Influent (mg/L)		Effluent (mg/L)		Removal Efficiency	
				N	P	N	P	N	P
Surface-Flow	Arizona, USA[5]	7	4.0	2.8	-	1.3	-	54%	-
	California, USA[2]	2	1.6	15.6	0.3	8.4	0.4	46%	-33%
	Connecticut, USA[4]	4	12.0	102	25.7	73.0	14.1	28%	45%
	Georgia, USA	9	5.5	7.8	1.2	0.7	1.2	91%	0%
	Washington, USA[1]	6	6.5	2.1	-	0.7	-	63%	-
Subsurface-Flow	Czech Republic[6]	14	-	50	10.1	29.7	7.0	41%	31%
	New South Wales, AU[3]	1	2.0	5.7	0.6	0.5	0.2	84%	66%
	New South Wales, AU[3]	1	4.0	5.7	0.6	0.4	0.1	90%	78%

[1]Beutel et al. 2009. Ecolog. Eng. 35, 1538-1546; [2]Díaz et al. 2010. Agric. Waste Manag. 97, 1813-1821; [3]Headley et al. 2001. Water Sci. Tech. 44(11-12), 77-84; [4]Newman et al. 2000. Ecolog. Eng. 14, 181-198; [5]Kadlec. 2008. Ecolog. Eng. 33, 126-141; [6]Vymazal. 2009. Desal. 246, 226-237

Implementation Checklist

PLANNING

Many important aspects of a wetland must be considered before construction can begin. Wetland planning consists of the following steps in the wetland checklist.

Step One:	Information Gathering
Step Two:	Consult with an Expert
Step Three:	Site Selection
Step Four:	Time for an Engineer

Step One: Information Gathering

*This step is **critical** because wetland design plans must be specific to <u>your</u> site*

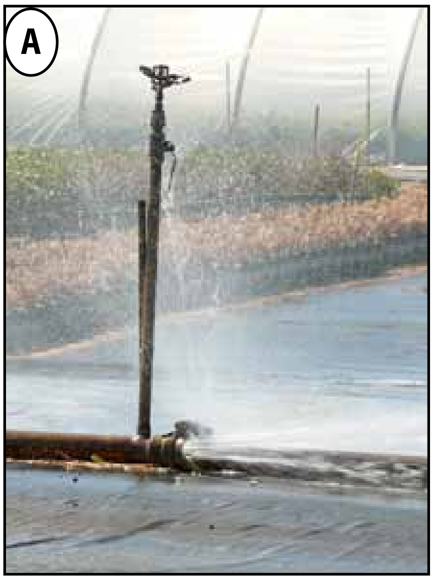
Before taking steps to install a wetland these questions must be answered:

1. What is the area of the land in production at your nursery?
2. How much water do you use per day?
3. What is the amount of runoff each day for various times of the year?
4. Have you implemented practices to decrease runoff volume?
5. Is stormwater management and containment necessary?
6. What are the nutrient and pesticide loads in your runoff?
7. Have you implemented practices to decrease negative production effects on water quality?
8. Does all of your runoff drain to the same area of your property?
9. If a constructed wetland is the right choice to manage your runoff, where is it best placed on your site?

The answers to these questions will serve as the basis for the remainder of your planning processes, and help as you consult with an expert to begin making design and construction decisions.

Also think about these important factors:

- Natural wetland systems can serve as a guide during planning and construction.
- Natural topography should guide wetland construction in both shape and orientation.
- Wetland cell number(s) should be dictated by runoff quality and quantity.
- Consider future nursery expansion plans throughout the wetland planning and construction process.
  - › Either by including runoff capture from future production areas into planned wetland size, or by
  - › Planning for additional cell construction during the initial design process.



Fix leaks and inefficient irrigation practices to reduce runoff volumes (A). Manage erosion to reduce sediment release of nutrients and pesticides (B). Evaluate water conveyance infrastructure to determine where wetland should be sited to best treat and cleanse runoff (C).

Step Two: Consult with an Expert

After you have answered the questions from Step One or if you need help answering some of them, contact one of the authors and then contact a representatives from your local Natural Resource Conservation Service and/or the Army Corps of Engineers so that appropriate permission and licenses are obtained. If you are not certain who to contact in your region, ask your local Extension Specialist for help in directing you to the appropriate personnel.

An on-site consultation is highly recommended to make sure that initial design considerations are adequately defined. Your consultant will be able to answer any remaining questions and walk you through the remaining steps necessary for constructed wetland construction.

You should be able to:

- Select a system type
  - *Surface-flow*
  - *Subsurface-flow*
- Determine how to configure the system
- Select design criteria for engineering
- Determine how much land will be required
- Determine the objectives of the constructed wetland
  - *Cleansing for release off-site*
  - *Cleansing for reuse/recirculation within your nursery*

Adequate retention times are dependent upon the target contaminant. The site selected should be large enough for current needs plus sufficient in area to accommodate future expansion.

Step Three: Site Selection

Time spent in careful site selection and wetland orientation will significantly lower construction costs. Land availability, topography, and soil types should all be considered. The wetland should be close to the source of the runoff to minimize the need for long ditches and pipes. Additionally, it should be downhill from the source whenever possible to minimize pumping. Large amounts of grading and earth moving can significantly raise construction costs.

Well-suited sites have the following characteristics:

- Close to the runoff source
- Large enough to accommodate the volume of runoff relative to the size of the wetland
- Sloped, but not excessively, to allow gravity flow of water without excessive erosion
- Contains soils that will prevent seepage (clay soils ideal)
- Above the water table
- Not on the flood plain
- Contain no threatened or endangered species
- Contain no archaeological or historical resources
- Not adjacent to residential areas
- Not near the edge of your property (allowing for buffer creation)

Land slopes to direct water flow into the narrow treatment wetland.

Also consider the following items as you select a site

Land Use and Access

Wetlands should be sited so that gravity drives water flow. Typically, they should not be located near residential areas. Areas should be easily accessible to earth-moving equipment and maintenance personnel. Be sure to include a large buffer zone surrounding the wetland to preemptively alleviate any problems that might result from the opinions of nearby landholders.

Land Availability

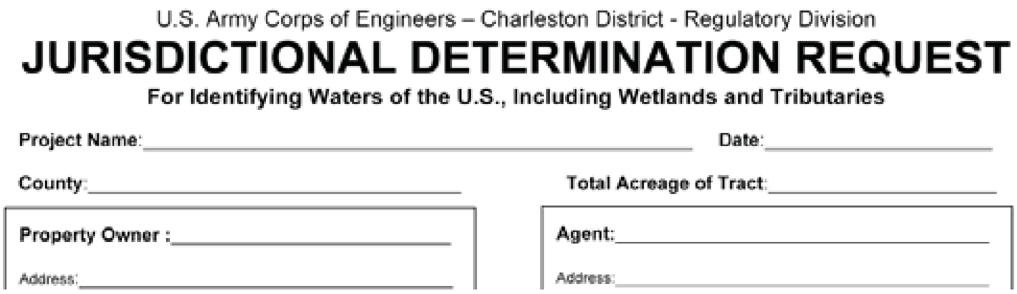
Since retention time (the amount of time that water is in a wetland) is critical for treatment efficacy, wetlands must be large enough to allow for adequate holding times.

Adequate retention times are dependent upon the target contaminant. The site selected should be large enough for current needs plus sufficient area to accomodate future expansion.

Topography and Environmental Resources

Gently sloping sites can be readily modified to hold water, which allows for least costly construction.

Always make sure that the area is not already designated as a wetland. The Army Corps of Engineers can help you determine if your proposed site already contains wetlands or if it is delineated as a floodplain.



U.S. Army Corps of Engineers – Charleston District - Regulatory Division

JURISDICTIONAL DETERMINATION REQUEST

For Identifying Waters of the U.S., Including Wetlands and Tributaries

Project Name:______ Date:______

County:______ Total Acreage of Tract:______

Property Owner :______ Agent:______

Address:______ Address:______

Permits and Regulations

Permitting requirements and water regulations will be specific to individual areas since state and municipal water standards vary in both existence and enforcement. *Contact state agencies now* to gather information on any requirements regarding wetland construction and water discharge. Typically, runoff discharge into any natural water source will require a permit.

Most states and many local municipalities have storm water ordinances *or* regulations that need to be followed. A discussion with a state agency may be necessary prior to *permitting* to evaluate the relationship between your wetland and all other nearby bodies of water.

Step Four: Time for an Engineer

By the time you have sorted out all of the answers and a wetland expert has reviewed your calculations and helped you finalize a preliminary plan, you are ready to speak with a civil engineer regarding the next phase of the project. An engineer will help you refine the initial plan by looking at the hydrology (water flow) of your proposed system and determining specifically these features:

- How big the wetland needs to be
- Soil suitability for wetland construction
- Final site and orientation selection
- Workability of your initial site selection
- Kinds and amounts of grading required to properly direct, collect, and detain water

With answers to these questions, a wetland construction plan can be drawn. Your plan will take into account many factors important to the remediation efficacy of the wetland, including a series of structures:

Cells

Cells are the units of constructed wetlands and are constructed by digging to create basins or by constructing dikes. When constructing a dike, the soils used must have small particle sizes that can be compacted to create a bank that will not allow water penetration. The height of the dikes should take into consideration the intended normal water volume, buildup of detritus, sediment deposition, and potential high water flows.

Dike sides should be sloped, and the vertical dimension should never be less than twice the height. Typically the bottom of the cell should be flat.

Bottom of wetland cells should be flat to permit even water drainage and flow for future wetland remediation efficiency.

Soils in dike and bottom of cells must have small particle size and compact readily to restrict water penetration.

Liners

Some precaution must be taken to ensure that water from the wetland does not mix with water in the environment. Clay soils can often be compacted to create a seal that is sufficient to prevent water from escaping.

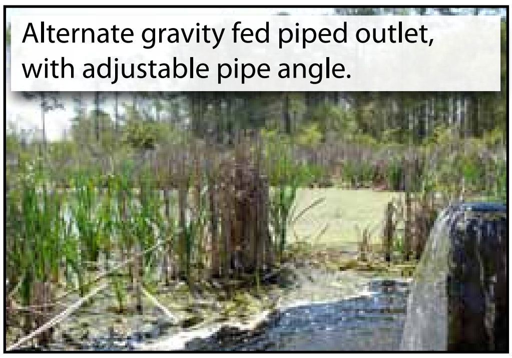
Sandy soils or others with large amounts of pore space will require additional methods. Laboratory analysis of the soil may be required before a sealing method can be selected.

A synthetic liner is not necessary if the native soil restricts water movement in a similar manner (i.e. if its coefficient of permeability is less than or equal to 1×10^{-7} cm/sec). Typically, soils that contain ≥ 15% clay can be compacted sufficiently so that a synthetic liner is not needed. In cases where additional lining is required, several options can be utilized including asphalt, synthetic butyl rubber, and plastic membranes. Special precautions must be taken when using pliable synthetic liners to prevent them from being damaged by stones and plant roots.

Inlets direct water into wetland cell

Outlet pipe to gravity feed water from one cell to next

Gravity fed outlet. Pipe angle can be adjusted to alter flow rate & pool depth



Alternate gravity fed piped outlet, with adjustable pipe angle.

Flow Control Structures

Flow control structures are used to control water levels in the wetland and typically include inlets and outlets. Their construction should allow for easy manipulation of water levels so that the wetland's efficacy can be maximized. All of the inlets should be independently adjusted to control flow distribution. Insure that all flow control structures are protected from possible animal or inadvertent human damage.

Inlets are pipes or channels that direct water into the wetland. As the length to width ratio of the wetland gets smaller, flow distribution becomes more critical. Inlets serve as the point of distribution control in wetlands with smaller length to width ratios. Inlets are generally 12-24 inches above the water surface with gravel or coarse rock directly underneath to prevent ponding and to allow for quick infiltration. Avoid open water near inlets to prevent algal growth.

Outlets are responsible for controlling water levels in wetlands. The responsible structure is typically a weir, spillway or riser pipe. Weirs can be adjustable as can riser pipes, while spillways are not adjustable. Water height is critical so adjustable height outlets can be easier to use. Outlet structures must be set up to allow for maximal flow. Slopes for spillways should be the same as those of normal dikes and should be lined with fabric or riprap to prevent gradual erosion of the spillway, which might lower water levels. Ensure that the discharge is high enough above any water levels to avoid system back-up in the event that the river or stream is at flood stage.

CONSTRUCTION & ESTABLISHMENT

After planning is complete, many important aspects of a wetland must be considered. The following steps are important for wetland construction and establishment.

Step Five:	Construction
Step Six:	Plant Establishment
Step Seven:	Filling the Wetland

Step Five: Construction

A knowledgeable contractor and skilled equipment operators will be required for this phase of the project. All plans should be reviewed and discussed with the engineer and the contractors during a pre-bid meeting. This meeting will provide an opportunity to explain the nature of the project. Many experienced contractors have never worked with constructed wetlands.

After a contractor is selected, a conference should be held with operators, the contractor, the civil engineer, and representatives from the Army Corps of Engineers and/or Natural Resource Conservation Service. This will provide an opportunity for all questions to be answered before work begins. Planning and pre-construction activities should be similar in scale to the size and complexity of the wetland project itself.

There are several different activities that must be considered during wetland construction. They include:

- Building access roads
- Clearing wooded areas
- Constructing dikes
- Digging basins
- Installing pipes and valves
- Mulching all disturbed areas
- Minimizing impacts on existing surface water resources

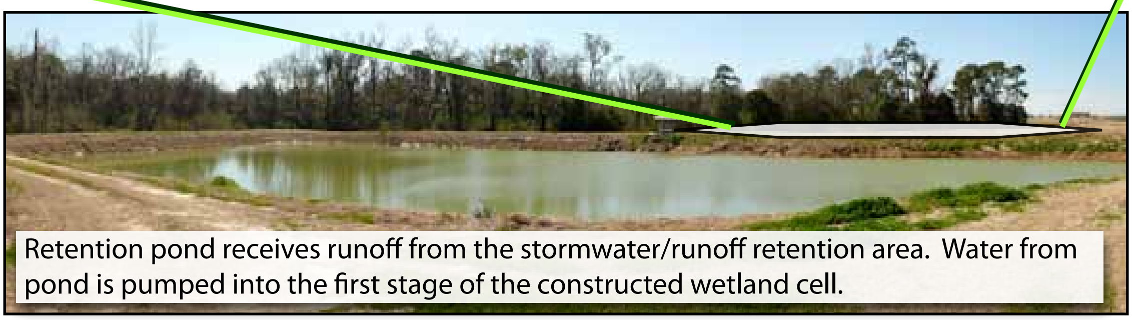
Note: Proper equipment selection is critical. Equipment size and type are important elements because a poor equipment choice can result in significant cost increases. Also, ensure that construction is following the plan, and address concerns as quickly as possible.

Access road between wetland cells for maintenance and monitoring tasks.

Dike construction to direct water flow and maintain pool depth in wetland cells.

Cell lined with bark mulch to provide organic matter for plant material.

Runoff retention area funnels runoff from production areas and the first 1/2" of rainfall into the retention pond.



Retention pond receives runoff from the stormwater/runoff retention area. Water from pond is pumped into the first stage of the constructed wetland cell.

Step Six: Plant Establishment

After grading and all other soil moving efforts are complete, the bottom of the wetland should be planted.

Plants chosen to colonize the wetland should be based on:

- *Water characteristics*
- *Soil type*
- *Wetland location*

Various semi-aquatic and aquatic plants are propagated for use in wetlands (Table 2). Plan for diversity when choosing species to establish a wetland.

Planting is typically done by hand using:

- Seeds (easiest and quickest)
- Seedlings or liners
- Storage organs (rhizomes, tubers, etc.)

Immediately following planting, small volumes of water should be added to the wetland to aid in plant establishment. After rooted plants are established, slowly raise the water level.

Various plant species will colonize a wetland over time, enhancing species diversity and wetland function.

Plants are placed in linear bands across the wetland and water level is slowly raised.

Canna 'Bengal Tiger'

Canna flaccida

Iris 'Full Eclipse'

Panicum hemitomon

Pontederia cordata

Typha latifolia

Sagittaria latifolia

Schoenoplectus californicus

Table 2. List of plant species recommended for use in surface- and subsurface-flow constructed wetland systems. Many of these recommended species accumulate extra nitrogen and phosphorus into their foliage and root system.

Habit	Common name	Botanical name	Height	Location[1]	Hardiness Zone	Invasiveness Potential[2]
Grasses	Redtop bentgrass	*Agrostis alba*	1.5 - 2'	Emergent	3 - 8	Moderate - High
	Maidencane	*Panicum hemitomon*	2 - 2.5'	6"	5b - 10	Low
Perennials	Broadleaf arrowhead	*Sagittaria latifolia*	3 - 4'	12 - 18"	2 - 11	Moderate
	Bulltongue arrowhead	*Sagittaria lancifolia*	1 - 3'	12"	7 - 11	Low
	Bulrush	*Schoenoplectus* spp., *Scirpus* spp.	3 - 12'	6 - 12"	2 - 11	Low
	Canna	*Canna flaccida*	2 - 4'	6"	7 - 11	Low
		Canna 'Australia,'	6 - 8'	3"	> 9	
		'Bengal Tiger,'	6'	3"	7b - 10	
		'Red King Humbert,'	4 - 6'	Emergent	8 - 11	
		'Yellow King Humbert'	4 - 6'	3"	8 - 11	
	Cattail	*Typha* spp.	5' - 10'	12 - 18"	2 - 11	High
	Elephant ear	*Colocasia esculenta* 'Black Magic'	1 - 2'	3"	8 - 11	Low
	Iris	*Iris ensenata 'Variegata,'*	2 - 3'	3"	4 - 9	Low
		Iris laevigata,	1 - 2'	10"	5 - 9	
		Iris 'Full Eclipse'	3 - 4'	8"	6 - 10	
	Pickerelweed	*Pontederia* spp.	2 - 3'	12"	3 - 9	Medium
	Red-stemmed thalia	*Thalia geniculata*	2.5 - 6'	12 - 18"	7 - 10	Low
	Sedge	*Carex* spp., Cyperus spp.	1 - 2.5'	3"	2 - 11	Low
	Soft rush	*Juncus effusus*	1 - 4'	3"	2 - 11	Medium

[1]Location - growth location from emergent (crown kept dry) to water depth tolerated

[2]State dependent- check your state weed listing

Step Seven: Filling the Wetland

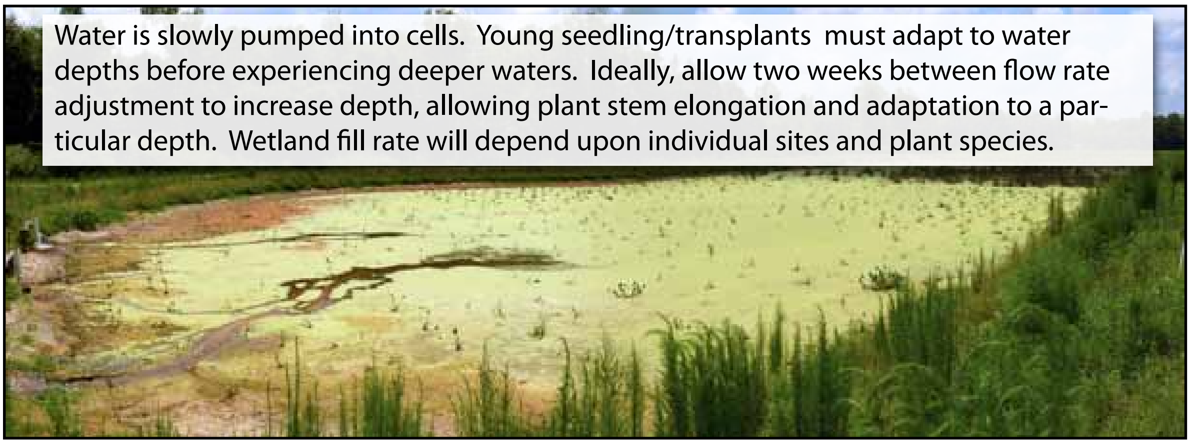
Before planting, the wetland "plumbing system" should be tested. After construction is complete, slowly add water to the wetland to ensure the proper functioning of all the water lines, pumps, and outlets. After verifying mechanical operations, permit a brief dry-down for planting and plant establishment and then continue to slowly fill the wetland.

Wetland remediation/treatment efficiency will not be optimal in the weeks during and immediately after filling. When filling wetlands avoid influx of large volumes of:

- Nutrient rich water (> 20 ppm N and > 5 ppm P)
- Polluted water (pesticide-rich runoff to avoid phytotoxicity in establishing wetland plants)

Consistent, yet low water flow rates should be maintained to avoid stagnation and provide nitrogen to establishing plant species. This period of partial use will also permit microbial communities to develop and adapt to wastewater components.

Nine to ten months after filling, the wetland should be established and ready to remediate wastewater. Over the next few years, remediation efficacy will increase as species diversity increases, providing more sinks/mechanisms for removal of nutrients and pollutants released into the wetland.



Water is slowly pumped into cells. Young seedling/transplants must adapt to water depths before experiencing deeper waters. Ideally, allow two weeks between flow rate adjustment to increase depth, allowing plant stem elongation and adaptation to a particular depth. Wetland fill rate will depend upon individual sites and plant species.

Three months after filling the wetland began, water levels are nearing full pool after the slow filling, which permitted vegetation growth and establishment above water line.

Ten months after wetland fill reached full pool, wetland plants have attained mature size and wetland remediation capacity is acceptable for wastewater treatment.

OPERATION

Peak wetland function requires periodic maintenance, many important aspects must be considered. Operational concerns consist of the following steps:

Step Eight: Monitoring
Step Nine: Maintenance

Step Eight: *Monitoring*

For the first few years of operation, regular samples (every four weeks - or more frequently depending on the contaminant of concern) should be collected from wetland inlets and outlets, especially where water exits the property.

Minimum laboratory water analyses should include nitrate, phosphate, total phosphorus and pesticide concentrations (if pesticide runoff is a concern). On-site water quality monitoring should include: dissolved oxygen, water temperature, EC (total dissolved salts or conductivity), and pH (see Table 3).

If nutrient concentrations in inlet water samples are consistently high, overfertilization of production areas is occurring. By gradually reducing fertilization inputs and monitoring inlet nutrient concentrations over time, you can develop appropriate fertilization rates for crops grown, and cost savings are possible due to decreased fertilization rates. After the first few years, inlet sampling may be reduced.

Outlet sampling helps maintain water quality control over the life of the wetland. This should be continued to ensure adherence to regulated nutrient limits.

Table 3. Suggested ranges for water quality parameters measured in constructed wetlands using a meter and from water samples collected and submitted to a laboratory for analysis.

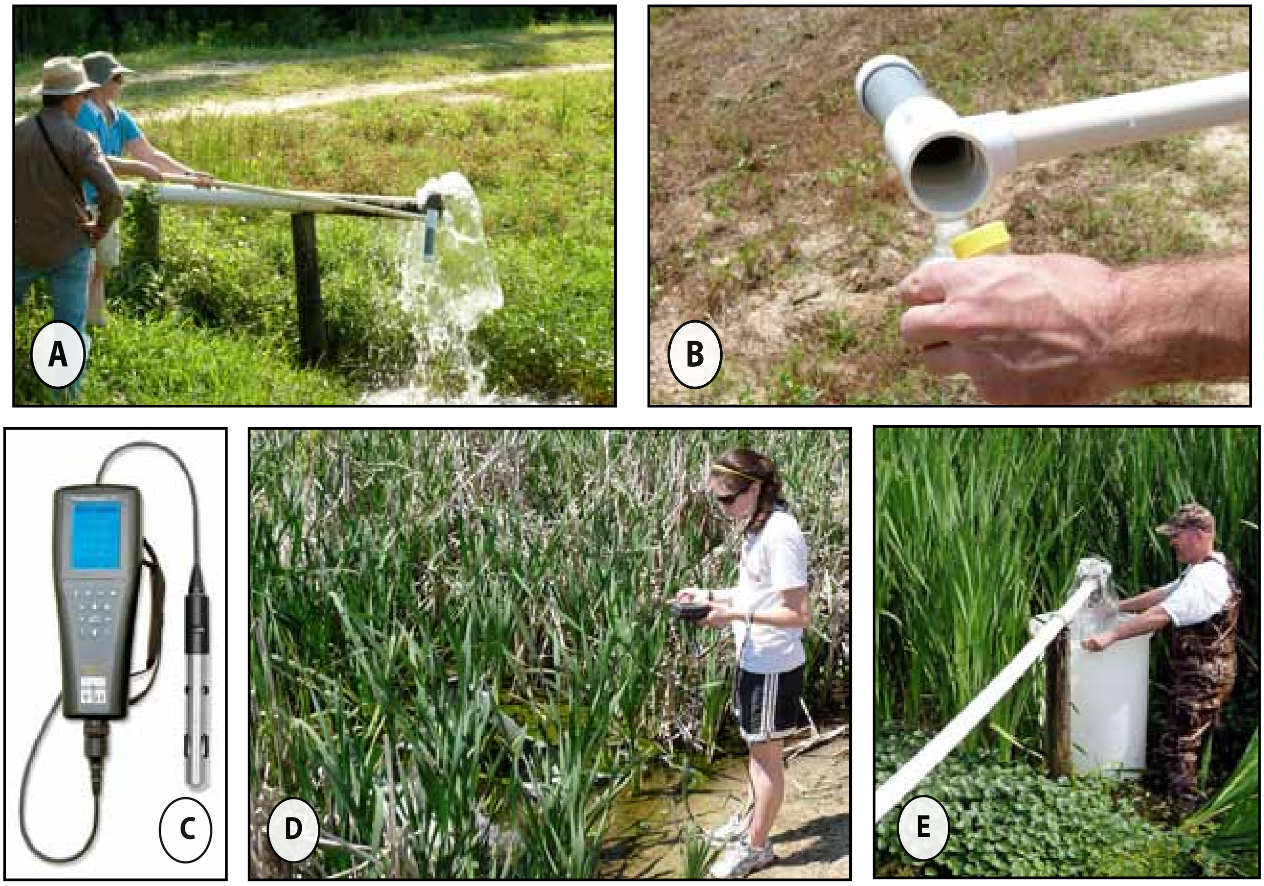
		Suggested Parameter Ranges			
Parameter	**Units**	**Establishing a Wetland**	**Using a Wetland**	**Effluent Reused for Irrigation**	**Effluent Released**
pH		6.0 - 6.5	[1]	[2]	[3]
EC	mmhos/cm	0.5 - 0.75	0.75 - 3.0	0.75 - 3.0	[3]
Dissolved Oxygen	ppm	[1]	[1]	4.00	5.00
REDOX	mVolt	[1]	(-) 100 - 300	-	-
Temperature	F	[1]	[1]	-	[3]
Sodium Adsorption Ratio (SAR)	meq	< 10	[1]	12 - 20	[3]
Sodium	ppm	< 70	< 100[1]	70 - 200	[3]
Alkalinity	ppm meq	< 40 - 90 < 0.7 - 1.5	[1]	90 - 520 1.5 - 8.5	[3]
Total Suspended Solids	ppm	< 50	> 50	< 50	[3]
NH_4^+ - Nitrogen	ppm	< 5.0	< 20[1]	[2]	[3]
NO_3^- - Nitrogen	ppm	< 20.0	< 100[1]	[2]	10.0, [3]
PO_4 - Phosphorus	ppm	< 5.0	< 20.0	[2]	0.05, [3]
Total Phosphorus	ppm	< 5.0	< 20.0	[2]	0.10, [3]

[1] Wetland will develop equilibrium state, depends upon wetland design choices.

[2] Limits set by nursery/greenhouse practices and treatment capacity.

[3] Check state or local regulations for limits, watershed dependent.

REDOX = reduction oxidation potential - see Glossary of Terms.



A. Collect water samples of about 1 pint from wetland inlets and outlets.
   1. Sample every two weeks for at least the first six months after wetland construction is complete.
   2. Once the wetland is established, water quality monitoring should occur on a monthly basis.
   3. If water flow to the wetland is disrupted for more than one week, monitoring frequency should increase to a weekly basis to determine when wetland treatment capacity has recovered or if additional corrective action should be taken.

B. For water samples sent to a laboratory for analysis:
   1. Collected water samples should be poured into approprite containers and stored on ice in a cooler or in a refrigerator until shipped. Sample bottles should be filled to the brim with little to no air-space remaining to prevent sample degradation.
   2. Ship same day or overnight to a qualified or certified laboratory - pack in an insulated box with an ice-pack so that the sample does not degrade.

C. For on-site water analyses, a multiparameter meter is useful for measuring pH, EC, TDS, dissolved oxygen, and water temperature.
   1. Dissolved oxygen and water temperature correlate with wetland health and also impact offsite surface water health and should be monitored to ensure the wetland effluent remains within acceptable limits (Table 3).
   2. If wetland effluent will be reused for irrigation, effluent pH, EC, and/or TDS should be monitored so that informed treatment and fertilization choices can be made (Table 3).

D. Collect and record on-site information each time you collect samples for laboratory analyses; this information can be measured using a multi-parameter meter or by using individual meters for each parameter of interest.

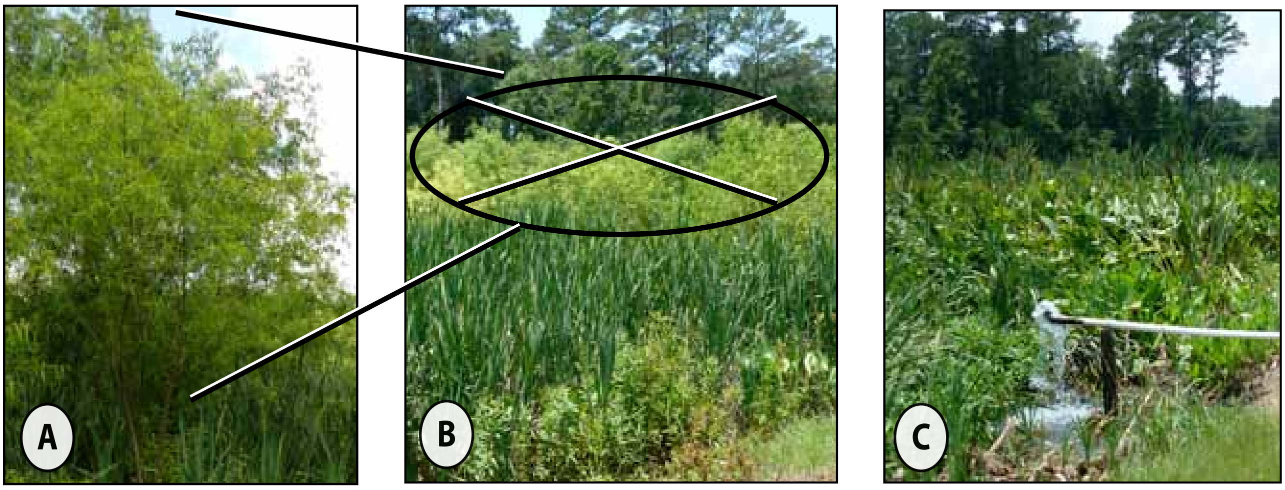
E. Periodic adjustment (calibration) of water flow rates into the wetland may be necessary. Maintaining the planned wetland hydraulic loading rate ensures that wetland hydraulic retention time is optimal for contaminant remediation.

Step Nine: Maintenance

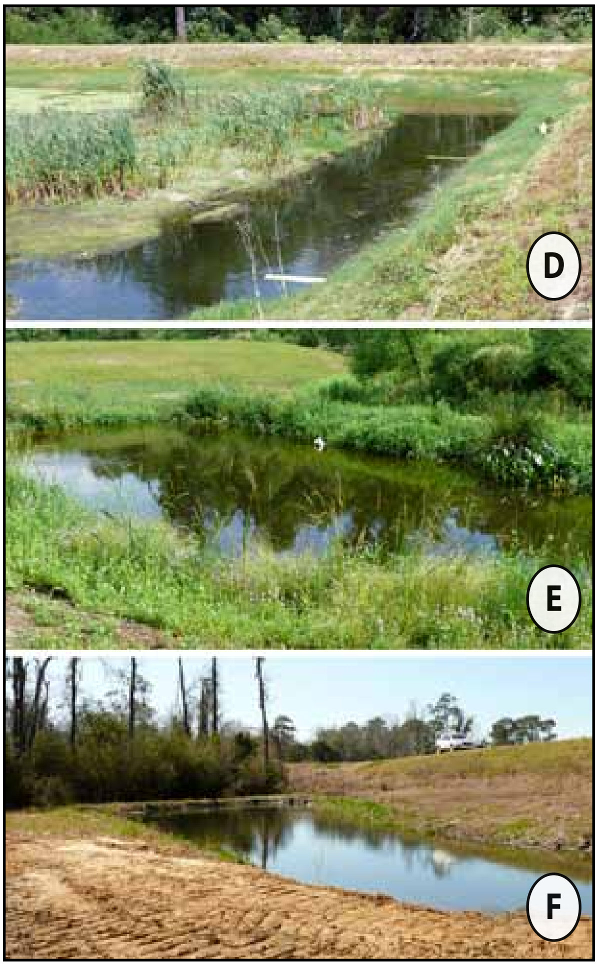
Wetland maintenance is relatively simple. Only a few tasks must be completed periodically to keep the wetland in good working order.

- Remove beavers/nutria from wetlands if they invade, because they will disrupt hydrology and short-circuit treatment efficiency
- Willows (*Salix* sp.) and other deep-rooted species should be removed from the wetland at regularly timed intervals.
  - Manual removal is effective for small plants.
  - Carefully targeted chemical means may be needed to control larger plants.

Roots of deep-rooted species can penetrate wetland hardpan, causing leaks, short-circuiting, and reduction of processing efficiency. In extreme circumstances, hardpan cracking can lead to ground water contamination.



Willow trees in an established wetland (A and B) should be removed (C). Ensuring that the wetland clay (plastic) liner is not disrupted and reducing the risk of groundwater contamination.



Other maintenance tasks include:

- Clearing vegetation from outlet pipes at end of wetland cells (D)
  - Ensures consistent flow from one wetland cell to the next
  - Reduces the chance of clogging and short-circuiting due to plant roots
  - Open water areas increase aeration and improve remediation of some nutrients
- Sediment removal from stilling ponds
  - Evaluate on a bi-yearly basis
  - Stilling ponds periodically fill with sediments and organic matter (E)
  - Sediment and organic matter can carry contaminants offsite during heavy rain events
  - Excess sediment can reduce settling time duration, resulting in sediment export
  - Periodic dredging and reshaping (F) of stilling ponds permits continued trapping and removal of sediment from wetland effluent

APPLICATION

The Final Step

Changing water quality from this

You now have the information you need to strategically plan and implement a constructed wetland to remediate runoff.

- Constructed wetland size and design style depends upon site-specific factors and can be tailored directly to your needs.
- Monitoring constructed wetland inflow may help you reduce fertilizer rates and save money.
- Constructed wetland effluent can be recycled and used as an alternative, cleansed water source for irrigation.
- Constructed wetlands are low maintenance tools that work for you throughout the year and help reduce your impact on the surrounding natural environment.


To this . . .

Glossary of Terms

Anaerobic- indicates the absence of oxygen, some other inorganic compound (such as nitrate or sulfate) is used as a final electron acceptor (energy source) by bacteria during respiration (metabolism, breakdown) of organic material (carboyhydrates).

Assimilate - to convert (nutrients/minerals) to substances suitable for incorporation into plant tissues.

Denitrification (denitrifier) - the conversion of nitrate to nitrogen gas. Denitrification is a natural process carried out by many microorganisms (denitrifiers) when sufficient oxygen is lacking. Instead of using oxygen as the final electron acceptor in metabolism, nitrate is used.

Desorb / Desorption - the release of a substance (phosphorus) from or through a surface.

Equilibrium status - is the state in which chemical activities or concentrations of the reactants and products have no net change over time. The state that results when the forward chemical process proceeds at the same rate as their reverse reaction. The reaction rates of the forward and reverse reactions are generally not zero but, being equal, there are no net change in any reactant or product concentration.

Free-water surface constructed wetland - has area(s) of open water and are similar in apperance to natural wetlands.

Internal loading - nutrient loading from natural sources within a wetland system such as nutrient release from decaying plant material, desorption of phosphorus from sediments, or sediment resuspension.

Reduction oxidation potential (REDOX) - a chemical reaction in which electrons are transferred from a donor to an acceptor. Redox conditions affect chemical and microbial processes and influence the biological availability of macro- and micro-nutrients in soils. The upper layers of surface-flow wetlands are the most energetic reaction zones - i.e. most nutrient transformation and removal occurs in the upper portion of the water column.

Remediation (phytoremediation) - a diverse collection of technologies that use plants to directly or indirectly clean up pollutants. It is loosely defined as the removal of pollution or contaminants from environmental media such as soil, groundwater, sediment, or surface water for the general protection of human health and the environment.

Sedimentation - the action or process of forming or depositing sediment (e.g. settling); it is related to the tendency of particles in a water suspension to settle and come to rest against a barrier (wetland lining).

Sorption - refers to the action of binding either by adsorption or absorption:

- Adsorption is the physical adherence or bonding of ions and molecules onto the surface of another phase (e.g. phosphorus bound to the surface of a clay aggregate).
- Absorption is the incorporation of a substance from one state into another of a different state (e.g. phosphorus moving from surface of clay into interal crystalline structure). Absorbed phosphorus is much more tightly bound, and less likely to undergo desorption processes under normal environmental conditions.

Subsurface-flow constructed wetland - typically utilize gravel as a root-bed substrate and are planted with aquatic and semi-aquatic plant species. Water level is typically kept below the surface of the gravel root-bed substrate, to minimize human and animal exposure, and flows from inlet to outlet.

Wetland - Land area that is wet during part or all of the year because of its location in the landscape. Also known as a swamp, marsh, bog, fen, or slough, depending on existing plant and water conditions, and on geographic setting.

References:
Kadlec, R.H. and Wallace, S.D. 2009. *Treatment Wetlands*. 2nd ed. CRC Press. Boca Raton.

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