G3691-5

The Wisconsin Storm Water MANUAL

Artificial Wetland Storm Water Management Systems

Artificial wetland storm water management systems (AWSMS) consist of watershed conservation measures, constructed wetlands and some combination of sediment basins, grass filters, deep ponds and polishing areas designed primarily to remove contaminants from storm water. When practical, natural landscape features that provide water quality improvement functions may be incorporated into the system. The selection, combination and order of the AWSMS components overcome limitations often encountered by single component practices.

Advantages of AWSMS include (Schueler, 1992):

- Reliable pollutant removal
- Dampening of flood flows and peaks
- Creation of wildlife habitat and aesthetic potential

However, AWSMS may not be appropriate for every situation. Disadvantages include:

- A relatively high land requirement
- Significant management demands during and after establishment
- Time required for vegetation to mature and achieve optimum performance
- Potential for adverse impacts such as increased water temperature within sensitive watersheds

AWSMS are constructed systems that mimic the complicated, interdependent contaminant removal mechanisms of natural wetlands. It is important to remember that these artificial systems are designed primarily to treat storm water runoff. Although they may be enhanced to provide some of the other functional values of natural wetlands, these considerations are secondary to the system's pollutant removal potential and should not be included if they compromise the pollution control function. These artificial systems are not intended to mitigate the historic loss of natural wetland habitat. As such, artificial storm water treatment systems are not to be considered either restored or mitigation wetlands.

Conversely, natural wetlands, as well as mitigation and restored wetlands created to replace the full range of wetland functions, should not be used to treat storm water runoff. Although natural wetlands provide water quality benefits, discharging storm water directly to natural wetlands can have adverse impacts.

According to the U.S. Environmental Protection Agency (US-EPA, 1993), water level fluctuations affect wetlands and wetland functions adversely. When hydrologic changes or pollutants exceed the assimilative capacity of natural wetlands, wetlands become stressed and may be degraded or destroyed.

The Wisconsin Department of Natural Resources (WDNR) strongly discourages the use of natural wetlands for storm water treatment. In fact, new storm water discharges to wetlands under WDNR regulatory authority (Wisc. Admin. Code NR 103) are prohibited if an alternative to the discharge is available. Even where no reasonable alternatives exist, such discharges are not allowed if they will lead to significant degradation of wetland function.

Artificial wetland storm water treatment systems have been successfully constructed and operated in Midwestern states, including Wisconsin and Minnesota. Two Wisconsin projects include the Lake View project and the Delavan Lake project.

The Lake View Industrial Park project near Kenosha created a 600-acre wetland complex along the Des Plaines River. The complex includes a storm water management function and provides water quality benefits. At Delavan Lake, an 85-acre wetland was constructed on a 145-acre site. The drainage basin is 16.8 square miles. The wetland, immediately upstream from Delavan Lake, is designed to provide natural water treatment by removing sediments and nutrients before they reach the lake. The wetland system includes three sedimentation basins, a shallow marsh, a sedge meadow and wet prairie areas. Extensive sampling of the wetland will continue into the future and should provide data on the capabilities of a Wisconsin AWSMS.

When properly designed, constructed and operated, AWSMS remove pollutants from storm water and reduce peak flows reliably for many years. In addition, AWSMS provide wildlife habitat, aesthetic appeal and educational and passive recreational opportunities. To minimize adverse water quality impacts from storm water, all systems should incorporate practices that promote watershed conservation and pollution prevention.

To function effectively, AWSMS need to be properly designed, correctly installed and diligently maintained. The guidelines in this chapter should assist with these endeavors. Although “free water surface” and “subsurface flow” wetlands have been constructed to provide water quality improvements, subsurface flow AWSMS usually are not appropriate in Wisconsin due to wide fluctuations in storm water flow and seasonal variations. Therefore, this publication will discuss only free water surface AWSMS.

The guidelines have been drawn from an extensive review of national and state research, as well as the practical experience and insights of state storm water experts. It is important to realize, however, that research into AWSMS is an ongoing process and further changes in design can be expected.

Principles

Efficient pollutant removal

The principal pollutants found in urban runoff include sediment, oxygen-demanding substances (organic matter), nutrients (mainly phosphorus and nitrogen), metals (copper, lead and zinc), pesticides, hydrocarbons and trash or debris (US-EPA, 1993). The form and fate of each contaminant will be influenced by the design and geographic location of the AWSMS, the time of year, hydrologic conditions and other factors.

Studies investigating the effectiveness of wetlands to treat storm water runoff have been limited. Table 1 summarizes reported pollutant removal efficiencies for a variety of Midwestern natural and constructed wetland systems. The range of values illustrates the variability of the results and the complexity of the relationships between wetlands and water quality. In general, AWSMS are effective at removing suspended solids and pollutants that adsorb to solids, but are not as effective at removing dissolved pollutants (US-EPA, 1993).

Table 1. Average removal efficiencies for Midwestern storm water wetlands (adapted from Strecker et al., 1992)

Study & location	System name	System type	TSS	VSS	TN	TK N	Org. N	NH_3	NO_3	TP	Ortho. P	Dis. P	COD	PB	ZN	CU	CD
Brown 1985, Minnesota	Fish Lake	natural wetland & pond	95	78	-20		36	0		37		28					
	Lake Elmo	natural wetlands	88	80	38		-36	50		27		25					
	Lake Riley		-20	20	20		7	25		-43		-30					
	Spring Lake	constructed wetland		-300	-20	-14		11	-86		-7		-10				
Wotzka & Obert 1988, Minnesota	McCarrons Wetland Treatment System	constructed wetland & pond	94	94	83	85			63	78		53	93	90			
Hickok et al. 1977 Minnesota	Wayzata Wetland	natural wetland	94					-44		78				94	82	80	67
Scherger & Davis 1982 Michigan	Swift Run	natural wetland	76			20				49				83			
Barten 1987 Minnesota	Clear Lake	constructed wetland	76			25		55		54	52	40					
Oberts et al. 1989	Lake Ridge	constructed wetland	85	67	24	28			17	37	-5	8		52			
Minnesota	Carver Ravine	constructed wetland & pond	20	1	-6	-10			9	1	-3	1		6			
Hey & Barrett	Wetland 3	constructed	72						70	59							
1991, Illinois	Wetland 4	wetlands	76						42	55							
(Des Plaines	Wetland 5		89						70	69							
River Project)	Wetland 6		98						95	97							

Pollutant removal mechanisms

In general, AWSMS remove pollutants through physical, chemical and biological processes including absorption, adsorption, filtration, microbial transformation (biodegradation), precipitation, sedimentation, uptake by vegetation and volatilization. These are summarized in table 2.

Planning guidelines

Designing and constructing an effective AWSMS is a challenging task, requiring a sophisticated understanding of hydrology, soils and wetland plant ecology. The design of an AWSMS must be based on a careful analysis of many complex relationships and characteristics within the watershed and on-site. These include future land uses in the watershed, velocity and magnitude of flow, water depth and fluctuation, circulation, seasonal and climatic influences, groundwater conditions, soil permeability and the long term contribution of all systems in the watershed.

An AWSMS should be a component of larger landscape plans for watersheds and proposed developments. Upland prairie or forest buffers and grassed swale systems will enhance the quality and reduce the quantity of water reaching AWSMS. A comprehensive landscape approach also will increase the site's marketability. Aesthetically, the natural appearance of an AWSMS can provide an excellent amenity to a community or place of work. Local residents or property owners need to recog-

Table 2. Contaminant removal mechanisms in AWSMS (adapted from Watson et al., 1989 and Horner, 1992)

Mechanism	**Description**	**Contaminant affected**	**Enhancement techniques**
Absorption	Assimilation of gas, liquid, or dissolved substance into another substance	• phosphorus • synthetic organics • oil	• long residence times • low flow velocities
Adsorption	Adhesion of dissolved pollutants to suspended solids, sediments or vegetation. (Electrical attraction between positively charged pollutant particles and negatively charged particles such as sediments)	• phosphorus • heavy metals • synthetic organics	• shallow water depth • long residence times • sheet flow • Al and Fe soils (remove P) • Organic soils (remove metals) • circumneutral pH
Filtration	Physical entrapment of suspended particles by vegetation, biota and sediments	• organic matter • phosphorus • nitrogen • pathogens • heavy metals • suspended solids • synthetic organics	• sheet flow • low flow velocities • dense vegetation
Microbial metabolism (biodegradation)	Desirable modification of pollutants by suspended, benthic and plant-supported micro-organisms	• nitrogen • synthetic organics • organic matter • heavy metals	• scattered vegetation • permanent pool of water • high plant and soil surface area
Precipitation	Chemical reaction between dissolved pollutants and other elements in water that form insoluble substances that settle	• heavy metals • phosphorus	• low flow velocities • long residence times • high alkalinity
Sedimentation	Physical settling of particles and attached pollutants	• organic matter • phosphorus • nitrogen • pathogens • heavy metals • suspended solids • synthetic organics	• long residence times • low flow velocities • sheet flow • dense vegetation
Uptake by vegetation	Respirational uptake through plant tissue and conversion into plant biomass	• nitrogen • phosphorus • heavy metals	• dense vegetation (large surface area)
Vaporization	Evaporation to the air	• oils • chlorinated hydrocarbons • synthetic organics	• high temperature • air movement (wind) • turbulence • reduced surface films

nize that AWSMS are living ecosystems that can provide a variety of positive sensory experiences.

The hydrologic and site data generated from the planning phase site investigations will provide essential information for adequately sizing the AWSMS. To maximize pollutant reduction, the system needs to be effective during all seasons and under a wide range of hydrologic and pollutant load conditions.

To ensure that the construction of an AWSMS does not increase upstream or downstream flooding, it may be necessary to route design floods through the watershed. The effect of any modification to the existing surface and / or subsurface drainage system on upstream and downstream landowners should be evaluated. Drainage should not be adversely affected without obtaining the appropriate permissions. All applicable state and local laws and regulations pertaining to flooding (for example, floodplain zoning requirements and laws pertaining to surface and subsurface drainage) must be followed.

To prevent adverse impacts to existing wetland systems, AWSMS generally should not divert storm water flows around or away from areas that received the flow prior to land development. Water diversion could dry existing wetlands and reduce their value and functions. In general, AWSMS should attempt to maintain the existing hydrology of natural wetlands. If hydrologic changes are proposed, the impact of the proposal on existing hydrologic systems needs to be assessed.

Ideally, the site investigation and selection process should include the following (Brodie, 1989):

- Review of existing site information, including aerial photographs
- Preliminary field survey of the site
- Subsurface exploration and collection of environmental data
- Evaluation of data, potential environmental effects and regulatory requirements

Figure 1 illustrates a general methodology for selecting and evaluating a site. The most important factors to consider in the planning phase for an AWSMS include inflow water quality, land availability, hydrology, site substrate and site topography. Each factor is discussed below.

Inflow quality

To ensure that an AWSMS is appropriate for a site and that the design will optimize storm water treatment, information about the type and concentration of pollutants discharging to the site should be collected. Urban nonpoint source models can be used to estimate pollutant loadings and concentrations. Information on other pollution sources such as wildlife, atmospheric deposition and point sources should also be considered.

If it is doubtful whether the system can successfully treat the pollutant load it will receive, then another management practice should be selected. Because of their attractiveness to wildlife, AWSMS should not be used to treat water containing significant amounts of bioaccumulative or non-degradable contaminants. A periodic monitoring schedule should be established.

Land availability

There must be enough land available to handle, at a minimum, runoff from the tributary drainage area during the design rain. An estimate of land area requirements can be made using the method presented in the design guidelines section that follows.

Hydrology

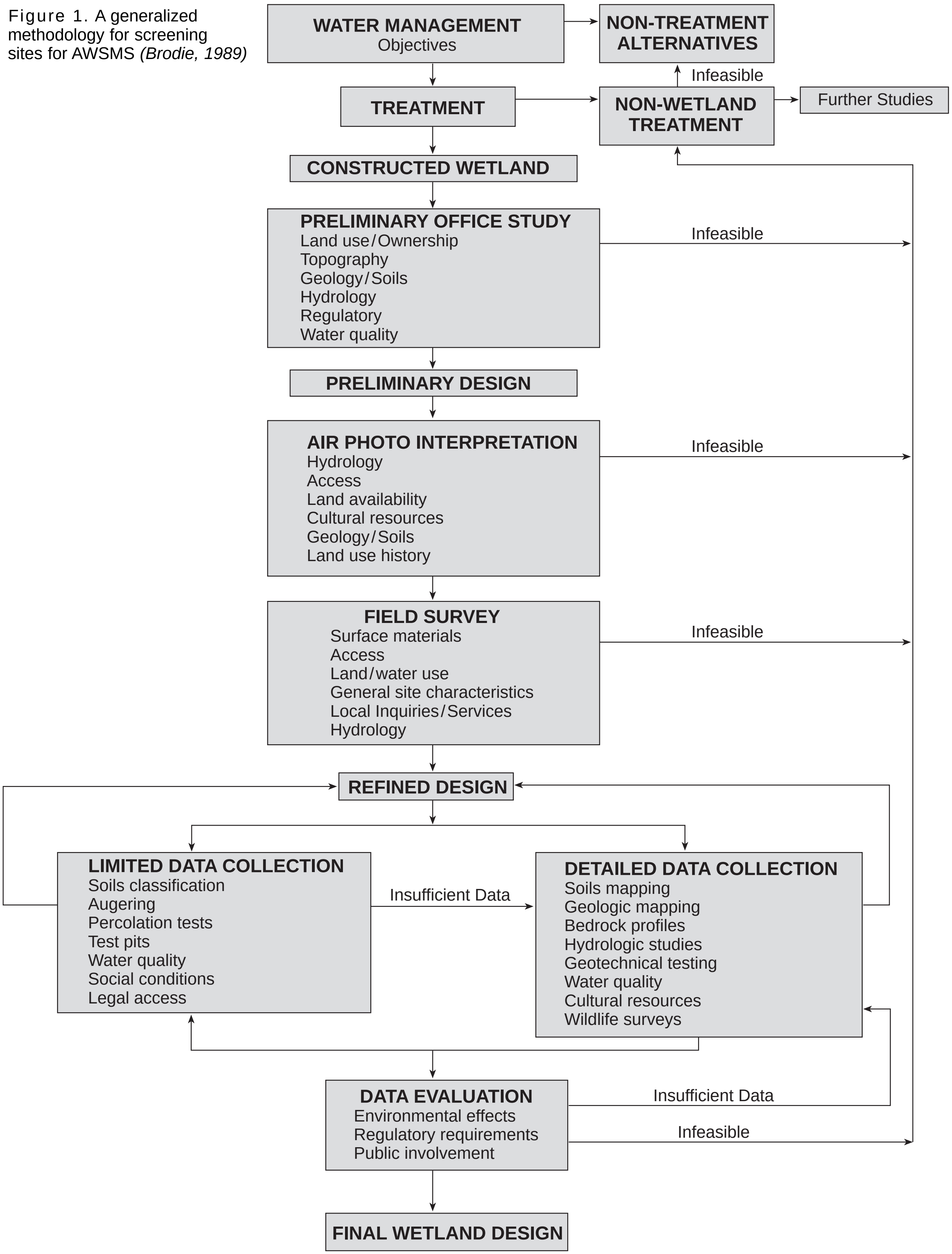
Hydrologic behavior is the most important site characteristic. If the proper hydrologic conditions exist or are developed, the chemical and biological conditions will, to a degree, respond accordingly (Mitsch and Gosselink, 1993).

AWSMS can be sited close to individual storm water sources or further downstream in a watershed. AWSMS sited in headwater areas will generally receive more irregular and less dependable inflows, potentially resulting in prolonged dry conditions.

This relative lack of flooding could prevent development of a healthy stand of wetland vegetation. However, this consideration must be weighed against the fact that if the AWSMS are distributed throughout the upstream portion of the watershed, less runoff and erosion might occur in the whole watershed as a result of storing water and sediments in the watershed uplands. Also, it may be that a landscape with a large upland buffering capacity and many small AWSMS may lend efficiency to pollutant and flow control because of the smaller amounts of contaminants and water that would need to be treated by each AWSMS.

Siting of the AWSMS further downstream in the watershed may result in increased flow to the system and less efficient pollutant removal. This must be balanced against the fact that an AWSMS located downstream in a watershed would be more likely to have permanent water and higher ancillary benefits due to more constant baseflows (Knight, 1992).

Figure 1. A generalized methodology for screening sites for AWSMS *(Brodie, 1989)*



A careful review of the watershed, including hydrology, topography and buffering capacity, should provide sufficient information to determine appropriate AWSMS sites. Adequate water should be present throughout the year to support wetland vegetation and functions.

Substrate

The ability of soils to retain water, support wetland vegetation and provide active exchange sites for adsorption of pollutants varies. Consequently, a site specific soil investigation must be completed. Investigations should provide information on soil thickness and depth, classification and composition, drainage characteristics, erosion potential and depth to bedrock or the water table. Variability in these conditions within the site should be considered. The Hydrologic Atlas series for Wisconsin, published by the U.S. Geological Survey (USGS), provides general information on surficial and bedrock geology and surface water and groundwater characteristics. For specific local information, driller construction reports should be consulted. Driller reports are available from the Wisconsin Geological and Natural History Survey (WGNHS).

Soil composition can affect AWSMS performance. For example, soils with greater extractable aluminum have greater potential for phosphorus removal than do organic soils. However, mineral soils generally have lower cation exchange capacity than organic soils. Organic soils can, therefore, remove some contaminants (such as certain metals) through ion exchange and can enhance nitrogen removal by providing an energy source and anaerobic conditions appropriate for denitrification (Mitsch & Gosselink, 1993).

Site soils and rocks should be evaluated for their use as construction materials for earthen embankments, spillways, riprap and liners. Such evaluations may include volume estimates, soil and rock sample analyses and erodibility (Brodie, 1989). In addition, soils must have sufficient stability to support embankments or other water control structures.

To ensure that the AWSMS will retain water, soil permeability rates must be estimated by conducting infiltration tests at the proposed bottom elevation of the AWSMS. Sites containing hydric soils (defined as soils that are saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part) should provide acceptable permeability rates. The USDA Natural Resources Conservation Service (NRCS) maintains lists of hydric soils. County hydric soil lists and soil survey maps may be obtained from NRCS field offices.

If hydric soils are not present, planners should investigate the feasibility of compacting the existing soil or providing a liner, and covering the area with peat, top soils, organic soils or soil amendments. Care should be taken not to accept material from sites with a history of receiving heavy pollutant loads.

Topography

To minimize costs, a location that requires minimal grading and excavating should be selected. To prevent erosion and maintain sheet flow, AWSMS should be located on sites with slopes less than 5%. Steeper slopes usually require more earth work and may be better suited for a detention basin than a wetland. USGS 7.5 minute topographic maps may be consulted for general information on area topography. For more detailed information, a site topographical survey should be conducted.

Design guidelines

Quantitative and qualitative consideration must be given to several design components. These include land requirements, configuration, substrate, hydrology, depth, gradient, pretreatment requirements, inlet and outlet structures and safety features.

An AWSMS should be designed either in combination with a detention pond or as an extended detention AWSMS. The pond / wetland (PW) system consumes less space than a wetland because the bulk of the treatment is provided by the deeper pond. This section discusses only the general design of ponds as related to AWSMS and will focus on the specifics of designing treatment wetlands. Guidelines for wet detention basins are found in *Wet Detention Basins* (G3691-2) of the *Wisconsin Storm Water Manual.*

Land requirements

The following calculation provides a rapid method for estimating the area of land needed to meet the treatment goals of the AWSMS. This calculation is based on the assumption that the AWSMS storage volume should equal the total runoff volume entering the AWSMS during the 1.5-inch rain event. The calculation is only an estimate because it is solely volumetric. It does not consider channel characteristics, slope, velocity, conveyance or similar parameters that would be evaluated in a hydraulic simulation model. However, for initial planning purposes, it should provide a valid approximation of AWSMS surface area requirements (Simon, et al., 1989). To ensure sufficient space for AWSMS structures and buffer zones, the calculated area should be increased by approximately 20%.

WE = (SA)(RU)/WD

WE = the approximate surface area of the AWSMS needed at the stage required to store water from the design storm (acres).

SA = tributary area of the watershed which will discharge to the AWSMS (acres).

RU = runoff depth predicted from the 1.5-inch rain event (feet).

WD = average storage depth of the AWSMS (feet) at the design capacity. For an approximation, the average depth can be assumed to be 2 feet.

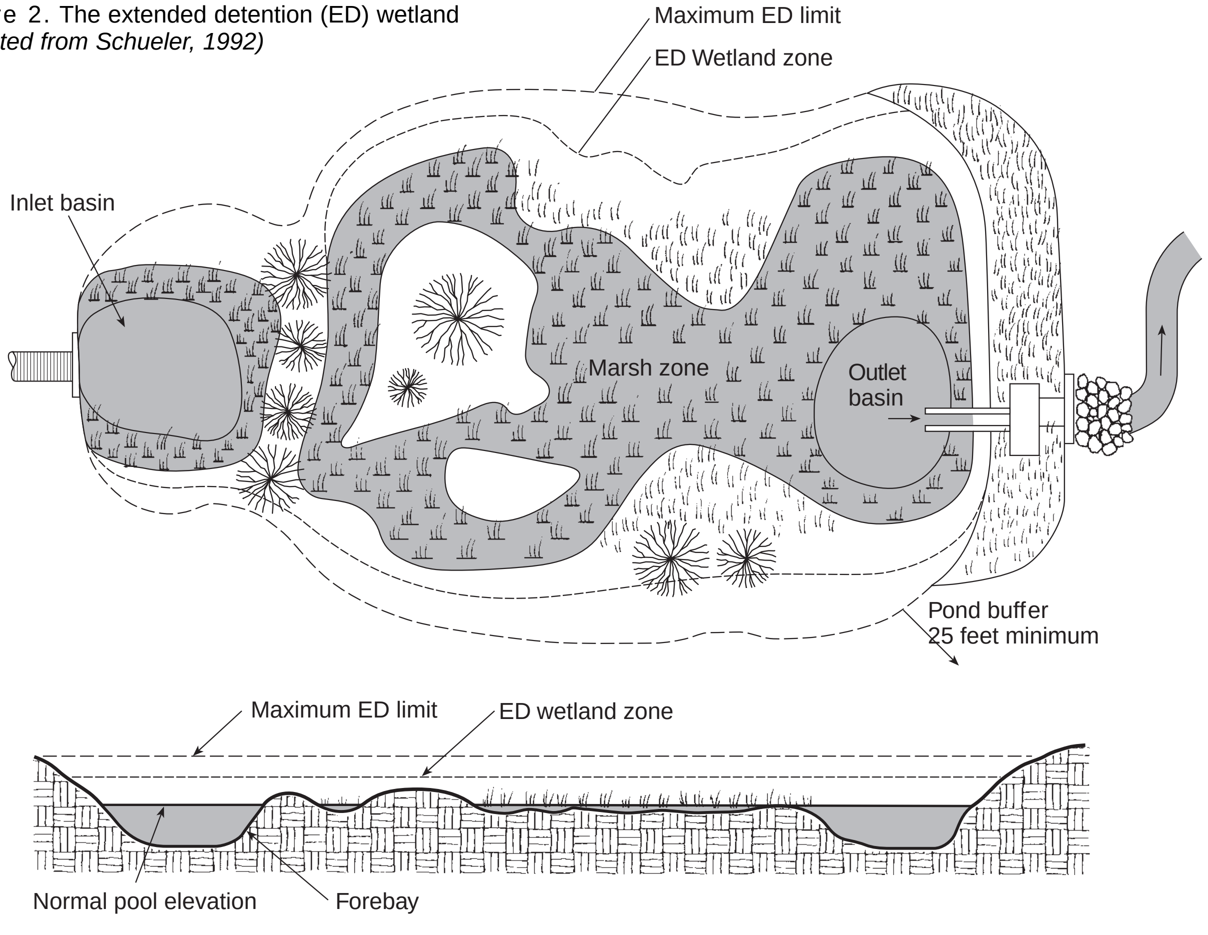
Configuration

To maximize treatment, the internal configuration of the AWSMS should be complex. Schueler (1993) reviewed nearly 60 monitoring studies that investigated the pollutant removal performance of storm water ponds and wetlands in North America. He noted that researchers consistently cited poor internal design geometry as the primary reason for low pollutant removal performance. The most common design problems included low length-to-width ratios, lack of pretreatment sediment basins, lack of structural complexity, inadequate treatment volumes and flow paths that tended to cause short circuiting.

To maximize treatment, designers should maximize the distance between the inlet and outlet and provide a high surface-area-to-volume ratio. To ensure adequate detention times, a length-to-width ratio of at least 3 to 1 is required. The configuration should enhance storm water distribution to maximize contact between storm water, substrate and vegetation.

The effectiveness of several removal mechanisms, such as sedimentation, adsorption and microbial transformation, are enhanced when AWSMS possess high surface area to volume (SA / V) ratios. The SA / V ratio can be increased by increasing surface area by adding internal structural complexity within the AWSMS (Schueler, 1992). A complex, extended detention AWSMS configuration is illustrated in figure 2.

Figure 2. The extended detention (ED) wetland
(Adapted from Schueler, 1992)



The water level within an ED wetland can increase by as much as two feet after a storm event and then return to normal levels within 24 hours. As much as 50% of the total treatment volume can be provided as ED storage, which helps to protect downstream channels from erosion, and reduce the wetland's space requirement.

Many organisms, including valued fish species such as trout, have very low tolerances for temperature increases. If AWSMS outfall temperatures need to be reduced to protect sensitive downstream areas, the surface of the deep water areas should be shaded with floating-leaved plants such as Watershield *(Brasenia schreberi)*, Spatterdock *(Nuphar luteum)* and Duckweed *(Lemna spp.)*. However, it is important to note that shading AWSMS usually reduces the concentration of dissolved oxygen in the effluent. Providing a north-south AWSMS alignment may also reduce temperature impacts.

Substrate

The results of a site soil investigation should provide sufficient information to determine if the existing substrate will support an AWSMS or if the substrate must be modified. Care should be taken to get representative samples of the entire site, since some sites will have only localized areas of low permeability. If existing conditions are not appropriate, modifications should be considered to adjust site permeability and the growing medium for wetland vegetation.

First, sites containing soils that are too permeable must be modified to provide a subsurface permeability of 0.14-0.014 in/hr (US-EPA, 1988). These rates will effectively seal the AWSMS bottom. Sealing methods include providing a clay or plastic liner, compacting existing soils or relying on sediment deposition during AWSMS operation in NRCS hydrologic soil groups C and D (Horner, 1992).

However, if groundwater contamination is a concern, an impermeable liner should be in place before operating the AWSMS. Groundwater protection liners must be strong, thick and smooth to prevent root penetration and attachment (Steiner and Freeman, 1989). If groundwater is within four feet of the liner, venting that allows gases on the bottom side of the liner to escape is recommended. This helps prevent the accumulation of gases that could form a large bubble and float the liner out of position in the AWSMS. Venting should also be provided in cases where groundwater fluctuations may trap air underneath the basin liner.

A second basic substrate modification involves placing hydric soils, peat, top soils (especially topsoil removed from other areas of the site during construction), organic soils or soil amendments on the liner or existing soils to provide the proper growing medium for wetland plants. To ensure enough room for roots to penetrate, the depth of soil (whether existing or modified) from the AWSMS bed to the liner should be at least one foot (Mitsch & Gosselink, 1993). Medium-fine textures, such as loams and silt loams, are optimum for establishing plants, capturing pollutants and retaining surface water.

Appropriate donor sites should be selected during the planning process. Hydric soils containing vegetative plant material or a seed bank may provide an excellent initial stand of vegetation. Although these soils enhance the diversity and speed of vegetative establishment, donor soil should not be collected from areas containing exotic species such as purple loosestrife. The donor material should be gathered at the end of the growing season if possible, and kept moist until placement (Shaver & Maxted, 1993).

Hydrology

Three basic hydrologic conditions should be considered in developing a functioning system:

1) An adequate water budget
2) Storage capacity
3) Hydraulic residence time for the critical hydroperiods when the system must function

Water budget

To estimate whether a site will receive and retain enough water to support an AWSMS, planners should collect sufficient information to estimate post-construction hydrologic inflows and outflows during each season for a variety of storm events. Because a permanent pool is essential, AWSMS should be built on a site only if inflows will equal or exceed outflows throughout most of each year.

The following hydrologic budget can be used to evaluate whether the site's hydrologic characteristics can support this system.

$$P + RO \geq ET + I + O$$

Where:

P = precipitation over the AWSMS
RO = surface runoff into the AWSMS
ET = evapotranspiration
I = infiltration to groundwater
O = outflow from the AWSMS

Precipitation data can be acquired from local weather stations. Surface runoff can be estimated by many models, as well as the simplified method described in the *Hydrology* section of this manual. Wetland evapotranspiration during the growing season can be estimated by multiplying reported Class A pan evaporation for the nearest evaporation station by a 0.8 conversion factor. Class A pan data are tabulated monthly and annually in *Climatological Data*, published by the U.S. National Oceanic and Atmospheric Administration, Asheville, North Carolina (Kadlec, 1989). Climatological data also may be obtained from the office of the Wisconsin State Climatologist. Infiltration rates should be obtained by conducting infiltration tests on the site.

If the AWSMS design will include a clay or synthetic liner to prevent groundwater contamination, infiltration can be assumed to be zero. These estimated inflows and outflows should provide enough information to determine if the current site conditions or site modifications will support the hydrologic requirements of a wetland.

These systems are generally dominated by surface water hydrology, but where groundwater inflow is a significant component it should be quantified as an input. A hydrogeologic investigation should be conducted prior to design to determine depth to high groundwater, groundwater flow direction and rate of flow, vertical and horizontal gradients, presence and extent of perched groundwater, soil descriptions, depth to bedrock and type of bedrock. Potential impacts on groundwater should be investigated. The unsaturated zone (below the ground surface and above the groundwater table) can remove pollutants depending on its thickness, particle characteristics and organic content.

Hydroperiod

Establishing the AWSMS hydroperiod is of primary importance because it determines the peformance and nature of the AWSMS. Hydroperiod is the duration of inundation measured over an annual wet or dry cycle. Seasonal and yearly patterns of flooding will be part of the hydroperiod of the AWSMS. Infrequent and non-periodic flooding and droughts are important for dispersing biological species to the AWSMS and adjusting resident species composition. After start-up, a variable hydroperiod exhibiting dry periods interspersed with flooding is a natural cycle. A fluctuating water level can often provide needed oxidation of organic sediments and can, in some cases, rejuvenate a system to higher levels of chemical reaction (Mitsch and Gosselink, 1993).

Storage

When designed for water quality control, the design volume of the AWSMS should be greater than or equal to the volume of runoff from a 1.5-inch rain under full projected watershed development. In addition, the storage volume must be sufficient to meet the peak flow discharge limitations for the 2-year, 24-hour design storm.

Hydraulic residence time

AWSMS size also should ensure an adequate hydraulic residence time (HRT), or detention of water in the AWSMS. The HRT is defined as the average time period for a particle to flow from the AWSMS inlet to the outlet. The HRT will vary with flow rate, seasonal and climatic influences, soil permeability, degree of mixing with water in storage and volume of available storage. The HRT and the amount of turbulence are important factors that affect the settling of suspended particles in the AWSMS (Martin, 1988). A site that is too small or has a rapid flushing rate provides poor trapping and may even cause re-suspension of previously deposited sediments during peak flows and the net export of particulates, nutrients and toxicants.

The theoretical detention time, which assumes a constant inflow rate and no dead storage volume, can be calculated as follows:

$HRT = (V/Qf)$

Where:

HRT = hydraulic residence time
V = AWSMS storage volume
Q = average discharge rate
f = void fraction (percentage of open water in AWSMS)

Kadlec et al. (1993) noted that wetland void fraction varied widely depending on the vegetation and short-circuiting of flow. A value of 0.75 is often assumed; however, a careful site analysis should provide a more accurate value.

The AWSMS should be designed to provide approximately 24 hours of detention for the 1.5-inch rain event. A 24-hour HRT will provide, at a minimum, the required 80% reduction in suspended solids from the water quality storm and peak discharge control of the 2-year storm. Extended detention facilitates denitrification (Silverman, 1989).

In addition, the velocity of flow passing through the vegetation of the AWSMS should be less than 1 foot per second in order to maximize treatment (Witthar, 1993). The design must ensure that runoff from larger storms does not wash sediments and nutrients out of the AWSMS into the receiving water.

Depth

To encourage diverse biogeochemical processes and plants, a variety of depth zones should be created within the AWSMS.

Shallow depths promote the growth and propagation of diverse wetland plants and improve the reliability of pollutant removal. Deeper water reduces vegetation growth and the effective contact time with both vegetation and soils. Generally, the shallow marsh will support the greatest density and diversity of emergent wetland plants and the highest surface area to volume ratio.

Target depths are useful in obtaining a range of depths within the AWSMS to increase the surface area to volume ratio, create nonturbulent flow conditions and increase the internal structural complexity of the AWSMS. Table 3 presents general target depth allocations for both the pond / wetland (PW) and the extended detention (ED) AWSMS designs (Schueler, 1992, MD-DNR, 1987).

Much of the sediment deposition may occur near the inlet as the incoming runoff velocity decreases upon entering the basin. Greater depths near the inlet help prevent sediment blockage and may facilitate cleanout.

The area of the shallow marsh should always be equal to or larger than the area of the deep marsh. During dry weather, the deeper AWSMS areas should contain a permanent pool approximately 2 feet deep that will minimize scour from large storms. The transition zone around the periphery of the normal pool should be very gently sloped so that it is temporarily flooded during most runoff events but drains as the detained runoff leaves the system. The area of this frequently flooded zone is greatest in the ED wetland system, where water elevations can increase 2 feet or more during storms. At capacity, the mean depth of AWSMS that conform to these depth allocations will be approximately 2 feet.

Design grades

The wetland area should be designed so that it has a very shallow sloping edge and a permanent pool. This configuration provides a variety of hydrologic conditions, with some areas permanently flooded and others temporarily flooded. These hydrologic conditions provide for the growth and propagation of diverse wetland plants and microbes and promote removal of both aerobic and anaerobic pollutants.

The AWSMS should be designed so that runoff entering the wetland will temporarily increase the normal pool elevation and spread over the transitional zone between wetland plants and upland vegetation.

This transitional zone is extremely important in terms of plant diversity, habitat and function. The maximum slope of the transition zone should be no greater than 10 horizontal to 1 vertical (10:1) and should extend at least 20 feet from the edge of the permanent pool (Shaver & Maxted, 1993).

To support vegetation and promote pollutant removal benefits, the maximum slope of both the shallow and the deep marsh should be no steeper than 10:1. To ensure stability, the maximum slope of the basins should be no steeper than 3:1. To minimize short-circuiting and ensure equal flow distribution, the lateral bed slope (across the width) should be zero (Watson & Hobson, 1989). The longitudinal bottom slope should also be essentially flat (no greater than 0.05%) (Hammer, 1992). To ensure that the AWSMS is aesthetically appealing, design grades should blend the newly created landform into the existing landscape.

Table 3. AWSMS target depths

	Depth below normal	Percent of surface area	
Component	**Pool** (inches)	**PW AWSMS**	**ED AWSMS**
Inlet basin	12–72	5	5
Outlet basin	12–72	5	5
Shallow marsh	0–12	20–25	20–40
Deep marsh	12–24	20–25	20–40
Transition zone (above normal pool)	0–24	5–15	10–30

Pretreatment components

Pretreatment components are designed to provide preliminary treatment of storm water before it enters the wetland component of the ASWMS. Pretreatment may be an integral component of the AWSMS, helping extend the life of the wetland.

Without pretreatment, sediment may rapidly accumulate, smother vegetation and quickly decrease AWSMS storage and treatment capacity. Pretreatment will reduce stress on the aquatic components of the system, localize maintenance needs and can dampen flows through the system. Pretreatment practices should be considered at all locations where storm water runoff enters the wetland.

A sedimentation basin (similar to a forebay in a detention pond) can be used as a pretreatment component. Such a basin could be as simple as a trapezoidal trench 3 to 6 feet deep. Baffles and diversions should be strategically placed to prevent trapped sediment from becoming resuspended during subsequent storms. The basin design should include a hard bottom (compacted soil) and vehicle access so that accumulated sediments can be removed easily (Wengrzynek & Terrell, 1990; Horner, 1992).

The inlet basin should constitute at least 5% of the total AWSMS area. Where there are multiple inlets to the wetland, the total area of all the basins should be at least 5% of the AWSMS area with the individual inlet basins sized with respect to their percentage of contributing flow (Shaver & Maxted, 1993).

Additional pretreatment components may include a trash rack, an oil and grease trap and a grass filter. The trash rack is a grate designed to trap debris. The oil and grease trap may be necessary for AWSMS that will receive runoff from streets and parking lots containing concentrations of oil and grease. The grass filter may be used to trap sediments before entering the wetland and maintain sheet flow at the entrance to the wetland. The filter may include a subsurface tile drainage system to increase infiltration and maintain an aerobic root zone. Scheduled mowing and removal of grass maintains a dense sod and removes nutrients assimilated by plant growth. It is easier to reestablish grass filters than aquatic communities (Wengrzynek & Terrell, 1990).

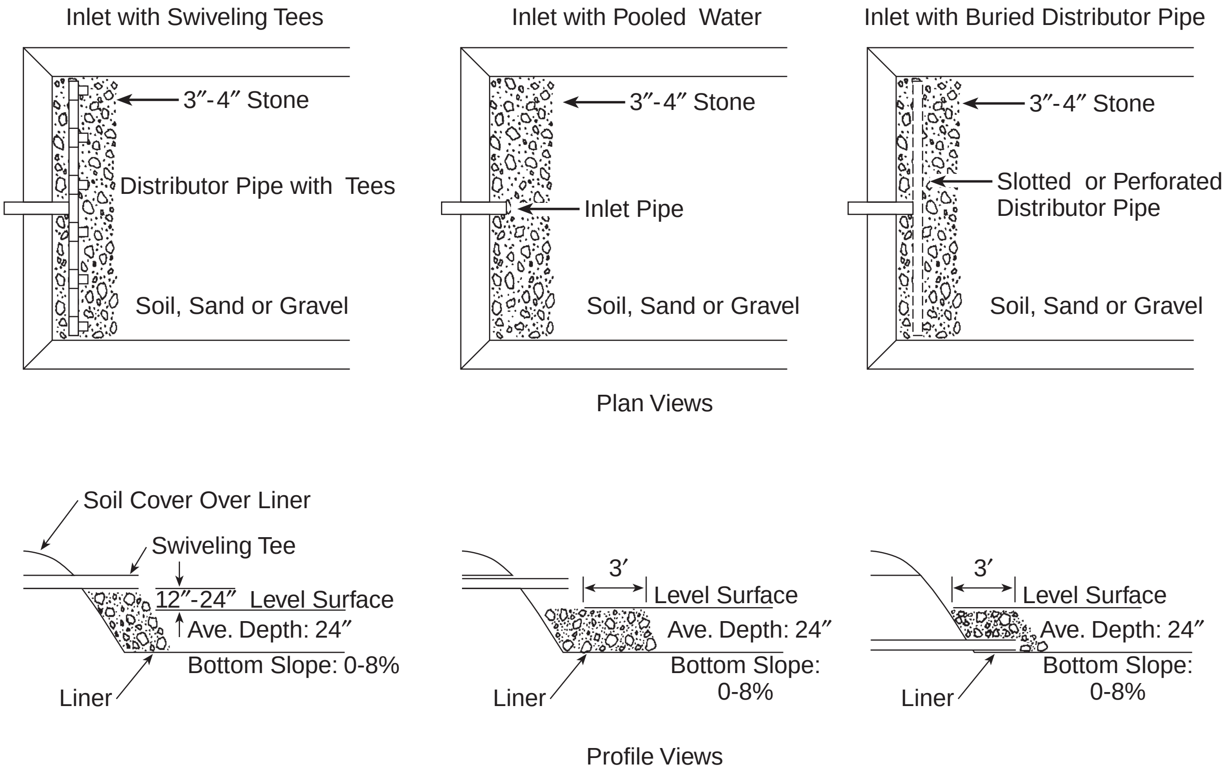
Inlets

Inlet structures should be designed to prevent high velocity discharges that could scour the AWSMS. Martin (1988) found that turbulence varies from storm to storm, depending directly on the inlet discharge structure, and less directly on rainfall intensity. According to Martin, highly turbulent inlet discharges scoured bottom sediments and caused increased pollutant loads at the outlet.

The AWSMS should also be designed to disperse, rather than channelize, flow through the system. Figure 3 depicts several types of AWSMS inlets. Controlled dispersion of the influent flow with proper diffuser pipe design can help to ensure low velocities for solids removal and even loading of the wetland so that anoxic conditions are prevented at the inlet area. The inlet can be designed so that water trickles over stepped riprap embankments to aerate the water. Use of limestone for the riprap will help buffer acid rain pH levels.

The inlet structure should be sized to handle the 2-year, 24-hour design storm flow and should be sited to minimize short circuiting. Hydrologic models should be used to estimate peak flows from design storm events for the contributing watershed. The inlet should be sized to release water at a velocity less than 1 foot per second (Witthar, 1993). An emergency spillway should be constructed to ensure that flows in excess of the design storm are safely diverted or discharged. This flow diversion structure allows the AWSMS to capture and treat the initial storm water runoff from storms larger than the 1.5-inch rain, and ensures that the hydraulic residence time needed for adequate treatment of runoff can be maintained.

Figure 3. Inlet designs for uniform stormwater distribution
(Source: modified from Watson and Hobson, 1989)



If the AWSMS configuration includes parallel cells, a flow splitter will be needed. A typical design contains parallel orifices of equal size at the same elevation in the splitter. Control orifices are sized according to the desired design flow. Options include pipes, flumes, and weirs. Valves are impractical because they require frequent adjustment. Flumes and weirs need not be standardized unless flow measurements are required. Flumes minimize clogging problems in applications with high solids, but are more expensive than weirs. Weirs are relatively inexpensive and can be easily replaced or modified to change flow to any cell.

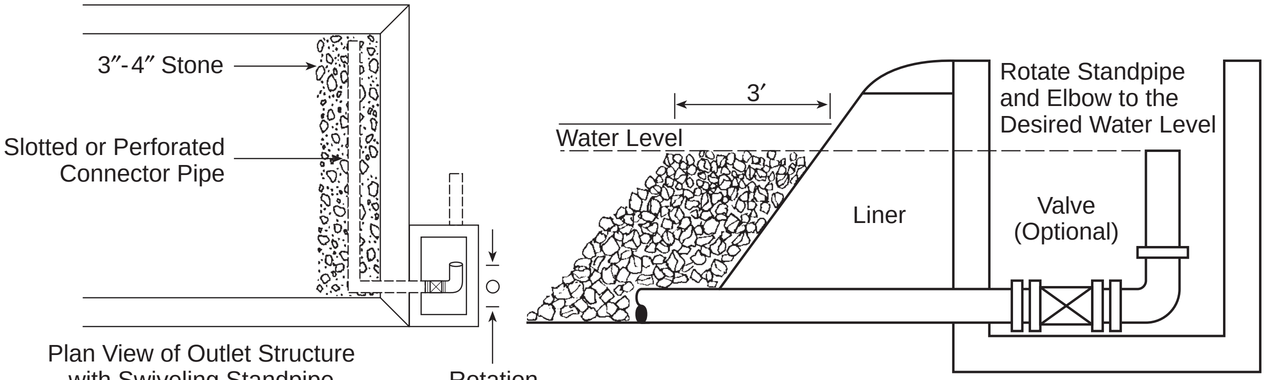
Outlets

The designer has several choices for the outlet of an AWSMS (figure 4). Where adequate maintenance and security can be maintained, outlets with removable boards may be used to control pool elevation. The use of such an outlet structure may not be appropriate in areas where vandalism may be a problem. Ideal design for water-level control allows water levels to be varied from zero (drained) to the maximum depth tolerance of desired wetland plant communities. If stop logs or weir plates are used, they should be of a type that effectively seals against leaks to help maintain water levels during periods of limited inflows. Multiple inlet and outlet weirs allow greatest hydrologic control and flexibility.

If an outlet pipe is used, it may become clogged by debris. To prevent this, a trash rack should be firmly attached to the upstream portion of the orifice. Another option is to install a reverse-sloped pipe about a foot below the permanent pool elevation. This outlet design has been found to avoid clogging (Schueler, 1992).

One drawback to this approach is the inability to see potential clogging of the pipe. All outlet pipes should include an adjustable gate valve to regulate outflow. In addition to the outlet pipe, it is advisable to install a drain capable of draining the AWSMS in 24 hours to allow for maintenance. The drain should be controlled with a lockable, adjustable gate valve, and an upward-facing inverted elbow placed on the end of the drain to extend above the bottom sediments.

Figure 4. Outlet water level control structures
(Source: modified from Watson and Hobson, 1989)



Plan View of Outlet Structure with Swiveling Standpipe

Control Structure with Swiveling Standpipe

Control Structure with Collapsable Tubing

Control Structure with Interchangeable Sections of Pipe

The AWSMS design should address potential problems associated with ice cover and frozen conditions. Provisions could be made for deepening water levels under the ice, draining the AWSMS and allowing baseflow to pass through quickly, routing water around the frozen AWSMS until spring thaw, or building a variable discharge outlet structure that gives flexibility depending upon winter conditions.

Vegetation

Vegetation is an essential component of all AWSMS. Microbes that transform nutrients attach to the substrate provided by vegetation. In addition, vegetative growth serves as a barrier that reduces the velocity of incoming storm water, promotes sedimentation, reduces the probability that sediments will resuspend, takes up nutrients and metals and filters incoming particulates. Decayed vegetation increases the organic content of the sediments, which promotes anaerobic decomposition and improved nitrogen removal.

AWSMS vegetation can be planted or the constructed basin can be left unplanted with the expectation that suitable vegetation will eventually develop. The primary reasons for planting vegetation are to influence the species composition and / or to establish a vegetated AWSMS as quickly as possible.

Other reasons for attempting to influence species composition include water quality considerations and provision for wildlife habitat, recreational opportunities and aesthetic appeal. Establishing wetland plants requires time and money, and the plants' long term survival is uncertain. However, leaving a site open until natural colonization occurs has several disadvantages. The site will be more susceptible to erosion, and invasive exotics are more likely to colonize and dominate the site. Unless a suitable seed bank of desired wetland plant species is present on-site, it is recommended that vegetation be planted.

Because AWSMS are expected to receive wide fluctuations in inflow water quantity and quality, robust species, like cattails and bulrushes (excellent plants for water treatment) should thrive. Although the development of "high quality" species might be desirable, sensitive species cannot be expected to survive the rigors of an AWSMS. Remember, AWSMS are designed for water quality control, not necessarily to provide diverse, unique vegetation.

To avoid negative impacts to nearby natural wetland areas, native, non-invasive species should be planted in AWSMS vegetative communities. Designers should select plants adapted to the local environment, commercially available, fast growing, requiring little maintenance and, to the extent possible, aesthetically pleasing to encourage the neighborhood's acceptance of the AWSMS.

Plants should also tolerate flooding, frequent saturation, low oxygen levels, high nutrient levels and variable conditions. Species that have a large stem surface area per unit bed area will provide the greatest area for storm water contact and microbe growth. Dense-growing species will reduce flow velocity and increase sedimentation and filtration. The tolerance of vegetative species to soil moisture levels may be relatively narrow, and the selection of vegetation must take this sensitivity into account.

The natural development of plant communities in zones corresponds closely to the water conditions of the AWSMS. Zones include the upland buffer, the transition zone, the storm water basin, the grass filter and the wetland itself. The wetland is further divided into zones including the emergent, submergent and floating plant areas. Additional information about shoreland plants and landscaping is available (UWEX, 1994).

Other structures and features

Extending the flow path through the AWSMS by adding dikes, berms, shallow marsh areas and multiple cells will minimize short-circuiting and enhance pollutant removal rates (Schueler, 1992). Finger dikes are commonly used in surface flow systems to create serpentine configurations and can be added in operating systems to mitigate short-circuiting. Divider dikes separate cells and attain desired length-to-width ratios.

Details for these structures are based on site-specific needs and objectives. Most are constructed of native soils, but finger dikes may also be constructed with sandbags or treated lumber. Dike design should meet the requirements of the NRCS Engineering Field Handbook (USDA-SCS, 1992). Dike freeboard should accommodate an organic matter accumulation rate of 0.5–1.5 inches per year in the AWSMS. Adequate freeboard and water level control is also necessary to provide capacity for flow beneath the expected thickness of ice cover (Hammer, 1992).

If the system is large enough, an island in the pond can act as a baffle and extend the flow path length through the AWSMS. Open water areas can be created by excavating about 3 feet below normal water level and deeper excavations can provide greater hydraulic residence times. To ensure adequate treatment, vegetated areas should greatly exceed open water areas. To prevent hydraulic short-circuiting, open water areas should not be connected along the flow path, but rather interspersed with densely vegetated shallow marsh habitat (Knight, 1992).

A buffer should be provided around the wetland both to separate the treatment area from developed areas and to reduce impacts on wildlife. The minimum buffer width should be 25 feet, measured from the maximum water surface elevation. The buffer should be sloped no steeper than 5:1. At least 75% of the buffer should be forested to discourage geese and provide better protection and habitat (Horner, 1992).

AWSMS are usually constructed by excavating and / or constructing berms. In general, AWSMS should be excavated into existing grades without the need for extensive berming. Structures such as distribution systems, berms, liners and weirs should be designed and constructed to provide reliability, safety and reasonable cost according to standard engineering techniques. Appropriate structural design and construction information is detailed in the *NRCS Engineering Field Handbook* (USDA-SCS, 1992) and *Technical Guide* (USDA-SCS, 1994).

The design should provide maintenance access roads as needed. Access roads should be designed with minimum 15-foot wide right-of-ways and slopes no steeper than 5:1. The road should be stabilized to withstand heavy equipment.

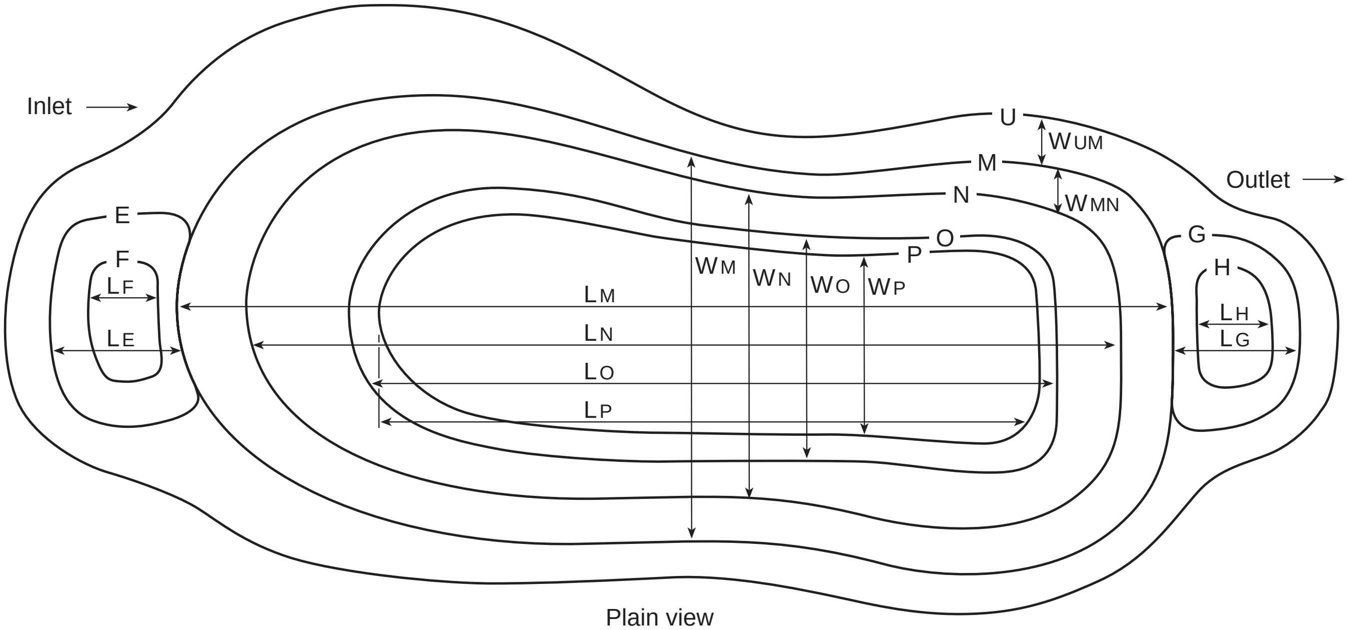
A polishing filter (a stable, relatively level vegetated site that may be grassland, wetland or forested area, either natural or constructed) may be desirable between the AWSMS outlet and the receiving body of water. This area serves as a final filter or buffer between the AWSMS and the receiving body of water.

One drawback to AWSMS, particularly in densely inhabited areas, is the potential for increased mosquito populations. This problem is minimized when water is continually flowing through the AWSMS. Manipulating the water level can also help control mosquito populations.

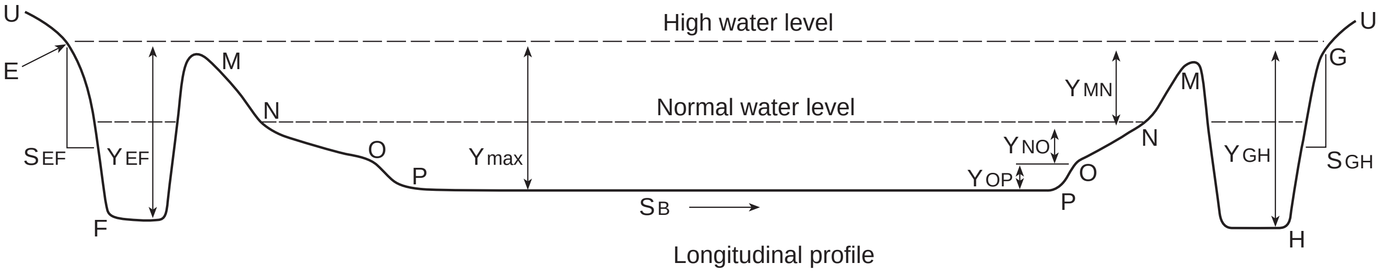
Safety features

The shallow depth of an AWSMS minimizes, but does not eliminate safety hazards. The shallow transition zone will promote dense vegetation growth which, in turn, will act as a natural barrier to the deeper permanent pool. Water deeper than 3 feet should not be easily accessible. The deeper area near the inlets and outlets should be constructed with safety shelves and be far enough away from the embankment so that the water is shallow in areas where there is access to the pond.

Figure 5. Simplified conceptual AWSMS dimensional design (not to scale)

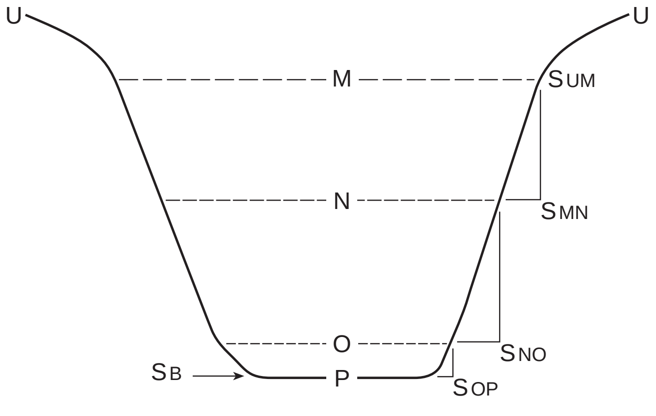


Plain view



Longitudinal profile

L = length
W = width
U = outer edge of upland buffer
M = outer edge of transition zone
N = outer edge of shallow marsh
O = outer edge of deep marsh
P = bottom of AWSMS
E = top of inlet sediment basin
F = bottom of inlet sediment basin
G = top of outlet sediment basin
H = bottom of outlet sediment basin
S = slope



Lateral profile

Design calculations

A simple, conceptual AWSMS that illustrates the principles discussed is provided in figure 5.

Design guidelines and typical values for the design AWSMS are presented in Table 4. Each design may be unique, so the standards used in a particular design need to be carefully considered.

Analytical solutions for AWSMS dimensions satisfying the previously presented guidelines are cumbersome. Due to the above constraints, many AWSMS dimensions become fixed when a length to width ratio and mean top length or width have been selected.

Because the configuration of the AWSMS should be irregular, the mean length and mean width can be used to approximate AWSMS area. Throughout the remainder of this discussion, lengths and widths will be treated as means. Actual construction will usually follow more irregular configurations. Because depths and slopes of the wetland area are somewhat flexible, they should be selected prior to employing the following analytical solution. The following trial-and-error procedure, adapted from Walker (1987), may be employed to find the length to width ratio and the length or width to satisfy the design criteria.

Table 4. Design guidelines and typical values.

Parameter	Typical design guideline
Total suspended solids	80% removal efficiency
Peak flow	Pre-development 2-yr peak flows ≥ post-development 2-yr peak flows
Volume at capacity	Runoff volume from a 1.5 inch rain (ED wetland) or volume of runoff from detention pond at capacity (PW wetland)
Hydraulic retention time	≥ 24 hours
Void fraction	≈ 0.75
Velocity	≤ 1 ft/sec
Infiltration rate	≤ 0.14 in/hour
Total sediment basin area	= 0.1 total AWSMS area A (acres)
Area of shallow marsh	≥ area of deep marsh
Mean depth at capacity	≈ 2 ft
Maximum wetland depth	≤ 4 ft
Transition zone depth	≤ 2 ft
Shallow marsh depth	≤ 1 ft
Deep marsh depth	≤ 1 ft
Inlet sediment basin depth	≤ 6 ft
Outlet sediment basin depth	≤ 6 ft
Upland zone slope	≤ 5:1
Transition zone slope	≤ 10:1
Shallow marsh slope	≤ 10:1
Deep marsh slope	≤ 10:1
Inlet sediment basin slope	≤ 3:1
Outlet sediment basin slope	≤ 3:1
Lateral bed slope	= 0
Longitudinal bed slope	≤ 2000:1 = 0.05%
Transition zone width	≥ 20 ft
Upland buffer width	≤ 25 ft
Length to width ratio	3:1

Select trial values for the length and the length to width ratio.

Initial values of length (L) and width (W) may be estimated using an assumed length to width ratio (R) and the recommended mean depth of 2 feet (D). For example, if the design volume (V) is 2 acre-feet and a length to width ratio of 3 is selected, then:

$V = (L)(W)D$
$\quad = (L)(1/R)(L)(D)$

(2 acre-feet) (43,560 square feet/ac.)
$\quad = L(1/3L)(2)$

L = 362 feet

and

$W = 1/R(L)$
$\quad = (1/3)(362 \text{ feet})$

= 120 feet

The estimated surface area would be:

$A = (L)(W)$
$\quad = (362 \text{ feet})(120 \text{ feet}) = 43{,}440 \text{ square feet}$

Site topographic features should also be considered to determine if these dimensions are compatible with topographic features.

Determine other dimensions

After trial R and L values have been selected, other AWSMS dimensions can be calculated. Designers often assume that the area of the sedimentation basins can be approximated by squares, that the area of the wetland can be approximated by a rectangle, and that the areas of the inlet and outlet sediment basins are equal. However, depending on water quality and quantity, it may be appropriate to provide a larger inlet than outlet. If the calculated values of intermediate lengths or widths are less than zero, design constraints are not feasible. The designer must return to Step 1 and adjust R and / or L or adjust wetland slopes and depths. Volumes are calculated using the average end area method where:

$V = ((A_u + A_l)/2)(D)$

Where V is the volume,

A_u is the area of the upper surface,
A_l is the area of the lower surface, and
D is the depth between the two surfaces.

To illustrate these calculations assume that a length / width ratio of 3 and a length of the upper water surface in the zone is 250 feet (Lu). The depth of water in the zone under consideration is 1.5 feet (D) and the slope of the wetland in the zone is 10:1 (z). Calculations to determine water volume would be:

Width of upper surface

$W = L/R = 250 \text{ feet}/3 = 83 \text{ feet}$

Area of upper surface

$A_u = (L_u)(W_u) = (250 \text{ feet})(83 \text{ feet}) = 20{,}750 \text{ square feet}$

Length of lower surface

$L_l = L_u - (2)(z)(D) = (250 \text{ feet}) - (2)(10)(1.5 \text{ feet}) = 220 \text{ feet}$

Width of lower surface

$W_l = W_u - (2)(z)(D) = (83 \text{ feet}) - (2)(10)(1.5 \text{ feet}) = 53 \text{ feet}$

Area of lower surface

$A_l = (L_l)(W_l) = (220 \text{ feet})(53 \text{ feet}) = 11{,}660 \text{ square feet}$

Volume in zone

$V = ((A_u + A_l)/2)(D) = ((20{,}750 + 11{,}660)/2 \text{ square feet})(1.5 \text{ feet}) = 24{,}308 \text{ cubic feet}$

This volume would need to be adjusted by the void fraction to determine the effective volume. Similar calculations can be made for each zone in the wetland.

Test results

The final step is to determine whether the total volume and mean depth calculated satisfy the design requirements. If so, no additional iterations are necessary. If design requirements are not met, return to step 1 and adjust the trial values of length, the length / width ratio or the slope steepness.

For example, using the same length to width ratio, the volume can be increased by increasing the length. The use of a spreadsheet to make the calculations will greatly facilitate the iterative calculations required to meet design volume requirements.

Design AWSMS configuration

As stated previously, the AWSMS configuration should be irregular, complex and blend into the natural landscape as much as possible. Areas and dimensions estimated by the above calculations should be used to guide the creation of design plans for appropriately shaped AWSMS. The design plans should be checked to ensure the AWSMS will provide sufficient storage volume and meet all design guidelines. The equations used for calculating volume increments are also applicable to irregular contours. The areas needed for the calculations should be derived from the contoured design plan using planimetry.

Construction guidelines

Proper construction is critical to efficient operation of the AWSMS. Careful supervision is imperative to ensure that grade and elevation specifications are met. Otherwise, considerable difficulty with short-circuiting and reduced treatment capacity may occur and be difficult to correct later.

Construction plans and specifications for the AWSMS should be based on information presented below. The level of detail depends on the size and complexity of the AWSMS, the physical characteristics of the site and the requirements established by regulatory agencies.

At a minimum, construction plans must include the following to ensure sufficient detail for accurate bid preparation and construction:

- Boundaries of construction activities, including clearing and grubbing limits
- Construction and maintenance access road
- Location of existing utilities (overhead and underground)
- Erosion control measures
- Quantities, locations and boundaries of borrow areas
- Trees and vegetation that will be left undisturbed
- Wildlife habitat enhancement structures
- Location, design plans and specifications, elevation, freeboard, upstream and downstream slopes, materials and permeability requirements for dikes, berms inlets, outlets and other structures
- Spillway location, elevation, type and design specifications
- Size, location, elevation, materials and type of water control structures
- Methods for determining permeabilities and other contract specifications
- Permeability requirements for pond bottom and sides including type, location and installation of liners if needed
- Elevations, contours and slopes for the AWSMS
- Location of subsurface drains
- Method of placement and type of rock, gravel, soil and limestone by elevations and depths
- Species, spacing, sources of supply and planting dates of wetland vegetation
- Seeding, mulching, sodding, liming and/or fertilizing requirements for dikes, berms and any other disturbed areas
- Provisions for on-site construction supervision
- Types and sizes and of construction equipment
- Location of endangered or threatened species, if any, and measures to avoid their disturbance.

A pre-bid conference with potential contractors is recommended to explain the concept, goals and requirements of the project. This meeting can be effective in soliciting accurate bids from qualified contractors (Tomljanovich and Perez, 1989). A pre-construction meeting with the selected contractor is also highly recommended.

Good construction techniques include use of correct equipment such as light foot-pressure, tracked vehicles for working on soft substrates, suitable soil placement equipment to achieve design grades, and suitable site preparation and planting equipment, which may range from standard farm equipment to bulldozers.

Except for liner compaction, wetland soils should not be compacted during excavation and grading. Compaction may limit root and rhizome penetration. The substrate should be soft enough to permit relatively easy insertion of plants into the soil. If the wetland soil is compacted, the soil should be disked or otherwise physically disturbed before planting and flooding.

Plants can be introduced by planting seeds, roots, rhizomes, tubers, seedlings or mature plants obtained commercially or from other sites; importing substrate and its seed bank; or relying completely on the seed bank of the original site. If permission is granted by the appropriate authorities and landowners, plants may be collected from nearby wetlands. Collecting wetland plants from public lands or public waters requires prior notice to the local DNR office, and additional restrictions may apply.

Erosion during construction should be minimized. It is particularly important that upstream construction areas implement effective erosion control plans, so that the AWSMS does not become overloaded with sediments. Upland drainage diversion structures, which pass upstream flows around the AWSMS until the site is stabilized, should be constructed.

Implementation of an effective erosion control plan during AWSMS construction will mitigate downstream impacts. The AWSMS should be constructed and planted prior to excavating the connection to the outflow channel. Refer to the Wisconsin Construction Site Erosion Control Manual for further guidance (WDNR, 1993).

Maintenance

Artificial wetland storm water management systems require maintenance for optimal performance. A detailed operation and maintenance manual, including an excavation and disposal plan for sediments, should be developed prior to construction. The manual should establish a schedule for monitoring and maintenance and, to ensure accountability, designate short- and long-term operation and maintenance responsibilities.

Operation and maintenance must be conducted by personnel familiar with the operation and maintenance manual and who know how to achieve the objectives of the AWSMS. The manual can be updated to reflect specific system characteristics learned during system operation.

The AWSMS should be designed so that maintenance needs are minimal. AWSMS are living ecosystems that will naturally evolve with time. It is important to remember that AWSMS do not become functional immediately upon construction; several years may elapse before nutrient retention is optimal.

During the one- to two-year start-up period frequent inspections and maintenance must be completed. To avoid adverse impacts to the AWSMS, the transition zone should not be mowed because grass clippings will increase nutrient loading to the AWSMS. Fertilizers and herbicides would similarly stress the system (Shaver & Maxted, 1993).

Periodic maintenance includes removing debris and litter (particularly at the inlets and outlets), monitoring water levels and plant vitality, providing structural repairs and erosion control, collecting and analyzing water quality samples, excavating and disposing accumulated sediment in the sedimentation basin and adjusting the inlet and outlet structures.

Over time the soils and vegetation of the AWSMS may reach a saturation point, limiting its ability to remove pollutants from the water. In addition, sediment accumulation could result in a loss of ponded portions of the AWSMS, or the formation of shallow channels that could reduce residence time and the mixing of storm water with pond water.

The frequency of sediment basin cleaning depends on the sediment load entering the AWSMS. Each basin should be inspected annually to ensure timely cleanout. When the sediment basin has filled to approximately 50% of its total volume, sediment should be removed, placed in an appropriate upland location and stabilized.

Planning an on-site sediment application area will save disposal costs. Cleaning pretreatment facilities such as sediment basins will significantly reduce the frequency of sediment removal needed in the AWSMS.

Maintenance remedies are available to address sediment accumulation. In some cases, the elevation of the water level in the permanent pond can be raised by raising the height of the outlet. This procedure can be repeated until the peak storage volume requirements of the basin are in danger of being compromised, at which time sediment excavation will be required to extend the life of the AWSMS.

Removal of the sediment by excavation requires draining some of the AWSMS water and could result in considerable damage to the wetland vegetation. If pretreatment measures are effective, sediment removal from the wetland should occur only infrequently. Even with cleanout, replanting may not be necessary because of the buildup of seeds within the basin.

Harvesting wetland vegetation is not recommended in Wisconsin. The disadvantages of harvesting include limiting the AWSMS configuration to that which is accessible by large equipment, increased maintenance costs and the need to dispose of the harvested vegetation. The AWSMS should not be burned because burning will release nutrients to the water.

Proper operation and maintenance of the AWSMS depends on a monitoring plan that provides information for judging the attainment of treatment objectives, performance efficiency and long-term viability. Basic elements of the monitoring plan include:

- Clearly stated treatment goals and monitoring objectives
- Statements of organizational and technical responsibilities, tasks and methods
- Quality assurance procedures
- Schedules
- Reporting products
- Resource requirements
- Budget

A well-conceived and clearly defined monitoring plan serves as a point of reference and source of perspective for maintaining a meaningful information base throughout the life of the project.

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Partial funding for this publication was provided by the Wisconsin Department of Natural Resources.

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