Greenhouse and Nursery Water Treatment Information System

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Constructed wetlands

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Constructed wetlands (CW) are a viable option for removing nutrients and other contaminants from effluent water, and have been used to treat many different types of wastewater for decades. These systems may be used to treat water being released to the environment or water that will be stored in holding ponds for recirculation. CW mimic the properties of a natural wetland, and filtration occurs as a result of various processes that are similar to those that take place in a natural wetland. There are numerous different types of CW, and they can be differentiated between based on dominant vegetation type, hydrology (surface vs. subsurface water flow), and direction of flow. The classifications of wetland most commonly used in greenhouse and nursery effluent treatment are surface and subsurface flow wetlands with emergent macrophytes (ie. plants that are rooted in the substrate and emerge above the water, such as rushes).

Surface flow (Free water surface)

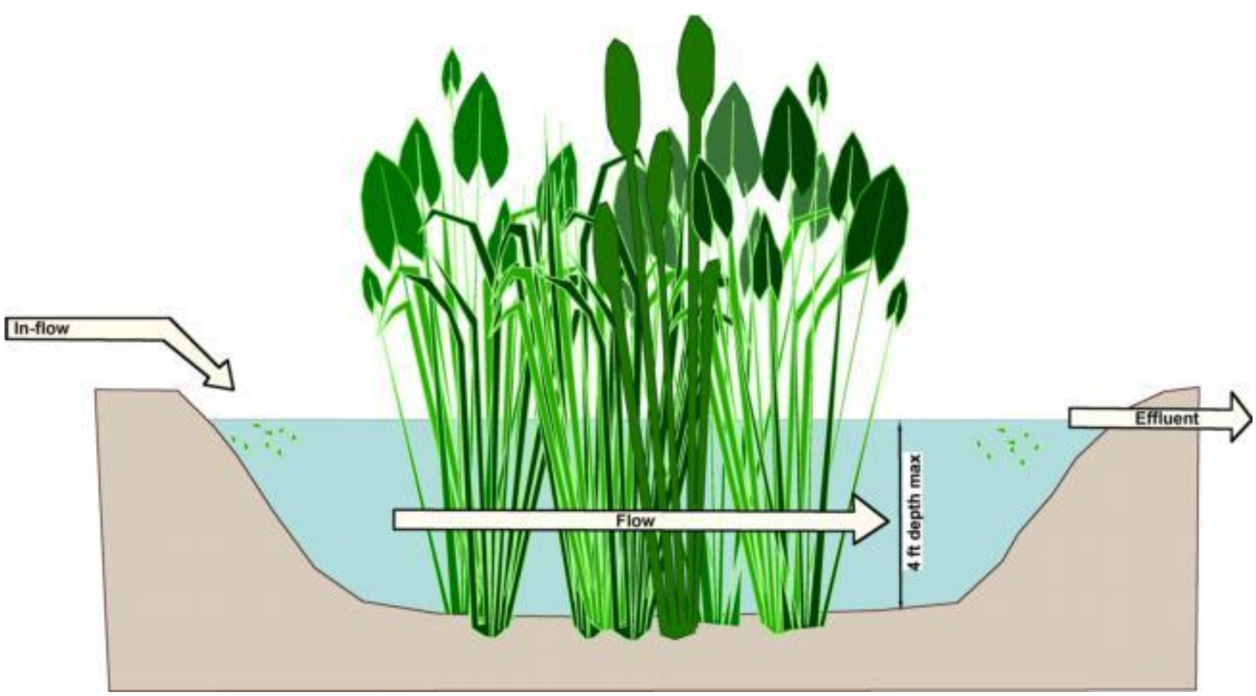

Fig 1. Diagram of a surface flow constructed wetland. Image by Dr. Sarah White (Oki and White, 2012).

A surface flow CW is comprised of a sealed basin or series of basins filled with 20-30cm of substrate and with a water depth of 20-40cm (Vymazal, 2010). Planted macrophytes root in the soil and emerge over the surface of the water. Effluent water is treated as it flows over the soil/substrate. These systems effectively remove organic material through microbial degradation and settling, and inorganic materials through settling alone (Vymazal, 2010). They are efficient at removing nitrogen (N) through denitrification and ammonia volatilization, but are unable to effectively remove phosphorus (P) as water does not tend to come in contact with soil particles (which adsorb or precipitate P; Taylor et al., 2006).

In order for sufficient filtration to take place, these systems should be designed to retain water for 3 to 3.5 days (Vymazal, 2010). If space is a limitation, required surface area of the wetland may be decreased if depth is increased (to a maximum depth of 4 feet; typical depth is 2-3 feet; Fisher, 2011). Generally, these systems require a much larger land area than the subsurface flow CW described below.

Subsurface flow

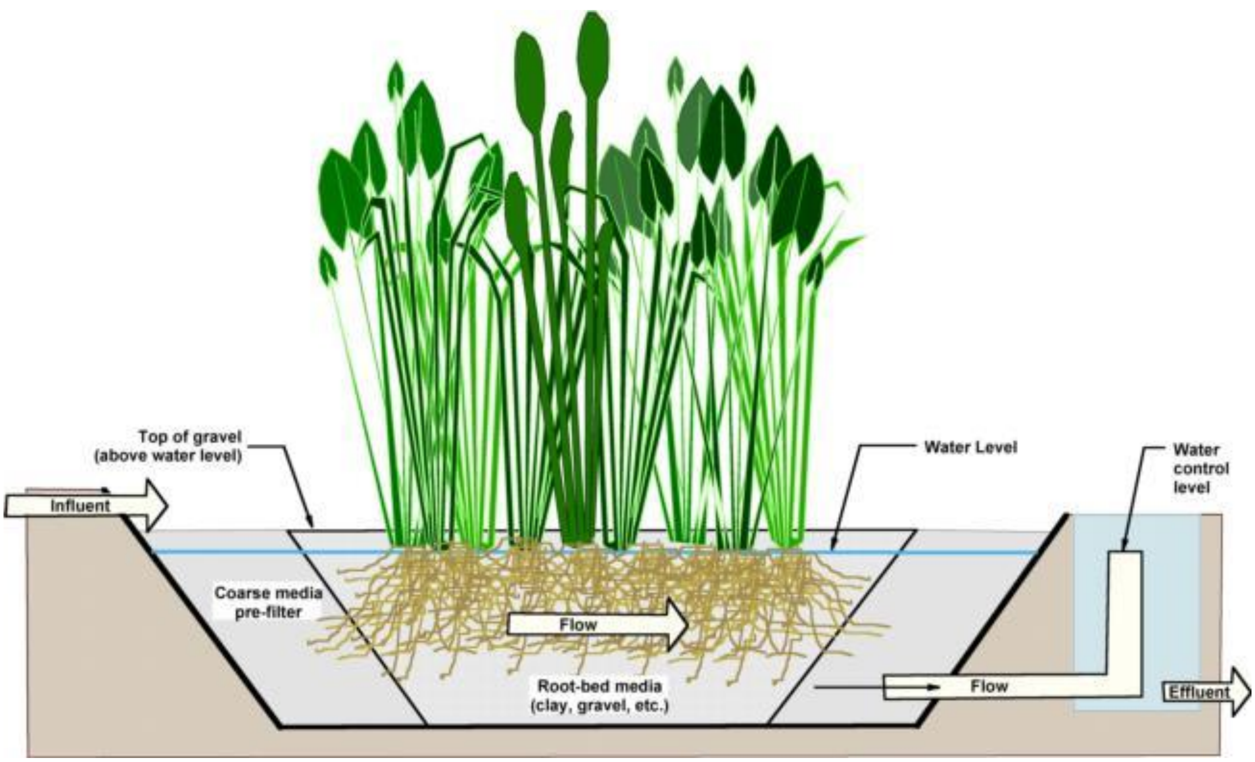

Fig 2. Diagram of a subsurface flow constructed wetland. Image by Dr. Sarah White (Oki and White, 2012).

Subsurface flow wetlands are made up of an impermeable basin filled with a 60cm layer of gravel or rocks of grain size 10-20mm (Vymazal, 2010). Wetland plants are typically rooted in the gravel layer. Water flows through the gravel layer and around the plant roots. Subsurface flow systems are differentiated between based on whether the main direction of flow is horizontal or vertical.

In a horizontal flow (HF) system, water enters through an inlet, flows slowly through the substrate, and exits through an outlet on the other side of the system. HF systems effectively remove organic material and suspended solids through anaerobic microbial and sedimentation, respectively. Nitrogen is removed mainly via denitrification, as ammonia volatilization may not take place due to lack of oxygen Generally, because of the lack of ammonia volatilization occurring, total N removal by these systems is low (Vymazal, 2007). Removal of phosphorus occurs via ligand exchange reactions (phosphate displaces water and hydroxyls on the surface of aluminum and iron hydrous oxides), but is typically low unless special materials are incorporated in the substrate (Vymazal, 2010).

In a vertical flow (VF) system the water is applied to the surface of the wetland. Dosing manifolds cover the surface of the wetland and they are batch fed using a timer controlled pump for consistent dosing or with a float activated pump which doses as necessary depending on the quantity of water requiring treatment. The water percolates downward through the sand or gravel medium where it is collected at the bottom of each cell and then pumped to the next cell for further treatment. The downward flow of the water in VF systems allows for much more oxygen rich (aerobic) conditions. The water levels in VF wetlands can easily be controlled in response to treatment needs and water volume. This offers much flexibility in the design of these systems depending on the characteristics of the wastewater. If necessary, cells with anaerobic, oxygen poor conditions (ideal for denitrification), can be designed by flooding bottom to top rather than top to bottom. Overall, these systems are effective for the treatment of wastewater containing nitrogen (ammonia and nitrate), organics, and suspended solids (Vymazal 2010). However, phosphorus removal is still low (Vymazal, 2007).

Constructed Wetland Design

Site selection

The site chosen for the wetland should be larger than the size of wetland currently required to accommodate for potential increase in operation size in the future (White et al., 2011). The site should be situated close to the effluent source and should not be located on a flood plain (White et al., 2011).

Size determination

It is difficult to give general size estimations that will be applicable to every site due to the many variables involved with constructed wetland design. Each wetland will need to be designed specifically for each site and the main factors that determine the size will be the amount of pollutant requiring treatment and the desired effluent concentrations of these pollutants. To calculate the total amount of pollutant that needs to be treated the concentration of the contaminant in wastewater is multiplied by the average wastewater flow rate.

For example, if the wastewater has a total nitrogen concentration of 20mg L^{-1} and the flow rate is 100,000 L day^{-1}, the N input into the wetland will be:

$$20mg\ L^{-1} \times 100{,}000\ L\ day^{-1} = 2\ kg\ day^{-1}$$

From this information the size of the wetland can be estimated by using a recommended loading rate. The loading rate, given as 'amount of pollutant/m^2 of wetland/day', is decided upon by the wetland designer based scientific research, experience, and in some cases a small pilot wetland can be used to determine its ability to treat the specific wastewater.

For this example an Ontario CW company suggested a vertical flow wetland with a loading rate of 2.4g/m^2/day (or 0.024 kg m^{-2} day^{-1}) the wetland size would be:

$$2\ kg\ day^{-1} / 0.024\ kg\ m^{-2}\ day^{-1} = 833\ m^2$$

This is simply an example of how wetlands are sized. Other variables often need to be considered that are closely related to production schedules, as the volume and quality of the wastewater will vary depending on the activity in the greenhouse or nursery. It is important to design a wetland that will be slightly larger than required in order to take into account peak flow rates rather than just average and to be prepared for unforeseen circumstances such as large precipitation events, for example.

Treatment Goals and Cost

When designing a constructed wetland for greenhouse or nursery wastewater there will be different treatment goals depending on the situation. CW can be designed so the water can be reused (for irrigation or other activities) or the wetland can be designed to treat water so it can be discharged into the environment (N.B. Discharge require a regulatory permit). The design of the wetland will greatly depend on whether or not the water is reused or discharged.

If the water is reused the treatment requirements are generally much lower. In most cases the goal will simply be to remove organics and solids, which can clog irrigation pipes. Removal of pathogens and pesticides is also desirable when reusing treated irrigation water. When water is reused it may be beneficial to keep some of the nutrients like N and P in the water rather then re-add them, this can greatly reduce fertilizer costs. CW designed to recycle water will be much smaller as the loading rates can be much higher.

When the goal is environmental discharge the CW will need to be larger and slightly more complex in order to meet regulatory discharge standards. In order to discharge most of the nutrients, especially N and P, will need to be removed from the wastewater. Therefore, extra design considerations will be necessary and the loading rates will be much lower in order to maximize pollutant removal.

The treatment goals and daily design flow will determine the size and cost:

Reuse				
Water Volume (L day^{-1})	Size (m^2)	Construction cost	Cost / L of daily design flow	Number of wetland cells required
10,000 - 25,000	133-333 m^2	$50-75,000	$5 - $3	3
25,000 - 75,000	333 – 1,000 m^2	$75-125,000	$3 – $1.65	3
75,000- 150,000	1,000 – 2,000 m^2	$125 – 225,000	$1.65 - < $1	3

Discharge				
Water Volume (L day^{-1})	Size (m^2)	Construction cost	Cost / L of daily design flow	Number of wetland cells required
10,000 - 25,000	400-1,000 m^2	$65 - 100,000	$6.50 - $4	4
25,000 - 75,000	1,000 –3,000 m^2	$100-250,000	$4 – $3.33	4
75,000- 150,000	3,000 – 6,000 m^2	$250 – 450,000	$3.33 - < $3	4

These estimates are based on information from Aqua Treatment Technologies for the design and installation of a vertical flow constructed wetland only. Collection & discharge structures etc. are not included in these estimates.

The price per unit area varies with the size of the wetland due to economy of scale

If discharge of treated water is to surface water, additional P removing technologies may be required.

Cell number

Each individual, standalone wetland unit is referred to as a cell. Multiple cells may be installed in series or in parallel, and this can allow for improved operational control and filtration efficiency (Georgia Environmental Protection Division, 2002). Use of multiple cells means flow to certain cells can be turned on or shut off depending on effluent flow rate at the time. Incorporating multiple cells can also facilitate adjusting water level in individual cells, which may be necessary for maintenance or repairs.

Plant type

Plant uptake does not contribute much to nutrient removal (<10%). However, they play an important role in providing surface area (in the form of roots) for bacteria to grow on, while also providing oxygen to the area around the roots (facilitating microbial processes such as nitrification). Plants may also provide insulation in temperate climates (Vymazal, 2010).

Plant species installed in the wetland must be able to withstand waterlogged conditions, the substrate type selected for the CW, and the climate of the area. Several species have been tested for use in constructed wetlands. The plants used are generally "macrophytes" (aquatic plants), although various grasses may also be used. Some species commonly used in constructed wetlands include reeds (*Phragmites australis)*, cattails (*Typha* sp.), and bulrushes (*Scirpus* sp.). For a list of some other commonly used species see p.22 of White (2011; http://www.clemson.edu/extension/horticulture/nursery/images/cws_howtoguide_small.pdf). It is likely best to employ native species in the wetland, to avoid any threat of species invasion. Increasing diversity of the plant community can improve N removal of the constructed wetland (Zhang, 2010).

As an alternative to rooted/emergent plants, the use of floating macrophytes in CW has also been tested. However, these species are typically used in tropical and subtropical regions (Polomski, 2009). In temperate regions, emergent macrophytes are likely preferable due to their ability to insulate (Vymazal, 2010).

We have been conducting research on selecting plant species for Na, Cl removal at the University of Guelph and the results will be available shortly.

Substrate type

The substrate used in constructed wetlands is typically sand, gravel, or crushed stone, as mentioned above. However, due to their coarseness these substrates are not particularly effective at removing P. Other substrates such as clay aggregates and steel slag have been tested and have been found to be effective for P removal (Vohla et al., 2009). However, because P is removed from water by being retained in the substrate (through adsorption or precipitation as minerals), these substrates will eventually become saturated with P (for example, after 5-6 years) and removal will decrease (Vohla et al., 2011). Although optimizing design and operation could extend substrate lifetime, the substrate will likely eventually have to be removed and replaced, which would be a difficult and costly task. While these P removing substrates have the potential to be of use for P removal from wastewater prior to discharge, they may be better incorporated into a separate cell specifically for P removal, or a non-vegetated media filter. For more information on substrates for P removal, please see our page on reactive media filters: http://www.ces.uoguelph.ca/water/NCR/Activated filters.pdf.

Performance in Cold Climates

Water treatment in constructed wetlands is driven by biogeochemical processes and temperature plays an important role in treatment efficiency. Water temperature affects the activity of microbes and plants and it can also determine the rate of important chemical reactions (Kadlec and Reddy, 2001). Overall, treatment efficiencies for different pollutants will decrease in winter months but certain design considerations can be made to mitigate this. The use of subsurface wetlands versus surface flow greatly helps to prevent freezing. Other things can be helpful such as lowering the water levels and allowing the accumulation of snow and dead vegetation on the surface of the wetland to insulate the system. Increasing the hydraulic retention time can also offset the decrease in treatment. In extreme cases the water can be stored in indoor facilities or be heated before it is introduced into the wetland. However, many greenhouses and nurseries decrease production in the winter resulting in less water requiring treatment.

Monitoring

Water temperature, dissolved oxygen content, pH, and EC should all be monitored on-site to ensure conditions in the wetland are stable (suggested ranges for these parameters can be found in the publication by White et al. (2011; http://www.clemson.edu/extension/horticulture/nursery/images/cws_howtoguide_small.pdf]).

It is recommended that water samples from the inlet and outlet should be taken around every four weeks (White, 2011). Outlet sampling is particularly important to ensure effective nutrient removal is maintained over the lifetime of the CW (White et al., 2011).

Maintenance

Maintenance costs are typically low. Regular maintenance will include removing vegetation from outlet pipes, as well as removal of potentially harmful species such as beavers and deep-rooted plant species which may disrupt hydrology (White et al., 2011). Occasional cell flooding may help to inhibit weeds, and period flooding and draining can help control mosquitos (Georgia Environmental Protection Division, 2002).

In subsurface flow systems, clogging will likely eventually occur due to the accumulation of plant debris, roots, sediment, and biofilm (Pedescoll et al., 2009). Clogging decreases hydraulic conductivity of the wetland cell and upsets flow and filtration efficiency. Clogging must be dealt with by removing and washing the filtration medium, replacing the medium, or adding an oxidizing agent such as H_2O_2 which can break down biofilm (Pedescoll et al., 2009). Removing clogging can be a very costly process, depending on the size of the wetland, and hydraulic conductivity can be monitored to keep tabs on degree of clogging (Pedescoll et al., 2009).

Pros and Cons

Pros:

- Effective at removing organic material, sediment, and N
- Effective at removing pesticides (Stearman et al., 2003)
- Low maintenance requirement and cost, as well as very low operation costs
- Provide habitat for wetland plants and animals
- Can help remove pathogens in water that is to be recirculated (although additional pathogen treatment will likely still be needed) (Williams et al., 1995)

Cons:

- Generally not effective at removing P (Vymazal, 2010)

- Clogging will eventually occur in subsurface flow systems, and can be costly to fix (Pedescoll, 2009)
- Effectiveness tends to decline during winter (White, 2011)
- May require a large land area, more so than some other effluent treatment options

Summary

Overall, CW can provide a relatively inexpensive means of treating effluent water in order to meet wastewater regulations and decrease impact on the environment. In addition to treating water before release to the environment, these systems can also be useful for treating water that will be recirculated, as they help remove organic material, sediment, pathogens, and pesticides. This may be especially useful to nurseries, where not all of the water used to irrigate is purposefully treated for pathogens before use. Possibly the major limiting factor is the land area available for construction, as CW can often be quite large.

Constructors

The following provides examples of constructors you may like to contact for further information:

Company name	Website
Aqua Treatment Technologies	http://www.aqua-tt.com/

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