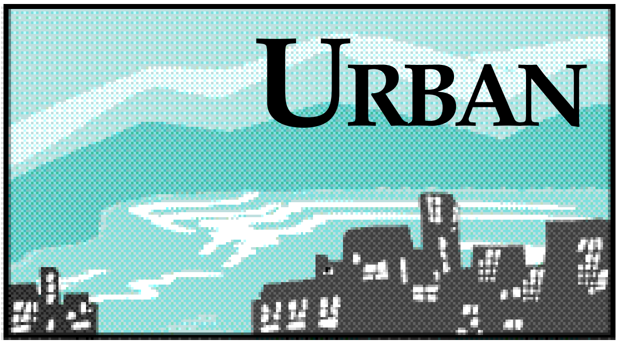

URBAN WATERWAYS

Designing Stormwater Wetlands for Small Watersheds

North Carolina has become a very desirable place to live and visit. The state has a robust economy, mild climate, and beautiful environmentally diverse landscapes. Thriving environmental communities such as mountain forests, piedmont streams, and coastal estuarine waters are major reasons why people choose to vacation or settle in North Carolina.

Yet the influx of people has also put a burden on environmentally sensitive areas of the state. New shopping centers, schools, offices, roads, and homes have increased the amount of stormwater runoff and have encroached upon or eliminated many sensitive environmental areas.

Perhaps the most documented impact has been on the state's wetlands. Wetlands are typically low-lying areas that have water tables near or at the surface for extended periods of the year. This wet hydrologic condition creates unique wetland soils (called hydric soils) and supports wetland vegetation.

Development and agricultural uses have converted roughly 50 percent of the state's historical wetlands into uplands, or drier land. This practice is not new; even George Washington took part in draining North Carolina's wetlands. Once drained, wetland soils are some of the most agriculturally productive in the state. Wetlands are often located adjacent to larger water bodies such as streams, ponds, and estuaries. By converting wetlands into drier land, property can become available for lucrative waterfront development. Historically, new development and wetland preservation have been viewed as mutually exclusive goals.

New development does more than affect the quality and amount of wetlands. With development comes an increase in pollutants such as sediment; nutrients, such as phosphorus and nitrogen; toxic chemicals and metals; oil and grease; and litter. These pollutants eventually enter North Carolina's streams, rivers, ponds, reservoirs, and sounds. The state of North Carolina now requires much new development to implement practices that reduce the amounts of pollutants reaching our water resources. These practices are referred to as Best Management Practices (BMPs). Some BMPs include pollutant reduction strategies (or practices) such as limiting fertilizer spread on lawns or limiting the amount of impervious surfaces in a watershed, such as roads and parking lots. Other BMPs are structural, meaning that they are constructed. Detention ponds, sand filters, and vegetative swales are examples of structural BMPs. (For an overview on structural BMPs, please see *Urban Stormwater Structural Best Management Practices,* AG-588-1, another publication in this series.)

An almost ironic structural best management practice is the stormwater wetland. Stormwater wetlands are designed to treat stormwater runoff from developed areas. Instead of being in conflict with development, wetlands

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can be created on property that originally did not meet wetland criteria to treat urban stormwater runoff from developed areas. This publication will focus on stormwater wetlands: their function, effectiveness, design, advantages and liabilities, and costs.

How Stormwater Wetlands Remove Pollution

Stormwater wetlands are designed for several reasons: improving water quality, improving flood control, enhancing wildlife habitat, and providing education and recreation. Moreover, the types of pollutants targeted to be removed can influence the design.

Wetlands in general, and stormwater wetlands in particular, use several mechanisms to remove pollutants. Stormwater wetlands employ perhaps more ways to remove sediments, nutrients, metals and chemicals, and even bacteria than any other structural BMP. These mechanisms include sedimentation, filtration, adsorption, microbial activity (nitrification and denitrification), and plant uptake. A summary of these mechanisms is given in Table 1.

Sedimentation and filtration are physical processes that remove particles, litter, and other debris. Sedimentation occurs because water moves very slowly in a wetland. Faster-moving water, like water flowing in storm drains, has more energy and is able, therefore, to carry sediment, trash, and other debris. Wetlands greatly reduce the water velocity, so once the water slows inside the wetland it loses its ability to carry these pollutants; thus, suspended particles tend to settle to the bottom of wetlands. Vegetation, which also provides filtration, aids in sedimentation, as the resistance of the plant mass helps reduce water's velocity. Because the inflow water must pass through wetland vegetation, some pollutants can be "snagged" by the plant mass. This is the process of filtration. Sedimentation and filtration are primary mechanisms for removing total suspended solids, litter and debris, nutrients attached to sediment particles—such as some forms of phosphorus, bacteria, and other pathogens that are also attached to sediment.

Adsorption onto soil particles—including other minerals—lying on the floor of the wetland is the primary mechanism for removing dissolved metals and soluble phosphorus. Soil particles have charges—similar to a magnet. So do dissolved metals and soluble phosphorus. When these charges are opposite, dissolved metals and phosphorus are attracted to the soil particles. This process is called adsorption. One drawback to adsorption is that there is a finite number of charged soil particles at the bottom of the wetland. Once all the available charged soil particles have sorbed with metals and phosphorus, then the adsorption potential of a wetland decreases dramatically. Scientists and engineers wrestle with this problem today.

Removal of nitrogen by a wetland is a rather complex set of processes. Wetlands provide a unique condition due to their vegetation living in submerged areas. Once a soil is saturated it becomes anaerobic, or without oxygen. Some wetland plants, however, use oxygen from the atmosphere to live, effectively pumping this oxygen down to their root zone. The net effect is to create small bands of aerobic (with oxygen) zones within an otherwise anaerobic environment. This unique environment allows organic forms of nitrogen to eventually be converted to nitrogen gas. Organic nitrogen decomposes into ammonia. Ammonia, through a process called nitrification, is converted into nitrate nitrogen. Nitrification is performed by nitrifying bacteria that live only in aerobic environments. The nitrate then diffuses to an anaerobic zone where denitrification takes place. Denitrification is the process of converting nitrate to nitrogen gas and is performed by denitrifying bacteria. Nitrogen gas is then released to the atmosphere, which already is about 80 percent nitrogen.

Other microbes in the wetland break down organic substances (reducing biochemical oxygen demand) and eat harmful pathogens. Wetlands provide favorable conditions for these microbial processes to occur.

Another, less significant, means of removing nitrogen and phosphorus from inflow is plant uptake. Wetland vegetation uses these nutrients as it grows. As plants die, however, nutrients are returned to the system. So, some view plant uptake as a temporary removal. To counter this problem, some people harvest portions of

Table 1. Pollutant and associated stormwater wetland removal mechanism

Pollutant removal mechanism	Pollutants
Sedimentation and filtration	Total suspended solids, floating debris, trash, soil-bound phosphorus, some soil-bound pathogens
Adsorption to soil particles	Dissolved metals and soluble phosphorus
Microbial processes (including nitrification and denitrification)	Nitrogen, organics, pathogens
Plant uptake	Small amounts of nutrients including phosphorus and nitrogen
Exposure to sunlight and dryness	Pathogens

(Adapted from Brix, 1993)

the wetland vegetation, thus encouraging new growth, new plant uptake, and less plant die-off.

Exposure to sunlight and dryness helps kill pathogens, which typically prefer wet conditions. While wetlands are typically wet, it is possible to design them so that certain areas are submerged during moderate to heavy rainfalls, but dry out between storms. Pathogens can become trapped in these dry regions and die. If pathogens are a concern, these typically dry areas can be made to comprise a larger percentage of a wetland area.

How Well Do Stormwater Wetlands Remove Pollution

Recent studies in North Carolina reinforce nationwide research that indicates wetlands are, on average, the most effective stormwater BMP at reducing pollutant levels. There is a wide range of national data showing exactly how well wetlands remove pollution, but the mean and median averages are very high. Compared with ponds, sand filters, bio-retention areas, and other practices, stormwater wetlands have the ***best*** median removal rate for total suspended solids, nitrate-nitrogen, ammonia-nitrogen, total phosphorus, phosphate-phosphorus, and some metals. Stormwater wetlands can remove these and other pollutants because of the many mechanisms that are employed to remove pollutants. Wetlands are truly a unique environment! A listing of pollutant removal effectiveness is given in Table 2.

All but a few median removal percentages are very high, except for organic nitrogen, whose removal level is essentially zero. This is due to the nature of wetlands. As vegetation dies, organic matter is transported from the wetland. Stormwater wetlands actually increase organic matter in adjacent water bodies after particularly large storms, which tend to flush the wetlands out. Some wetland designs, therefore, include a large flow by-pass (flow splitter) that allows larger storms to circumvent the wetland. There is great variability in the measured effectiveness of stormwater wetlands to remove various pollutants. Much of this variability can be attributed to wetland design, the nature of the watershed, or time of year the site was monitored. Wetlands that are greatly undersized, and therefore susceptible to frequent flushing by storms, are typically not as effective as properly sized wetlands. Also, if the monitoring occurs when a storm like a hurricane passes over the watershed, the possibility of large amounts of debris being flushed out increases. As this event is monitored, it is shown that the wetland actually leaks, or emits pollutant. Longer-term monitoring is usually needed to accurately assess a wetland's ability to remove pollution.

Table 2. Pollutant removal effectiveness of stormwater wetlands

Pollutant	Number of samples	Median pollutant removal percentage	Range
Total suspended sediment	35	78%	-29% to 99.5%
Soluble phosphorus	15	40%	-34.5% to 75%
Total phosphorus	35	51%	-9% to 99.5%
Ammonia (as NH_4)	19	43%	-55.5% to 72%
Nitrate-nitrogen	30	67%	-100% to 90%
Organic nitrogen	12	1%	-31% to 43%
Total Khedjahl nitrogen (TKN)	10	14.5%	-10.3% to 81%
Total nitrogen	22	21%	-25% to 83%
Copper	10	39.5%	2% to 84%
Lead	17	63%	23% to 94%
Zinc	16	53.5%	-73.5% to 90%

(Adapted from Brown and Schueler, 1997)

Selecting a Site for a Stormwater Wetland

The two primary factors for selecting an appropriate site for a stormwater wetland are the availability of water to feed the wetland and site topography. On sandy soil, it is also important to verify water table depth. The base of the wetland should be about 6 inches lower than the seasonally low water table. This guarantees that water will be in the wetland for the majority of the year, which is critical for plant and animal habitat. If the water table is very deep, constructing a stormwater wetland in sandy soil can become cost prohibitive. Perhaps a different practice, such as bio-retention is more appropriate. If a wetland is being constructed in primarily clayey soil, then it is possible to perch the wetland above the water table. The depth to water table in clayey soils, therefore, is not necessarily important. However, the clay bottom of the wetland must have low enough permeability so that the wetland does not go dry.

Not surprisingly, flat sites are much better suited to wetland construction than hilly areas. This reduces much of the cost created by excavation and hauling—the primary construction expenses. Other factors influencing wetland site selection are:

1. Would the wetland be near unattended small children?

2. What kind of buffer would be between the wetland and residential areas?
3. Is the site forested or predominantly clear?
4. Would there be an easy outlet for water once it was released from the wetland?
5. Would the wetland's location allow easy maintenance?

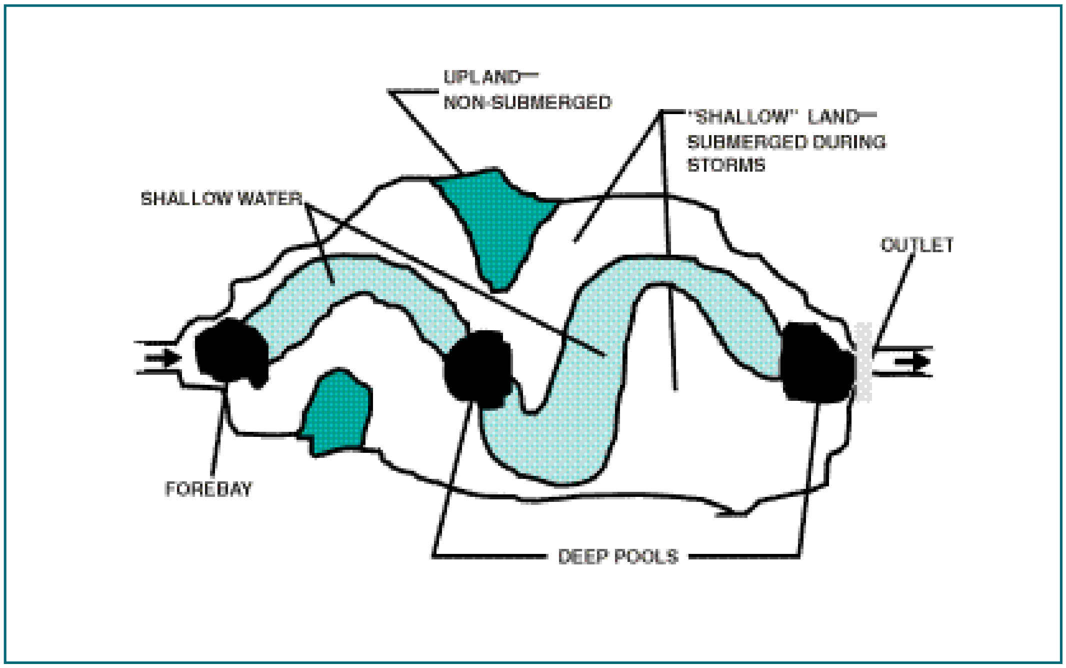

Figure 1. Plan view of a stormwater wetland.

Stormwater Wetland Features

Stormwater wetlands have many features in common, such as forebays, deep pools, shallow water areas, areas that are only submerged during storms or "shallow land," non-floodable areas, a retention device, and two outlet devices. These features are crafted within the wetland to create a long, sinuous path for water to follow as it flows through the wetland. This flow path is designed to prevent short-circuiting, to increase stormwater retention time, and to improve treatment of stormwater. See Figure 1 for a plan view of a stormwater wetland.

Forebays

Forebays are placed where runoff enters the wetland. It is here that much of the sedimentation occurs. The forebay is typically a deeper area of the wetland, at least 2½ feet deep. If sediment or litter is a concern, it will be important to design the wetland so heavy equipment will have easy access to the forebay. Proper maintenance of the forebay will help keep the rest of the wetland from filling with debris. Designers from mid-Atlantic states have found that sizing the forebay's surface area to be 10 percent of the total wetland surface area has proved adequate.

Deep Pools

Deep pools are an important part of the wetland if it is to support fish. The 2½-feet-deep-minimum pools are designed to retain water even during drought. They are too deep for most wetland vegetation to grow in (though some water lilies thrive in water this deep). Fish habitat is particularly vital if mosquito control is a design requirement. Mosquito larvae-eating fish (gambousia) need deep waters to survive. The surface area of deep pools can range from 5 feet-diameter circles to much larger areas. In total, deep pools should occupy 5 to 10 percent of the wetland's surface area.

Shallow Water

Shallow water areas are part of the "bread and butter" of the stormwater wetland. This is where wetland vegetation thrives; the plants can pump oxygen into their root zone, establishing the conditions necessary for nitrification. At low flow, water should follow the course of the shallow water area. Water is designed to be between 6 and 12 inches deep in the shallow water zone before a storm, with greater depths during rainfall. The shallow water zone occupies roughly 40 percent of the wetland's total surface area.

"Shallow Land"

The land feature that dominates the wetland, "shallow land," is typically dry except during storms when it is submerged. This land should be between 0 inches and 12 inches above the water at normal pool. By having a variety of terrain, a wider variety of vegetation can be grown. Certain plants only like being wet some of the time. A wider variety of plants leads to a wider variety of animals, which leads to more mosquito predators. This "shallow land" typically accounts for 30 to 40 percent of the total surface area of the wetland. If bacterial die-off is an important part of the design, this feature could be larger.

Upland/Non-Floodable Areas

Some regions of the wetland can be designed to never be submerged normally. These non-floodable areas can serve as observation points if the wetland will be used for educational or recreational purposes. Other varieties of vegetation more common to upland regions can grow on these upslope areas. Often this is where many varieties of trees and shrubs can be planted. The land can range from 2 to 4 feet or even higher above normal pool, with the dictating factor being the height of water during storms. Non-floodable areas technically are not wetland zones. They can comprise as much or as little of the total treatment system as desired.

Outlets

The primary spillway serves two purposes. First, it stores water during smaller rain storms, allowing runoff to be slowly released by drawdown devices. Second, it successfully passes excess water through the wetland when heavy rains fall. The spillways are often weirs constructed of treated lumber (though the wet conditions make them susceptible to rot), metal sheet piles, or even concrete. The retention device, as seen in Figure 2, must be constructed so that water does not rise above the top of it during a design storm—such as the 25-year, 24-hour storm. Typically a deep pool is constructed immediately upstream from the weir.

Water levels within the wetland are regulated by drawdown structures such as weirs, riser-barrels, and small orifices. For maintenance purposes it is best to install a pipe that can be used to drain the wetland of all its water, except for that in deep pools. Another drawdown device is needed to slowly release water from the storage area of the wetland, which is the volume of water held between the elevation of the weir crest and the desired normal pool. A series of small holes can be drilled through the weir for this purpose, or another drawdown pipe can be installed through which water can drain. A small trash rack installed around the drawdown keeps the small orifices from getting clogged by debris. A technique for calculating the size of the drawdown holes is shown in a following section. The principal spillway and drawdown device with associated water depths are shown in conjunction in Figure 3.

Figure 2. A typical retention device has two prominent features as shown in this photograph. First is the principal spillway. In this photograph the principal spillway is the wooden weir. The second is a drawdown device. In this case the small riser pipe has holes drilled into it behind the protective rocks. The difference in elevation between the drawdown device and the principal spillway dictates the wetland's temporary storage volume.

Designing a Stormwater Wetland

Sizing the Wetland

The first question often asked when designing any structure is, "How large does it need to be?" Assuming the wetland is designed to improve water quality, it should be sized to treat runoff from the first flush (typically runoff from the first inch of rainfall). To treat this runoff, stormwater wetlands are designed to store all the runoff from the first flush. A rough estimation of depth of runoff can be calculated using the following Natural Resources Conservation Service (NRCS) curve number equations:

Runoff (inches) = (Precipitation – 0.2 S)^2 ÷ (Precipitation + 0.8 S), Where S = 1000 ÷ CN – 10 and Precipitation is set at 1 inch (the first flush)
CN = Curve Number

Curve numbers are indicators of a watershed's ability to store water (through initial storage and subsequent infiltration) or, conversely, shed water through runoff. A high curve number suggests a very impervious area, such as a parking lot that sheds nearly all rainfall, while a low curve number suggests an area that allows for storage and infiltration, such as a wooded area in sandy soil. A sample of curve numbers is given in Table 3.

Curve numbers vary by soil type. Sandier soils found in soil groups A and B have lower curve numbers because they are more permeable than the clayey soils of groups C and D. To find the soil type or types in your watershed, please refer to your local county soil survey, which can be obtained from your county's soil and water conservation district office or local Extension office.

The runoff value calculated by the curve number method is depth. This is a one-dimensional number: how much water will run off land *per* a given area. However, to calculate total runoff volume for the stormwater wetland to treat, the runoff value must be multiplied by the watershed area.

Treatment (or Retention) Volume (acre-inches) = Runoff (inches) x Watershed area (acres)

With the storage volume of the wetland known, it is then possible to calculate the surface area needed. The depth of storage is determined by plant tolerance for various water depths. This depth ranges from 6 to 12 inches depending on vegetation type and duration of inundation. Assuming plants can withstand a 12-inch variation in water depth for two to three days and that wetland porosity (or fraction of free space in which to store water) is 1.0[1], a rough calculation of wetland surface area would be as follows:

Surface Area (acres) = Watershed Volume (acre-inches) ¸ 12”

This estimation method usually produces surface areas of a wetland that range from 7 percent of the watershed area for parking lot drainage (CN=98) to slightly more than 1 percent of watershed area if the drainage were to come from homes on ½-acre lots on rather clayey class C soils (CN=80). This type of runoff condition is common for developing areas of piedmont North Carolina such as in Charlotte, the Triad, and the Triangle.

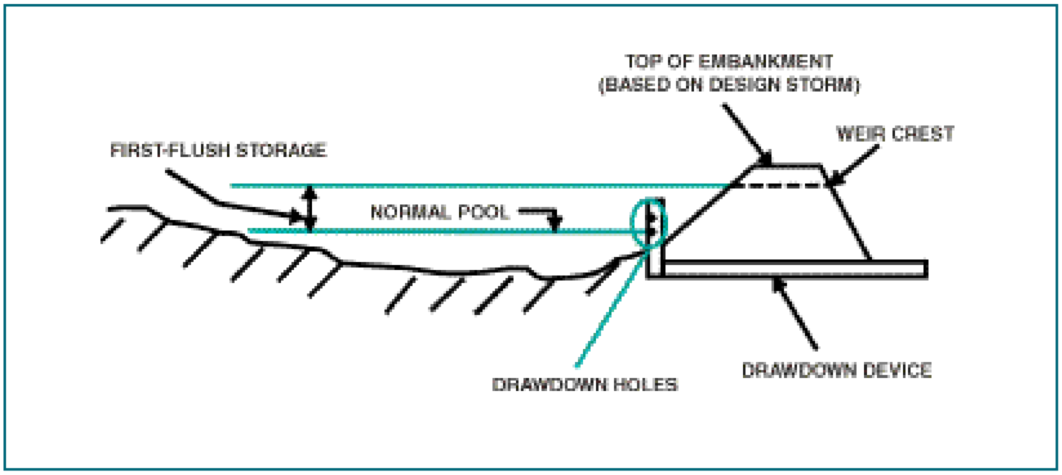

Figure 3. Cross section of wetland bottom showing water elevations.

Table 3. Some NRCS (formerly Soil Conservation Service) curve numbers for urban areas. Note: Soil Groups A and B are or tend to be sandy soils, while Soil Groups C and D are or tend to be clayey soils.

Land Use	Soil Group A	Soil Group B	Soil Group C	Soil Group D
Paved parking lots, roofs	98	98	98	98
Paved roads with curb and gutter	98	98	98	98
Paved roads with open ditches	83	89	92	93
Gravel roads (including right-of-way)	76	85	89	91
Paved roads (including right-of-way)	74	84	90	92
Commercial and business district (85% impervious)	89	92	94	95
Industrial district (72% impervious)	81	88	91	93
Townhouses (1/8 acre lot)	77	85	90	92
Residential lot (1/4 acre)	61	75	83	87
Residential lot (1/2 acre)	54	70	80	85
Residential lot (1 acre)	51	68	79	84
Residential lot (2 acres)	46	65	77	82
Open space (golf courses, lawns, parks, cemeteries) with grass cover < 50%	68	79	86	89
Open space with grass cover 50% to 75%	49	69	79	84
Open space with grass cover > 75%	39	61	74	80
Woods in fair hydrologic condition	36	60	73	79

(Taken from USDA—Soil Conservation Service, 1986)

[1] Wetland porosity would vary from 0.0 to 1.0. A value at or near 0.0 would indicate a wetland storage volume completely filled with vegetation. That is, there would be no room to store water because plant mass would occupy all free space. A value at or near 1.0 suggests that plant mass takes up very little, or none, of the storage volume available for water. The author believes the fraction for most wetlands would tend to be much closer to 1.0 than 0.0.

Determining Retention Time

With surface area and depth of storage area determined, it is now necessary to design the outlet structures—typically a weir and a drawdown device. The crest of the weir and the base of the drawdown device's inlet are vertically separated by the depth of storage. Assuming the depth of storage is 12 inches, the distance from the crest of the weir to the orifice invert (bottom of the drawdown hole) of the drawdown device is also 12 inches. The drawdown device regulates normal pool and detains the runoff from a 1-inch storm for at least a couple of days. To achieve maximum treatment of the runoff, the storage volume should be retained for as long as possible. However, water from one storm should be treated—and released—before the next storm arrives. To select retention time, the average time between storms must be known. Table 4 shows the average period between storms for several locations in North Carolina.

For example, in Wilmington, the mean number of days between rainfall is 3.8, the median number of days between storms is 3, and two-thirds of all storms have at least two days of dry weather between them. A maximum retention time should be set between the mean and median interval between rainfalls, somewhere between 3 and 3.8 days. To optimize runoff treatment, a minimum retention time must be established as well. A minimum number of days to drain stored runoff can be set where the probability of a more frequent rainfall is 1 in 3. In North Carolina two-thirds of storms are separated by at least 2 days of dry weather. Therefore, a minimum retention time is 2 days for Wilmington. The size and the number of drawdown holes should be determined so that water stored from a 1-inch rainfall is emptied within 2 to 3 days.

The water table is lowered by having water drain through small weep holes, or orifices. The orifices serve as the drawdown device and can be constructed by drilling holes through a wooden dam or having a riser pipe serve as the orifice. The pipe with a riser could run through an earthen portion of a dam. The equation that calculates flow through submerged holes is the orifice equation:

Q = Cd ´ A ´ Ö (2gh),
Where,
Q = Outflow through orifice,
Cd = Coefficient of Discharge (default = 0.60),
A = Cross-sectional area of hole,
g = gravity, and
h = height of water over centerline of the hole.
See Figure 4.

Table 4. Number of days between precipitation events (primarily, measurable rain) for selected cities in North Carolina. Data are taken from Southeast Region Climate Center from 1988 to 1998. Fourth column indicates the number of days with a probability of time between storms of 67 percent.

City	Median	Mean	67% of dry periods greater
Asheville	3	3.6	2
Charlotte	3	4.1	2
Elizabeth City	3	3.7	2
Greensboro, Winston-Salem, High Point	3	4.0	2
Raleigh-Durham	3	3.9	2
Wilmington	3	3.8	2

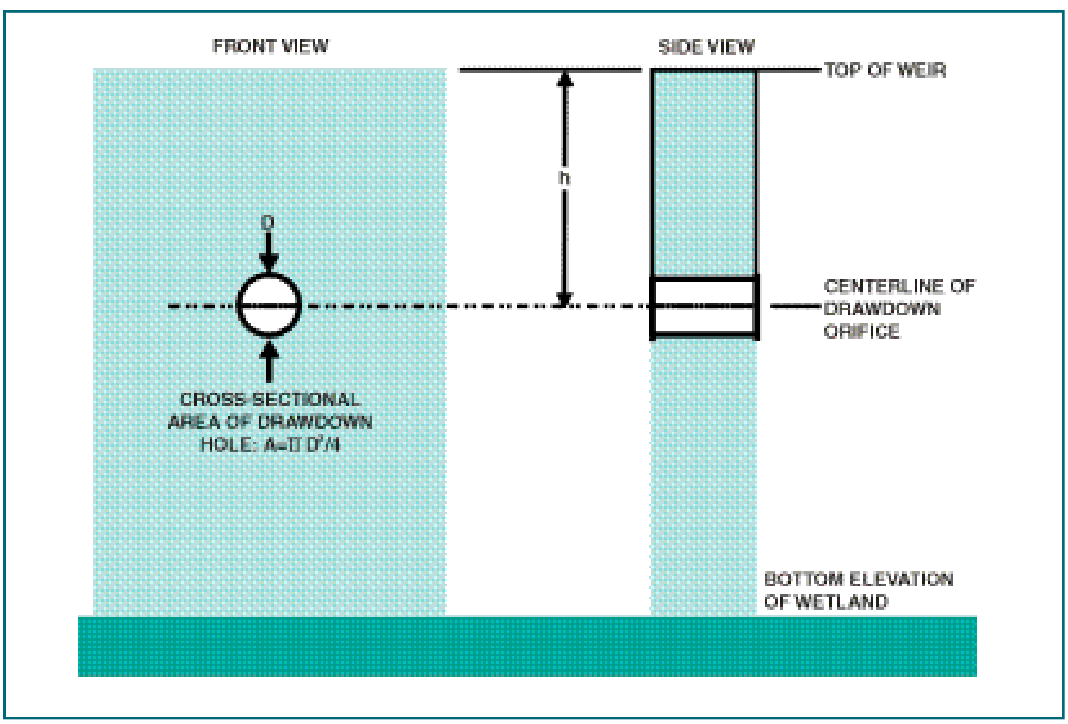

Figure 4. Orifice equation parameters for wetland drawdown device. Both views are from a cross section of a weir with drawdown orifice drilled through middle.

The orifice equation calculates the amount of water flowing through the hole at a given time. Assuming no inflow, the level of water in the wetland will drop as a function of the amount of water flowing through the orifice and therefore leaving the wetland. As the water drops, the height of water above the orifice drops, meaning the rate of flow through the orifice decreases. It is usually not possible to calculate time needed to draw down the level of the water by using the equation once. An iterative process is necessary.

1. Set the height of the water above the drawdown device (assuming a 1-inch rainfall, this height should equal that of the weir crest).
2. Calculate a flow rate (Q) at this height, using the orifice, or other governing flow, equation.
3. Determine the volume of water leaving the wetland by multiplying the flow rate by a pre-set time interval (such as 15 minutes).
4. Reducing the water in the wetland by the volume determined in step 3 lowers the height of the water level. To calculate a new water level, first establish a relationship between volume of water (storage) and water elevation (stage). A simple stage-storage relationship is given in the following example: a 4-feet-by-2-feet box is filled with water until the depth is 3 feet. The stage-storage relationship for this box would be that for every 8 cubic feet of volume that leaves the box, the height of the water level in the box drops 1 foot.[2]
5. Use this new height to calculate a new flow and repeat the process.

In essence we are routing water through the drawdown device as seen in Table 5. The size and number of holes

Table 5. Iterative calculation of drawdown of wetland storage by an orifice
Input data: Number of holes = N = 1
Area of hole (2” X 2” square) = A = 4 sq in
Coefficient of discharge = Cd = 0.60
Gravity = g = 32.2 ft/s²
Storage volume parameters = VOL = 80’ wide X 160’ long X 1’ deep = 12,800 cu ft
Storage surface area = SA = 80’ wide X 160’ long = 12,800 sq ft

Time (15-min interval) *(min)*	**Height over centerline of hole *(ft)***	**Outflow *(cfs)***	**Change in volume *(cu ft)***	**Change in height of water *(ft)***	**New height for next time interval *(ft)***
T	H (T)	Q = N*A*Cd* Ö(2*g*H)	DVol =T*Q	DH = DVol / SA	H (T+1) = H – D H
0	1.0	0.134	120	0.009	0.99
15	0.99	0.133	120	0.009	0.98
30	0.98	0.132	119	0.009	0.97
45	0.97	0.132	119	0.009	0.96
60	0.96	0.131	118	0.009	0.95
75	0.95	0.131	118	0.009	0.94
90	0.94	0.130	117	0.009	0.94
105	0.94	0.129	116	0.009	0.93
120	0.93	0.129	116	0.009	0.92

Note: Selection of Dtime small enough so that Dheight is small as in above table.

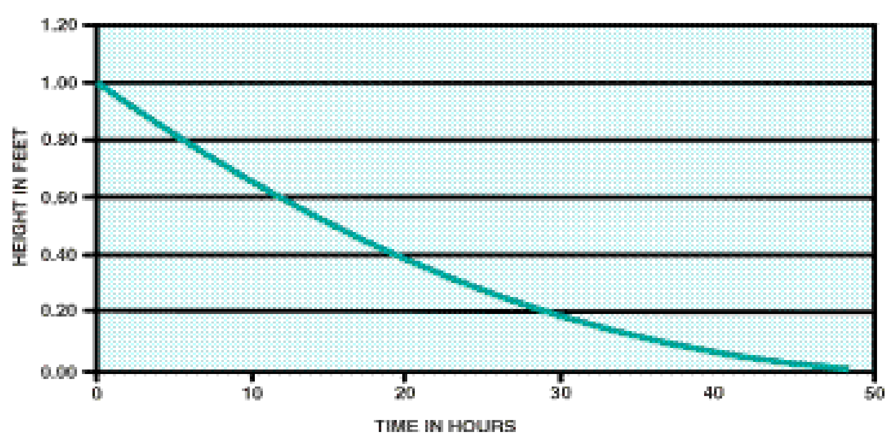

Figure 5. Wetland drawdown as a function of time as determined by stormwater routing from example in Table 5. (Malcom, 1997)

[2] For more information on establishing the stage-storage relationship please refer to H. R. Malcom’s *Elements of Stormwater Design*, North Carolina State University, 1996, Raleigh, NC.

govern how fast the water elevation drops. The designer can adjust these values until the total drawdown time is roughly 2 to 3 days. In the example shown in Table 5 and Figure 5, total drawdown time is 49 hours. For larger wetlands, the drawdown device could be a narrow weir. Calculating drawdown for this type of device is similar to that of an orifice except with a new governing equation (for rectangular weirs):

$Q = Cw \times H^{1.5} \times L$,

Where, Q = outflow, Cw = Weir Coefficient (3.0 except if sharp crested, then 3.33), H = height of water upstream of (not directly over) weir, and L= length of weir.

Designing the Primary Outlet

To this point the focus has been on water that is captured by the wetland and then slowly released. However, storms whose rainfall exceeds 1 inch will probably produce some runoff that is not retained by the wetland. This water is either routed around the wetland, bypassing the system altogether, or it flows through the wetland and passes over a principal spillway. The spillway is most often a weir constructed of wood, metal, or concrete. The base is set at the elevation where runoff from the 1-inch rainfall is completely stored—as mentioned earlier, this elevation is between 6 and 12 inches higher than normal pool. The top of the outlet is established so that water does not overtop it during larger storms, such as a 25-year, 24-hour rainfall. The top of the embankment is still higher because additional freeboard is needed to prevent mass failure during very large storms. The exact design storm is determined by the designer based on downstream conditions. Wetlands typically do not store amounts of water that could result in catastrophic (life-threatening) conditions if the outlet were to fail. Accordingly, most wetlands are designed to safely withstand 25- or 50-year storms. If the cost of rebuilding the primary outlet is sufficiently high, a larger design storm may be necessary. Routing procedures, which relate inflow to the wetland and outflow from the wetland, are used to determine water heights within the wetland. If the water elevation rises too high, then the weir length of the outlet can be made longer (flow is directly proportional to weir length). A routing scheme similar to, though expanded from, the one shown in Table 5 can be used on small watersheds. For a detailed description of routing, see *Elements of Stormwater Design* by H. R. Malcom available through the Industrial Extension Service at North Carolina State University for an extremely practical guide for use in North Carolina.

Wetland Plant Selection

Topography within wetlands is designed to be variable. One of the primary reasons is to increase plant diversity. Monocultures of plants pose aesthetic, nuisance, and possible water quality problems. By undulating the bottom of the wetland, it is nearly impossible for a monoculture such as lilies, cattails, or common reed to establish itself. Wetland plant selection is both an art and a science. Plants prefer certain water depths or elevations. Water that is too deep or conditions that are too dry will kill them. Lilies *(Nymphaea spp.)*, for example, survive in water that is between 2 to 3 feet deep; cattails *(Typha spp.)* withstand water levels from saturation to being inundated 18 inches deep and tolerate substantially higher water levels for short periods of time; sycamores prefer to be out of the normal pool of water, but "don't mind getting their toes wet." Some vegetation can withstand full sunlight; others need shade. Most wetland vegetation is deciduous, that is, it becomes dormant in the winter. But some species such as rush *(Juncus spp.)* are nearly evergreen or evergreen. Some wetland species, such as cardinal flower, are much more attractive than others, like cutgrass.

A planting guide is primarily dictated by the needs of the wetland. However, certain factors should be addressed when planting stormwater wetlands.

1. Stormwater wetlands work best at removing excess nitrogen when oxygen is being pumped into the root zone. In spring, summer, and fall, this is not a concern. However, in the winter when most plants are dormant, some evergreens are needed so that some nitrification can occur. Some particularly abundant species that are nearly evergreen include J*uncus effusus* and *Juncus coriaceus*, or common rush. These plants can survive in shallow water and at the edge of water, which makes up the majority of the wetland area. Evergreens not only improve water quality in the winter, but they also lend color to a wetland when it is otherwise very drab. Other evergreens include: Atlantic white cedar *(Chamaecyparis thyoides)*, pond pine *(Pinus serotina)*, sweet bay *(Magnolia viginiana)*, coastal dog hobble *(Leucothoe axillaris)*, inkberry *(Ilex glabra)*, and ti-ti *(Cyrilla racemiflora)*.
2. It is very important to avoid non-native and very aggressive plants. By selecting an overly aggressive plant, a potentially diverse community could be outcompeted and converted into a monoculture. Many of these plants are well known because they are so aggressive that they are ubiquitous. At a minimum, ***do not introduce*** these plants into the wetland; it may even be necessary to remove them

if they begin to establish themselves, especially during the early stages of the wetland's life. If a biological diverse ecosystem is desired, avoid these plants: Asiatic dayflower *(Murdannia keisak)*, cattails *(Typha spp.)*, Chinese privet *(Ligustrum sinense)*, common reed *(Phragmites australis)*, duckweed *(Lemna spp.)*, and giant duckweed *(Spirodela spp.)*. Other more desirable species *(Juncus effusus)* are invasive from high seed production. Planting diversity is maintained by regular maintenance or through design with varying water levels.

3. The best time to plant herbaceous vegetation in wetlands is late March through early June and again in September and October. The best time to plant trees and shrubs in wetlands is from November through early to mid March. This is critical when scheduling wetland construction. Just remember that maintenance (periodic watering during drought conditions) may be required at least until the plants are established.
4. Wetland plants may be obtained from mail-order seed sources, through greenhouses or nurseries, or with local transplants. Installation time and resulting costs are usually the deciding factors in plant acquisition. Typically, lower costs and increased survival come with using plants grown locally using neighboring seed sources. The lack of availability of certain species may require the use of transplants. Transplants require additional care to ensure survival. Transplants should not be allowed to dry and should be planted shortly after being dug.

Wetland vegetation manuals are extremely helpful, including *Common Wetland Plants of North Carolina*, produced by the N.C. Department of Environment and Natural Resources, Division of Water Quality. Table 6 lists several species of plants that can grow in the various regions of the wetland (deep pool, shallow water, shallow land, non-floodable areas) and includes trees, shrubs, herbaceous plants, rushes, sedges, and aquatic plants. Table 6a relates common names with their Latin counterparts. These lists are by no means exhaustive.

Table 6. Suggested wetland vegetation by stormwater wetland zone

Wetland zone	Trees	Shrubs	Herbaceous	Sedges/ rushes	Aquatic herbs
Deep pool (> 2.5' deep)	Bald Cypress	N/A	N/A	N/A	Cow lily, Water lily, Water lotus
Shallow water (0" – 12" deep)	Atlantic white cedar, Bald cypress, Black willow, Overcup oak, Swamp tupelo, Water tupelo	Sea Ox-eye, Swamp Dog-hobble, Swamp Rose	Arrow arum, Arrowhead, Cardinal flower, Lizard's tail, Pickerelweed, Southern blue flag	Rice cutgrass, Rush (juncus), Soft stem bulrush	N/A
Shallow land (0" – 12" above water)	Black Willow, Green ash, Pond Pine, River Birch, Sweetbay, Water Oak, Willow Oak	Buttonbush, Coastal dog-hobble, Elderberry, Inkberry, Silky dogwood, Sweet pepperbush, Ti-ti	False nettle, Rose mallow, Smartweed, Touch-me-not	Rush (juncus), Wool grass	N/A
Non-floodable land	Cherrybark oak, Red maple, Sycamore, Tulip poplar, Water oak, White pine	Great laurel, Rhododendron, Wax myrtle	Grape fern, Southern lady fern	River oats, Wire grass	N/A

Table 6a. List of wetland vegetation by common name and *Latin name*

Trees	Sweet pepperbush *(Clethra alnifolia)*
Atlantic white cedar (*Chamaecyparis thyoides)*	Ti-ti *(Cyrilla racemiflora)*
Black willow *(Salix Nigra)*	Wax myrtle *(Myrica cerifera)*
Cherrybark oak *(Quercus pagoda)*	**Herbaceous**
Green ash *(Fraxinus pennsylvanica)*	Arrow arum *(Peltandra virginica)*
Overcup oak *(Quercus lyrata)*	Arrowhead *(Sagittaria spp.)*
Pond pine *(Pinus serotina)*	Cardinal flower (*Lobelia cardinalis)*
Red maple *(Acer rubrum)*	False nettle *(Boehmeria cylindrica)*
River birch *(Betula nigra)*	Grape fern *(Botychium spp.)*
Swamp tupelo *(Nyssa biflora)*	Lizard's tail *(Saururus cernuus)*
Sweet bay *(Magnolia viginiana)*	Pickerelweed *(Pondtederia cordata)*
Sycamore *(Platanus occidentatlis)*	Rose mallow *(Hibiscus moscheutos)*
Tulip poplar *(Lirodendron tulipifera)*	Southern blue flag *(Iris virginica)*
Water oak *(Quercus nigra)*	**Grasses/Sedges/Rushes**
Water tupelo *(Nyssa aquatica)*	Common rush *(Juncus effusus)*
White pine *(Pinus strobus)*	Rice cutgrass *(Leersia oryzoides)*
Willow oak *(Quercus phellos)*	River oats *(Chasmanthium latifolium)*
Shrubs	Smartweed *(Polygonum spp.)*
Buttonbush *(Cephalanthus occidentalis)*	Soft stem bulrush *(Scirpus validus)*
Dog-hobble *(Leucothoe spp.)*	Wiregrass *(Aristida stricta)*
Elderberry *(Sambucus canadensis)*	Woolgrass *(Scirpus cyperinus)*
Inkberry *(Ilex glabra)*	**Aquatic Herbs**
Rhododendron *(Rhododendron maximum)*	Cow lily *(Nuphar lutea)*
Sea ox-eye *(Borrichia frutescens)*	Water lily *(Nymphaea odorata)*
Swamp rose *(Rosa palustris)*	Water lotus *(Nelumbo lutea)*

Limitations of Stormwater Wetlands

Stormwater wetlands are designed to offer optimal treatment of stormwater. They are arguably the best BMP available to reduce most pollutants and certainly the best at removing excess nitrogen from stormwater. They can also be outstanding recreational and educational facilities. However, inherently there are a few limitations associated with wetlands. They require a lot of land—as much as or more than any other BMP in some cases. This land also must be relatively flat and have a reliable water source (groundwater or perched water).

Much of the concern over wetlands in the past has been with animal life that may be found there. Mosquitoes are often first to come to mind. In fact, mosquitoes can become a significant problem in wetlands with a monoculture of plants, such as cattails or *Phragmites*. However, wetlands can be designed, as described earlier, to have a wide variety of plant species that can provide a habitat for a diverse group of animals. Many of the species, including dragonflies, frogs, some birds, and fish, eat mosquitoes or their larvae. One unwelcome animal—in some people's mind—is snakes, which do inhabit wetlands. Therefore, access should be limited for small children if this is a concern. Another liability associated with small children is the somewhat deep water (2.5 feet) in parts of the wetland. While not as deep as ponds and lakes, the "deep" water of a wetland can be a potential drowning hazard. It is possible to have shallow shelf areas around the deeper pools so that if someone were to fall into the wetland, he or she would land on the shelf rather than fall into the pool.

Stormwater wetlands are a relatively new stormwater treatment device, so very little maintenance cost data are known. This lack of knowledge is a drawback for some, but it appears that the cost for maintaining a wetland is somewhat similar to the cost of maintaining a pond.

Estimating Wetland Costs

Wetland costs can fall into three main categories: land, construction, and maintenance. Land cost is, of course, the most variable, depending upon location, but is often the largest single cost associated with wetlands in North Carolina, especially in urbanizing areas. Assuming a $40,000-per-acre value, a wetland treating 50 acres of runoff (roughly a 1-acre wetland) would cost $40,000 before any earthwork or landscaping took place. Construction costs are broken down into excavation and grading, hauling of excess earth, wetland plant purchase and/or installation, construction of the primary outlet, and construction of a drawdown device. Some other small miscellaneous costs may or may not be incurred, such as fish stocking, rip-rap installation for inlet and outlet protection, and design and installation of interpretive signs.

Table 7. Sample land and construction costs of a stormwater wetland (taken from North Carolina case studies)
NOTE: The table is based on a 1-acre wetland treating a 50-acre watershed.

Cost type	Description	Unit cost	Total cost	Cost per acre of watershed treated
Land	Land values may vary from $10,000 - $400,000 per acre in N.C. Assume $40,000 at this site.	$40,000/ac	$40,000	$800
Excavation and grading	A total of 4,800 cubic yards (1 acre X 1 yard depth).	$8/cy	$38,400	$770
Hauling	Area adjacent to site used to spread excess earth—costs included in Excavation costs.	Part of above costs	Included in Excavation and grading costs	Included in Excavation and grading costs
Vegetation	Some local transplants, some natural establishment, and a few ornamental plants from local nursery.	$0.30/sf	$13,000	$260
Spillway and drawdown	Treated lumber used for aesthetic purposes. Drawdown holes drilled through principal spillway.	$0.25/sf	$11,000	$220
TOTAL LAND AND CONSTRUCTION COSTS			**$102,400**	**$2,050**

The primary construction cost is for earthwork, including excavation, grading, and hauling. Excavation and grading costs for wetlands constructed in the piedmont and coastal plain of North Carolina have ranged from $4 to $9 per cubic yard, with a tendency toward economies of scale. Hauling costs dramatically increase with the distance the excavated soil needs to be carried. If the soil can be disposed of on site, tremendous savings can be made.

Costs associated with vegetation are highly variable. It is possible to transplant some vegetation from nearby road ditches and allow much of the wetland's vegetation to naturally establish, which reduces costs considerably. However, wetlands are often required to meet aesthetic standards. So, special care must be taken when selecting plants. If plants are purchased from wetland nurseries, costs will undoubtedly increase, but the wetland will more likely serve an aesthetic purpose. Another factor to consider in wetland vegetation is desired spacing. If a fully established ecosystem is desired within one year, plants must be placed close together. More plants mean more money. Finally, if a nursery is used, the species of wetland vegetation can greatly affect costs. Costs have ranged from as low as $0.30 per square foot where plants came from selective harvesting and natural establishment to $1 per square foot where nursery vegetation was used.

The costs of the principal outlet and drawdown device depend on the size of the watershed, and, consequently, the size of the wetland. More water means a bigger dam. In North Carolina, the cost of outlet and drawdown construction has ranged from $0.25 to $1 per square foot of wetland area.

Maintenance costs vary by watershed type. A watershed that is under development will result in higher amounts of sediment reaching the wetland, thus increasing the frequency of maintenance. Watersheds with more human activity can result in more litter and debris. Occasional inspection of the dam, principal spillway, and drawdown device is also necessary. Table 7 shows a summary of costs for a sample wetland.

Summary

Stormwater wetlands are becoming a standard best management practice in treating stormwater runoff from urban areas. When designed and installed properly, stormwater wetlands are effective at removing pollutants, providing habitat, and serving as educational and recreational amenities. They can also be safe and somewhat unobtrusive if carefully designed. If you have any questions on stormwater wetlands, please contact your local Cooperative Extension staff, an N.C. DENR Division of Water Quality regional office, or your local soil and water district.

For More Information

Contact your county Cooperative Extension agent about other publications in the Urban Waterways series.

Other Resources

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