BIOFILTERS
(Bioswales, Vegetative Buffers, & Constructed Wetlands)
For
Storm Water Discharge
Pollution Removal

Guidance for using Bioswales, Vegetative Buffers, and
Constructed Wetlands for reducing, minimizing, or eliminating
pollutant discharges to surface waters

DEQ

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Department of Environmental Quality

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This document is an attempt to compile the best available information on the design and use of biofilters (bioswales, vegetated filter strips, and constructed wetlands) so that those sites that may have an application of one or the other of these vegetated filtering systems will have information to make the best decision on the design, construction, implementation, and maintenance of these Best Management Practices. It is not a design manual but a practical, based on experience and knowledge of sites that implemented these BMPs, useful information on what works and does not work when designing, constructing, and operating them. Research is needed to determine the effect these BMPs will have on turbidity and other pollutants but there are indications that their effect will be positive and of environmental benefit.

Bioswales and constructed wetlands are being used more and more to address pollutants in storm water runoff. Many installations of these BMPs have failed or have not been as successful as was hoped when their use was first contemplated. Most of the limited success or failures can be attributed to insufficient information being available or to bad or no expert input into the design, construction, vegetating, or maintenance of the bioswale or constructed wetland. It is hoped that this document will provide that useful information and reason to seek out those that have the expertise to be of help.

As long as a constructed wetland is not built in a natural wetland, waterway, or floodplain, EPA and the Oregon Division of State Lands views the wetland as a private treatment method that does not require wetland permitting and it is treated different from the way a natural wetland is treated.

Additional copies of this document are available on the internet at http://www.deq.state.or.us/nwr/stormwater.htm.

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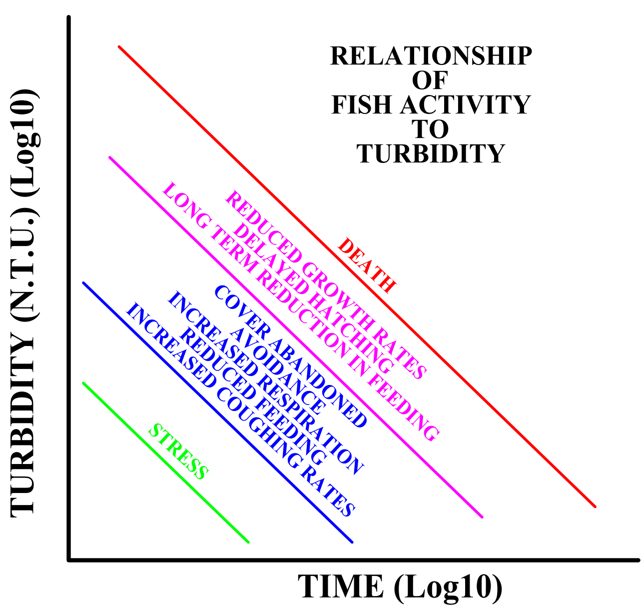
Background

Nature uses vegetated depressions, wetlands, marshes, etc. to clean storm water runoff by removing sediments, turbidity, heavy metals, and other pollutants. How this is accomplished is complex. Some pollutants are removed by vegetation uptake, some by natural flocculation from decomposing vegetation, some by just slowing the flow down enough for sedimentation to occur, and some by biota consumption and ionic attraction around the root structure.

Many pollutants migrate attached to soil particles and soil particles in themselves are considered a pollutant. When storm water runoff leaves a site, unless there is effective erosion protection such as vegetation, soil also leaves the site, in the forms of sediment, suspended solids, and microscopic soil particles called colloidal suspension, dissolved solids, or turbidity. The soil particulate can be clay, minerals, organic material, heavy metals, etc. Sediment usually will readily settle out. Suspended solids will settle out providing the velocity of the runoff stream is not too large. Turbidity usually will not be removed from the water column with out something else acting upon it to remove it.

Sediment and suspended solids are detrimental to fish spawning beds. Turbidity reduces light penetration, increases water temperature, smothers stream bottom habitats, smothers larvae, clogs or damages gill structures, and reduces oxygen in water. The level of turbidity that it takes to be detrimental varies with duration. (See chart below.)

Turbid and Clean Storm Water



Studies reported by Lloyd et al (1987) describe rainbow trout avoidance of turbid water above 30 Neophelometric Turbidity Units (NTU). The avoidance of turbid water has been documented by both field and laboratory studies. Bilby (1982) observed coho salmon avoidance at water turbidity levels above 70 NTU. The avoidance behavior has been associated with the fish's ability to see. Several studies discussed by Lloyd et al (1987) suggest significantly reduced angler success at turbidities ranging from 8 - 50 NTU which suggests a reduced ability of the fish to locate prey. Lloyd (1987) cites Buck, 1956, Tebo 1956, Bartsch 1960, Oschwald 1972, Ritter and Ott 1974, and Langer 1980 as providing additional descriptions of reduced angler success associated with turbidity. The USEPA (1977) reported that cutthroat trout abandoned redds, sought cover and stopped feeding when a turbidity of 35 NTU was encountered for two hours. In addition USEPA (1977) reported reduced growth and feeding at 50 mg/l TSS.

Summary of Turbidity (NTU) Cited Impairment Thresholds	
Turbidity	**Impairment**
5-25	Reduced primary production
8 (8-50)	Reduced angler success
11-49	Emigration (salmonid)
(3-30)	Cough response/Avoidance (salmonid)
21	Reduced salmonid population density
25	Reduced feeding and growth in salmonid, prolonged exposure
30	Trout avoidance
35	Redds abandoned
50	Juvenile displacement
60	Feeding and territorial behavior disrupted
70	Avoidance by older salmonid

Economical methods for removing turbidity and suspended solids from storm water runoff are limited. Bioswales and constructed wetlands my be the most economical approach, when both initial and maintenance costs are considered, for removing turbidity and suspended solids along with other pollutants.

General

Before delving into specifics concerning vegetative removal of pollutants through the use of bioswales, phytofiltration (vegetative filter buffers), and constructed wetlands it is important to look at the mechanisms and conditions that actually remove the pollutants. These conditions and mechanisms can be broken out into three areas:

1. Soils,
2. Biological organisms, and
3. Vegetation.

Soils

Constructed wetlands, phytofiltration, and bioswales can be successfully built and operated in most soil types provide the subsoil in the area of the biofilter is optimized for the maximum benefit of the biofilter. The subsoil can include soil, sand, gravel, rock, and organic materials such as compost or composted biosolids (composted sewage treatment plant sludge). Sediments, naturally settled suspended solids and colloidal suspensions (turbidity) will accumulate in the biofilter from the low velocity of water flow, natural flocculation, bioactivity, and decaying vegetation to add to the substrate (bottom) where vegetative uptake can make use of it. The substrate is important and should be uncompacted because:

- it will support many of the living organisms (biota) that make the biofilter work,
- the permeability of the substrate affects the movement of water through the biofilter,
- many chemical and biological transformations take place within the substrate as part of the soil food web,
- contaminate storage is provided, and
- a source of carbon, microbial attachment and material exchange is provided.

Soils must be non-compacted to promote good root development, biological organism development, water retention for dry periods, and to provide some filtering and infiltration. They must initially contain carbon and nutrients for initial vegetation and biota (biological colonies) establishment.

Under some conditions infiltration is undesirable due to either the pollutants being removed or to the need to retain water for through the dry season. In this case either a liner must be established or a confining impermeable layer such as clay must be installed below the depth of the active growth media of soil.

When soil is used as a filtering media, the following soil properties that should be considered are:

- Cation Exchange Capacity (depending on the pollutants of concern),
- Anion Exchange Capacity (depending on the pollutants of concern),
- pH,

- Electrical Conductivity,
- texture,
- organic matter, and
- air entrainment or soil compaction.

If the pollutants to be removed from the storm water are positively charged (ions) metals such as Copper, Cadmium, Iron, Manganese, Aluminum, Mercury, etc., then an anionic (negatively charged) soil should be present. Most soils are negatively charged. The recommended CEC is at least 15 **m**illi**eq**uivalent/100 grams of soil. On the other hand, if turbidity or colloidal suspensions are to be removed from the storm water then, an cationic or positively charged soil would be helpful. A positively charged soil is not necessary, due to other mechanisms in the wetland, which will provide the positive charge to attract the negatively charged colloidal particles.

Clay Types			Organic Matter	200-400 meq/100 g
Kaolinite	3-15	meq/100 g		
Illite	15-40	meq/100 g		
Montmorillonite	80-100	meq/100 g		

The retention of heavy metals and nutrients is influenced by the pH of the soil. The pH of the soil should be between 6.5 and 8.5 for optimal results. Soil pH also impacts the CEC. Soil CEC can be expected to increase up to 50% by increasing the pH of the soil from 4.0 to 6.5 and almost 100% if the pH were increased from 4.0 to 8.0.

The soil Electrical Conductivity influences the ability of the vegetation and the microbial food chain to process the pollutants and nutrients in the storm water flow. An EC of 4 micromho/centimeter or less is the ideal level for good plant and biota growth.

Soil texture can impact the infiltration characteristics and influence the Cation Exchange Capacity.

Sand	1-5 meq/100 g	Fine Sandy Loam	5-10 meq/100 g
Loam	5-15 meq/100 g	Clay Loam	15-30 meq/100 g
Clay	>30 meq/100 g		

Since constructed treatment wetlands are often constructed by excavating, the soil is often depleted of organic material that is necessary for plant growth and good microbial activity. Organic material can also consume oxygen and thus create an anoxic environment that may not be conducive to the desired biological environment unless nitrate reduction or neutralization of acidic drainage is desired. Compost or some other organic material must be reintroduced into the soil. The amount of compost additive used should be carefully considered for the desired results.

Biological

Biofilter pollutant removal is largely regulated by microorganisms. The biota acts as a major stabilization, removal, and conversion mechanism for organic carbon and many nutrients. It appears that most biological action occurring in a constructed wetland is anaerobic. Due to flow fluctuations over the year, some biological action is fracultative (both aerobic (air breathing) and anaerobic depending on the seasonal conditions). Microbial action:

- converts or transforms many substances into insoluble or harmless substances,
- positively changes the reduction/oxidation (redox) increasing the processing capacity of the wetland soil to remove pollutants, and
- is a major contributor to the recycling of nutrients.

Non-compacted or disturbed soil contains voids or air spaces. In submerged soils water replaces the air in those spaces and microbial action rapidly consumes the residual air. Microbial action changes from aerobic to anaerobic and the soil becomes anoxic (without oxygen). This soil then becomes a reducing environment, which is important for removal of pollutants such as nitrogen and metals. Also a loose non-compacted substrate is important for good vegetation root growth.

The establishment and maintenance of a healthy biological colony may be the most important aspect of the construction and continuing viability of the biofilter. The right biota for the biofilter is important because it is the microorganisms to a great extent, which capture and convert pollutants and nutrients into a form, which can be easily consumed by the vegetation. Many pollutants are in an insoluble form, which vegetation can not use. The biological food chain converts these nutrients and pollutants from their stable insoluble form into ones, which are easily consumed by the vegetation established in the biofilter. The microorganisms work in a symbiosis with the plants to capture and uptake the pollutants and nutrients in the storm water runoff. Endomycorrhiza or arbuscular mycorrhizae fungi help the vegetation root structure bring in water and nutrients from as much as fifty feet away from the plant roots. These organisms can help the plant survive in the summer and in drought conditions.

The establishment of health soil biota can be accomplished through the tilling of compost into the soil of the biofilter during construction or through the preparation of the biofilter soil by the addition of a carbon source, fertilizer, material to loosen the soil, and commercially available biological organisms.

Biological organisms will collect pollutants and change them into a form that makes them more susceptible to vegetation uptake or renders them in a form that is not a pollutant.

The soil must be uncompacted for the biota to thrive and to allow the vegetation roots to develop properly. Further detailed information on the use of compost for biota establishment and decompaction of the biofilter's soil can found in the document "Environmental Protection and Enhancement with Compost" at http://www.deg.state.or.us/nwr/stormwater.htm and other documents.

Vegetation

Sedimentation comes about through reduced flow, ion exchange, and natural flocculation. Slower velocities within a biofilter allow higher retention times of pollutants and settling of the larger particle sized pollutants. Many of the particles suspended in the storm water are negatively charged. There is a positive charge at the base of the vegetation in a biofilter that attracts and settles these negatively charged particles. As vegetation ages and discards plant material or dies a natural flocculent can be released, which attracts negatively charged pollutant particles and causes them to settle out. Soil will filter out pollutants in any water that flows through the soil subsurface. Vegetation will consume pollutants and transfer them into their plant matter.

Native plant species are a must in Oregon for use in biofilter design. Proper selection of native species can provide year-round vegetative cover without need for supplemental irrigation or fertilization. Furthermore, native species usually provide high habitat value for indigenous birds and other animals. Exotic non-native species can become invasive if allowed to proliferate. Local municipal agencies, the County Soil Conservation Service Field Office of the Department of Agriculture, or environmental restoration groups can provide guidance on appropriate species. Local landscape ordinances often provide lists of acceptable and non-acceptable plants and grasses.

The picture above shows the filtering effect of sedge. Notice the clearer water on the right side of the picture (downstream).

The selection and planting of vegetation should be in accordance with the pollutants to be removed, and the flow and velocity design requirements for the biofilter. Selection of turf or woody plants depends on the desired capacity and residence time of the storm water and pollutants in the biofilter. Woody plant materials should only be planted on the side slopes. Trees should only be planted along the edge of the biofilter to provide shade to minimize the temperature increase to the water in the dry months. A lower canopy of shrubs and grasses should be planted underneath the trees.

Bioswales are generally composed of three basic vegetation zones: highest (xeric), middle (mesic), and lowest (hydric). Plant the lowest zone with species that can tolerate standing water and fluctuating water levels. Plant the middle zone with species that tolerate slightly drier conditions and more infrequent fluctuating water levels. Middle zone plants, along the slopes, are often selected for erosion control. Plant the highest zone with species adapted for drier conditions.

Grass meets many of the functional criteria for biofilter vegetation, such as dense cover, fibrous root or rhizome structure, and upright growth form. This plant material must be seeded for uniform coverage at rates high enough to provide a dense stand of grass. If a biofilter is planted in the early summer supplemental irrigation or use of compost or a product such as DriWater™ may be required to ensure germination and growth prior to the wet season. Geotextiles, such as jute matting, compost, and straw mulching may be needed to provide physical protection of the seed and slope, if the biofilter is planted shortly before the wet season. Hobbs & Hopkins of Portland has a bioswale system that contains a liner that can be applied in the wet season with seeding to take place in the late spring. The vegetation grows down through the liner rather than up through as with most geotextiles. This bioswale system could also be used on the banks of wetlands

Annual grasses are fast-germinating and fast-growing plants that spread quickly and extensively through seed dispersal. These plants react immediately to moisture, producing a fast ground cover following the first rains. They are appropriate for situations requiring quick, temporary channel protection and where full, even coverage is desired. Plant growth is usually stimulated by mowing. This can be beneficial during dry periods as plants require less water when kept small.

Perennial grasses grow more slowly than annual grasses. Perennial grasses are generally sod-forming or bunch-grasses. Sod-forming grasses develop stems and shoots from underground rhizomes. Bunch grasses grow in clumps and require dense stands to cover the ground completely. The growth period of perennial grasses corresponds with available moisture and favorable temperatures (late winter to midspring for western states). Shallow-rooted perennial grasses die back to the underground runners, root masses, and stem bases when the supply of surface water disappears during drought.

Plants for biofilters in arid climates may require irrigation for establishment and for dry periods. To ensure seed germination and grass establishment, temporary irrigation, compost, or products like DriWater™ can be used to help establish grass. A permanent irrigation system should be provided for and used in regions with significant dry seasons.

Vegetation selected for biofilters should be natural for the region in which the bioswale is located. The vegetation should not be dormant in the October through May season. Low maintenance and aesthetics in some areas are other considerations. Remember that mowing or cutting of the vegetation usually reduces their ability to remove pollutants by vegetation uptake but some vegetation removal will probably be necessary in order to maintain the vegetations ability to continue to uptake the incoming pollutants in the storm water. Two books available on wetland vegetation in Oregon are*: Wetland Plants of Oregon & Washington*, by Jennifer Guard, 1995; and *A Field Guide to the Common Wetland Plants of Western Washington & Northwestern Oregon*, by the Seattle Audubon Society and the Washington Native Plant Society, Sara Spear Cooke, Editor, 1997.

Some types of vegetation to consider are: rushes for heavy metal and nutrient uptake; reedgrass for TSS and erosion control; common reed for TSS, nutrient uptake, and chemicals; water-starwort for absorption of toxics; water-purslane for filtering and uptake of toxics; burreeds for pollutant uptake; clover for erosion control and nitrogen capture; and Mexican mosquito-fern for uptake of toxics. Many other types of vegetation will help remove TSS and turbidity. Cattail phosphorus removal is on the order of 80 percent. Cattails are very good for removing pollutants from storm water but have several drawbacks. Among these drawbacks are: they are highly invasive and tend to take over the swale, have a dormant cycle that can extend for a year or more, and they tend to overly restrict the flow in the bioswale requiring abnormally high amounts of maintenance of the bioswale.

Cattails crowding out other vegetation in bioswale

Bluegrass has a nutrient uptake of 200 pounds per acre, a phosphorus uptake of 29 pounds per acre, and a potassium uptake of 149 pounds per acre each year. Tall Fescue has a nutrient uptake of 135 pounds per acre, a phosphorus uptake of 24 pounds per acre, and a potassium uptake of 149 pounds per acre each year. Brome Grass has a nutrient uptake of 166 pounds per acre, a phosphorus uptake of 29 pounds per acre, and a potassium uptake of 211 pounds per acre each year. If the clippings from the mowing or the grass are removed then, this will give an indication of the shallow soil and/or pollutant runoff removal rates for these various grasses.

Pollutant removal from vegetative uptake drops after the vegetation matures unless the dead vegetation is constantly removed to break the cycle of re-entrainment through the re-release of the pollutants from the decaying vegetation. Vegetation should be selected for the climate, the expected pollutants, the expected depth of the water, and the season that the vegetation needs to be active (usually in the late fall, winter, and spring during the rainy season).

Bioswale Vegetation

The following is a list of bioswale vegetation for Northwest Oregon furnished by GreenWorks P.C.

Bioswale Bottom Groundlayer	
Scientific Name	***Common Name***
Agrostis tenuis	Colonial Bentgrass
Carex densa	Dense Sedge
Carex obnupta	Slough Sedge
Deschampsia cespitosa	Tufted Hairgrass
Eleocharis palustris	Creeping Spikerush
Epilobium densiflorum	Dense Spike-Primrose
Hypericum anagalloides	Bog St. John's- Wort
Juncus acuminatus	Taper-Tipped Rush
Juncus articulatus	Jointed Rush
Juncus effusus	Common Rush
Juncus tenuis	Slender Rush
Mimulus guttatus	Common Monkeyflower
Potentilla gracilis	Northwest Cinquefoil
Ranunculus alismifolius	Dwarf Buttercup
Ranunculus occidentalis	Western Buttercup
Saxifraga oregana	Oregon Saxifrage

Side Slopes Groundlayer	
Scientific Name	***Common Name***
Bromus carinatus	California Brome
Deschampsia cespitosa	Tufted Hairgrass
Elymus glaucus	Blue Wildrye
Festuca occidentalis	Western Fescue Grass

Side Slopes Understory	
Scientific Name	***Common Name***
Cornus stolonifera	Redosier Dogwood
Crataegus douglasii	Black Hawthorne
Lonicera involcrata	Black Twinberry
Oemlaria cerasiformis	Indian Plum
Physocarpus capitatus	Ninebark
Rosa nutkana	Nootka Rose
Rosa pisocarpa	Peafruit Rose
Salix scouleriana	Scouler Willow
Salix sitchensis	Sitka Willow
Sambucus racemosa	Red Elderberry
Spiraea douglasii	Douglas' Spiraea
Symphoricarpos albus	Snowberry

Side Slopes Overstory	
Scientific name	**Common name**
Abies grandis	Grand Fir
Alnus rubra	Red Alder
Fraxinus latifolia	Oregon Ash
Thuja plicata	Western Red Cedar

There are several ways to establish the vegetation in the bioswales; sodding, seeding, and plug planting. Properly installed sod can provide immediate protection from erosion and some immediate vegetation benefits. Reseeding of the seams between adjacent sod sections may be necessary. Soil preparation is important. After grading of the swale channel, stones or clods greater than one-inch in diameter should be removed. The sod strips should be laid perpendicular to the direction of flow. The sod should be rolled or tamped after it is laid and should be secured with staples or pegs on 3:1 or greater side slopes or in areas of high velocity flows. Seeding is accomplished by scarifying into the soil or by hydroseeding. Seed should be irrigated carefully in order to establish a dense cover prior to the rainy season. Some vegetation such as bunch grasses, rushes, and shrubs or trees are most commonly planted from containers.

Trees should also be planted along bioswales that have flow year round and which discharge to temperature sensitive receiving waters so that aquatic life is not adversely affected. This will reduce the heat gain during the late spring, summer and early fall seasons.

Constructed Wetland Vegetation

Many of the grasses mentioned for bioswales may be used on the banks of the wetland but can not be used in the wetland itself due to their low tolerance for long duration submergence.

The vegetation selected must match the expected depth of water and climate in which the wetland is to be constructed. Native wetland vegetation for the area should be used. Generally, grasses that may be acceptable for bioswales will not be acceptable for wetlands due to the submergence time and the depth of submergence being greater in a wetland which would overly stress the bioswale type vegetation sufficiently to kill it or render it ineffective at the time needed to remove pollutants. Consideration must be given to where the water will come from in order to keep the wetland vegetation alive in the summer and to the dormant cycle of the vegetation.

Vascular plants (the higher plants which grow above the water surface) and non-vascular plants (algae) are important to a wetland. Photosynthesis by algae increases the dissolved oxygen content of the water which affect the nutrient and metal reactions. Vascular plants:

- stabilize substrates (soils) and minimize channel flow and open channels in the wetland,
- slow water flow allowing for the heavier suspended particulates to settle out,
- uptake carbon, nutrients, and metals,
- transfer atmospheric gases to the soil,
- diffuse oxygen from their subsurface structures creating aerobic biota sites within the immediate surrounding substrate (soil),
- create microbial attachment areas on their subsurface structure, and
- create decaying material which increases flocculation and increase the biota.

The following Northwest Oregon Wetland plant list is furnished by GreenWorks P.C.

Emergent Groundlayer	
Scientific Name	***Common Name***
Carex stipata	Saw-Beaked Sedge
Carex obnupta	Slough Sedge
Deschampsia cespitosa	Tufted Hairgrass
Eleocharis acicularis	Needle Spike-Rush
Eleocharis ovata	(Common) Ovate Spike-Rush
Glyceria occidentalis	Reed Mannagrass
Juncus ensifolius	Dagger-Leaf Rush
Juncus oxymeris	Pointed Rush
Leersia oryzoides	Rice- Cut Grass

Emergent Groundlayer	
Scientific Name	***Common Name***
Sagittaria latifolia	Wapato
Scirpus acutus	Hardstem Bulrush
Scirpus microcarpus	Small-Fruited Bulrush

Scrub Shrub Groundlayer	
Scientific Name	***Common Name***
Agrostis tenuis	Colonial Bentgrass
Carex densa	Dense Sedge
Carex obnupta	Slough Sedge
Deschampsia cespitosa	Tufted Hairgrass
Epilobium densiflorum	Dense Spike-Primrose
Juncus acuminatus	Taper-Tipped Rush
Juncus articulatus	Jointed Rush
Juncus effusus	Common Rush
Juncus tenuis	Slender Rush
Mimulus guttatus	Common Monkeyflower
Potentilla gracilis	Northwest Cinquefoil
Ranunculus occidentalis	Western Buttercup
Saxifraga oregana	Oregon Saxifrage

Scrub Shrub Understory	
Scientific Name	***Common Name***
Cornus stolonifera	Redosier Dogwood
Crataegus douglasii	Black Hawthorne
Lonicera involcrata	Black Twinberry
Physocarpus capitatus	Ninebark
Rosa nutkana	Nootka Rose
Rosa pisocarpa	Peafruit Rose
Salix scouleriana	Scouler Willow
Salix sitchensis	Sitka Willow
Sambucus racemosa	Red Elderberry
Spiraea douglasii	Douglas’ Spiraea

SCRUB SHRUB Overstory	
Scientific Name	***Common Name***
Abies grandis	Grand Fir
Alnus rubra	Red Alder
Fraxinus latifolia	Oregon Ash
Thuja plicata	Western Red Cedar

Bulrushes are very tolerant of high nutrient levels.

Several planting methods may be used to plant the wetland. The use of nursery starts is best as they are more likely to establish and prosper that seeding and there is less invasive vegetation establishment. Five to seven plant species should be selected with three which are aggressive and that can establish rapidly. The plantings should be made during the growth season. After excavation of the wetland, the excavation should be kept flooded until planting occurs. Before planting the excavation should be drained and checked for the appropriate depth zones for the plants to be established. Different species should be planted in zones and not mixed so that the take over of a particular species can be minimized.

Soluble forms of phosphorus as well as ammonia are partially removed from storm water runoff by planktonic and bethic algae. Algae consume nutrients and convert them into biomass, which then settles to the bottom of the wetland providing the material for the uptake needed by the vegetation for sustainable growth.

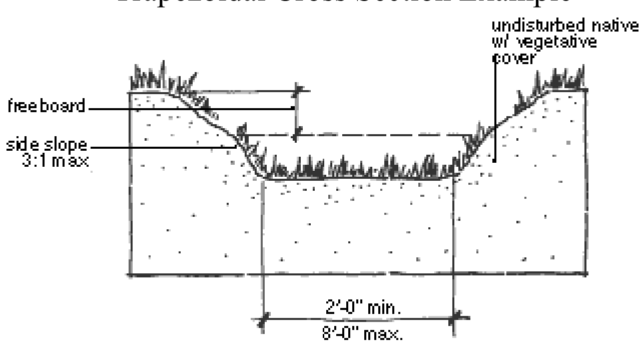
Trees should be planted around the wetland to reduce the heat gain and the warming of the water, which may adversely effect aquatic life downstream from the wetland.

Assistance should be obtained in the selection of the vegetation from a wetlands biologist and/or from the local NRCS Field Office (http://or.nrcs.usda.gov). A program called VegSpec is available on the internet at http://www.nrcs.usda.gov/technical/efotg/ in section IV.C. Technical Resources of the Field Office Technical Guides, that may be helpful in selecting the vegetation. The soil type is required to use this program. The specific soil type does not necessarily have to be that which you have but something similar in the list to that which you have is necessary.

Bioswales

Bioswale is the term generally given to any vegetated swale, ditch, or depression that conveys storm water. The fully vegetated bioswale and the open channel bioswale (roadside example at the right) are the two basic types of vegetated swales based upon the degree of vegetation. Some subtypes of bioswale are based upon their general cross-sectional shape, i.e. “U”, “V”, and “trapezoid”. Generally, the “U” and “V” shaped swales are just ditches that have become naturally vegetated and they are usually open channeled. The Trapezoidal fully vegetated bioswale is the most effective bioswale at removing pollutants. Open channels do not add much more than infiltration to the process of removing pollutants. When bioswales are designed, they are designed to address a certain storm event such as the two year or ten year 24-hour storm event. Statistically, around 90 percent of the storm events will be less than this design amount. Open channels typically are open to the extent that this 90 percent flow is in the open channel which results in very little bioremediation of the storm water most of the time. Fully vegetated, trapezoidal cross-section bioswales will result in much better remediation of the pollutants in the storm water runoff than open channels or the other cross-sections.

Trapezoidal Cross Section Example



Bioswales provide good treatment of stormwater runoff without the extensive maintenance required for some other stormwater BMPs. Pollutant removal rates increase when bioswales are well maintained, and as the residence time of water in a swale increases.

The effectiveness of bioswales is also dependent upon the retention time of the storm water in the bioswale. The longer the retention time, generally, the higher the removal efficiency. The type of vegetation and the life cycle that the vegetation is in will also effect the pollutant removal rate. Consultation with a biologist is greatly beneficial when considering what vegetation to plant in the bioswale. Dormant vegetation will only reduce the storm water runoff velocity and not provide the benefits of vegetation uptake of the pollutants. Some reduction in the bacterial uptake and conversion of pollutants to more stable less toxic configurations will still take place but probably at much reduced rates.

Stormwater runoff contributes pollutants to streams, rivers and lakes. Pesticides, herbicides, and fertilizers come from residential lawns, commercial landscaping, and recreational facilities like golf courses. There can be residuals that leach from land that was once farmland. Heavy metals come from vehicles, buildings, roofs, and industrial sites. Oil and grease drip regularly from cars onto streets, parking lots, and are occasionally dumped into storm drains by residents performing maintenance on vehicles and equipment. Pathogens and bacteria in runoff can come from pet waste, broken or leaking sanitary sewers, wildlife, or sanitary sewer overflows.

Bioswales can remove and immobilize or break down a large portion of pollutants found in stormwater runoff. Bioswales have achieved high levels of removal of suspended solids (TSS), turbidity, and oil and grease. They can also remove a moderate percentage of metals and nutrients in runoff. This lower level of removal compared to sediment or oil and grease is due partly to the large percentage of metals and nutrients that appear in dissolved form in runoff. The term "dissolved form" includes microscopic particulate that generally is referred to as turbidity.

Bioswales can achieve good removal of metals or nutrients that are attached to suspended soil particles through settling of the solids by natural flocculation and vegetation uptake. Infiltrated storm water uses the soil and, in some cases depending upon the pollutant, the microbiology in the soil to filter dissolved pollutants from runoff. Since most bioswales infiltrate only a portion of their flow, removal rates for pollutants in dissolved form are lower than those for sediment or oil and grease unless retention time for the pollutants in the bioswale is sufficient for natural flocculation, infiltration, biological conversion/consumption, and/or vegetative uptake to occur.

Nutrients, including nitrogen and phosphorus, appear in urban runoff in dissolved form as well as attached to sediment particles, and can be removed by settling, flocculation, vegetation uptake, and infiltration. They are then broken down or converted to other forms by the biota, and are stored in the soil or taken up by plants. Nutrient remobilization can occur in the winter when plants become dormant or if the soil is transported. However, periodic mowing of swales and removal of the mowed vegetation can reduce remobilization.

Like nutrients, metals appear in both dissolved form and attached to sediment particles. Metals removal rates by swales can be maximized by:

* maximizing the amount of water captured by a swale through infiltration;

* increasing the pH of a bioswale's flow--basic flows drop out more metals;

* increasing the cation exchange capacity and pH of the bioswale's soil (soils with more organic matter remove a greater amount of metals); and

* maximizing the density of a bioswale's vegetative cover without unduly restricting the flow.

Metals reduction concentrations ranging from twenty to sixty percent in the storm water runoff have been documented in studies of bioswales. The higher reduction values were common for well-designed and maintained swales, and the lower reduction values were seen for swales with patches of bare soil or short retention times.

Since much of the metals removal ability of bioswales has been related to infiltration, an important concern is whether the heavy metals will accumulate to toxic levels in the bioswale underlain soil and whether they will migrate into and contaminate the ground-water. In removing heavy metals either through vegetation uptake or through soil filtration, a bioswale concentrates them. Maintenance of the bioswale vegetation by mowing or removing dead vegetation will remove some of the accumulated metals. Soil particles will attract and bind much of the remaining concentrations of the metals. Studies of bioswales in sandy, loamy, and clayey soils, found that in many cases metals accumulated only in the top several inches of soil. In clayey and loamy soils showed metals accumulating only in the top two inches of soil.

Some people consider the filtration of the storm water through the soil as being one of the largest benefits to using bioswales. Experience dealing with septic systems indicates that there can be a limit to the amount of filtration that can be obtained by the soil in filtering out and retaining some pollutants. The degree of the soils ability to continually remove some pollutants depends to some extent on whether or not the pollutant is biologically degradable.

Metals have not been found to accumulate to toxic levels in grassy swales. One study in 1986, of a bioswale adjacent to a four-lane high-way carrying 29,000 vehicles per twelve hours fifteen years after its construction, showed metals levels in the grassy bioswale were far below the required standards for metals in municipal wastewater sludges recommended for agriculture usage, with the exception of lead, which was at the standard. The lead probably came from the use of leaded gasoline in that time frame. With the elimination of leaded gasoline since that time, concentrations of lead in swales constructed in the last few years would probably not be as high as that measured in the particular study.

Biologic action accounts for the high removal of oil and grease from swales. A minimum seventy-five percent reduction of oil and grease was found in one study in a bioswale with a residence time of approximately 9 minutes. A check of the length of the same bioswale equivalent to a residence time of four and a half minutes resulted in a minimum oil and grease removal of forty-nine percent. It has been found that, to a certain extent and with a small lag time, as the concentration of oil and grease increase the removal efficiency increases. The lag is probably due to the time required for the establishment of a additional new growth of bacteria and the increased efficiency was probably due to the increased bacteria present.

In the few studies that have been done on pathogen removal by swales, grassy swales have not been found to significantly reduce concentrations of escherichia coli (e. coli) bacteria. This could be due to the fact that swales attract more wildlife which add to the e. coli in the swale. There is no conclusive information as to whether swales will or will not remove pathogens.

Besides removing pollutants from storm water runoff, bioswales provide storm water detention and thus can reduce the increased peak flow rate that is the result of increased impervious surfaces from site development. Many municipalities in Oregon are now requiring water quality or detention ponds or devices to mediate the expected increased peak flow rates from development and thus reduce or eliminate increased stream flows which typically cause stream bank erosion. Bioswales can be an alternative to those detention facilities.

Vegetation

Swale vegetation must meet certain criteria for the vegetation planted along a swale to maintain channel stability and improve the bioswale's ability to filter pollutants from stormwater. The vegetation must:

* provide a dense cover and a root or rhizome structure that holds the soil in place in order to resist erosion;

* during water quality level flows (event design), it must stand upright in order to provide maximum residence time and pollutant removal;

* tolerate a bioswale's soil conditions (pH, compaction, composition); and

* tolerate periodic flooding and drought. It must not be dormant during the period of the year that the pollutants are to be treated.

In some cases, the bioswale vegetation must also meet aesthetic and functional criteria by selecting the appropriate plant for the use, water cycle, aesthetic goals, and local government codes. Many municipalities require setbacks from intersections, require low height vegetation for visibility at intersections, along parking lots, streets, and pedestrian walkways, or for police surveillance. Bioswales and their plant materials can present unique and different visual characteristics from conventional drainage or landscape design. Turf grass lawns, woody perennials, drought-tolerant, riparian or exotic plants, and cobbles can all be used, depending on the desired aesthetic effect.

BIOSWALE DESIGN

In areas were there is insufficient land length available to obtain the retention time necessary in order to gain the maximum effect of a bioswale, it is better to install a bioswale in conjunction with some other treatment system such as a sand filter for whatever pollution removal that can be accomplished than to not install one. Bioswale design parameters to consider are: settling pond or chamber at the inlet; excess runoff considerations; cross-section selection; swale slope; swale width; swale vegetation selection; level spreader use; storm design event; flow velocity; vegetative bed compaction and porosity; and construction season for the bioswale.

Design Event and Runoff Expectations:

The most polluted runoff usually occurs during the first portion of a storm cycle. The oils, metals, and other pollutants accumulated over a dry period are washed off rooftops, roadways, and other surfaces in the first light rain or in the first minutes of a large storm. In subsequent storm cycles this pattern is repeated, with the first rains carrying the highest concentration of pollutants. The term usually associated with this phenomena is "first flush".

The first consideration to make is what storm event the bioswale should be designed to handle. Serious consideration should be made of the degree that site construction has compacted the soils and the type of soils present on the site. A design guide developed by the US Department of Agriculture Natural Resource Conservation Service called TR-55 can be of assistance in calculating the amount of runoff from a site for a given rainfall event. TR-55 can be downloaded from the internet web site at: http://www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55.html. For some sites, especially heavy clay or heavily compacted sites and long duration storm events, designing the swale for 100% runoff may be the best conservative approach to use. Both the peak and design duration storm events should be investigated. The two-year 24-hour storm event should be the minimum that the bioswale is designed to treat. A map of the Oregon two-year 24-hour storm events can be found on the internet at: http://www.wrcc.dri.edu/pcpnfreq.html. Check with your local government to see whether or not they have a different design storm event in their codes. The storm peak runoff will be higher than the 24-hour average. A metered water quality or detention pond at the head of the swale could serve as the sedimentation pond and as a means of controlling the flow rate to the swale.

In the past, stormwater management has focused almost exclusively on flood protection through the use of water quality or detention ponds. Systems that can accommodate these peak flows are more than adequate to convey small storms, which occur much more frequently. So, the small storm and its impacts are often overlooked. Yet, small storms, because of their frequency and cumulative impacts, make the largest contribution to total annual runoff and have the greatest impact on water quality. For this reason, stormwater design must consider both the peak volumes for flood control, as well as the water quality volume for pollution control.

The water quality volume (24-hour design storm) is usually established by local or regional agencies and varies depending on local conditions. It is defined as the amount of runoff that must be treated before being released into a conveyance storm drain network or receiving water.

The Water Environment Federation/American Society of Civil Engineers in their jointly published Urban Runoff Quality Management (1998) adopted an eighty percent annual capture rate as a standard of practice for water quality volume. This translates into approximately the first one-half to one-and-a-half inches of rain depending on annual rainfall and local rainfall patterns. It can also be translated as a two-year recurrence interval storm, or the size storm that has a fifty percent chance of occurring in any given year.

The Center for Watershed Protection, recommends a ninety percent annual capture rate. Under this rule, grassy swales are sized to treat ninety percent of the annual volume of runoff in a watershed.

The bioswale inlet can be designed to allow peak flows to bypass the bioswale and be conveyed by a conventional conveyance system. This also prevents the larger, higher velocity flows of large storms from washing out any accumulated sediment or eroding the vegetation in the bioswale. To determine the appropriate design storm for a particular area, consult local rainfall data or contact a local municipality or flood control, public works, or stormwater agency for the required standard. While the design storm is typically expressed as a depth, the associated rainfall intensity is also required to design the channel cross section. The bioswale will treat runoff only as fast as it arrives at the swale, and this is governed by how much rain falls on the ground over a given period of time, how much evaporation takes place, and how much infiltration occurs.

Bioswales are usually a part of a larger storm drainage system that drains water from developed areas. They must also be sized to convey a peak flow design storm without eroding. The design storm is often the two-year, five-year, or ten-year, twenty-four-hour storm, although municipalities may have adopted other standards for their swales or open channels. As with the water quality design storm, the local municipality, planning department, flood control, public works, or stormwater agency will provide the required standards.

When designing a swale to handle a certain storm event occasionally a storm event of grater volume than the design event will occur and result in the runoff overflowing the swale. Some thought should be given to measures that can be taken to reduce the problems such overflow would create. These measures might be to temporarily provide for overflow onto adjacent parking areas or landscaped areas adjacent to the swale. Another method would be to design an overflow system to accommodate the excess flow directly into a storm sewer.

Geometric Design Principles

The basic components of bioswale design include: longitudinal slope, cross section (shape), length, and roughness. Roughness is a function of the vegetation coverage and type.

Longitudinal Slope

The longitudinal slope of a bioswale is a critical design element that effects the design of the bioswale and its performance. Appropriate slopes typically range from one percent to six percent.

The optimal longitudinal slope of a bioswale is between one and two percent. Low slopes limit erosion by reducing water velocities and increase pollutant removal by increasing residence (contact) time of water in the swale. As longitudinal slope and velocity increase, erosion may increase and pollutant removal rates typically decrease.

On slopes less than or equal to one percent, drainage is marginal, and standing water may be present if the underlain soil type does not allow much infiltration or the water table remains high. Perforated drain pipe can be installed in the bottom of the bioswale to allow for this drainage. It might be useful to install a valve on the drain pipe near the down gradient end of the piping so that the ponded water may be drained as required. The reason for this is that excess draining of the bioswale bottom will deplete needed water reserves that are necessary for the vegetation through the dry summer months which would require more frequent irrigation for the vegetation to be active at the beginning of the wet season.

Bioswales are not recommended on slopes greater than six percent unless they can somewhat follow the slope contour to limit the swale slope to less than six percent.

Bioswales with longitudinal slopes of from two to six percent require check dams or weirs spaced approximately every fifty to 100 feet along the length of the bioswale to reduce the speed of flow. Check dams reduce velocity, increase residence time, protect plant material from erosion, and enhance pollutant removal.

Swale Cross Section (Shape)

There are four basic cross sections for bioswales: rectangular, triangular, trapezoidal, and parabolic. Trapezoidal cross sections are the most common shape for bioswales because they are easy to construct, offer good hydraulic performance, facilitate maintenance, and are aesthetically pleasing. Triangular cross sections can also be appropriate if the side slopes are very gentle (approximately 10:1 or shallower). Rectangular cross sections are generally not used for grassy swales because they are difficult to construct and maintain, difficult to establish with vegetation in the sides, and because the vertical side slopes can present a safety hazard.

In general, shallow side slopes are more desirable, although they increase the amount of area required for the bioswale. A 3:1 slope (horizontal:vertical) is considered the steepest to limit erosion and/or slippage of the slopes. A 5:1 slope is considered the steepest slope that allows regular mowing.

Bottom Width

A wide, flat swale bottom maximizes the available treatment area and pollutant removal while also providing ease of maintenance. In order to be able to mow the vegetation in a bioswale, the bottom should be at least two feet wide. The maximum free width of the bioswale bottom should be less than eight feet wide to avoid rilling and gullying and ensure sheet flow.

Depth

The bioswale should be at least six inches deeper than the maximum design flow depth. This additional depth is known as "freeboard," and provides a safety factor to prevent the bioswale from overflowing onto adjacent areas if the channel becomes obstructed or if runoff volumes exceed the design size.

Length

The time it takes water to flow from its inlet into the bioswale to the bioswale's outlet is the “residence time” or retention. Residence time for bioswales should be at least five minutes. The designer should seek to maximize a bioswale's length, since this will increase the residence time, or "contact time" of runoff with the vegetation in the bioswale. In general, the greater the residence time, the greater a bioswale's ability to remove pollutants from runoff.

Water Velocity

The speed at which water flows in the bioswale is its velocity. Velocity is calculated for two storm sizes: water quality design storm and the peak flow design storm. Velocity should be less than or equal to one-and-a-half feet per second for the water quality design storm, and below five feet per second or the erosive velocity of the channel for the peak flow design storm. This is generally three to six feet per second depending on vegetation type and the use or erosion control fabric or other stabilization method. Erosion may be a problem if average discharge velocities frequently exceed three feet per second. Where velocities make erosion a concern, erosion control fabrics or geotextiles may be used to achieve added erosion resistance while still allowing the growth of a dense stand of vegetation.

Inlet

An inlet method of directing water into a bioswale that is commonly seen is to provide for continuous inflow along the entire length of the bioswale (sheet flow). This is easy to achieve by eliminating curbs next to streets and parking lots. In this way, inflows are spread over a wide area, erosion is minimized, and pollutants are dispersed widely among the vegetation. One of the draw backs with this is that the residence time for the storm water entering the bioswale is not maximized. If the flow is evenly distributed along the full length of the bioswale then the average residence must be figured from the center of the length of the bioswale to the discharge point.

When a concentrated inlet such as a pipe or curb cut is used, an energy dissipater and flow spreader should be used where the water enters the bioswale to rapidly spread the flow over the full width of the bioswale. This will limit erosion, maximize the bioswale pollutant removal efficiency, and reduce the need for maintenance.

The asphalt edge of a street or parking lot that drains directly into a bioswale may crack over time due to plant growth or occasional car traffic. To avoid this problem, a concrete or stone band (or other hard edge) can be placed to finish the asphalt edge. The top of the band should be at the grade of the asphalt to allow for water to pass over the band and into the bioswale.

Check Dams/Weirs

Check dams, or weirs, pool water upstream of the weir, increasing residence time and infiltration. A number of check dam designs have been implemented in the field, including notched concrete weirs, board check dams, and stone check dams. Check dams should include an orifice for very low flows and to minimize long-term ponding that may foster mosquito growth.

The frequency of placement and design of check dams should be governed by longitudinal channel slope and geometry. To obtain maximum storage from stable check dams, they should be located such that the upstream limit of ponding from one check dam is just below the downstream edge of the adjacent check dam. To prevent mosquito development, check dams should be designed to pond water to a depth that will infiltrate within twenty-four hours of the end of a storm. Infiltration testing prior to construction of the bioswale will be helpful in determining whether or not there is likely to be a problem in this area. An underdrain (French Drain) system may have to be installed with valving to control the ponding.

CONSTRUCTION

During construction, the soil in the bottom and sides of the bioswale have typically become compacted and may be deficient in many of the basic elements necessary to provide the optimal growth of the vegetation to be planted. The soil in the bottom and sides of the bioswale should be prepared before the vegetation is planted. Preparation of the soil should include tilling in additives such as grit in the form of sand and gravel, or ceramic grit, and/or compost to reestablish infiltration capability and, in the case of compost, organics for vegetation growth and reestablishment of voids for air.

Ceramic Grit Installed in Bioswale

If sand and gravel or ceramic grit is used, some form of nutrients and organics must be added to recreate topsoil. Typical mixture ratios for mixed-yard-debris compost should be around 1:3 compost to existing soil. Compaction of the soil from construction can extend to a depth of thirty inches or more depending on soil type and moisture content. So whatever method is used to recreate the natural infiltration rate should extend at least twelve to twenty-four inches into the bioswale bottom and sides. See the article on compost on the Oregon DEQ web page at http://www.deq.state.or.us/nwr/stormwater.htm for more information on soil compaction and compost. Caution should be exercised if plug planting and fertilization are used instead of complete bioswale bed preparation. This practice can result in localized subsurface water ponding and associated root rot, and/or restricted root growth and root ball formation which will eventually result in loss of much of the vegetation planted.

It usually takes at least two years to effectively establish the bioswale vegetation unless compost amendment of the subsurface soil occurs. This means that to prevent erosion and loss of vegetation during the first year, some method must be used to protect the seeds, if seeding is used, other vegetation planted, and provide for the soil isolation and armoring from the water flow. The use of biodegradable geotextiles laid over seeds or the use of a liner through which vegetation can grow from the top down will provide the necessary isolation and armoring needed. The main ingredient needed to provide the isolation and armoring is complete soil coverage and good anchoring of the material. A tight weave jute mating has proven effective in use for this isolation and armoring as has a new material being used by Hobbs & Hopkins as part of their Bioswale System.

Jute Geotextile Mat

Bioswale System Liner

Erosion control fabrics are usually classified into mulches; organic, biodegradable, and non-biodegradable blankets and netting; and soil-filled turf reinforcement mats. The use of tackified mulches should only be considered for low-velocity swales or bioswales planted early in the summer and irrigated for vegetation establishment. Note that mulches will add to the nutrient load in the bioswale until it is consumed and may be subject to increased erosion until the vegetation is fully established.

Erosion control blankets and netting can be made completely of or in combinations of jute, coconut fibers, straw, excelsior, and various plastics, and are usually installed stapled or staked into the ground or weighted down with rock or gravel. A seed mixture may be installed in the mat or they may be installed over the seed. Biodegradable blankets or nets degrade thus stabilizing the swale over the short term but providing no long-term protection.

Turf reinforcement mats (TRMs) are flexible, synthetic mats filled with soil. They provide long-term channel and vegetation stabilization at velocities in the range of fourteen to twenty feet per second.

The following are common problems encountered during construction which result in problems for the best effective bioswale vegetation establishment.

- Crews unfamiliar with the concept behind bioswales;
- timing of the construction of the bioswale is delayed;

- compaction of the bioswale subsoil and subsequent failure to correct the problem;

- poor timing of bioswale construction, such that the bioswale is inundated with sediment-laden runoff, seeding is washed off by the first rains, or erosion occurs in the bioswale and turbidity laden waters are discharged ;

- cost cutting occurs in the selection and planting of the vegetation; and

- poor preparation of the swale channel to accept flows, i.e. check dams are not installed.

The construction period is also typically the period when greatest erosion occurs. If a swale is located downstream from a construction site, it may collect sediment from the site. This is an indication of how effective the swale is--sediment that settles in the swale is sediment that does not flow off-site into receiving waters. Prior to the completion of construction, sediment can be excavated from the swale and redistributed as topsoil on-site.

Water Quality Effect: Monitoring and Performance

There are two ways of measuring the effectiveness of bioswales at removing pollutants. The first is by measuring the particular pollutants of interest by their concentrations in water entering and exiting the bioswale and calculating the difference. This method does not account for the infiltration of the pollutants along the length of the bioswale which may be released at some future time or have to be remediated in the future. The second method involves performing a mass balance of pollutants in the bioswale throughout the length of the bioswale. This method will result in information on the amount of pollutants retained in the soil and vegetation of the bioswale.

Obtainable Efficiencies:

Obtainable reductions of pollutants in bioswales are:

Total Suspended Solids –	83 to 92%
Turbidity (with 9 minutes of residence) –	65%
Lead –	67%
Copper –	46%
Total Phosphorus –	29 to 80%
Aluminum –	63%
Total Zinc -	63%
Dissolved Zinc –	30%
Oil/Grease –	75%
Nitrate-N –	39 to 89%

These results can be obtained for a bioswale at least 200 feet in length with a maximum runoff velocity of 1.5 ft./sec., a water depth of from one to four inches, a grass height of at least 6 inches, and a minimum contact (residence) time of 2.5 minutes.

Maintenance

Although through proper vegetation selection a bioswale may be relatively low maintenance, some bioswales may require regular plant maintenance for aesthetic reasons. This maintenance includes regular mowing, irrigation, and pruning. Mowing or cutting back the vegetation also reduces evapotranspiration and reduces the amount of pollutant uptake until the vegetation reestablishes full growth.

Vegetation in the bioswale should be trimmed every year or two to prevent woody species from taking over. Clippings from plants should be disposed of properly as they may have absorbed hazardous toxins. Removal of vegetation clippings following this practice removes pollutants that have been absorbed by the vegetation. Fertilizers and herbicides are a source of organic compounds which are some of the pollutants that are removed by the vegetation in a bioswale and their use for maintenance of the bioswale should be avoided as much as possible.

Regrading may be necessary to reshape the bioswale cross-section as sediments collect and form pools. As with plant waste, sediments should be removed and disposed of properly.

Regular maintenance activities for bioswales should include inspection of surface drainage systems to ensure removal of any sediment buildup and trash; repair of surfaces that have been damaged by erosion, rodents, vehicles or other causes; care of plant materials; replacement of dead plants; and regular irrigation during dry periods. Inspections and repair to bioswales should be scheduled far enough in advance of the first seasonal rains to allow for any repairs that may be necessary, and during and after each major storm. Trash and debris left to accumulate in either the storm drainage system leading to the bioswale or in the bioswale can restrict the flow of water causing localized flooding and possible erosion, create sediment buildup, and create aesthetic problems that create poor public perception of the site.

EXAMPLES

HOBBS & HOPKINS BIOSWALE SYSTEM

Swale with ceramic grit installed.

Swale with erosion/turbidity protection blanket and Check Dams installed.

Swale with seed/mulch being applied on top.

Bioswale with emerging vegetation.

PARKING LOT BIOSWALES

Oregon State Police Department Parking Lot Mini Bioswales- Portland

Oregon Museum of Science and Industry Parking Lot Mini Bioswales - Portland

Oregon Museum of Science and Industry Parking Lot Mini Bioswales – Portland

Portland Community College Parking Lot Mini Bioswale

GRASSY BIOSWALES

Lawn Bioswale in Texas

Spokane Park and Ride Lawn Bioswale

Reed College – Portland

SW Scholls Ferry Road – Portland

Residential Development Grassy Bioswale at Fairview Lake used during subdivision construction

COMMERCIAL BIOSWALES

City of Portland Bureau of Environmental Services Laboratory Bioswale – St Johns

Gifford Pinchot National Forest Head-quarters Bioswale

Washington County Commercial Development Bioswale – Beaverton

Spring at end of first year above and Fall of the same year at right.

RURAL BIOSWALES

Within one year of construction **Three years after construction**

Hawthorn Ridge next to SE 162 Avenue - Portland

Center for Urban Horticulture Bioswale - Seattle

Gresham Bioswale

School Bioswale

Parking Lot Mini Bioswale **Wide Main Bioswale**

Arrata Creek School
9821 Arrata Place, Troutdale

INDUSTRIAL BIOSWALES

Kinzua Resources, L.L.C. – Pilot Rock, Oregon

View looking south toward the outfall **View looking North from the outfall**

Storm water runoff from this lumber company drained off the impervious surfaces to a low area and then ran off to Birch Creek. The runoff, prior to the construction in 2000, of the nearly 400 feet long bioswale was high in Total Suspended Solids (190 - 810 mg/l) and zinc (0.011 - 0.86 mg/l). After the bioswale construction, initial testing show that the TSS has been reduced to between 26 and 100 mg/l and zinc has been reduced to blow 0.1

mg/l. Prior to construction of the bioswale there was always runoff from one of the two preexisting outlets even during light, short duration rainfall events. Now there is minimal runoff out of the one final outfall.

Weyerhaeuser Warrenton Log Yard

Naturally vegetated drainage ditches prior to bioswale construction

Construction of bioswale in 2001
(Notice swale divider in picture on the right)

Bioswales approximately 1 year later

STREET RUNOFF BIOSWALE

At Construction in 2001 **One Year Later**

On Baseline Road at Beaverton Creek

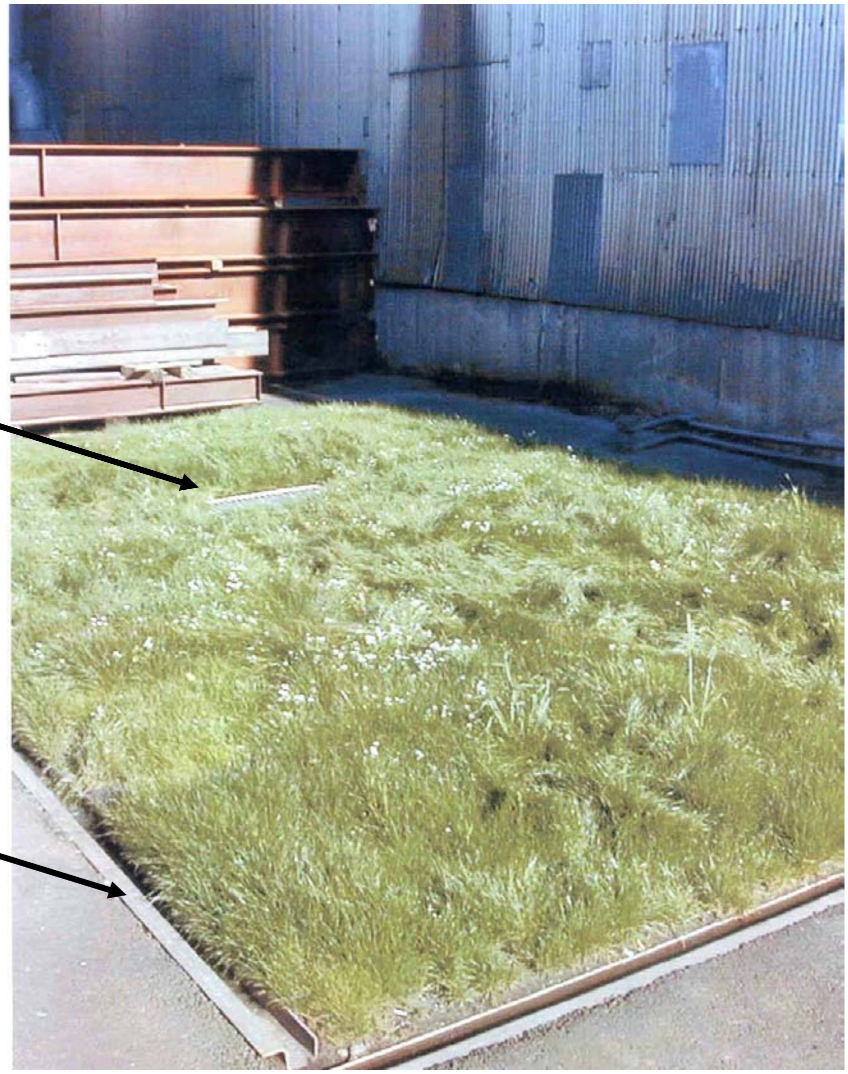
Phytofiltration

In this document, the term "Phytofiltration" will be used to refer to the use of vegetation uptake of pollutants in storm water runoff in vegetated strips rather than in bioswales or constructed wetlands. There is no excavated channel although the area under consideration will slope to an outlet. The flow across the vegetated strip will be in sheet flow and the vegetation will typically not be a wetland species.

The picture above shows a mostly impervious 11.5 acre industrial site (Fought & Company Inc.) with a 195,750 square feet galvanized corrugated roofed building. The zinc levels in the storm water discharge ranged from 4.31 mg/L to 9.13 mg/L from the roof with a permit benchmark of 0.6 mg/L. Cleaning and painting the roof is an option that would have a significant cost**.** The site chose to divert all of the roof runoff to one catch basin and use vegetation to remove the zinc. The amount of space required for this was so insignificant that the area which is located next to the building just in from the lower left hand corner of the above picture does not show very well in the above picture.

An area approximately twenty feet wide by thirty feet long was prepared by removing the asphalt and adding a mixture of sand (70%) and porous ceramic grit (25%) along with a microbial nutrient to a depth of 8 inches. A grassy vegetation seed mixture from Hobbs & Hopkins, Pro-time 705 PDX Ecology Lawn Seed Mixture, was applied. On the peripheral of the area troughs were installed with level outfall edges to the grassy area to encourage sheet flow to the catch basin.

The vegetation must be watered in the summer and maintained by cutting an removal of the grass to a composting facility so that the zinc will not continue to build up but be removed.



Testing for the last two years shows the zinc discharging into the catch basin is now ranging from 0.05 mg/L to 0.34 mg/L, an approximate 97% reduction.

This Phytofiltration makes use of the biological microorganisms which convert the zinc into a form which is readily acceptable to the vegetation for uptake.

Other pollutants can be removed using this method of filtration. A couple of things need to be considered in the construction of a filter strip.

a. The longitudinal slope should be 2% or more and groundwater needs to be below the vegetation root depth unless the vegetation specifically can withstand the constant water at the roots.
b. The filter strip should be located in an unshaded area of the site.

Constructed Wetlands

Constructed wetlands are man-made, engineered wetland areas created through excavation and/or berming. They typically differ from natural or restored wetlands in that they are located in areas where no wetland existed before. The regulatory status of constructed wetlands is unique in that they can be created, used, and eliminated generally without permits or other regulatory input with the exception of possibly land use regulations. The basic types of constructed wetlands are shallow marsh, 2 or 3 celled pond/marsh, extended-detention, and pocket wetland. Extended-detention and pocket wetlands are less effective in removal of some types of pollution than other types of wetlands either as a result of the open channel or the reduced retention time of the storm water. They are particularly good for the removal of nutrients and conventional pollutants such as oil and grease and some heavy metals. Constructed wetlands can be classed as either surface flow, subsurface flow, or hybrid systems, which are a combination of both.

Surface flow wetlands have the water level and flow above the ground surface and vegetation is rooted and emerges above the water surface. The near surface water layer is aerobic while the deeper water and substrate are usually anaerobic. Subsurface flow wetlands have the water flow below the surface of a sand and gravel bed in which the roots of the vegetation penetrate to the bottom of the bed. Subsurface wetlands are frequently used to lower the 5-day biochemical oxygen demand (BOD_5) which causes reduced oxygen levels in the storm water runoff. Subsurface wetlands provide greater attachment surface area for biota and may treat storm water faster and thus promote smaller constructed wetlands for the same level of treatment.

Wetlands designed for sediment and turbidity removal also serve as mechanisms for removal of phosphorus and pesticide removal. Phosphorus and pesticides are absorbed and attached to soil particles that enter the wetland.

Constructed wetlands have been used to some extend for the secondary or tertiary treatment for sewage treatment where they are very cost and performance efficient at removing nutrients, suspended solids, metals, and other pollutants. The life of this type of treatment wetland can be as long as 20 years. To date, constructed wetland life for treatment of storm water is unknown but should with minimum maintenance exceed the life of a wastewater treatment wetland. The following discussion will focus on the use of constructed wetlands for the treatment of storm water.

Since maintaining water in the constructed wetland is so important, constructed wetlands should not be built in well draining (type A) soil unless a liner is used or a method of providing off season water to keep the wetland viable are considered. Use of a liner would minimize water loss to infiltration but also give up any potential pollutant benefit to that in filtration. This is desirable in some areas especially where the depth to the water table is great in the summer and a source of summer or dry weather supplemental water is lacking or difficult and costly to obtain. If a liner is to be used, the soil above the wetland must be carefully constructed to provide the growth medium for beneficial biota and for initial organics and nutrients for vegetation establishment.

Providing that the water does not freeze, wetlands can perform sedimentation in cold weather. Wetland substrate, where decomposition and microbial activity occurs, can generate sufficient heat to keep the subsurface layers from freezing. The rate of decomposition will slow as the temperature drops so if the wetland is needed to perform during cold weather it may be necessary to created a larger constructed wetland for this condition. Wetlands will lose large amounts of water in the summer to evapotranspiration. If there is too great a vertical distance between the root zone of the vegetation and the ground water level in the summer, a liner will be needed to minimize the loss of water to infiltration and a source of water during this time may be needed in order to provide for the survivability of the wetland vegetation.

Basic Design and Construction:

- Suitable for larger sites, up to 100 acres.
- Shape should be long and relatively narrow. A length to width ratio of 5:1 is preferred, with a minimum ratio of 2:1 to enhance water quality benefits. The longer length allows more travel time and opportunity for infiltration, biofiltration and sedimentation.
- Soils should be tested to determine suitability. Best when located in clay loams, silty clay loams, sandy clays, silty clays and clays.
- For storm water, the permanent pool depth should be not more than 18 inches deep. This depth is a function of the selected vegetation's ability to grow and thrive in the water depth.
- Cannot be used in areas with shallow depth to bedrock or unstable slopes.
- Needs to have a shallow marsh system in association to deal with nutrients.
- Should be multi-celled preferably three of equal sizes, the first cell should be 3 feet deep to trap coarse sediments and slow turbulence (settling basin or pond). They need to be designed as a flow through facility, and the pond bottom should be flat to facilitate sedimentation.
- Side slopes should be 2:1, not steeper than 3:1, and 10 to 20 feet in width.
- Pond berm embankments over 6 feet should be designed by a registered engineer. Berm tops should be 15 feet wide for maintenance access and should be fenced for public safety.
- Baffles can be used to increase the flow path and water residence time.
- Should have an overflow system/emergency spillway to deal with a 100 year 24-hour flood, and a gravity drain.
- Access to the wet pond is to be limited with a gate and signs posted.
- For mosquito control either stock the pond with fish or allow it to be drained for short periods of time (do not kill the marsh vegetation). Full vegetation with no clear or open water tends to eliminate or at least restrict mosquito populations.
- Selection of vegetation should be done by a wetland specialist. Three to eight different types of vegetation should be used.
- Oil/water separators can be used prior to the constructed wetland depending upon

the surrounding land uses. Generally this is not necessary as the vegetation tends to break up and consume oil and grease.

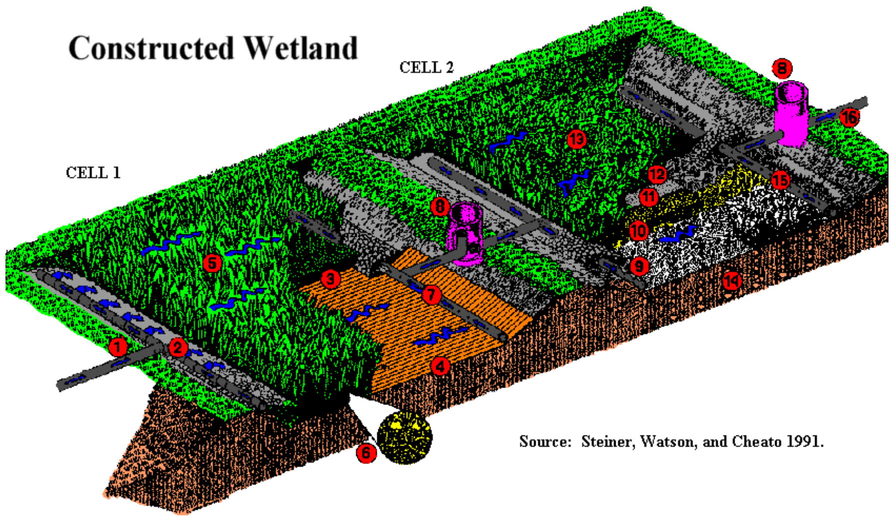
- Relatively low maintenance costs.

Design Considerations:

Characterize the quantity and quality of the storm water runoff to be treated by sampling the storm water prior to designing the wetland and modeling the runoff and rainfall data.

- Constructed wetlands have larger land requirements for equivalent service compared to wet or water quality detention ponds.
- Relatively high construction costs.
- There is a delayed efficiency until plants are well established (1 to 2 seasons).
- Need a buffer width of 25 to 50 feet.
- Water level fluctuations can kill plants so water level control is a must.
- A sediment pond on the inlet is needed to remove sediments prior to the wetland and thus decrease wetland sedimentation and maintenance costs
- An inlet flow distribution system is needed to enhance maximum wetland efficiency.
- A flow discharge system is needed to ensure that flow across the full width of the wetland is discharged evenly and thus ensure maximum wetland usage.
- May have to be excavated to the water table to ensure dry season water source.
- Full vegetation with no open channels is needed to maximize efficiency and discourage waterfowl usage, which could increase bacterial contamination of the water with fecal coliform and e. coli bacteria.
- Should be designed to retain for 24 hours the rainfall runoff from 2-year storm event.
- Vegetation selection should be chosen not only for pollutant uptake and climate but also for ease and frequency of maintenance.
- Extremes in weather and climate should be considered not the average.
- Design with the landscape not against it.
- Replanting of vegetation which initially fail may be necessary.
- A liner may be necessary to assist in retention of water due to losses from infiltration through the summer months depending on the seasonal level of groundwater.

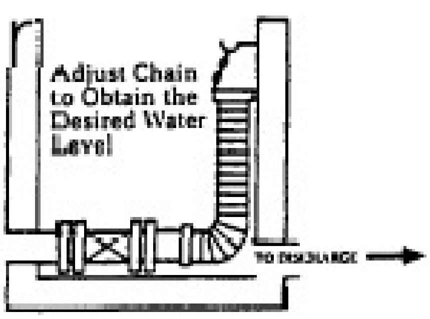
Wetland Design

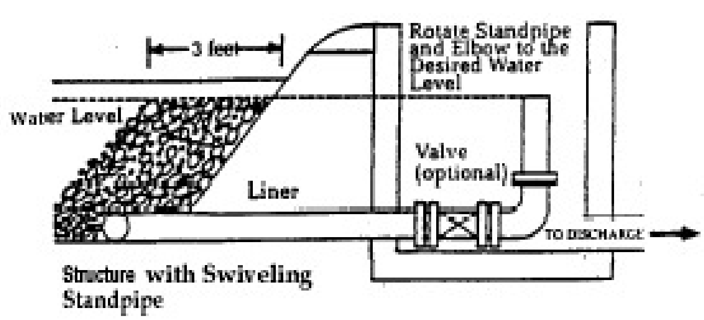


The example above is one that is used for sewage treatment but has many of the aspects desired in a constructed wetland for storm water runoff. Some type of sedimentation chamber or pond should be located upstream so that the heavier settleable solids will settle out prior to the wetland and thus reduce the load on the wetland. This settling pond should be designed with a maximum velocity through the pond of around 1 to 1.5 feet per second and a depth below the outfall of several feet to retain the sediment. This allows for most of the sediment removal to occur in the settling pond and not in the wetland.

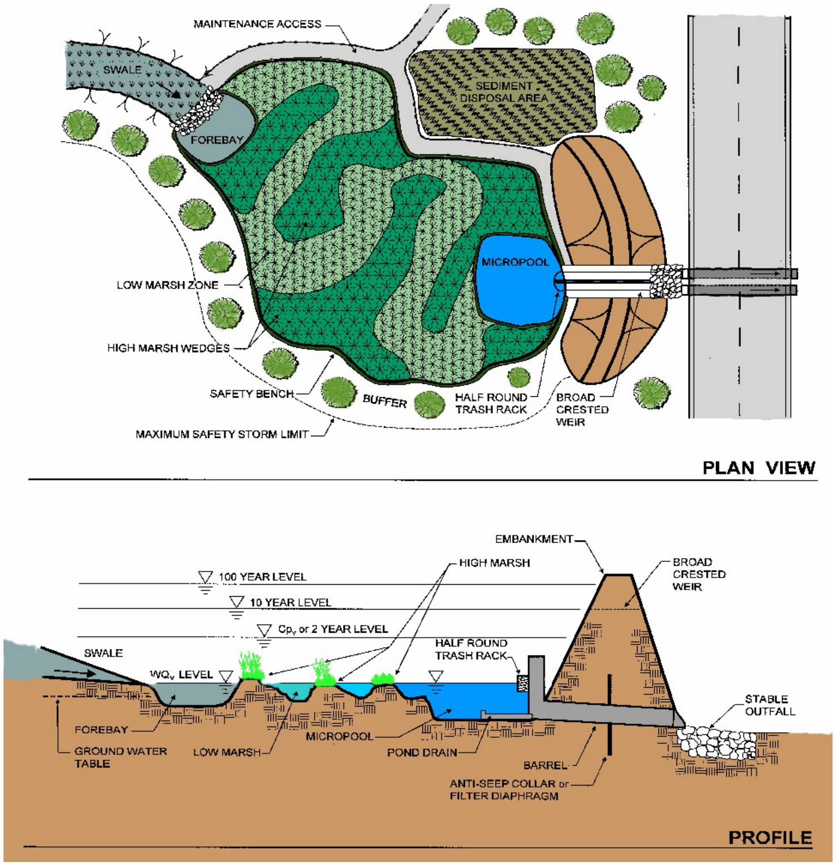
As the runoff leaves the settling pond, it enters a wetland inlet distribution system consisting of a submerged perforated pipe covered by rip rap or a ditch with level lower bank on the wetland side 90 degrees to the wetland length and roughly perpendicular to the inlet flow pipe or ditch. This flow distribution system allows for full even parallel flow across the full width of the wetland. A point inlet would provide for short circuiting of the wetland and dead areas of flow that would not provide much in the way of treatment.

Wetland outlet distribution structures should be of similar design as the inlet distribution structures. The level of water in the wetland can be controlled by adjustable weirs, rotateable pipe elbows, expandable flexible piping, or other methods.





The most efficient wetland is one that is completely vegetated with no open water. Open water tends to provide concentration of the flow due to decreased flow resistance and results in short circuiting and decreased pollutant removal efficiencies for the wetland surface area used. If large variations in expected flows need to be provided for, the wetland that provides for high and low flows may be necessary. An example of such a wetland is shown below.



In the example at the bottom of the previous page, short circuiting is addressed through the use of a deep and a shallow meandering channel both of which are to be completely vegetated but which allows for two different rainfall events.

In the first example, a wetland discharge system is also needed to collect the discharge flow across the full width of the wetland evenly. Again this can be accomplished through the use of a perforated pipe covered in rip rap located at a lower elevation in the wetland than the inlet distribution device or with another ditch with a level bank perpendicular to the wetland length. The ditch banks and internal surfaces on both types of ditches must be lined or armored in some way to ensure that erosion does not take place in the ditch or on the ditch banks. Both the inlet and the discharge ditches, if used, must be of sufficient width and depth to ensure that the entering and discharging volume of storm water is handled in such a way as to ensure an even distribution of water across the wetland.

Retention time for the water in a constructed wetland should be a minimum of thirty-six hours. To be successful, the design of a constructed wetland should include input from a hydrologist, wetland specialist, wetlands plant specialist, and an engineer. Some method of providing water during the dry season needs to be considered or the vegetation will be dormant or dead at the time it is needed when the rains arrive.

Pocket wetlands have been used at commercial and industrial sites and by TriMet on their westside light rail line. It is doubtful due to their size that these pocket wetlands remove a large amount of pollutants but the do remove some. In some cases where insufficient land is available to allow for a fully functioning wetland, removing some of the pollutants from storm water runoff is preferable to not removing any.

The Natural Resources Conservation Service has a Wetland Conservation Standard for Constructed Wetlands, Code 280, that should be reviewed during the design phase of a constructed wetland.

Maintenance:

Phosphorus removal may be significant only during the first few years of vegetation establishment. This may be because in the first few years of vegetation growth the plants have a high demand for nutrients and phosphorus until the vegetation is established and a cycle of growth-death-growth recycling of the nutrients and phosphorus occurs. This would lead to the conclusion that a constructed wetland, in order to continue to remove certain pollutants, must have the dead vegetation removed and not allow it to recycle so that the nutrients and pollutants will always be removed from the incoming storm water and not from the dead vegetation. In this way the pollutant uptake will always be from the storm water and not from the decaying vegetation of past uptake. Monitoring the phosphorus and other pollutants entering and leaving the constructed wetlands will give a better feel for when the removal of the dead vegetation should take place. Some of the decaying vegetation needs to be available to provide for some of the nutrients and biomass necessary for good vegetative growth. Excess decaying vegetation will reduce the vegetative uptake of the pollutants from the incoming storm water.

Maintenance is of primary importance in order to maintain the pollutant uptake of a constructed wetland.. A maintenance plan needs to address removal of dead vegetation prior to the winter wet season, debris removal from trash racks, sediment monitoring in the upstream settling ponds or forebays are likely to contain significant amounts of heavy metals and possibly organics. Maintenance of the constructed wetland actually starts in the construction phase with the addition of organics such as compost to the soil. With proper maintenance constructed wetlands can function for 20 years or longer. Any mowing of the banks of the constructed wetland should also include a method for removal of those trimmings periodically. Mowing or cutting back the vegetation also reduces evapotranspiration and reduces the amount of pollutant uptake until the vegetation reestablishes full growth. Undesirable woody plant growth should be removed as soon as it is discovered. The method for controlling the water level in the wetland will have to be adjusted periodically as vegetation is established and as sediments accumulate in order to maintain the optimum water depth for the vegetation. The sediment forebay or settling pond will need to be checked and cleaned out in order to maintain good removal of the heavy sediments before they enter into the wetland. Depending on the ratio of heavy sediments to light colloidal suspensions and the design and size of the forebay or settling pond, the forebay or settling pond should be cleaned out every three to five years. A design that allows the forebay or settling pond to be drained independent of the wetland is highly desirable for this reason. Generally, studies have shown that the sediment form forebays or settling ponds to be non hazardous but to be sure they should be periodically tested especially from industrial and commercial sites.

Obtainable Removal Efficiency:

Heavy metals =	36-80%	Nitrate =	65%
Total Phosphorus =	40-100%	COD =	2%
Total Nitrogen =	28-90%	Total Copper =	80-95%
Total Lead =	80-95%	Total Zinc =	80-95%
Sol. Reactive Phosphorus =	75%	Ammonia =	- 43%
Total Suspended Solids =	90-100%	Bacteria =	60-80%
BOD_5 =	80-100%		

*Higher efficiencies are associated with the use of larger pond/marsh area and volume. These efficiencies assume that the intensity of the storm water inflow does not exceed the capacity of the wetlands and that the pollutants are not in a concentrated form from a large spill or discharge. Removal rates will vary with loading rates, retention time, and other factors.

Oregon Constructed Wetlands

Several natural wetlands have been reestablished or rehabilitated with new plantings in Oregon. There are several constructed wetlands being used for secondary and tertiary treatment of sewage. There appears to only a few constructed wetlands outside of pocket wetlands used for treatment of roadside, parking lot, or park storm water runoff in Oregon. Three of these, one from an aggregate mining site, one from an industrial site, and one from a public building, are two to three years or more in age and are located in DEQ's Northwest Region. An additional industrial storm water runoff constructed wetland is in the design stage.

EXAMPLES

COMMERCIAL OFFICE/LAB CONSTRUCTED WETLAND

City of Portland Bureau of Environmental Service's St. Johns Laboratory

PUBLIC PARK CONSTRUCTED POCKET WETLAND

Before Vegetation Establishment

About Two Years Later

Gabriel Park in Southwest Portland

AGGREGATE MINING SITE CONSTRUCTED WETLAND

Initially a Sediment Pond
Off Judd Road in Clackamas County

Lower Pond About Two Years Later

Upper Settling Pond for the Same Time Frame

One of the concerns with this wetland was that the inlet discharged to the sediment pond perpendicular to the length of the wetland (from the side) and did not have a method for spreading the flow across the full width immediately upon entering the wetland. Another concern was that the vegetation selected was not very applicable or appropriate. No wetland biologist was consulted. As can be seen the predominant vegetation is cattails, which are either dead or dormant in the wet season. The last two pictures were taken in late winter.

INDUSTRIAL CONSTRUCTED WETLAND

South of Tillamook, South of Anderson Creek, East of Highway 101

This constructed wetland serves a log yard, airport, and composting facility. Initial turbid inlet storm water can be seen in the picture to the right. The clear water is the existing water in Anderson Creek. After initial construction the inlet sediment chamber was widened in an effort to lower the inlet storm water runoff velocity for heavy sediment settling and the wetland size was roughly doubled to increase the turbidity and Total Suspended Sediment reduction. The site has not completed the vegetating of the wetland and only a couple of wetland plants were used instead of a more varied mix of vegetation. TSS reduction appears sufficient to meet the site's permit benchmark of 130 mg/l. Turbidity and TSS would further be reduced with a better designed settling forebay, a better inlet runoff water distribution system, and a distributed outfall water pick up system. The present wetland short circuits with an estimated 65% usage almost all of which is open channel.

The above view is from Highway 101 looking NE

The nonvegetated increased area of the wetland is very visible from this view.

POCKET CONSTRUCTED WETLANDS

Clean Water Services at corner of S.W. Cornelius Pass Road and W. Baseline Road
Collects Storm Water Runoff from Roadside and Roads

Lacks variation in vegetation but appears to perform well.

Commercial Pocket Constructed Wetland at the corner of S.W. 185th Avenue and N.W. Walker Road in Washington County serving the Storm Water Drainage from a Gas Station and an Oil Change Business.

The vegetation, cattails, have been cut back during maintenance of the wetland. Again there is not sufficient diversity of vegetation to be as efficient as this wetland could be. It is likely to take a couple of years before the vegetation can reestablish itself.

4800 Meadows

References

Benefits to Downstream Flood Attenuation and Water Quality as a Result of Constructed Wetlands in Agricultural Landscapes, Taylor A. DeLaney, American Farmland Trust, September 1995, http://www.farmlandinfo.org/cae/caepubs/delaney.html

Bioswale System, Hobbs & Hopkins Ltd., http://www.protimelawnseed.com/

Bioswales, Metro, August 1997, http://www.metro-region.org/growth/main/shared.html

Compost Markets Grow With Environmental Applications, BioCycle, Journal of Composting & Recycling, Vol. 40 No. 4, April 1999, http://www.environmental-expert.com/magazine/biocycle/april/article3.htm

Constructed Wetlands and Bioswale Landscaping Contractor – GreenWorks P.C. –24 NW 2nd Avenue, Suite 100, Portland, Oregon (503) 222-5612 - http://www.greenworkspc.com/

Constructed Wetlands Factsheet, National Small Flows Clearinghouse, http://abe.www.ecn.purdue.edu/~epados/onsiteOnline/cwetfact.htm

Constructed Wetlands for Erosion Control, Erosion Control, May/June 2001, http://www.forester.net/ec_0105_constructed.html

Constructed Wetlands Treatment of Municipal Wastewaters, EPA Office of Research and Development, EPA/625/R-99/010, September 2000, http://www.epa.gov/cgi-bin/claritgw?op-Display&document=clserv:epa-cinb:1122;&rank=4&template=epa

Declaration of Interdependence; Mycorrhizal fungi are the 'tiny little secrets' for successful plants; Mike Amatanthus; Mycorrhizal Applications, Inc.; http://www.mycorrizae.com

Ecosystem Studies of the Des Plaines River Experimental Wetlands, 1989/90, William J. Mitsch, Wetland Research, Inc., School of Natural Resources, The Ohio State University, mitsch.1@osu.edu

Efficient Fertilizer Use – The Soil Defined; Dr. Sam Kincheloe; http://www.agcentral.com

Guiding Principles for Constructed Treatment Wetlands, October 2000, EPA 843-B-00-003, US Environmental Protection Agency, http://www.epa.gov

A Handbook of Constructed Wetlands, Volume 1, General Considerations, Luise Davis, USDA-Natural Resources Conservation Service and the US Environmental Protection Agency-Region III, Mid Atlantic Region, http://www.epa.gov/owow/wetlands/water-sheds/cwetlands.html

Individual and Cumulative Effects of Wetland Water Quality Interactions, Carol A. Johnston, Natural Research Institute, University of Minnesota, cjohnsto@nrri.umn.edu or cjohnsto@nsf.gov

Modeling and Simulation of Wastewater Treatment Plants, BioCycle, Journal of Composting & Recycling, Vol. 40 No. 4, April 1999, http://www.environmental-expert.com/magazine/biocycle/april/article4.htm

Natural Resources Conservation Service Conservation Practice Standard: Constructed Wetland Code 280, http://159.189.24.10/wli/constds/wlicp280.htm

Oregon NRCS Field Offices, http://or.nrcs.usda.gov

Nutrient Cycling & Maintaining Soil Fertility; Centers at Piketon, The Ohio State University Extension; http://www.ag.ohio-stat.edu/~prec/soil/n_cycle.htm

Oregon Division of State Lands Wetland Information and Fact Sheets, http://www.oregonstatelands.us/wetlandsintro.htm

The Role of Wetlands in the Control of Nutrients with a Case Study of Western Lake Erie. William J. Mitsch, Brian C. Reeder, and David M. Klarer, http://clapton.uts.ohio-state.edu/swamp/Mitsch.html

Storm Water Technology Fact Sheet: Storm Water Wetlands, EPA Office of Water, EPA 832-F-99-025, September 1999, http://www.epa.gov/owmitnet/mtb/wetlands.pdf

Storm Water Technology Fact Sheet – Vegetated Swales, EPA Office of Water, 832-F-99-006, September 1999, http://www.epa.gov/OW-OWM.html/mtb/vegswale.pdf

Study of Compost Use in Bioswales for Compost Market Expansion, Clean Washington Center, June 1997, CM-96-3, http://www.cwc.org/organics/organic_htms/cm963rpt.htm

Technical Reference 55, Urban Hydrology for Small Watersheds, 1986, USDA Natural Resources Conservation Service, can be downloaded from the "Technical Tools" section at http://www.ncg.nrcs.usda.gov.

Turbidity, National Resources Research Institute, Water on the Web, http://wow.nrri.umn.edu/wow/under/parameters/turbidity.html

Vegetated Swales, **L**andscape **A**rchitecture **T**echnical **I**nformation **S**eries, Tom Richman, Keith H. Lichten, Jennifer Worth, Bruce K. Ferguson, December 23, 1998, http://www.asla.org/latis/latis03.cfm

VegSpec, a vegetation specification program, http://www.nrcs.usda.gov/technical/efotg/ in section *IV.C. Technical Resources of the Field Office Technical Guides*, Natural Resource Conservation Service