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Constructed Wetlands for Water Purification

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Constructing Wetlands for Water Purification

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Section 1: Introduction to Constructed Wetlands

Course Description

The constructed wetland (image) is a shallow, earthen impoundment or group of cellular impoundments, which contain hydrophytic vegetation, designed to treat both point and nonpoint sources of water pollution.

Its primary physical components include the aquatic vegetation, substrate for plant and microbial growth, the basin or cells, associated structural devices for water management, and the water that flows through the system.

The waste treatment mechanisms it employs are a complex mix of physical, chemical, and biological processes.

Introduction

This course focuses on the use of constructed wetlands used to treat wastewater*.

In wetland ecosystems, there are biological, chemical, and physical processes that naturally clean and filter water.

Manmade constructed wetlands are designed to mimic the processes found in a natural wetland ecosystem. They use wetland plants, soils, and microorganisms to clean water in a way that is often less expensive than more traditional water treatment systems.

When properly designed, built, and operated, a constructed wetland can provide high quality water treatment, while also adding aesthetical enhancement and wildlife habitat to your site.

**Note:* *Much of the course addresses the implementation of constructed wetlands for the use of treating agricultural and livestock effluent.*

Principal physical components

The waste treatment mechanisms amongst the components of the constructed wetland are a complex mixture of physical, chemical, and biological processes.

Principal physical components found in a CW include:

- aquatic vegetation (hydrophytes)
- substrate for the plant life and microbial growth
- wetlands basin
- structural devices for water management
- water flowing through the system

Hydrophytic vegetation

Wetland plants, or hydrophytic "water loving" vegetation, are those plants which have adapted to grow in a low-oxygen (anaerobic) environment, associated with prolonged saturation or flooding.

Hydrophytic plants have adapted to anaerobic soil conditions through the use of alternative methods for collecting oxygen.

For example:

- **Speckled alder** - use the hypertrophied lenticels in the bark
- **Rush and grass species** – utilize their hollow stems
- **Cattails** – use their air filled cells (aerenchyma) in the roots

History of constructing wetlands

1930s

The first recognized use of wetlands to treat animal waste in this country was at a beef feedlot in Iowa, dating back to the 1930s.

1990s

It was not until the late 1980s and early 1990s, however, that animal waste constructed wetlands achieved widespread use.

NRCS guidelines

In 1991, the Natural Resources Conservation Service (NRCS), which was then known as the Soil Conservation Service (SCS), developed a set of technical guidelines for the design of constructed wetlands (CWs) used to treat wastewater from livestock facilities.

The design criteria in that document were based on the most state-of-the-art information available at the time.

EPA guidelines

In 1997, the EPA sponsored the publication of a literature review, database, and research synthesis on animal waste constructed wetlands throughout the US and Canada.

The study presented information from more than 70 sites including pilot and full-scale facilities.

Evaluation of the EPA datasets on CWs

Evaluation of the database revealed that only part of the many installed systems in this country have been thoroughly monitored. However, enough information had been provided to allow for the development of new design criteria for animal waste systems.

These data sets have been analyzed in light of treatment wetland performance models that were originally developed for municipal wastewater.

Performance data from testing of constructed wetlands treating wastewater for livestock operations have been used to calibrate those models and allow performance estimation based on flow rates and pollution concentrations.

Those models and parameters are described in this course for the design of new constructed wetlands.

Use of natural wetlands

The use of natural wetlands have been used to treat municipal wastewater; however, they are not used for animal waste treatment because of the complexity of their design, the difficulty in obtaining the required permitting, and the potential risk associated with degrading natural wetland resources.

CWs are a fairly inexpensive and low-maintenance option for agricultural applications, capable of treating a number of wastewater types.

Treatment applications might include:

- milk-house (dairy) wash water
- farmyard runoff
- tile drainage outflow (from the removal of excess water in agricultural fields)
- aquaculture wastewater
- abattoir (aka slaughterhouse) wastewater
- winery and food processing water

Section 2: Use of CWs in Colder Regions

Functioning in colder climates

Constructed wetlands work in all kinds of climates.

All wastewater treatment is biologically based, and biological reactions slow down at low temperatures and go dormant, but do not cease entirely.

Dormant but still functioning

Cold climate constructed wetlands use native wetland vegetation to help naturally treat wastewater.

In the winter, when plants are dormant, their roots are still able to provide surface area for beneficial bacteria that aid in the treatment process.

Areas with greater emergent wetland vegetation, for example cattails and rushes, tend to accumulate more snow around the dormant plants, which provides helpful insulation.

Issues in extreme cold

If snow cover is limited or if extreme cold conditions are expected, additional challenges may be encountered. One issue being the formation of Ice which can cause hydraulic short-circuiting or failure.

Also, nitrogen and BOD removal are temperature dependent processes which mean that cold climate systems need to be larger and deeper to assure proper treatment.

Strategies to address these extreme cold challenges may include:

- increasing treatment area
- insulating from heat loss
- deepening installation for freeze protection
- recirculating the water to keep it from freezing

Reducing heat loss by use of a insulator

The temperature in a wetland is controlled by ground heat from the earth and loss of heat to the environment.

Heat losses can be minimized during cold temperatures by insulation (e.g., vegetation litter, snow, mulch, dry gravel) to preventing ice formation and freezing.

A combination of sources are available to provide insulation to a constructed wetland, including vegetation litter, snow, mulch, and dry gravel.

The thickness of the mulch layer is calculated/modeled by determining the overall heat flow resistances of each material using the layer thickness and thermal conductivity.

Site-specific climate data from late winter is used to calculate the heat flow resistance provided by annual snow fall and snow cover.

February is typically the time of year when wetland water temperatures are still quite cold, but daytime solar radiation is increasing and melting snow cover, thus increasing the potential for ice to form on the wetland surface at night.

Surface flow systems in colder climates

Though surface flow wetland systems are exposed to the elements, they still tend to function year-round. However, there is a seasonal reduction in the efficiency of the system overall, which occurs in winter in some regions.

Even in the colder northern climate of Canada, SF wetlands have proven successful in treating animal waste.

Conditions to avoid during colder months

There are conflicted opinions concerning the ability of constructed wetlands to be effective in the colder regions of the world, where functional aspects such as microbial activity are greatly reduced.

Though as long as the wetland doesn’t experience conditions such as overloading, drying out, or being subjected to extended periods of extreme cold, the quality of the system’s effluent can be expected to be suitable for most non-potable uses.

Section 3: Surface and Subsurface Flow Wetlands

Surface Flow Wetlands

Three types of constructed wetlands

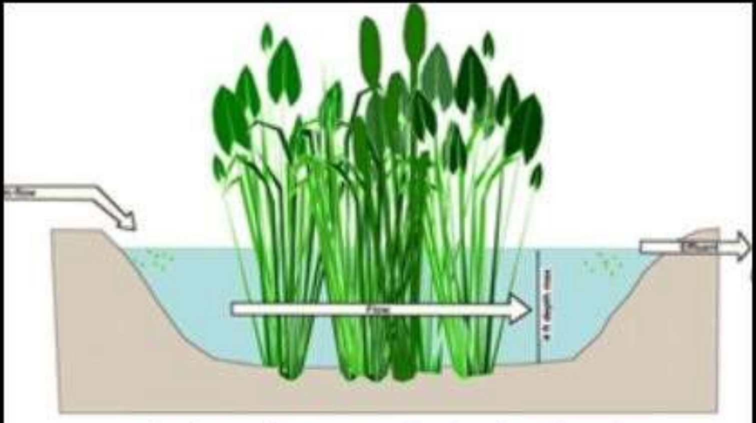
There are three main types of constructed wetlands used for treating wastewater:

- surface flow systems (SF)
- subsurface flow systems (SSF)
- floating aquatic plant (FAP) systems

Most common wetlands type

The most commonly used wetland type in North America, and throughout the world for wastewater treatment is the surface flow (SF) wetlands.

The SF wetland was the only choice which was recommended by USDA's NRCS agency for the treatment of livestock facility wastewater, in its technical guidelines issued in 1991.



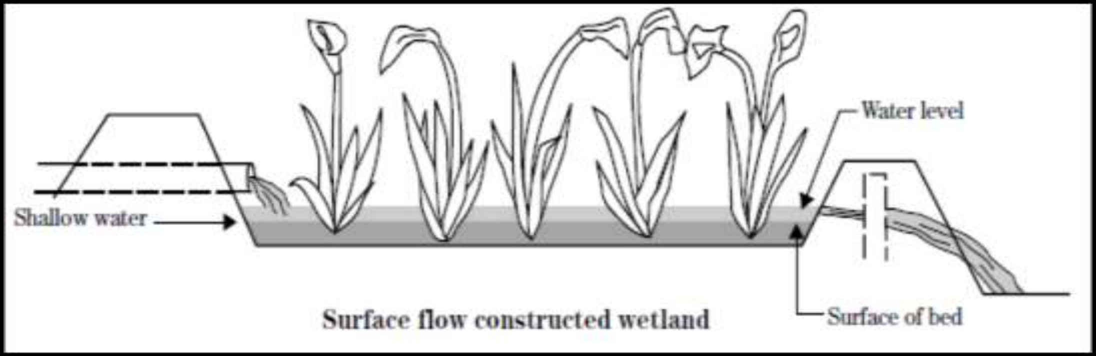
Surface flow constructed wetlands

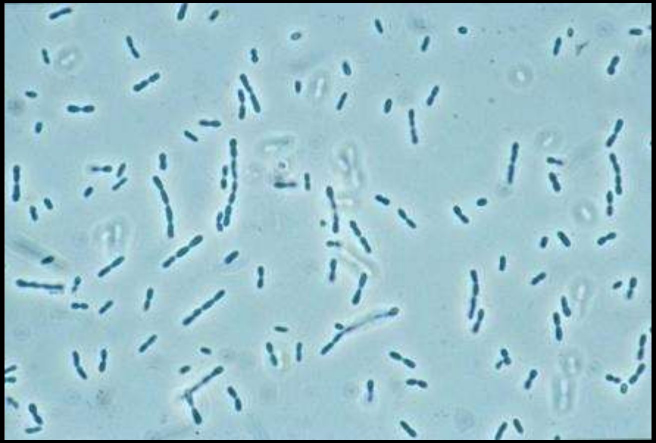
SF system layout

SF wetlands are shallow, earthen basins planted with rooted, emergent wetlands vegetation.

Water flows across the surface at depths that typically range from 6 to 18 inches, depending on the type of vegetation and other design factors.

The bottom slope must be flat from side to side, but may be flat or have a slight gradient from the inlet side to outlet side of the basin or cells.





Treatment mechanism

Much of the treatment results from the activities of microorganisms, principally bacteria and fungi that thrive in this type of wetland environment.

Many of the organisms become attached to submersed plant stems and litter, while others integrate with the soil/plant-root matrix.

The entire water column is alive with microorganisms that contribute to the treatment process.

SF wetland aka free water surface (FWS) wetland

Wastewater in the SF wetland flows across the surface of the bed and is visible.

Thus, it is sometimes called a *free water surface* (FWS) wetland.

SF wetlands have been used to treat effluent from waste treatment lagoons, waste storage ponds, and milk houses as well as runoff from open feedlots.

They have also been used to treat acid mine drainage and runoff from croplands and discharges from aquaculture facilities (image).

Pretreatment of animal waste

The effluent from most animal confinement facilities should be directed through a pretreatment process to reduce the total solids and nutrients prior to entering an SF wetland.

The high concentration of fecal solids and other constituents of wastewater coming from the confinement facility are unsuitable for most wetland plants without being pretreated.

Pretreatment is vital in reducing the high concentrations of solids and ammonia often associated with wastewater from livestock facilities.

SF vs SSF vs FAP systems

Data on the performance of SF constructed wetlands for treating wastewater from livestock facilities throughout the US, indicate that this type of wetland can be highly efficient in treating wastewater from confined animal feeding facilities.

SF wetlands are relatively inexpensive when compared with SSF wetlands.

In addition, SF wetlands are relatively easy to manage and maintain, especially when compared with FAP systems.

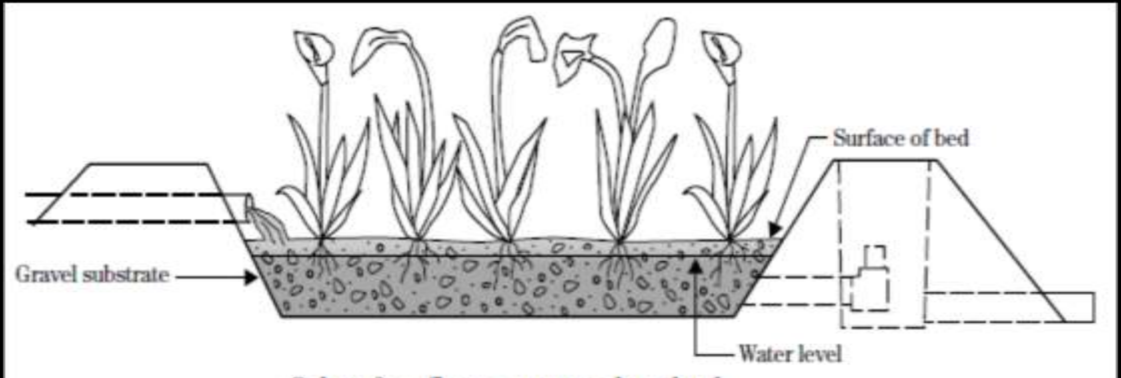
Subsurface Flow Wetlands

Subsurface flow wetlands

The SSF wetland consists of a bed of gravel, rock, or soil media through which the wastewater flows.

The bed is placed below ground level, and wastewater enters the bed at approximately mid-depth.

Above this bed, emergent, hydrophytic vegetation is planted at the surface of the wetland, often in a shallow layer of pine straw, wood chips, or other mulch, with the roots of the plants extending into the saturated bed.



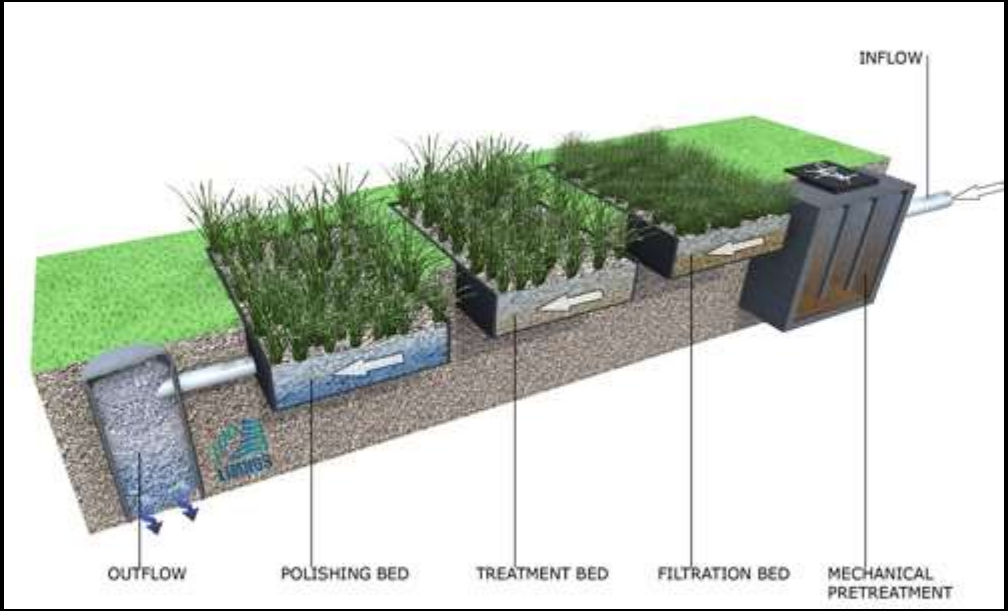
Subsurface flow constructed wetland

Critical factors to consider

The water surface is maintained at an elevation just below the surface of the bed.

The bottom slope, the porosity of the medium, and the daily average flows are critical engineering factors that must be considered to maintain the proper hydraulic gradient of the wastewater as it passes through the bed.

Failing to consider these factors may result in a water level that drops below the roots at the downstream end or a water level that rises, resulting in ponding of water on the surface.



Concerns with high water tables

In areas that have shallow groundwater or a seasonal high water table (image), groundwater can infiltrate into the bed and disrupt the hydraulic conditions and treatment efficiency of the system.

Wastewater can also migrate from the subsurface wetland into the surrounding soil or groundwater.

In this case hydraulics, treatment efficiencies, and plant survival could be altered. For these reasons, an impervious, fabricated liner should be installed in some SSF wetlands.

Better suited for domestic wastewater uses than livestock facilities

While SSF wetlands are successfully treating domestic wastewater, their use in treating wastewater from livestock facilities appears limited. The reasons for this are twofold.

First, the porous bed can be easily plugged with solids. Even pretreated wastewater from most livestock facilities has high concentrations of solids.

Secondly, installing a large rock bed would be prohibitively expensive for most operations.

More expensive system to install

The costs to install a SSF system can be expected to be at least five times the cost to install a surface flow system.

SSF wetlands may possibly be used to treat small flows that have low-solids content, such as water used to clean milking equipment in a small dairy.

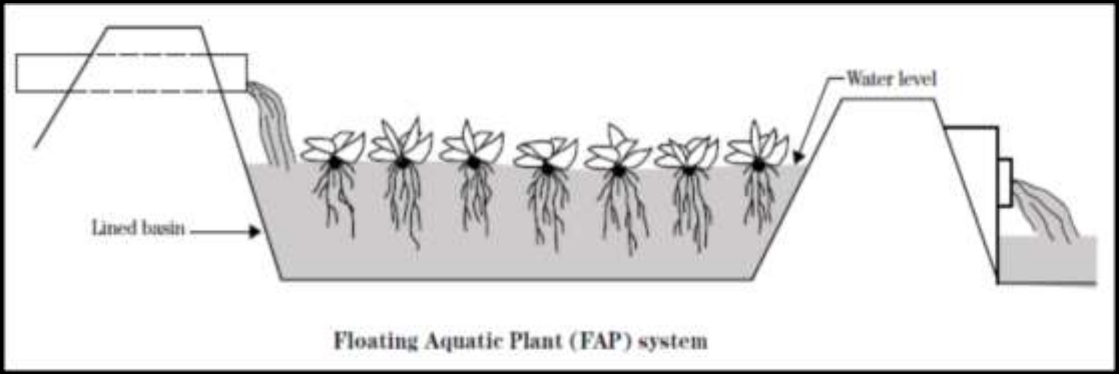
For this use, a septic tank would need to be installed upstream of the wetland.

Section 4: Floating Aquatic Plant Systems

FAP systems

The floating aquatic plant (FAP) system consists of a pond or series of ponds in which floating aquatic plants are grown. Water depth is a critical factor with FAP systems.

The ponds must be maintained at a depth sufficient to prevent emergent plants from growing, but shallow enough to ensure adequate contact between the roots of the floating plants and the wastewater.



Water depth range

The typical range for water depth should usually lie between 3 and 5 feet.

In FAP systems plants grow profusely and extract a large amount of nutrients from the wastewater.

Since harvesting is an essential management requirement for this type of CW system, the number, size, arrangement of ponds, and method of harvesting must be considered during the initial planning stage.

Water Hyacinths and Duckweed

The most common floating plants used for wastewater treatment are water hyacinths (image) and duckweed.

Both water hyacinths and duckweed grow rapidly and generally provide enough shade to prevent the growth of algae.

By preventing the growth of algae, they prevent large diurnal swings in pH and dissolved oxygen concentrations associated with algal blooms.

The growth rate of water hyacinths is typically between 150 and 270 pounds per acre per day.

Rate of nitrogen and phosphorus removal by FAP systems

Based on data compiled on several municipal FAP systems, the rate of nitrogen (N) removal was an average rate of 17 pounds N per acre per day when N loading ranged from 8 to 37 pounds per acre per day.

Phosphorus (P) removal at municipal treatment plants generally does not exceed 30 to 50 percent, assuming an active harvesting.

Lower P removal is typical of unharvested FAP systems.

Growth rates and recommended climates

Duckweed (image) which is grown in wastewater can double its area of coverage each 4 day period when grown at a temperature of 80 degrees Fahrenheit.

Duckweed is more tolerant of cold weather than Water Hyacinths and can be grown at least 6 months of the year in all regions of the country, and year round in southern coastal areas.

However, Water Hyacinths are not well suited for growth in the northern two-thirds of the country.

Both Duckweed and Water Hyacinth grow at such astounding rates, that plans should be made to deal with the excessive byproduct.

Both plant species qualify as excellent sources for use as livestock feed, or as compost.

Harvesting for livestock feed

Duckweed has a low-fiber, high-protein, and high mineral content, giving it an excellent potential for use as livestock feed.

Compared with water hyacinths, duckweed contains at least twice the protein, fat, nitrogen, and phosphorus.

Both species contain roughly 92 percent water.

After harvesting, plants can be dried in the sun or through mechanical means.

Mixing the dried material with other ingredients to form a pelleted feed has been employed, especially with duckweed.

Composting

Composting is another viable alternative for converting these plant species into a usable resource.

Research has shown that the “Lemna gibba” species of duckweed (image), can survive well after several days in the supernatant from a swine waste treatment lagoon, with an initial total Kjeldahl nitrogen (TKN) concentration of 255 milligrams per liter and an ammonia concentration of 168 milligrams per liter.

However, the improvement in ammonia removal was significant when the wastewater was diluted with clean water at a ratio of 1:

Invasive species

Though both of these species of aquatic plant have the potential to removal high levels of pollutants from wastewater, care should be used to prevent these invasive species from making their way into other bodies of water (image).

In the image, Water Hyacinth clogs the Tuoniang river in southern China's Guangxi province.

Disadvantages of FAP systems

In comparing SF and FAP systems for municipal wastewater, indications are that FAP systems tend to have the following downfalls:

- lower reaction rates
- higher construction and operating costs
- more sensitivity to cold temperatures
- more susceptibility to plant pests and pathogens
- uses invasive plant species which have the potential to cause ecological damage elsewhere

The issue of plant pests and the need for a high level of pest management might be overcome by using a combination of plant species.

If the FAP is considered for treating animal waste, an economic evaluation should be conducted during initial planning to determine if the end product, such as a high-value feed product, can offset the higher costs of installation, operation, and management.

Surface flow systems – most widely used

As noted so far in this course, the SSF and FAP wetlands systems have some disadvantages when used to treat certain forms of municipal wastewater such as from animal waste.

The SF wetlands have been successfully and widely used around the country and are currently the preferred method of treating animal waste.

For this reason, the focus of attention in this course will be on the surface flow (SF) type of constructed wetlands, from here on.

Section 5: Nutrient Reduction

Nutrient reductions

The surface flow (SF) type of constructed wetland can provide important benefits for confined animal operations (image).

These benefits relate to:

- improved nutrient management
- odor reduction
- water quality improvement
- wildlife enhancement
- aesthetics
- economics

Nutrient conservation vs reduction

In some situations, it can be advantageous to conserve the nutrients in the waste since the nutrients can be used as a fertilizer product.

However, other situations may call for the need to reduce nutrient loads either out of necessity, such as not having enough land for proper spreading, or because such reductions will provide some other advantage.

Nutrient reduction often becomes a necessity when land area for spreading is limited.

In such cases the options may be limited to:

- reducing the number of animals
- changing to a crop or cropping sequence that allows for higher nutrient use
- providing additional treatment of the wastewater

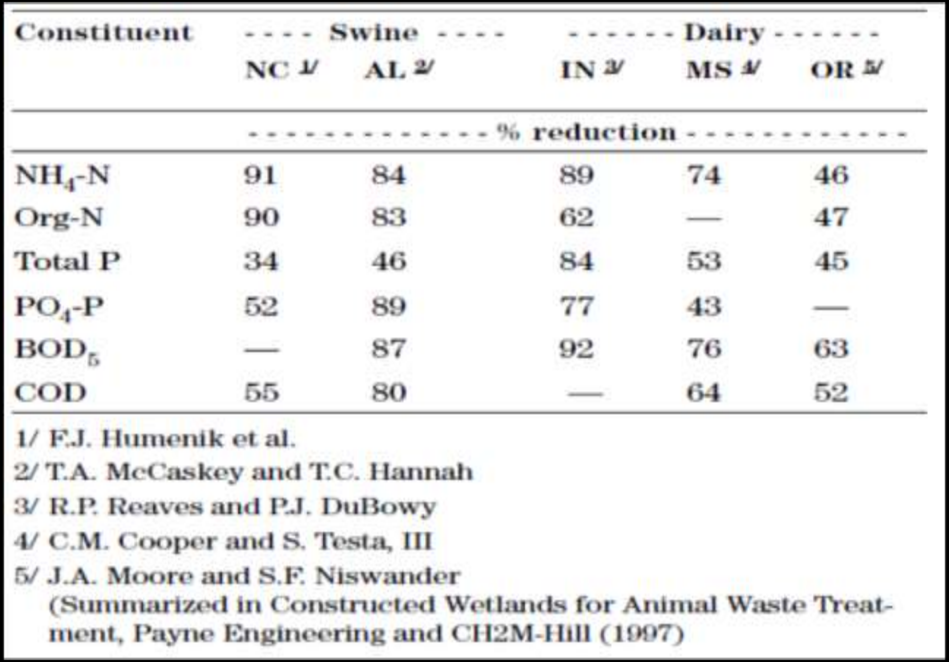
In either case, economics will also become a factor.

If an agricultural operation has a liquid waste system and elects to reduce the nutrient content of the waste, the SF constructed wetland can be a viable option. Here, the wetland can be sized so that nutrients available after its treatment are consistent with the nutrient management plan for the application site.

SF systems comparison (dairy vs swine)

The table (below) shows the benefits of using a SF wetland system to remove nutrients and organics from wastewater. (Annual percent change in pollutant concentrations from two swine and three dairy facilities following treatment of waste treatment lagoon effluent in SF constructed wetlands)

The two wetland systems shown in the table differ in location, age, design, and type of wastewater; nevertheless, the data illustrates that SF constructed wetlands can provide significant reductions in nutrient loads.



Constituent	Swine		Dairy		
	NC 1/	AL 2/	IN 3/	MS 4/	OR 5/
	% reduction				
NH_4-N	91	84	89	74	46
Org-N	90	83	62	—	47
Total P	34	46	84	53	45
PO_4-P	52	89	77	43	—
BOD_5	—	87	92	76	63
COD	55	80	—	64	52

1/ F.J. Humenik et al.
2/ T.A. McCaskey and T.C. Hannah
3/ R.P. Reaves and P.J. DuBowy
4/ C.M. Cooper and S. Testa, III
5/ J.A. Moore and S.F. Niswander
(Summarized in Constructed Wetlands for Animal Waste Treatment, Payne Engineering and CH2M-Hill (1997)

Section 6: Odor Control

Land application of wastewater

Using the “land application” method for disposing of wastewater can result in odors that are offensive to neighbors, even at a considerable distance downwind from the application site.

Anaerobic environment reduces odors

The anaerobic environment of a SF wetland system can reduce these odors by reducing volatile solids concentrations.

In addition, as wastewater passes through the wetland, the effluent typically has clearer color and less intense odor than the raw effluent from most waste treatment lagoons and waste storage ponds.

Supernatant and sludge

Where a constructed wetland is used to treat the effluent from a waste treatment lagoon, only the supernatant portion should be discharged to the wetland.

The discharge of accumulated sludge from the lagoon into the wetland may kill the plants and create operational issues.

Thus, sludge removal and its utilization apart from the wetland must be considered in planning.

The image shows an activated sludge facility. Activated sludge refers to the active biological material in the wastewater slurry mixture.

Section 7: Protecting Surface and Groundwater

Protecting surface and groundwater

The proper management of livestock waste is essential in protecting surface and groundwater sources from being contaminated by nutrients, oxygen-depleting organics and ammonia, suspended and settleable solids, and microbial contaminants.

However, wastewater from livestock facilities, even after being treated in waste treatment lagoons or incidental treatment in waste storage ponds, can have high levels of pollutants that can degrade surface water or groundwater quality, making them unfit for uses such as human consumption.

Unavoidable contamination due to “land applications”

When wastewater from a waste treatment lagoon or storage pond is applied to land, its pollutants still have the potential to enter surface water because of over-application or through the transport of residual pollutants during storm runoff.

This is especially true if buffer zones between the land application sites and nearby water sources are insufficient.

Discharging of effluent from CWs

To ensure the highest level of protection for surface water, discharging of wetland effluent into surface water is not recommended although high treatment efficiencies have often been achieved with CWs.

While reported treatment efficiencies vary, ammonia nitrogen and biochemical oxygen demand (BOD5) have been reduced through wetland treatment by more than 75 percent over an extended period for some systems.

Effluent storage; then land applied

Yet, despite these high levels of removal, the quality of wetland effluent may still not meet State discharge limits all year for all pollutants.

Therefore, it is recommended that treated effluent be stored (image) and land applied as opposed to discharging under a State-authorized permit.

Discharge permits

Those in charge of confined feeding facilities who wish to discharge treated effluent into nearby water sources must first obtain a National Pollution Discharge Elimination System (NPDES) permit from the State regulatory agency.

Allowable discharge limits are based largely on the characteristics or waste assimilative capacity (or dilution purification potential) of the receiving stream and total maximum daily loads (TMDLs) allowed.

Sampling and monitoring requirements

Wastewater sampling and flow monitoring on a regular basis are typically required, which means that the treatment system must be reliable enough to meet discharge requirements throughout the year.

A system permitted to discharge also typically requires a higher level of management and maintenance.

Although the quality of wetland effluent may not meet discharge requirements, it may be high enough to be used for other purposes than land application. Such uses may include flushing, cooling, and dust control.

Section 8: Benefits of Constructed Wetlands

Wildlife enhancement

Constructed wetlands tend to attract various forms of wildlife, such as birds, small mammals, amphibians, reptiles, and a variety of dragonflies (image) and other insects.

Wetlands become habitats for wildlife, which will frequent the area for food or make it their home.

Cell arrangements to enhance habitat

While all arrangements of wetland cells will enhance the CW as a wildlife habitat, the layout can be modified to attract specific types of wildlife.

In areas where biosecurity is a concern, consideration should be given to excluding migratory and other nonresident wildlife to minimize the potential for spread of disease to other operations.

Inhabitants of CWs

An EPA publication released in 1999, indicated that over 1,400 species of wildlife have been identified as inhabitants of constructed and natural treatment wetlands.

They include 700 species of invertebrates, 78 species of fish, 21 species of amphibians, 31 species of reptiles, 412 species of birds, and 40 species of mammals.

More than 800 species were reported in constructed wetlands alone.

Aesthetical benefits

Wetlands add a unique beauty to the landscape that in many regions of the country changes through the seasons.

Even when planted with typical plantings, the visual characteristics of the system change as natural wild plants invade the system.

While the choice of plants may be limited for the initial or upstream segments of the system because of the high concentrations of some pollutants, a greater variety of more colorful plant species may be placed at downstream locations within the wetland system where wastewater quality improves.

Economic benefits

Each wastewater operation must be evaluated individually to decide if the installation of a constructed wetland will provide an economic benefit.

The benefit could come from reducing the land application area enough to install a solid set system versus a more labor-intensive traveling gun or center pivot system.

Even if an economic analysis shows no net benefit from the installation of a constructed wetland, some operators may be willing to sacrifice the annual economic benefit to save on the time spent in handling of waste.

Economic factors

Some key factors to be considered in an economic assessment include:

- Construction costs
- Value of nutrients lost through treatment by the wetland
- Equipment and labor costs to land apply wastewater
- Value of land used by constructed wetland
- Value of crop lost because of land taken out of production by the constructed wetland
- Cost of operation and maintenance

Section 9: Treatment Process and Biochemical Conversions

Treatment mechanisms

Many physical, chemical, and biological mechanisms occur within treatment wetlands.

Some are relatively simple; others are complex, while some are not fully understood in terms of their contribution to the overall treatment process.

The principal treatment mechanisms are described in this section.

Biochemical conversions

The wetland is alive with microorganisms that convert chemical compounds from one form to another.

A large number of these organisms are attached to plant stems and litter and to sites throughout the soil and plant root complex.

Others are free floating within the wastewater stream.

Obligate and facultative anaerobes (anaerobic digestion)

Since wastewater from most livestock facilities is generally low in or devoid of dissolved oxygen, the primary treatment organisms within the wetland are either obligate anaerobes (those requiring an oxygen-free environment) or various facultative types.

Gas byproducts of anaerobic digestion

The principal end products of anaerobic digestion are carbon dioxide (CO2) and methane (CH4); however, a variety of other minor gases are also generated in small quantities.

Thus, the organic content of the wastewater as measured by 5-day biological oxygen demand (BOD5), chemical oxygen demand (COD), and volatile solids (VS) can be greatly reduced through wetland treatment.

Anaerobic bacteria also convert organic nitrogen (Org-N) into the ammonia forms:

- NH4+
- NH3

Ammonia and nitrogen

Both forms, as expressed in the equilibrium equation $NH_4^+ \leftrightarrow NH_3 + H^+$, are considered to be ammonia nitrogen.

The conversion of ammonia to nitrite (NO_2) and then to nitrate (NO_3^-) requires an aerobic environment.

Aerobic organisms are those requiring free-oxygen for respiration. Such an environment may be in microscopic zones around the roots and rhizomes of wetland plants and on substrates near the water surface.

As the anaerobic, ammonia-laden wastewater is drawn into the root zone, any aerobic organisms present begin converting ammonia to soluble nitrate.

Some of the NO_3^- is used by the plants, but much of it migrates back into the surrounding anaerobic region.

Within this region, specific types of anaerobic bacteria denitrify the NO_3^-, converting it to atmospheric (N_2) gas, which is then liberated to the atmosphere.

Sulfur and iron

Other compounds also go through biochemical conversions.

Sulfur compounds can be converted to hydrogen sulfide under anaerobic conditions, and iron compounds can be reduced.

Some compounds are lost to the atmosphere, and others are stored in the wetland sediment.

Phosphorus removal

Phosphorus doesn’t have a gaseous state. Thus organic P is converted through biological mechanisms to soluble P.

Then:

- lost in the wetland effluent
- extracted by the plants
- bound within the soil profile
- entrapped within the permanent peat-like bed that forms on the floor of the wetland (accretion)

Cation exchange

Phosphorus is often removed in relatively high concentrations in many surface flow wetlands during the initial startup. Much of this removal is due to the available cation exchange sites in the wetland soil.

After 1 to 5 years, P levels usually drop to a stable long-term removal rate. In some conditions, the wetland may develop a temporary negative removal rate, releasing more P than it removes.

Since clay soil has a high cation exchange capacity, a wetland constructed in clay soil will most likely provide a longer period of high P removal than a wetland with sandy soil.

Typical removal rates for total P for animal waste constructed wetlands are in the range of 40 to 60 percent based on earlier NRCS design criteria (USDA NRCS 1991).

Section 10: Accretion, Settling, and Filtration

Accretion

Accretion refers to the long-term buildup of a peat-like material on the floor of a SF wetland or on top of the filter bed of a SSF wetland.

This material consists of settleable solids from the waste stream, the remnants of decayed plant litter, and microbial biomass.

Recent additions of loose litter or thatch are not considered part of the accreted material.

Long term accretion rates

Accretion is the primary long-term removal process for phosphorus and metals after the soil has been saturated with these elements.

Design heights for constructed wetland embankments must take into consideration, the long-term accretion rates; the rate of buildup is typically less than a half inch per year.

When the depth allowance for accretion has been reached, the accumulated material should be removed to maintain the hydraulic effectiveness of the wetland cell. However, as stated accretion is a long-term process.

As an example, with an accretion rate of a half inch annually, it would take 24 years to fill 1 foot.

Settling and filtration

Solids entrained within the influent wastewater can settle to the bottom of the wetland and becomes part of the accreted material or can be filtered or entrapped by the plant stems and bottom litter.

The floating material and settleable solids can be retained through this mechanism.

Any settleable organic matter is eventually converted to more stable end products through biochemical conversions.

Some of the material entering the wetland is relatively inert and, therefore, degrades slowly or becomes part of the permanently stored material in the accretion.

Section 11: Volatilization of Ammonia

Volatilization

Volatilization refers to the release of a compound from the surface of a liquid to the surrounding atmosphere.

The rate of transfer from the liquid phase to the gaseous phase is governed by standard chemical equilibrium equations for the compounds in question.

If the concentration of a compound in a gaseous phase is low or nonexistent, such as an extraneous compound would be in the Earth’s atmosphere, the fraction contained in liquid phase continues to evaporate (converted to gaseous phase) until equilibrium is reached.

Ammonia

Ammonia is a compound that readily volatilizes, and is one of great importance in animal waste management.

Ammonia concentrations in anaerobic waste treatment lagoons typically represent 60 to 70 percent of the total nitrogen concentration, with the other 30 to 40 percent being in organic form.

These same percentages apply to wastewater that enters most animal waste constructed wetlands.

While some nitrogen is lost through the denitrification process, additional N may be lost through the volatilization of ammonia.

This is explained in part by this equilibrium equation for ammonia:

$$NH_4^+ + OH^- \Leftrightarrow NH_3 \bullet H_2O \Leftrightarrow NH_3\uparrow + H_2O$$

NH_3 – gaseous ammonia

In this equation, NH_3 is the gaseous phase of ammonia.

The expression $NH_3 \bullet H_2O$ represents the loose attachment of the un-ionized NH_3 molecule to the H_2O molecule.

At the air/water interface, NH_3 can be volatilized; in which case the equation shifts to the right.

If no equilibrium in NH_3 concentrations between air and water is reached, NH_3 is volatilized and the equation continues to shift toward more free $NH_3\uparrow$.

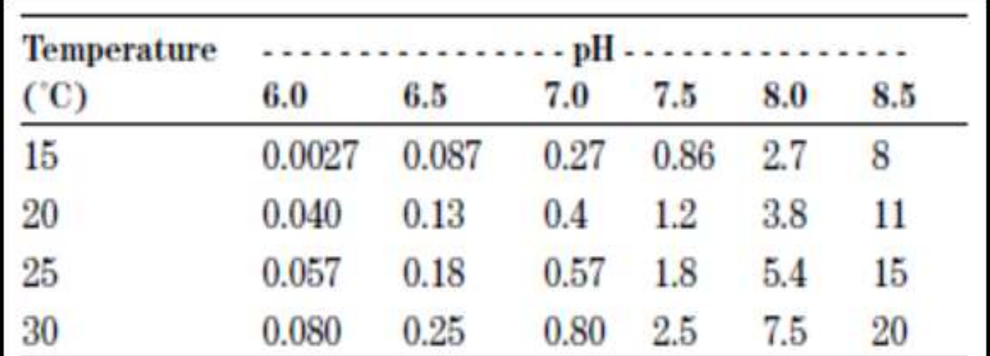
The equation also illustrates the interrelationship between pH and the ammonia forms.

Under highly alkaline conditions (high OH^-), more NH_3 becomes available in solution and more is available for volatilization. In addition, the process is affected by temperature.

Effects of pH and temperature on ammonia

Temperature and pH have an affect on the amount of un-ionized ammonia present in an aqueous solution.

The table below shows the percent of un-ionized ammonia (NH3) in aqueous solutions as related to pH and temperature:



Temperature (°C)	pH					
	6.0	6.5	7.0	7.5	8.0	8.5
15	0.0027	0.087	0.27	0.86	2.7	8
20	0.040	0.13	0.4	1.2	3.8	11
25	0.057	0.18	0.57	1.8	5.4	15
30	0.080	0.25	0.80	2.5	7.5	20

pH and volatilization

Wastewater entering constructed wetlands from anaerobic waste treatment lagoons usually has pH in the range of 7.0 to 7.5. At 77 degrees Fahrenheit, between 0.57 and 1.8 percent of the available ammonia is in the un-ionized form.

In waste treatment lagoons and constructed wetlands, the movement of wind across the surface of the wastewater enhances volatilization.

Since the pH cannot be easily raised to enhance NH3 volatilization, the process of ammonia removal in waste treatment lagoons and constructed wetlands is naturally slower than that in industrial and municipal systems where aeration is provided and pH is controlled.

Nitrogen loss due to ammonia volatilization

Nevertheless, as much as 90 percent of the original N entering an anaerobic waste treatment lagoon is lost, mostly through volatilization of ammonia.

It is believed that a considerable amount of N is also lost in constructed treatment wetlands as a result of this process.

Research on ammonia losses from rice fields fertilized with ammonium indicates that loss rates were comparable to plant uptake for dense stands of macrophytes.

In addition, various studies on the subject of ammonia volatilization concluded that “volatilization typically has limited importance, except in specific cases where ammonia is present at concentrations greater than 20 mg/L.”

Influent ammonia

The influent ammonia concentration to constructed wetlands from livestock operations generally exceeds 20 milligrams per liter.

For wastewater from swine operations that has been pretreated with a waste treatment lagoon, this influent ammonia concentration ranges from 200 to 300 milligrams per liter.

Because of this, it would appear that ammonia volatilization is a significant pathway for the loss of N in this type of wetland.

Further research on this issue is needed to quantify amounts lost under various climatic conditions.

Section 12: Interactions with Soils

Reactions occurring within the soil

When wastewater enters the soil/plant-root matrix, various reactions can take place depending on the type and amount of clay, hydrous oxide, and organic matter present.

Also, the nature and type of chemical constituents in the solute, as well as the pH and cation exchange capacity of the soil play vital roles in the retention and conversion of pollutants.

Reactions within the soil complex include:

- ion exchange
- adsorption
- precipitation
- complexation

Cation exchange

Cation exchange is the dominant exchange process in soils.

In this process positively charged particles (cations) that are bound electrostatically to negatively-charged (anionic) sites on soil colloids are exchanged with cations in the soil solution with little or no alteration of the solids.

Since soil colloids have a net negative charge, many positively charged molecules in wastewater are readily bound within the soil profile.

Adsorption and precipitation

Adsorption refers to the “adhesion of gas molecules, dissolved substances, or liquids to the surface of solids with which they come in contact,” while precipitation denotes the formation of “a sparingly soluble solid phase”.

These two processes are often in competition, and determining which one dominates is often difficult.

Sorption, a term often used to describe adsorption and absorption, can involve weak atomic and molecular interactions (physical sorption) or stronger ionic-type bonds similar to those holding atoms in a molecule (chemisorption).

The latter process is thought to be the primary mechanism for phosphate retention in acid.

Other interactions

A host of other interactions can occur within the soil. Metals, for instance, can react with soil in a variety of ways.

In addition to the inorganic reactions that occur, metals may be subject to complexation, chelation, and biological transformations in organic soils.

The purpose of this section of the course is not to explain the often complex interactions that can occur when wastewater enters the soil profile, but to simply illustrate that the soil is a vitally important and intriguing part of the treatment process within constructed wetlands.

Section 13: Evapotranspiration

Evapotranspiration

Losses of water to the atmosphere from a wetland's water surface and soil (evaporation) and from the emergent part of the wetland plants (transpiration) are referred to collectively as evapotranspiration (ET).

Since ET affects the overall water balance of a waste treatment system, it becomes an important factor in design.

Factors that affect the rate of ET include:

- incoming solar radiation
- back radiation
- cloud cover
- time of year
- latitude
- wind velocity
- amount of open water exposed to winds
- percent of water surface covered by litter or emergent plants

Predicting ET losses

Any attempt to predict ET losses based on energy balances could be a difficult task and could result in outcomes that may be no better than using empirical methods.

With this in mind, the following guidelines are presented for estimating ET:

Surface flow wetland ET over the growing season is nearly equivalent to 0.8 times Class A pan evaporation.

Climate apparently has little effect on this relationship. Monthly and yearly Class A pan evaporation data can be obtained from data published by NOAA.

Wetland ET and lake evaporation are approximately equal.

This is simply a corollary of the paragraph above because Class A pan evaporation is roughly 1.4 times lake evaporation.

For small wetlands, the ratios to pan and lake evaporation may not be adequate for predicting ET.

While these ratios can be applied effectively to wetlands as small as 0.25 acre (0.1 ha), they may not be reliable for smaller wetlands because of the advective influences of the surrounding climate.

In other words, ET is enhanced in small wetlands much as it is with potted plants. The importance of ET can be seen in a simple calculation for a wetland with a 2-acre surface area.

Seasonal ET losses

Assuming, based on climatic data, a lake evaporation of 36 inches per year. The annual ET would be about 261,360 cubic ft / year or nearly 2 million gallons.

This annual value is somewhat misleading because ET is not evenly distributed throughout the year; ET rates are typically much higher during the summer than during winter.

In areas such as central NC, studies have shown that it is common for evaporation rates to be a half inch daily during hot dry summer periods.

Even in northern climates, all wastewater applied to a treatment wetland can be lost through ET during a dry summer, as occurred twice in 10 years at a municipal treatment wetland in Michigan.

Supplemental water to compensate for ET

For this reason, consideration should be given to supplemental water that may be needed for the system.

Given the choice between the more detailed and rigorous method of determining ET and the use of empirical methods, the latter is recommended for estimating ET for animal waste treatment wetlands.

Regardless of the method used, it should be noted that ET can result in a high degree of variability in hydrodynamics throughout any single growing season.

Section 14: Nutrient Uptake

Nutrient extraction from effluent

Wetland plants extract nitrogen, phosphorus, potassium, and various minor nutrients and metals from livestock wastewater.

These constituents of wastewater may be used in the development of plant stems and leaves, or they may be stored for an extended period in the roots and rhizomes.

Emergent plants used in SF and SSF wetlands remove nutrients during the growing season, but a large part of these nutrients are returned to the litter mass as plants die back in winter.

Nutrients in accretion and subsurface structure

A fraction of the decaying litter is released in the wetland effluent.

However, some of the nutrients become part of the accretion, while others are permanently or semi-permanently stored in the subsurface structure of the plants.

Harvesting of plants to lower nutrient levels

Harvesting plants in SF and SSF wetlands will remove only a minor amount of nutrients and other pollutants relative to the other processes noted above. Therefore, harvesting is not recommended.

However, in FAP systems, nutrient removal by plants is significant simply because the plants and, hence the nutrients are harvested and removed from the system.

Section 15: Planning for a Constructed Wetland

Integrating a CW into a total AWMS

An *agricultural waste management system* (AWMS) may have numerous components.

If treatment is required, a constructed wetland could be integrated into the total system along with other structural, vegetative, and management components.

Like other components, the wetland must be examined in light of other considerations, such as economics, odor control, wildlife enhancement, and regulations.

AWMS components

The embankments and water level controls are structural components.

The wetland plants and grass on the embankments are vegetative components, while all aspects of controlling water levels and maintaining vegetation and embankments are management considerations.

The wetland is only one component of the total system, and interaction of all components should be addressed in an overall AWMS plan.

Water management, nutrient management, and other aspects of the system are subsets of the AWMS plan.

Planning team

Although the constructed wetland is part of a system, some planning factors specific to the wetland component must be addressed.

An interdisciplinary team, consisting of engineers, soil scientists, geologists, agronomists, biologists, and others, must be involved in the site-specific details and methods for integrating this component into the system.

Section 16: Pretreatment and Wastewater Characterization

Pretreatment

Wastewater from all confined animal feeding operations must be treated before it is discharged to a constructed wetland.

Raw, untreated effluent typically contains concentrations of solids, organic matter, and nutrients high enough to kill most wetland plants.

Waste treatment lagoons, waste storage ponds, and settling basins have been used for pretreatment, but the selection depends on the characteristics of the raw wastewater and the desired level of treatment.

For instance, an underground tank has been used to collect runoff from an open lot at a small dairy before the effluent is discharged to a wetland, and the results were satisfactory.

However, solids must be removed regularly in such situations, and the use of a septic tank or a small settling basin is impractical in most situations where a large number of animals are involved or where the solids cannot be removed on a regular basis.

Wastewater characterization

The characteristics of the wastewater being discharged to a wetland must be determined in advance to see first if the pollutant load will be too great for the wetland and then for the purpose of designing the wetland.

The wastewater characterization should address both the pollutant load and the volume produced.

Pollutant load

Laboratory testing should be used to determine the pollutant loads, and measurements made to determine volumes produced.

Estimates for pollutant load and volume produced are necessary for new systems.

For purposes of design, the wastewater pollutant load can be characterized by estimating techniques or by analyzing the supernatant of the pretreatment facility.

Estimates must be used if the system is new and the pretreatment facility has not yet been installed or is not fully operational.

However, for design of a constructed wetland that will be added to an already operational waste management system, it is always best to use lab test data for the actual wastewater proposed to be treated by the wetland.

Sampling of supernatant

If a waste treatment lagoon or other pretreatment facility is in place and nearly full, a representative sample of the supernatant should be collected and analyzed.

The following should be taken into consideration:

- Total Kjeldahl nitrogen (TKN)
- Ammonia nitrogen (NH3 + NH4 + – N)
- Total phosphorus (TP)
- Total suspended solids (TSS)
- pH
- BOD5

Ideally, samples should be collected during several months to reflect both warm-season and cool-season conditions.

Samples must represent the conditions when the pretreatment component will discharge to the wetland.

Estimates for discharge only

The estimates should only include the supernatant or that part of the wastewater stream that will be discharged to the constructed wetland.

For instance, data tables may indicate that the nitrogen load can be reduced by 80 percent in an anaerobic waste treatment lagoon through volatilization.

However, half of the remaining 20 percent may be retained in the settled sludge. In other words, only about 10 percent of the original N may be available for discharge to the wetland through the supernatant.

Volume produced

A reasonable degree of accuracy is needed in determining annual and seasonal wastewater flows.

Information about volumes is needed not only for designing the wetland, but also for planning effluent storage and land application requirements.

The total volume of wastewater produced and entering the wetland includes input from such sources as:

- manure (which displaces water in the pretreatment facility)
- flush-water
- rainwater

Section 17: Site Evaluation – Soils and Effluent Storage

Onsite evaluation

An onsite evaluation is essential to determine if any physical restrictions will inhibit the installation of the wetland or require modifications in design, layout, and operation.

Various forms of geospatial digital documentation can be used in the evaluation process, such as:

- Local GIS systems with associated thematic overlays
- Other geospatial data sets from agencies: USACE, FEMA, NOAA
- USDA soil maps
- USGS contour and topo maps
- USDA aerial photography

Soil borings

Soil borings or backhoe pits should be dug at several locations within the boundaries of the proposed wetland site.

Borings or pits should extend to a depth of at least 2 feet below the proposed constructed bottom elevation of the wetland to determine if permeable seams, shallow bedrock, or high water table are present and to evaluate soil permeability.

Seepage

The hydraulic head (h) is relatively small for constructed wetlands (usually less than 18 in); therefore, the potential for seepage is expected to be minimal, assuming a moderately clayey soil is available or a well-compacted liner is installed.

However, a detailed evaluation of potential seepage should be conducted at questionable sites (sandy soils, underlying limestone rock).

To reduce the potential for seepage, soils should contain a relatively high concentration of clayey material.

Clay Soils

Soil classified as clay, sandy clay, sandy clay loam, or clay loam is suitable for use in a wetland.

Clayey soil may inhibit the growth of some wetlands vegetation, but traditional plants, such as cattails, bulrushes, and reeds, have adapted to this type soil.

Using a Liner

If the soil in the top 12 to 15 inches is highly permeable (sandy) or a sand or gravel seam is located within this layer, the surface material should be removed and a compacted clay or fabricated liner installed.

Once the liner is installed, the original material can be replaced.

Since the rooting depth of most surface flow wetland plants is typically less than 12 inches and about 80 percent of the root mass for most emergent plants is in the top 6 inches of soil, the top of the liner should be 12 to 15 inches below the intended surface of the wetland.

In other words the medium for plant growth that overlies the liner should be at least 12 inches thick.

Depth to bedrock

A soil investigation also determines the depth to and type of bedrock.

A liner should be considered if bedrock consists of easily solubilized limestone or if fractured sandstone is within 3 feet of the proposed wetland bottom.

The characteristics of the soil and soil depth should be carefully evaluated in this case.

Effluent storage

Wetland effluent must be stored unless permits have been obtained to allow for its discharge to surface water.

The storage facility, at a minimum, must be large enough to contain the effluent volume from the wetland between land application events or other uses.

The storage facility must also be designed to contain runoff water, direct precipitation on its surface, and the input from other sources.

An alternative to this type storage is returning the effluent to the upstream pretreatment facility.

Water Budget

A water budget is needed to determine the required capacity of the storage facility, whether it is located in a downstream pond or in the pretreatment facility.

Section 18: Site Evaluation – Topography and Land Area

Topography

The topography of the land impacts the size and layout of the wetland system and the construction costs.

All wetland cells should have a level bottom side-to-side and a flat or nearly level bottom lengthwise.

If the land has considerable slope, several cells may need to be installed in series to maintain a relatively constant water depth.

A new embankment is needed with each new cell; thus, more area is needed for the system.

Fit into the topography to balance earthwork

The wetland should fit within the existing topography in such a way that, when possible, earthwork cuts and fills can be balanced during construction.

A slight slope in the direction of the outlet end of each cell allows for complete drainage of the cell for maintenance.

However, the same purpose can be achieved by installing a deep zone at the end of the cell that can be used as a sump for pumping and draining the cell.

Land area

The land area used for the wetland and downstream storage pond depends on the level of treatment desired and the topography.

In some cases the amount of land required for the wetland component includes more dry land for embankments than actual wet land or surface water area.

Land use

The economic consequences of replacing productive land with a treatment wetland should be evaluated in light of production lost as well as benefits gained.

Also, the installation of the constructed wetland will mean a reduction in nutrient content and, therefore less land needed for spreading waste at the final application site.

Section 19: Site Evaluation – Flood Plains and Water Sources

Fresh water considerations

The proximity of the wetland to the nearest fresh water resources should be noted within the AWMS plans.

The placement of the wetland must conform to State regulatory requirements concerning setback distances from wells.

Also the following groundwater criteria should be determined:

- depth to the groundwater
- distance to nearby wells
- depth of the nearby wells

Water sampling

If the wetland location satisfies the separation distance from a well, but only marginally so, well water samples should be collected prior to construction and evaluated for:

- fecal coliform
- fecal streptococcus bacteria (or other bacteria so specified by the regulatory office)
- nitrates (NO3–N)
- ammonia nitrogen (NH3 + NH4–N)

Without preconstruction sampling and testing, it cannot be established whether the wells were contaminated prior to the operation of the constructed wetland.

Monitoring wells

If shallow depth to groundwater is noted, installation of at least one monitoring well downslope of the wetland or in an area selected by a qualified geologist is suggested.

State regulatory officials should be consulted if a seasonal high water table will be in close proximity to the bottom of the wetland.

Flood plain protection

Flood plains are lowland areas that are adjacent to rivers, lakes, and wetlands and are covered by water during a flood.

The ability of the flood plain to carry and store floodwater should be preserved and respected to protect human life and property from flood damage.

Preservation of an active flood plain with adequate capacity is also important in maintenance of stream/riparian ecological function. For this reason constructed wetlands should be placed outside the flood plain if possible.

Another reason for placing constructed wetlands outside the flood plains is so they will not be subject to inundation and damage.

Flood plain delineation

Flood plains are delineated by the frequency that a flood of a given magnitude has the probability of occurring, such as the 1-year, 25-year, 50-year, and 100- year flood events.

If site conditions require location of constructed wetland within a flood plain, it should be protected from inundation or damage from at least the 25-year storm event.

Of course, if planning and design for a larger flood event is required by laws, rules, and regulations, such an event should be the one used.

Important considerations for when and if a constructed wetland is being planned within a flood plain are:

- If the installation of the wetland will cause upstream or cross-stream flooding during a flood event.
- The cost to protect the wetland and downstream storage pond from overtopping by the design flood event.

The State regulatory agency and possibly the USACE and FEMA may need to be consulted if a wetland and storage pond are to be placed within a flood plain.

Section 20: Site Evaluation – Other Factors

Fencing

Fencing off the wetland area may be required by some State regulatory agencies.

Also it may be required to prevent grazing animals from having access to the area.

Grazing animals such as cattle, goats, and sheep can seriously damage wetland plants and the embankments.

Fencing or other preventive measures may be needed to keep out burrowing animals, such as nutria and muskrats, both of which have been a problem in constructed wetlands.

Jurisdictional wetlands determinations

The constructed wetland should not be planned for an area defined as a jurisdictional wetland.

Jurisdictional Determinations are issued by the Army Corps of Engineers (USACE), and determine whether region of water will be regulated under Section 404 of the Clean Water Act (CWA).

These are often determined by performing a jurisdictional delineation of waters on a property.

Jurisdictional delineations

Jurisdictional Delineations are performed on a property in order to delineate which waters are Waters of the U.S. and are therefore subject to CWA 404.

Most often, a preliminary jurisdictional delineation is submitted to the Army Corps by the permit applicant, which the Corps then verifies.

The applicant can decide whether they would like a final approved delineation or would like to proceed with an application with only a verified preliminary delineation, which makes for a shorter process.

Neighboring properties

If the livestock facility and other waste management components are already in place, the addition of a treatment wetland should be of little concern to neighbors as compared with other more noticeable components.

Since odors are often the major issue with livestock facilities, the addition of the wetland should be promoted for its benefits to air quality.

Nevertheless, the location of the wetland can still be a concern simply because of its proximity to property lines or because of the types of wildlife that might be attracted to these systems.

Mosquitos

Although serious mosquito problems have not been reported at most animal waste constructed wetlands, the possibility for problems exists.

Mosquitofish may be able to survive in some wetlands for treating livestock wastewater and provide a natural control of mosquito breeding.

If mosquito problems occur, controls may include scheduled manipulation of water levels or the application of a bacterial insecticide.

Section 21: Hydrologic and Climatologic Data

Hydrologic data collection

Data on precipitation, pan evaporation, and temperature are needed for design of the wetland and the downstream storage pond. This data must be gathered during the planning process.

Pan evaporation is a measurement that combines or integrates the effects of several climate elements:

- Temperature
- Humidity
- rain fall
- drought dispersion
- solar radiation
- wind

Use of rainfall and evaporative datasets

Rainfall and evaporation data, along with other inputs, are used to determine annual flow through the wetland.

These are used in the Field Test Method to size the wetland's:

- hydraulic retention time in the wetland
- effluent volumes
- size of effluent storage facilities, (whether located downstream or upstream)
- overall water budget, (which is important in planning the land application component of the system)

Determining the annual flow rate

All sources of direct precipitation and runoff must be considered in determining the annual flow rate for the design equation.

This may include direct rainfall on the waste treatment lagoon and wetland as well as runoff from embankments, roofs, open lots, and other areas draining into the system.

This information is combined with data on manure and flushwater volumes to determine monthly and annual flows into the wetland.

It is also key to designing for dormant-season storage and establishing land application requirements.

Evapotranspiration (annual losses)

The annual ET within a wetland is presumed to be equivalent to lake evaporation.

Lake evaporation is generally considered to be about 80 percent of pan evaporation.

ET losses in a constructed wetland can exceed a livestock facility’s wastewater production during the warm season of the year.

Where this will occur, a continuous flow through the wetland must be assured by managing the upstream treatment facility or by introducing water from another source to prevent the wetland from drying out.

Temperature data

Temperature data are used in equations to size the wetland. If the wetland is being designed for a discharge, average monthly ambient temperature for the coldest month should be used for water temperature.

A wetland system can be designed for year-round operation even where ice will cover the wetland throughout most of the winter.

In these cases, the anticipated thickness of the ice and expected maximum depth of wastewater flow are considered along with other factors. However, this type operation is not recommended for animal waste constructed wetlands.

Discharge temperatures

If wastewater is stored during the winter months and if a discharge is planned, the average monthly temperature for the coldest month during the discharge period should be used for design.

However, if the wastewater is released to the wetland only during the warmer months and if the wetland is used to reduce nutrients to a specific level required by the nutrient management plan for the land application area, then the average temperature over all months of the warm season should be used in design.

Hydraulic detention time

No hard and fast recommendations are provided in the literature for hydraulic detention time.

However, it is obvious that some fraction of time is necessary for biological processes to reduce concentrations of most pollutants.

Reed et al. (1995) have suggested that a hydraulic retention time of 6 to 8 days is necessary to provide for oxygen transfer in fully developed root zones to affect desired levels of nitrification.

This and other limited information for other pollutants suggest that a minimum detention time should be 6 days.

Longer detention times provide more complete treatment. A 14-day detention time may be a good target.

Regulatory requirements

Planning must consider applicable regulations governing the installation of constructed wetlands.

They would include regulations pertaining to jurisdictional wetlands, odors, and setback distances from property lines, wells, neighboring houses, streams, roads, and other areas of concern.

Section 22: Impact on Wildlife

Disease transmission to wildlife

Though little data exists, there is still some concern regarding the potential for the transmission of diseases and the impact of the bioaccumulation of toxic substances on migratory wildlife.

The EPA indicates that “quantitative data of direct or indirect toxic effects to wildlife in treatment wetlands are generally lacking.”

The EPA acknowledges that some potential for detrimental effects to wildlife may exist because of the chemical forms of some toxic substances.

They also indicate that “wetland environments are typically dominated by plant and animal species that are hardier and less sensitive to pollutants than more sensitive species that may occur in other surface water.”

Reasonable risk of transmission

Given the wide use of municipal and industrial treatment wetlands throughout the world and the scarcity of data available concerning potential damage to wildlife, it appears that treatment wetlands present a low risk for transmission of disease or for bioaccumulation in any migratory animals, especially those that may be associated with animal waste.

Planners might also take into account the fact that migratory animals have traditionally had access to other types of animal waste practices such as open feedlots, and treatment lagoons.

Thus the installation of a constructed wetland would probably provide no greater danger than these existing systems.

Section 23: Design of Surface Flow Wetlands

Background on established design principles for CWs

The design of wetlands for animal waste treatment uses best available technology based on data from a number of animal waste treatment wetlands throughout North America and on proven technology in the field of municipal waste treatment wetlands.

As with the design of other biological treatment processes, the design of treatment wetlands is not an exact science because biological processes are often subject to influences that are highly unpredictable and variable, such as climatic changes.

Nevertheless, the state of the art has advanced considerably, and wetlands can be sized and treatment performance predicted within a fairly high degree of accuracy, given the fact that anomalies occur from time to time.

Early design guidelines

In the early 1990s, the Agricultural Stabilization and Conservation Service, now the Farm Service Agency, initiated a trial cost-share program for constructed wetlands to treat wastewater from livestock and aquaculture facilities.

Technical guidance was needed to support this program. Only a few animal waste constructed wetlands were in place at that time so the amount of data on treatment efficiencies on which to base this guidance was limited.

Therefore, to meet the need for technical guidance, the NRCS National Headquarters formed an interdisciplinary team to review available information on constructed wetlands and develop requirements for planning, design, construction, operation and maintenance, and monitoring of constructed wetlands.

The document resulting from this effort, Constructed Wetlands for Agricultural Wastewater Treatment Technical Requirements was published August 9, 1991.

This chapter and Practice Standard 656, Constructed Wetland, replace these technical requirements. The technical requirements were issued with a caution: “Significant parts of the technology are not well understood”.

Consequently, caution should be exercised in approving constructed wetlands outside the ASCS cost sharing program.”

They further indicate that the performance of constructed wetlands developed under the program should be monitored with assistance of university personnel and State natural resource and regulatory agencies.

Presumptive method and Field Test method

Two procedures were presented for performance monitoring, the presumptive method and the field test method:

Presumptive method - The presumptive method is based on estimates or presumptions about certain pollutants entering the wetland.

With this approach an estimate is made of the amount of BOD5 or nitrogen produced by the animals and the amount lost through treatment before entering the wetland.

The presumed amount of influent BOD5 or N was then applied to a given areal loading rate (i.e., 65 lb BOD5/acre/d) to determine wetland size.

This methodology was taken from design information developed by TVA and used in 1989 to design a treatment wetland for a swine research facility at Auburn University's Sand Mountain Experiment Station in Alabama.

Fixed areal loading rate

The design was based on a fixed areal loading rate that is intended to provide treatment to the level required for municipal constructed wetland effluent to be discharged meeting the standard discharge limit of 30 milligrams per liter of BOD5 or less.

Since constructed wetlands for animal waste treatment are generally not designed for discharge, use of a design loading rate meant to provide treatment to a level to allow discharge may be treatment in excess of what is actually needed.

Field test method

The field test method was based on equations developed by Reed et al. (1988). This approach was typically applied to municipal treatment wetlands.

It assumes that samples of wastewater in the pretreatment facility can be analyzed before designing the wetland.

The following information would be entered into an equation, to determine the surface area:

- a given influent and expected effluent BOD5
- total nitrogen (TN) concentration
- average daily low rate
- temperature data
- decay rate constants for given pollutants
- average depth of the wetland
- an effective wetland volume factor

Porosity

The effective wetland volume factor, sometimes called *porosity*, is the amount of wetland water volume not occupied by plants and expressed as a decimal.

The methods presented in the NRCS technical requirement assumed that the effluent concentration would not exceed typically allowed discharge limits for BOD5, ammonia, and total suspended solids.

The establishing of these limits for the design of the wetland was not intended to encourage discharges, but was rather to serve as a benchmark and to promote consistency in design throughout the country.

Discharge guidelines

In addition, the NRCS guidelines stated that effluent could be discharged only if appropriate Federal, State, and local permit requirements were satisfied.

Otherwise, the guidelines required that the wetland effluent be collected in a storage facility and held until it could be land applied or recycled.

After several years of evaluation and after the national database on animal waste constructed wetlands were compiled, it became apparent that the original design methods needed to be modified.

It was also clear that wetlands could be sized for nutrient management or odor control rather than sizing to satisfy regulatory discharge.

Modified design approaches

As a result of these findings, a modified presumptive method and a new field test method were developed. These methods are based on new equations advanced in the larger field of wetland design and on data from many animal waste constructed wetlands.

The revision of these approaches to design is presented in this course. The primary goal of both approaches is nutrient management. In other words, the wetland is sized so that the total annual nutrient load (TN or TP) in the wetland effluent matches the annual needs of the crops at the final land application site.

The land area available for spreading wastewater is assumed to be the limiting factor.

The earlier presumptive model (USDA 1991) was a one-size-fits-all approach with the goal being to reduce pollutant levels to those allowed for discharge (30 mg/L BOD5).

No provision was made for adjusting the outflow concentrations to some value other than those fixed by NPDES permit requirements.

The previous field test model could be used for that purpose, but procedures for doing so were not discussed.

Vegetative surface area

The newer models use an areal loading technique to determine wetland size versus volumetric loading.

The earlier presumptive method used this approach, but the earlier field test method was based only on volumetric loading.

Areal loading is based on the premise that a large fraction of the biological treatment within the wetland is associated with microorganisms attached to the surfaces of submerged litter, fallen leaves, soil, and plant stems.

As much as 90 percent of the treatment may be associated with vegetative surface area. Thus, raising the water level to increase detention time does not produce a proportional increase in treatment performance.

This is because the additional substrate added from the newly submerged plant stems is small in comparison to the amount of substrate already submerged.

Therefore, it has been concluded that surface area of the wetland is paramount to effective treatment as opposed to water depth.

Consequently, surface area of the wetland is determined by theoretically applying a given amount of a particular pollutant over some unit of surface area per unit of time.

Units of loading are expressed in such terms as pounds per acre per day.

It should be understood, of course, that the use of such units does not imply that influent wastewater is sprayed uniformly over the entire surface area of the wetland; rather, it is simply an expression needed to quantify the relationship between rate applied and surface area of the treatment unit.

Section 24: Wastewater Storage

CWs not designed for discharge to surface water

Unlike municipal wetland systems that typically have permits to discharge to surface water; constructed wetlands for treating livestock facility wastewater are generally not designed for discharge.

Rather, the effluent from an animal waste constructed wetland is collected, stored, and then applied to the land or used for other purposes.

The storage period may be the dormant season when wastewater cannot be land applied, or in warmer climates where year-round application occurs, it may simply be the planned period between applications.

Dormant season storage

Wastewater, whether treated or not, must be stored during the dormant season when conditions do not allow its environmentally safe land application.

Since a constructed wetland is capable of providing treatment, although at a reduced level, during the dormant season, its operation can continue even though the effluent cannot be immediately land applied.

However, a downstream storage must be provided for the treated effluent generated during this period.

On the other hand, if it is desired to operate the wetland only when its treatment performance will be at or near optimum, the wetland's operation is ceased during the dormant season.

This requires that the wastewater generated by the livestock operation be stored in a facility upstream of the wetland. Even then a storage facility downstream of the wetland may be needed.

Storage requirements

Developing water budgets based on how the wetland will be managed is essential in determining this storage requirement.

If the wetland is managed to be either empty or nearly empty at the beginning of the dormant season, the wetland itself may be capable of storing all or part of the precipitation falling on its surface and embankments.

Downstream storage must be provided for the part the wetland itself cannot store.

Of course, if the wetland is operated so it is at full depth at the beginning of the dormant season, downstream storage requirements will not be offset by storage capabilities of the wetland.

Operation during the dormant (winter) season

Operating the wetland during the dormant season will result in some reduction in treatment efficiency.

This must be accounted for with a temperature adjustment factor in the Field Test Method of design.

Design for cold weather operation must also counter the effects of freezing on pipes and on the overall hydraulics of the system.

No dormant season storage (annual operation)

When the constructed wetland is operated for the entire year (annual operation), dormant season storage is not required upstream of the wetland.

However, pretreatment ahead of the wetland is still needed to remove settleable solids and reduce the concentration of other pollutants.

The volume of wastewater flow into the wetland is spread evenly over the year. Constructed wetland effluent storage would include that volume necessary to facilitate managing land application or other uses and provide management flexibility.

Section 25: Presumptive Method

Presumptive method

The presumptive method allows sizing a wetland when the animal production facility or pretreatment facility is not already on hand, and, hence, the actual concentrations of a given pollutant are not immediately known.

In this case, design is based on estimates (presumptions) about the amount of a given pollutant that will enter the wetland on an average daily basis.

Information on pollutant loads is derived from waste production tables and predicted levels of treatment occurring within a particular type of pretreatment facility.

Such information is available in chapter 4 of the NRCS Agricultural Waste Management Field Handbook (2008) and other recognized technical sources.

It should be noted that for an existing system where the addition of a constructed wetland is being considered, final planning and design should be made based on laboratory analysis of the pretreatment facility's effluent and with use of the field test method.

Procedure (English units only)

The following steps are taken to design a SF wetland using the presumptive method.

The size of the wetland for this example is based on nitrogen as being the controlling nutrient.

Step 1

Estimate the average daily and annual TN loading to the constructed wetland, TNd (lb TN/d) and TNa (lb TN/yr).

A standard estimating technique, such as those provided in the USDA NRCS Agricultural Waste Management Field Handbook (1992) or other technical publications, should be used.

The estimated influent TN is based on the amount of TN produced by the animals less losses occurring during handling, storage, or treatment prior to discharge to the constructed wetland.

Step 2

Determine cropland requirements to utilize TNa loading (acres).

This step allows determination of whether further treatment of the proposed wetland is needed because of excess nutrients.

If the computation shows that less acreage is needed based on nitrogen than is actually available, then no wetland is needed.

However, the fact that there may be a design goal, requiring even more treatment than may be required for nutrient management, should be noted and emphasized. For example, a high quality flushwater may be the goal.

The recommended method for determining the acreage needed for land application is to base it on soil tests and accompanying fertilization recommendations.

If these recommendations are not available, an estimate can be made following the nutrient budgeting procedures of AWMFH Chapter 11, Waste Utilization.

Step 2 (continued)

Regardless of the method used, the losses occurring during application and the nutrients in the organic form that will not be available during the first year after application need to be considered.

The equation below may be used for this computation:

$$\text{Acreage} = \frac{\text{TN}_a}{\dfrac{\text{Crop TN requirement}}{\dfrac{\text{\%TN remaining after losses}}{100}}}$$

The annual TN loading to the constructed wetland, (TNa) is in terms of pounds per year as determined in step 1.

Crop TN requirement is in terms of pounds per acre per year determined as described above.

The crop requirement is adjusted to compensate for losses by multiplying the crop requirement by the percentage remaining after losses occurring during application and those following application, such as leaching.

Step 3

Estimate daily total TN required for the available cropland, Ni (lb/d).

The estimated total daily TN required for the available cropland, Ni, is determined by multiplying the available cropland acreage by the crop requirement adjusted to compensate for losses.

The crop TN requirement is in terms of pounds per acre per year and is determined as described in step 2.

Again, the crop requirement is adjusted for losses as described earlier.

$$N_1 = \frac{\text{Available cropland} \times \text{Crop TN requirement}}{365\ \text{d/yr} \times \frac{\%\ \text{TN remaining after losses}}{100}}$$

Step 4

Estimate the average daily constructed wetland influent volume, Qd (gal/d).

Appropriate technical references and local climatic data are used to estimate the volume of wastewater to be discharged to the constructed wetland on a daily basis.

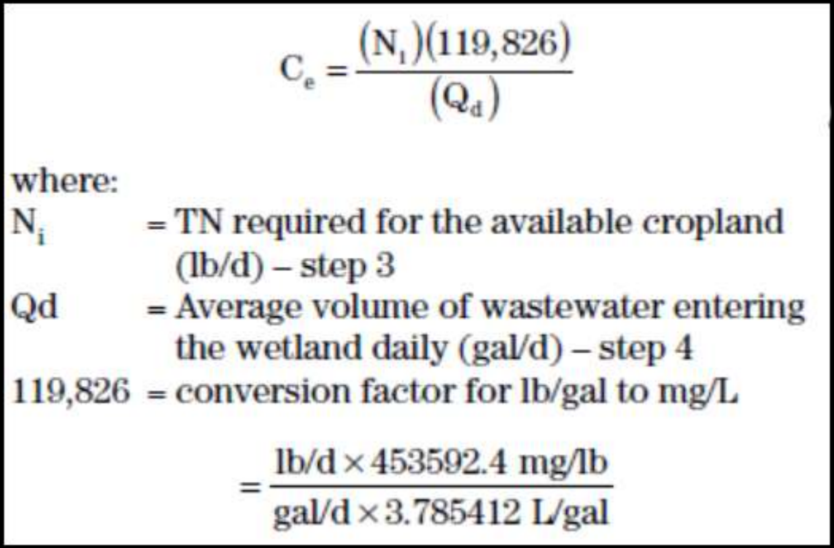
Wastewater inputs to the wetland occur from such things as manure displacement, precipitation less evaporation on the surface from the pretreatment facility, precipitation, runoff, flushwater, and other inputs.

Superior to making estimates based on published data is to measure the volume of wastewater generated.

Step 5

Calculate the average daily total TN effluent concentration needed from the wetland to satisfy daily input on the available acreage, Ce (mg/L).

Using the daily TN required for the available cropland, Ni, in terms of pounds per day (step 3), the average daily wastewater volume loading, Qd, in gallons per day (step 4), and applying the appropriate conversion factors, the constructed wetland effluent N concentration (mg/L) is determined.



$$C_e = \frac{(N_i)(119{,}826)}{(Q_d)}$$

where:

N_i = TN required for the available cropland (lb/d) – step 3

Qd = Average volume of wastewater entering the wetland daily (gal/d) – step 4

119,826 = conversion factor for lb/gal to mg/L

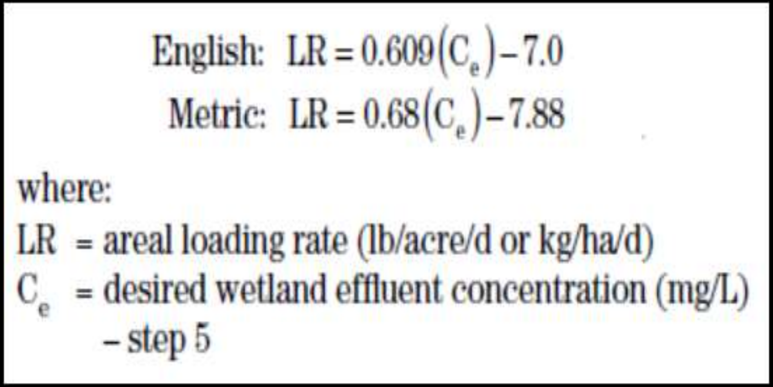
$$= \frac{\text{lb/d} \times 453592.4 \text{ mg/lb}}{\text{gal/d} \times 3.785412 \text{ L/gal}}$$

Step 6

Determine areal loading rate to the constructed wetland, LR (lb/a/d or kg/ha/d). The following equation, in English or metric units as appropriate, is used to determine the constructed wetland areal loading.

The above equation is not valid for values of Ce less than 11 mg/L.

If such high levels of treatment are desired, possibly to meet discharge requirements, use of the Field Test Method is recommended.



$$\text{English:}\quad LR = 0.609(C_e) - 7.0$$

$$\text{Metric:}\quad LR = 0.68(C_e) - 7.88$$

where:

LR = areal loading rate (lb/acre/d or kg/ha/d)

C_e = desired wetland effluent concentration (mg/L) – step 5

Step 7

Determine surface area of the wetland (acres).

Determination of the surface area of the constructed wetland is based on the daily TN input from the pretreatment facility in terms of pounds N per day (step 1) and the areal loading rate, LR, in terms of pounds per acre per day (step 6) using the equation:

The equation computes the water surface area for the wetland:

$$\text{Surface area} = \frac{\text{TN}_d}{\text{LR}}$$

The total area required by the constructed wetland is water surface area, embankment area requirement, and maintenance access area requirement.

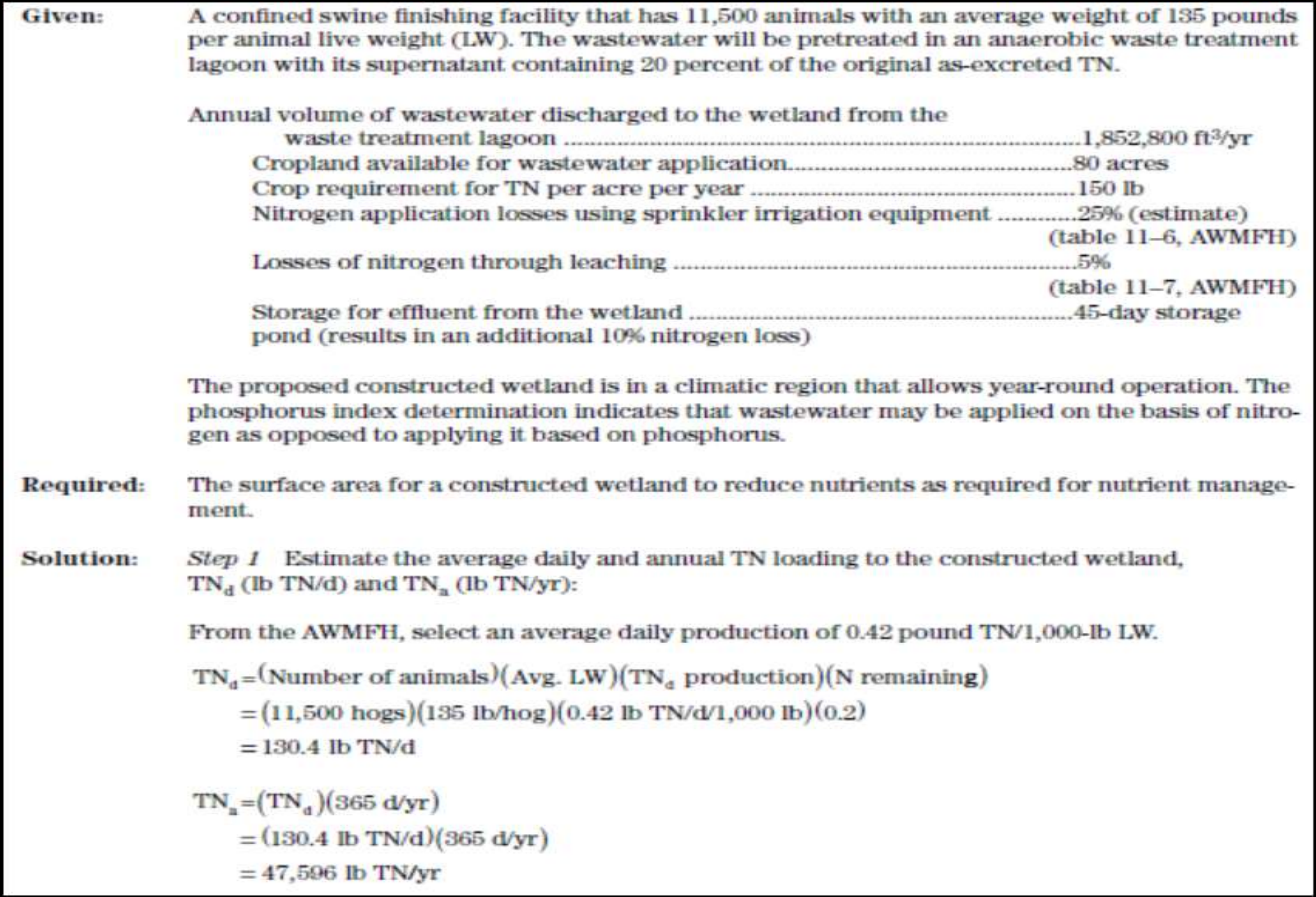
Example - Presumptive Method

Example

The following example is for a confined swine finishing facility that has 11,500 animals with an average weight of 135 pounds per animal live weight (LW).

The wastewater will be pretreated in an anaerobic waste treatment lagoon with its supernatant containing 20 percent of the original as-excreted TN.

Step 1



Given: A confined swine finishing facility that has 11,500 animals with an average weight of 135 pounds per animal live weight (LW). The wastewater will be pretreated in an anaerobic waste treatment lagoon with its supernatant containing 20 percent of the original as-excreted TN.

Annual volume of wastewater discharged to the wetland from the waste treatment lagoon	1,852,800 ft^3/yr
Cropland available for wastewater application	80 acres
Crop requirement for TN per acre per year	150 lb
Nitrogen application losses using sprinkler irrigation equipment	25% (estimate) (table 11–6, AWMFH)
Losses of nitrogen through leaching	5% (table 11–7, AWMFH)
Storage for effluent from the wetland pond (results in an additional 10% nitrogen loss)	45-day storage

The proposed constructed wetland is in a climatic region that allows year-round operation. The phosphorus index determination indicates that wastewater may be applied on the basis of nitrogen as opposed to applying it based on phosphorus.

Required: The surface area for a constructed wetland to reduce nutrients as required for nutrient management.

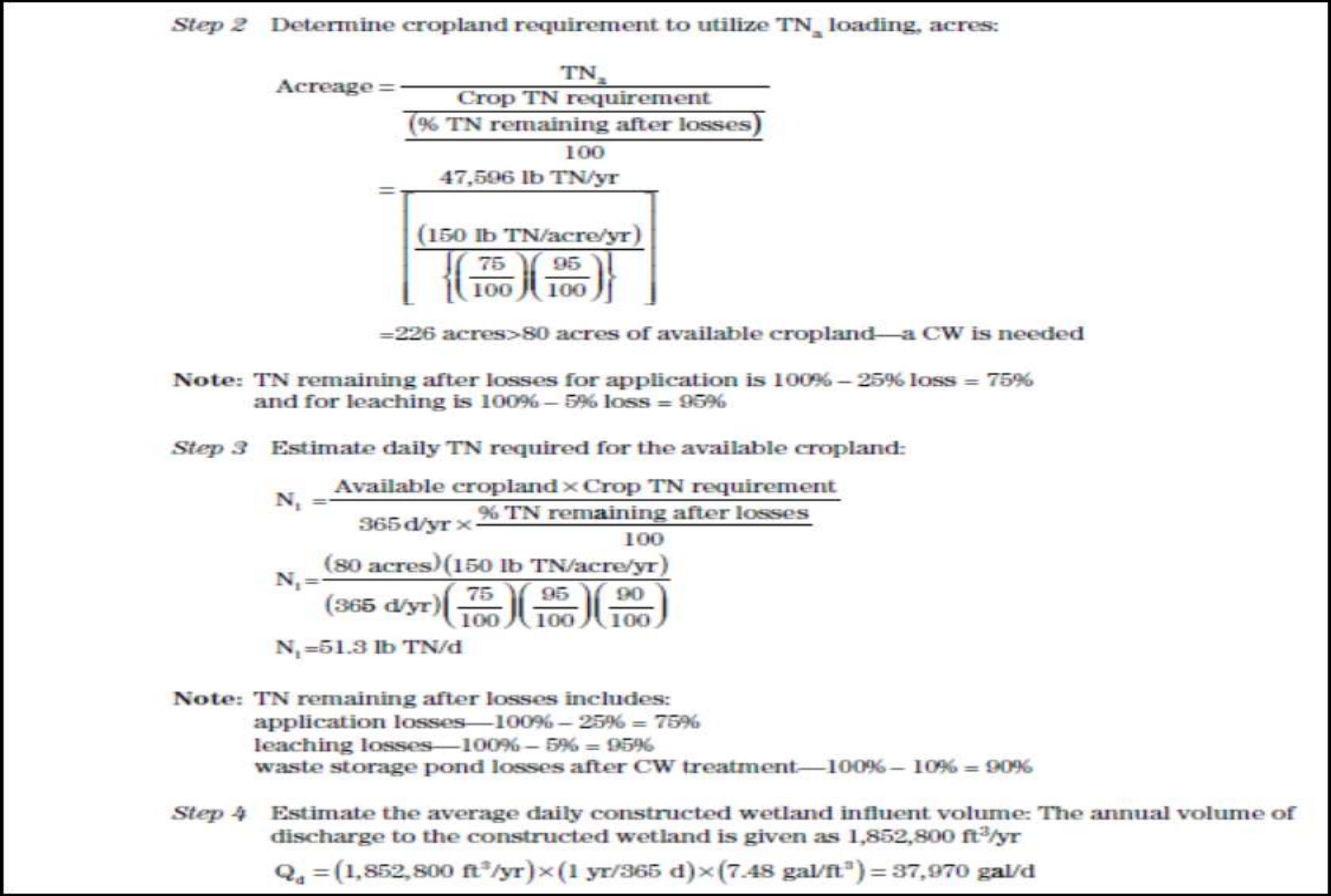
Solution: *Step 1* Estimate the average daily and annual TN loading to the constructed wetland, TN_d (lb TN/d) and TN_a (lb TN/yr):

From the AWMFH, select an average daily production of 0.42 pound TN/1,000-lb LW.

$$\begin{aligned} TN_d &= (\text{Number of animals})(\text{Avg. LW})(TN_d \text{ production})(\text{N remaining}) \\ &= (11{,}500 \text{ hogs})(135 \text{ lb/hog})(0.42 \text{ lb TN/d/1,000 lb})(0.2) \\ &= 130.4 \text{ lb TN/d} \end{aligned}$$

$$\begin{aligned} TN_a &= (TN_d)(365 \text{ d/yr}) \\ &= (130.4 \text{ lb TN/d})(365 \text{ d/yr}) \\ &= 47{,}596 \text{ lb TN/yr} \end{aligned}$$

Step 2 through 4



Step 2 Determine cropland requirement to utilize TN_a loading, acres:

$$\text{Acreage} = \frac{TN_a}{\dfrac{\text{Crop TN requirement}}{\dfrac{(\%\text{ TN remaining after losses})}{100}}}$$

$$= \frac{47{,}596 \text{ lb TN/yr}}{\left[\dfrac{(150 \text{ lb TN/acre/yr})}{\left\{\left(\dfrac{75}{100}\right)\left(\dfrac{95}{100}\right)\right\}}\right]}$$

=226 acres>80 acres of available cropland—a CW is needed

Note: TN remaining after losses for application is 100% – 25% loss = 75% and for leaching is 100% – 5% loss = 95%

Step 3 Estimate daily TN required for the available cropland:

$$N_1 = \frac{\text{Available cropland} \times \text{Crop TN requirement}}{365 \text{ d/yr} \times \dfrac{\%\text{ TN remaining after losses}}{100}}$$

$$N_1 = \frac{(80 \text{ acres})(150 \text{ lb TN/acre/yr})}{(365 \text{ d/yr})\left(\dfrac{75}{100}\right)\left(\dfrac{95}{100}\right)\left(\dfrac{90}{100}\right)}$$

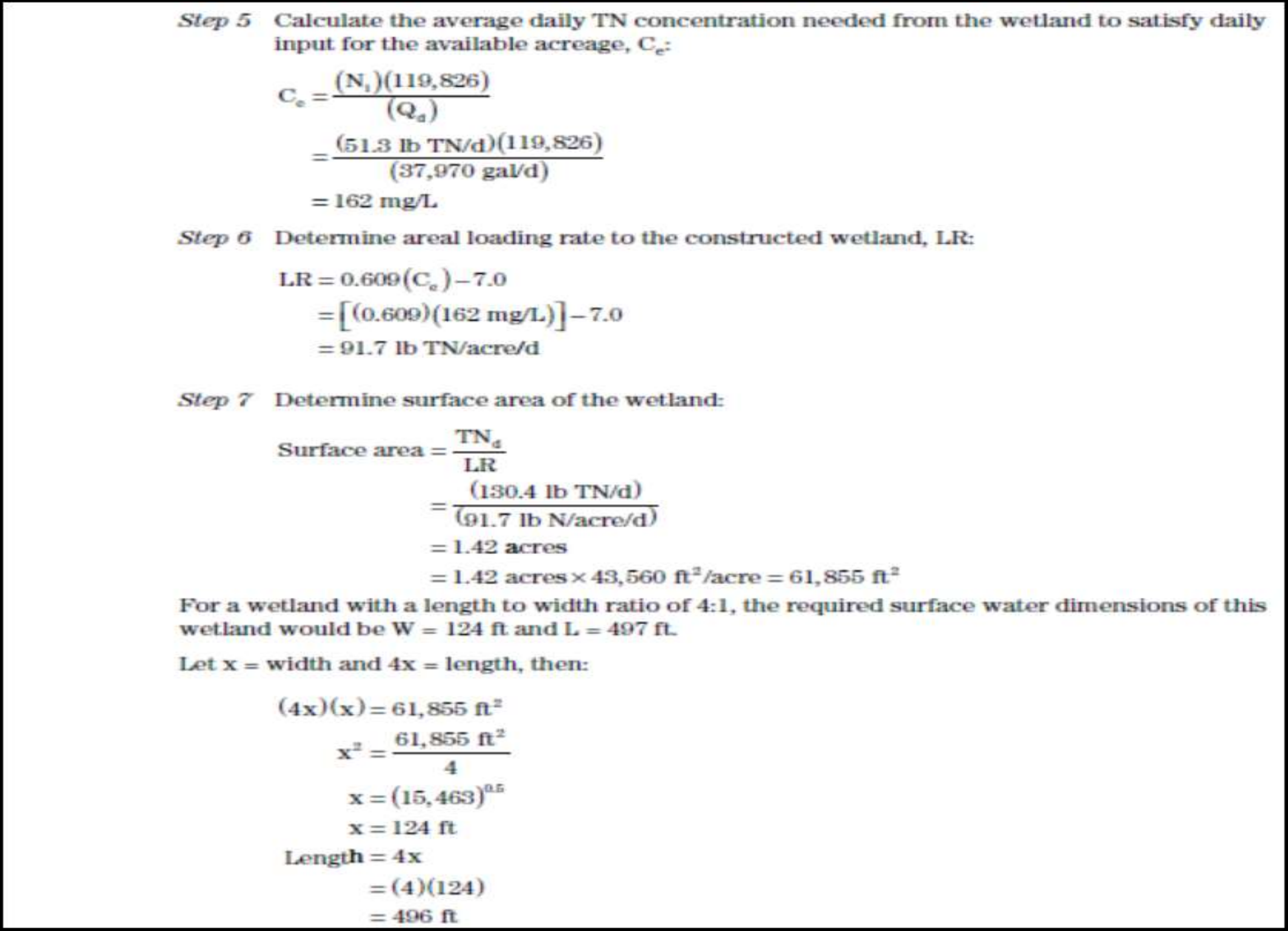
$$N_1 = 51.3 \text{ lb TN/d}$$

Note: TN remaining after losses includes:
application losses—100% – 25% = 75%
leaching losses—100% – 5% = 95%
waste storage pond losses after CW treatment—100% – 10% = 90%

Step 4 Estimate the average daily constructed wetland influent volume: The annual volume of discharge to the constructed wetland is given as 1,852,800 ft^3/yr

$$Q_d = (1{,}852{,}800 \text{ ft}^3/\text{yr}) \times (1 \text{ yr}/365 \text{ d}) \times (7.48 \text{ gal/ft}^3) = 37{,}970 \text{ gal/d}$$

Steps 5 through 7



Step 5 Calculate the average daily TN concentration needed from the wetland to satisfy daily input for the available acreage, C_e:

$$C_e = \frac{(N_i)(119{,}826)}{(Q_d)}$$

$$= \frac{(51.3 \text{ lb TN/d})(119{,}826)}{(37{,}970 \text{ gal/d})}$$

$$= 162 \text{ mg/L}$$

Step 6 Determine areal loading rate to the constructed wetland, LR:

$$\text{LR} = 0.609(C_e) - 7.0$$

$$= \left[(0.609)(162 \text{ mg/L})\right] - 7.0$$

$$= 91.7 \text{ lb TN/acre/d}$$

Step 7 Determine surface area of the wetland:

$$\text{Surface area} = \frac{\text{TN}_d}{\text{LR}}$$

$$= \frac{(130.4 \text{ lb TN/d})}{(91.7 \text{ lb N/acre/d})}$$

$$= 1.42 \text{ acres}$$

$$= 1.42 \text{ acres} \times 43{,}560 \text{ ft}^2\text{/acre} = 61{,}855 \text{ ft}^2$$

For a wetland with a length to width ratio of 4:1, the required surface water dimensions of this wetland would be W = 124 ft and L = 497 ft.

Let x = width and 4x = length, then:

$$(4x)(x) = 61{,}855 \text{ ft}^2$$

$$x^2 = \frac{61{,}855 \text{ ft}^2}{4}$$

$$x = (15{,}463)^{0.5}$$

$$x = 124 \text{ ft}$$

$$\text{Length} = 4x$$

$$= (4)(124)$$

$$= 496 \text{ ft}$$

Section 26: Field Test Method

Field testing

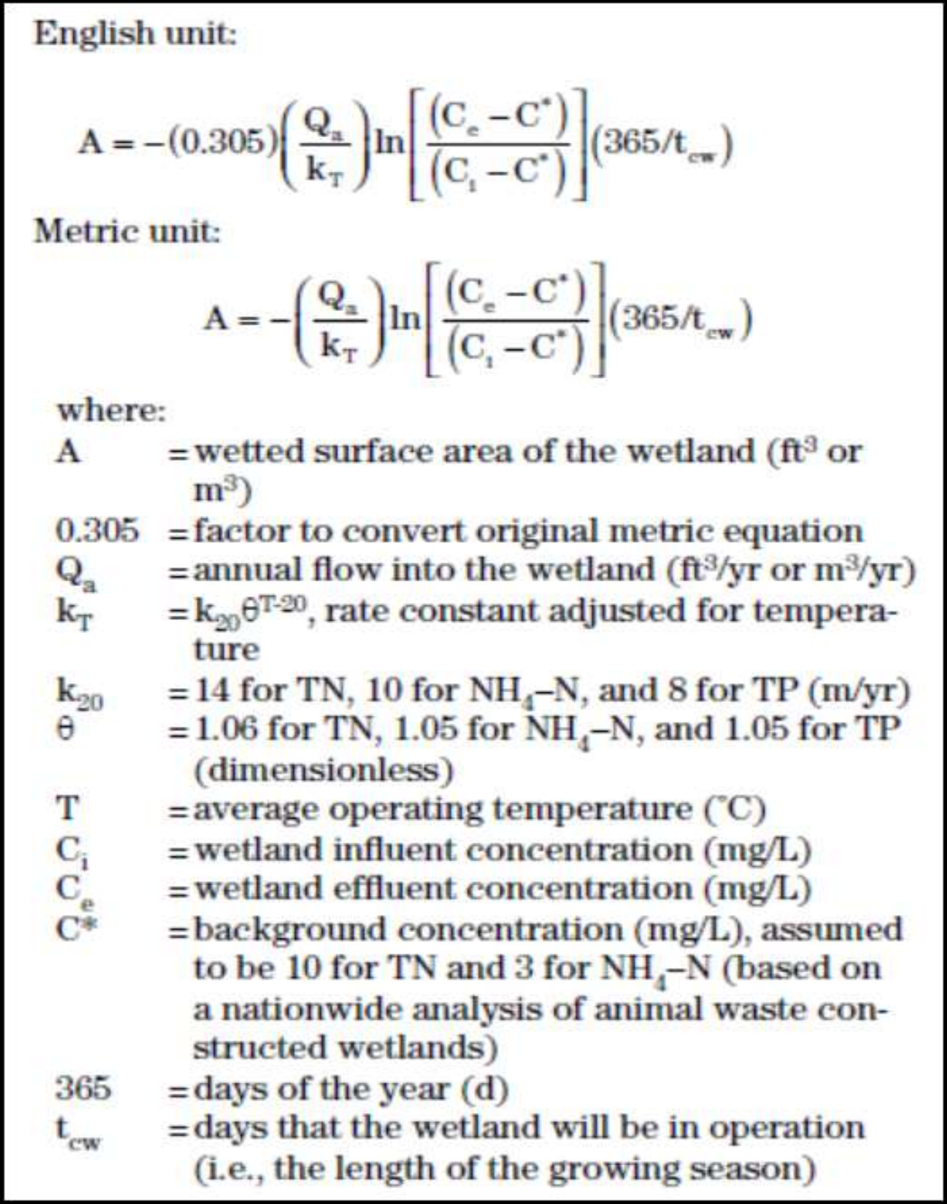
Field testing provides the most accurate way to determine the size of the wetland.

Samples of the pretreatment wastewater are collected and analyzed, and the information is applied to the following equation for both English and metric units:

The basic equation (less the factor 365/tcw) was developed originally for municipal treatment wetlands.

Rate constants specific to animal waste constructed wetlands were developed from the national database on animal waste constructed wetlands and applied to the following equation (next page), also called the k–C* model.

k-C* model equation



English unit:

$$A = -(0.305)\left(\frac{Q_a}{k_T}\right)\ln\left[\frac{(C_e - C^*)}{(C_i - C^*)}\right](365/t_{cw})$$

Metric unit:

$$A = -\left(\frac{Q_a}{k_T}\right)\ln\left[\frac{(C_e - C^*)}{(C_i - C^*)}\right](365/t_{cw})$$

where:

A = wetted surface area of the wetland (ft^3 or m^3)
0.305 = factor to convert original metric equation
Q_a = annual flow into the wetland (ft^3/yr or m^3/yr)
k_T = $k_{20}\theta^{T\text{-}20}$, rate constant adjusted for temperature
k_{20} = 14 for TN, 10 for NH_4–N, and 8 for TP (m/yr)
θ = 1.06 for TN, 1.05 for NH_4–N, and 1.05 for TP (dimensionless)
T = average operating temperature (°C)
C_i = wetland influent concentration (mg/L)
C_e = wetland effluent concentration (mg/L)
C^* = background concentration (mg/L), assumed to be 10 for TN and 3 for NH_4–N (based on a nationwide analysis of animal waste constructed wetlands)
365 = days of the year (d)
t_{cw} = days that the wetland will be in operation (i.e., the length of the growing season)

k–C* model

This model should be used where a pretreatment facility is already in place and samples can be readily collected.

An alternative would be to collect samples from the pretreatment facility at a nearby facility that is expected to have the same characteristics (number of animals, size of pretreatment facility) and therefore, the same wastewater characteristics.

Samples from the pretreatment facility are analyzed for the constituent of concern (TN, NH4–N, or TP) to determine wetland influent concentration (Ci).

In addition, the annual flow (Qa) from the pretreatment facility must be calculated as well as the wetland effluent concentration for the nutrient of concern.

Average operating temperature used in the equation is based on the site temperatures when the constructed wetland will be actually operated.

For example, if the constructed wetland is operated only during the growing season with the wastewater stored upstream through the dormant season, the temperature for the equation will be the average for the growing season.

This, of course, will require that the stored volume of wastewater be treated in addition to what is generated during the growing season.

Provisions for storage have been included in the equation with the factor 365/tcw.

The field test method differs from the original field test method presented in the NRCS technical requirement (USDA 1991) in that the size of the wetland is based on areal loading as opposed to volumetric loading.

The same is true of both the original and new presumptive methods.

(See prior information on areal versus volumetric loading and the information that follows the field test method example.)

Procedures for the Field Test Method

Field test method

The following steps are taken to determine the surface area for a SF wetland using the field test method.

Subsequently, the example on the next page will demonstrate the calculations for each step.

This example uses English units.

If metric units are desired, use the proper units and conversion factors for the equations chosen.

Step 1

Estimate the average daily and annual constructed wetland influent volumes, Qd (gal/d and ft3/d) and Qa (ft3/yr).

This step is the equivalent of step 4 in the presumptive method.

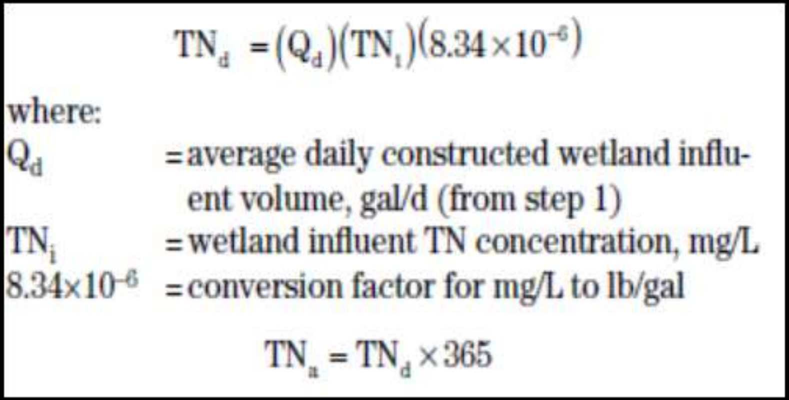
Appropriate technical references and local climatic data are used to estimate the volume of wastewater to be discharged to the constructed wetland on a daily basis.

Wastewater inputs to the wetland occur from such things as manure displacement, precipitation less evaporation on the surface from the pretreatment facility, storm runoff water, flushwater, and other inputs.

Step 2

Estimate the average daily and annual TN loading to the constructed wetland, TNd (lb TN/d) and TNa (lb TN/yr).

This computation is based on laboratory results of pretreatment facility effluent and the volume of wastewater in gallons per day (step 1) entering the wetland.



$$TN_d = (Q_d)(TN_i)(8.34 \times 10^{-6})$$

where:

Q_d = average daily constructed wetland influent volume, gal/d (from step 1)

TN_i = wetland influent TN concentration, mg/L

8.34×10^{-6} = conversion factor for mg/L to lb/gal

$$TN_a = TN_d \times 365$$

Step 3

Determine cropland requirement to utilize the annual total N loading (acre). This is the equivalent of step 2 in the presumptive method.

If treatment for nutrient management is the goal of constructed wetland treatment, this step allows the determination of whether further treatment of the proposed constructed wetland is needed.

If the computation shows that less acreage is needed based on nitrogen than is actually available, then no wetland is needed for nutrient concentration reduction.

As noted in the presumptive method, the design goal may be something other than nutrient management.

The goal could be to improve the water quality for such a purpose as a high quality flushwater or dust control.

In such cases the issue as to whether the treatment of a constructed wetland is needed is not an issue and this step could be skipped.

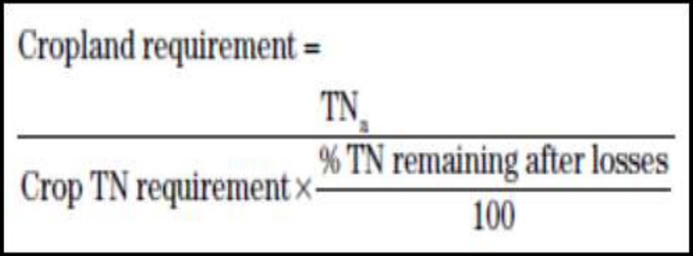
The general equation for determining the cropland area requirement without a constructed wetland follows.

The annual TN loading is determined by multiplying the daily TN loading to the constructed wetland in pounds of TN per day taken from step 2 by 365, the days in a year.

The crop N requirement is best based on soil test and fertilizer recommendations. If these recommendations are not available, an estimate can be developed using the procedure in AWMFH chapter 11.

The crop TN requirement is in terms of pounds of N per acre per year. Regardless of how the crop requirement is established, the amount must be adjusted for anticipated losses, such as from application and leaching.

In the equation that follows, this is given as a percentage of TN remaining after the losses:



$$\text{Cropland requirement} = \frac{TN_a}{\text{Crop TN requirement} \times \frac{\%\ \text{TN remaining after losses}}{100}}$$

TNa is the annual TN loading in pounds per year (step 2), crop requirement in pounds per acre per year, and TN remaining after losses expressed as a percentage.

Step 4

Estimate daily TN required for the available cropland, Ni (lb/d).

This is the equivalent of step 3 in the presumptive method.

The general equation for making this estimate follows:

$$N_1 = \frac{\text{Available cropland} \times \text{Crop TN requirement}}{365\ \text{d/yr} \times \dfrac{\%\ \text{TN remaining after losses}}{100}}$$

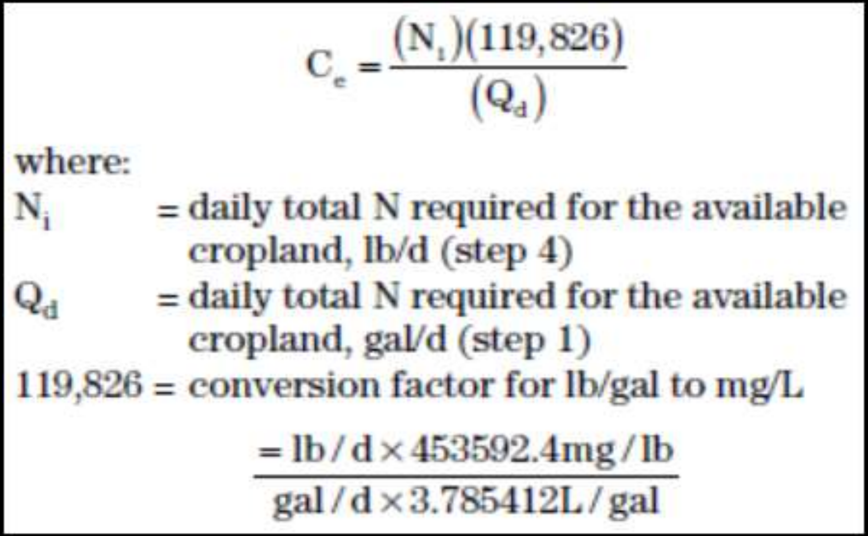
The crop TN requirement was established in step 3 as was the percentage of TN remaining after losses.

Available cropland is in acres, crop TN requirement is in pounds N per acre per year, and TN remaining after losses is expressed as a percentage.

Step 5

Calculate the average daily total N effluent concentration needed from the wetland to satisfy daily input on the available acreage, Ce (mg/L).

Using the daily TN required for the available cropland in pounds per day, Ni, from step 4 and the average daily wastewater volume loading in gallons per day (step 1), the appropriate conversion factors are applied to determine the constructed wetland effluent N concentration (mg/L).



$$C_e = \frac{(N_i)(119{,}826)}{(Q_d)}$$

where:

N_i = daily total N required for the available cropland, lb/d (step 4)

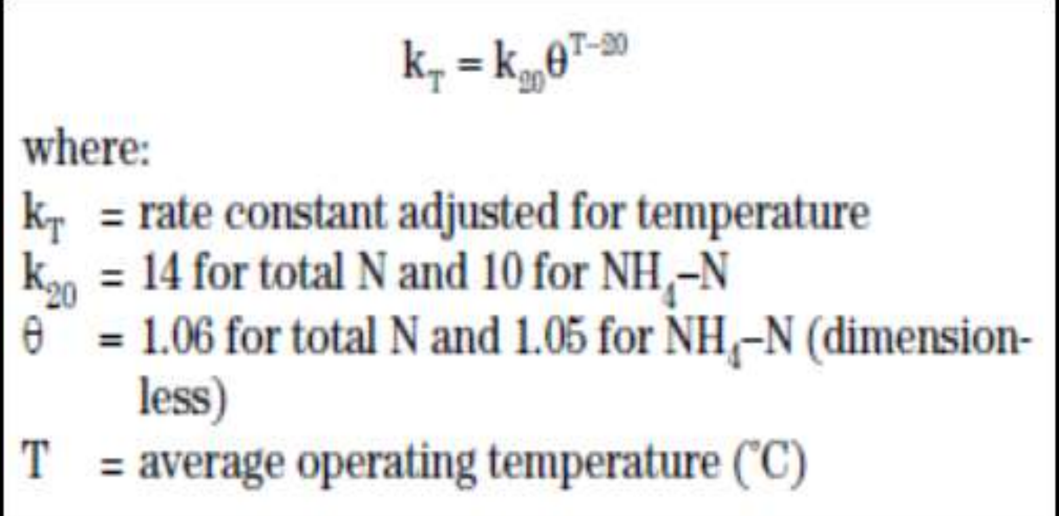
Q_d = daily total N required for the available cropland, gal/d (step 1)

119,826 = conversion factor for lb/gal to mg/L

$$= \frac{\text{lb}/\text{d} \times 453592.4\text{mg}/\text{lb}}{\text{gal}/\text{d} \times 3.785412\text{L}/\text{gal}}$$

Step 6

Calculate kT:



$$k_T = k_{20}\theta^{T-20}$$

where:

k_T = rate constant adjusted for temperature

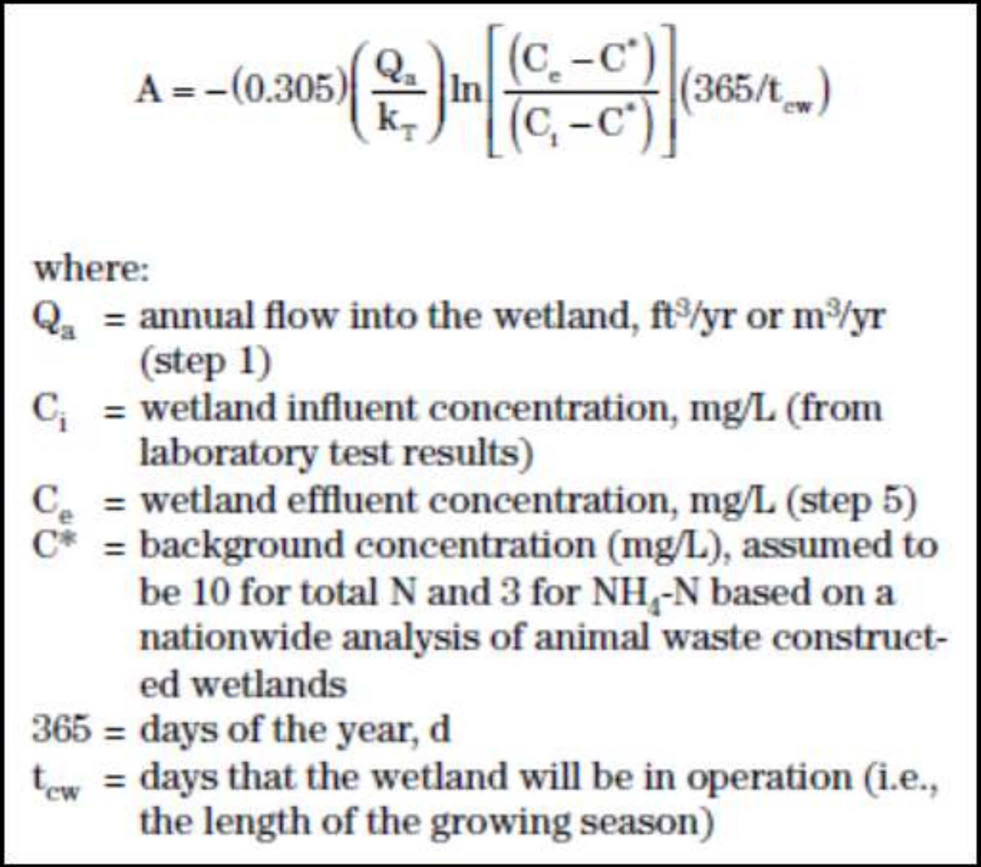
k_{20} = 14 for total N and 10 for NH_4–N

θ = 1.06 for total N and 1.05 for NH_4–N (dimensionless)

T = average operating temperature (°C)

Step 7

Determine surface area of the wetland, A (sq. ft.).



$$A = -(0.305)\left(\frac{Q_a}{k_T}\right)\ln\left[\frac{(C_e - C^*)}{(C_i - C^*)}\right](365/t_{cw})$$

where:

Q_a = annual flow into the wetland, ft^3/yr or m^3/yr (step 1)

C_i = wetland influent concentration, mg/L (from laboratory test results)

C_e = wetland effluent concentration, mg/L (step 5)

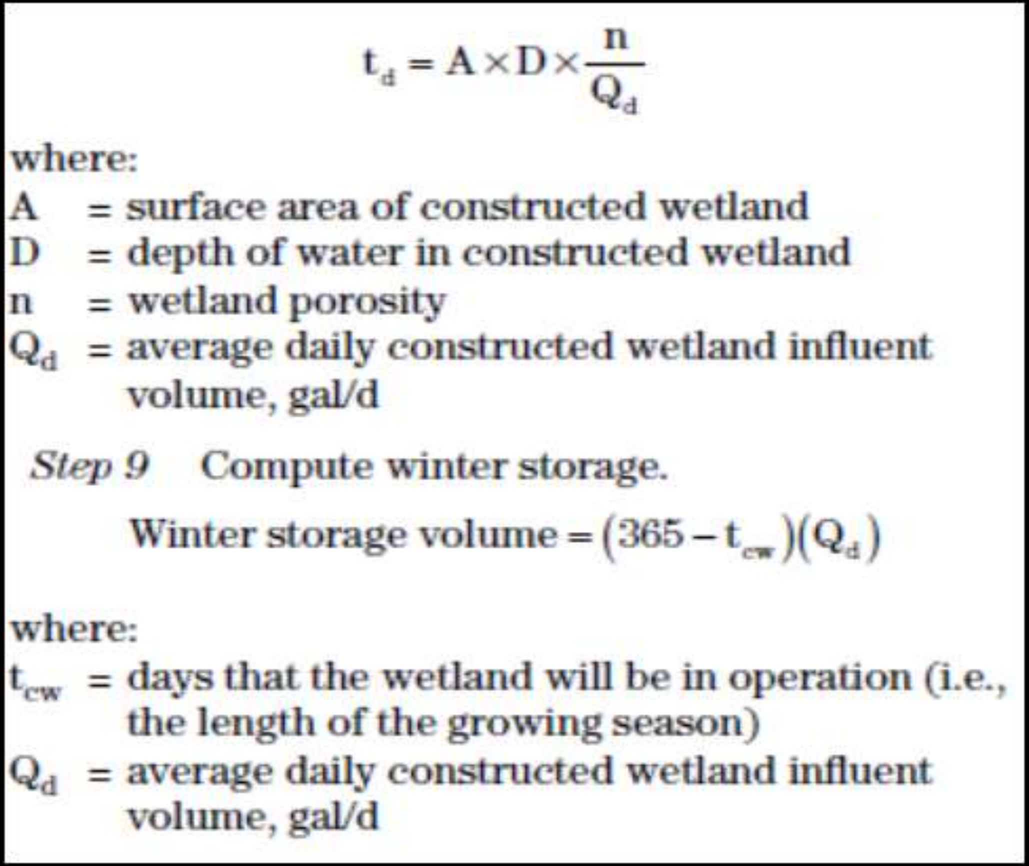
C^* = background concentration (mg/L), assumed to be 10 for total N and 3 for NH_4-N based on a nationwide analysis of animal waste constructed wetlands

365 = days of the year, d

t_{cw} = days that the wetland will be in operation (i.e., the length of the growing season)

Step 8

Compute theoretical hydraulic detention time, td.



$$t_d = A \times D \times \frac{n}{Q_d}$$

where:

A = surface area of constructed wetland

D = depth of water in constructed wetland

n = wetland porosity

Q_d = average daily constructed wetland influent volume, gal/d

Step 9 Compute winter storage.

$$\text{Winter storage volume} = (365 - t_{cw})(Q_d)$$

where:

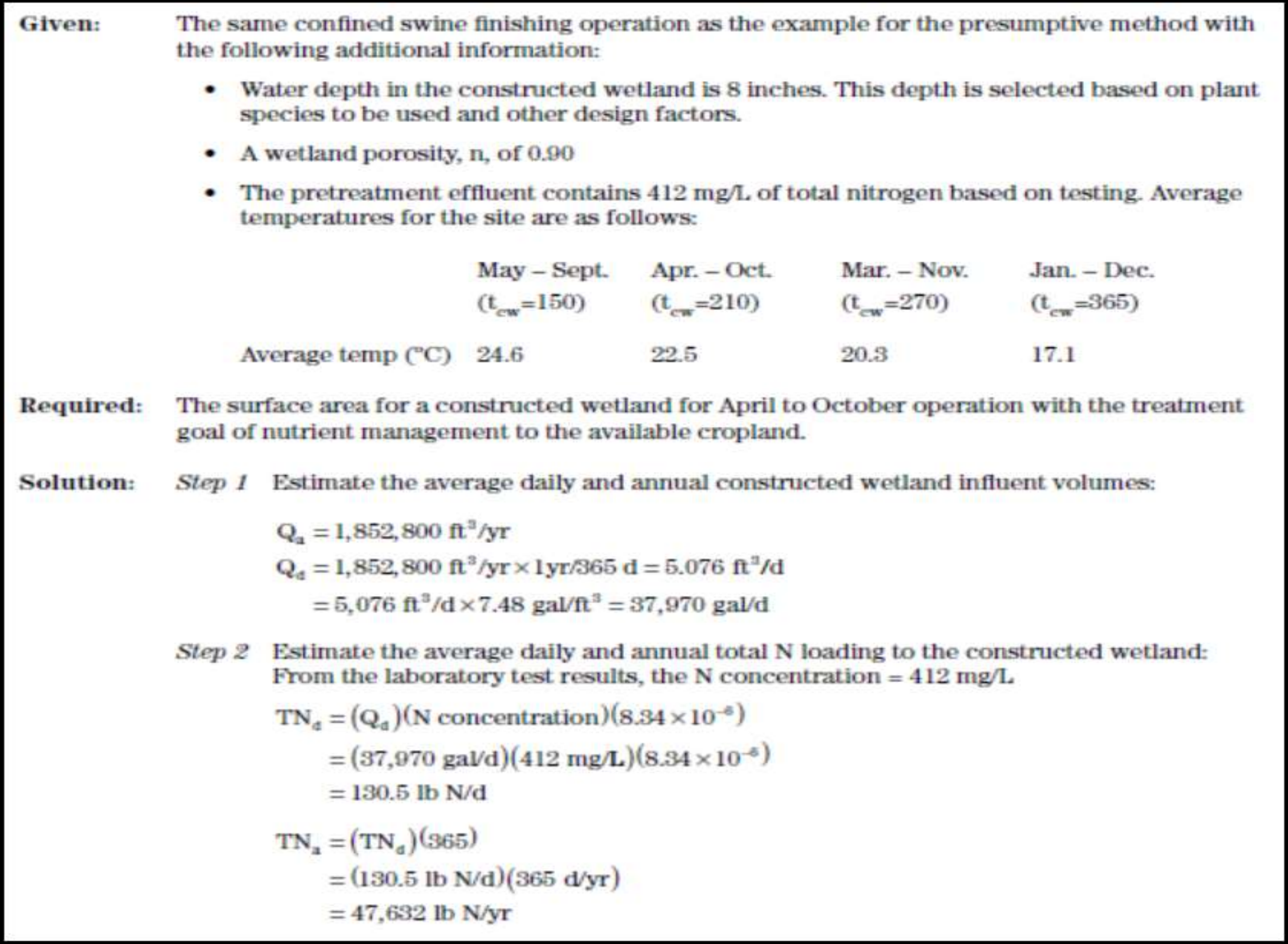
t_{cw} = days that the wetland will be in operation (i.e., the length of the growing season)

Q_d = average daily constructed wetland influent volume, gal/d

Example - Field Test Method

Steps 1 and 2

Below is an example of the same confined swine finishing operation as the example for the presumptive method, with additional information added.



Given: The same confined swine finishing operation as the example for the presumptive method with the following additional information:

- Water depth in the constructed wetland is 8 inches. This depth is selected based on plant species to be used and other design factors.
- A wetland porosity, n, of 0.90
- The pretreatment effluent contains 412 mg/L of total nitrogen based on testing. Average temperatures for the site are as follows:

	May – Sept. (t_{cw}=150)	Apr. – Oct. (t_{cw}=210)	Mar. – Nov. (t_{cw}=270)	Jan. – Dec. (t_{cw}=365)
Average temp (°C)	24.6	22.5	20.3	17.1

Required: The surface area for a constructed wetland for April to October operation with the treatment goal of nutrient management to the available cropland.

Solution: *Step 1* Estimate the average daily and annual constructed wetland influent volumes:

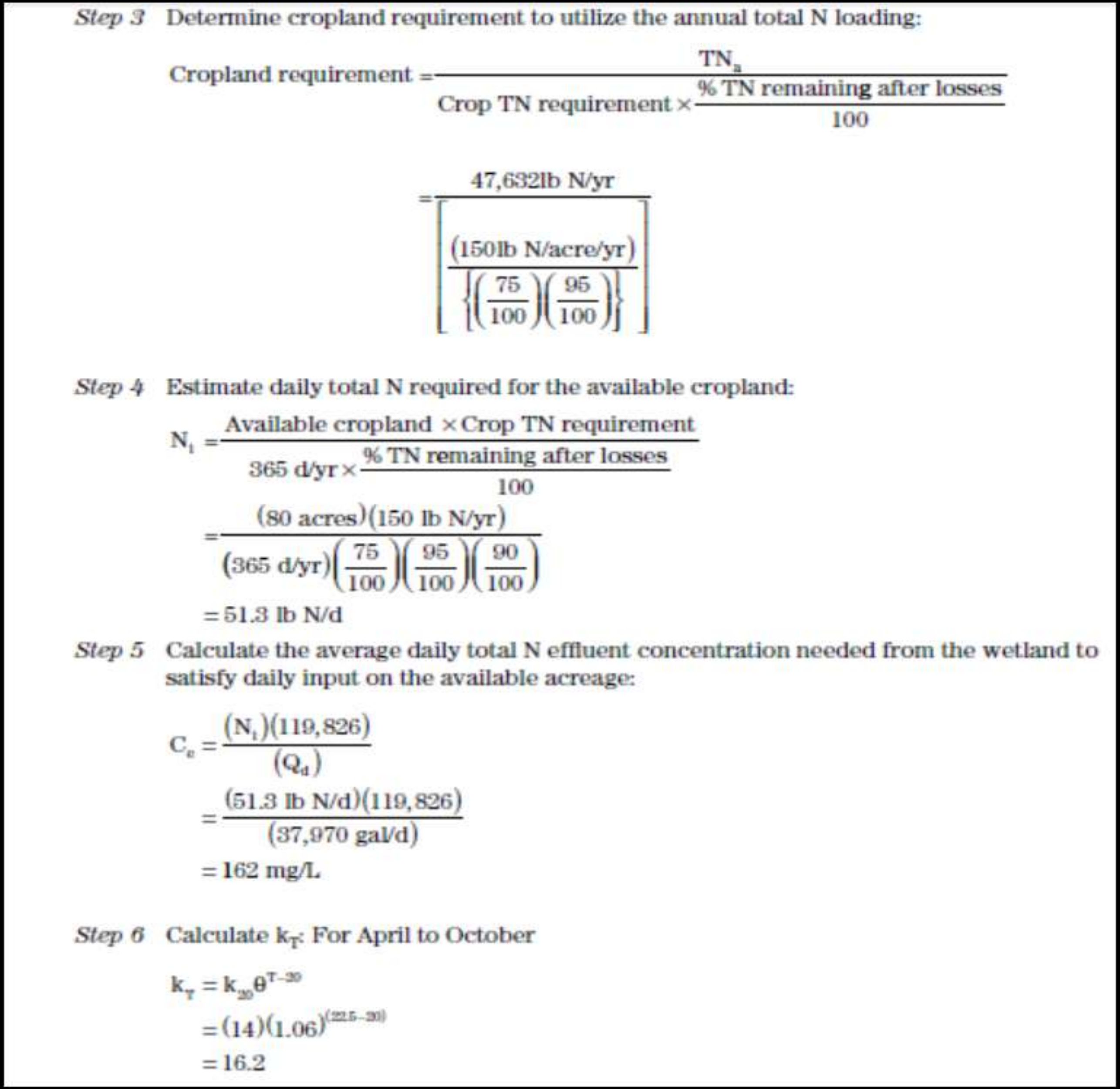
$$\begin{aligned} Q_a &= 1{,}852{,}800\ \text{ft}^3/\text{yr} \\ Q_d &= 1{,}852{,}800\ \text{ft}^3/\text{yr} \times 1\text{yr}/365\ \text{d} = 5.076\ \text{ft}^3/\text{d} \\ &= 5{,}076\ \text{ft}^3/\text{d} \times 7.48\ \text{gal/ft}^3 = 37{,}970\ \text{gal/d} \end{aligned}$$

Step 2 Estimate the average daily and annual total N loading to the constructed wetland: From the laboratory test results, the N concentration = 412 mg/L

$$\begin{aligned} TN_d &= (Q_d)(\text{N concentration})(8.34 \times 10^{-6}) \\ &= (37{,}970\ \text{gal/d})(412\ \text{mg/L})(8.34 \times 10^{-6}) \\ &= 130.5\ \text{lb N/d} \end{aligned}$$

$$\begin{aligned} TN_a &= (TN_d)(365) \\ &= (130.5\ \text{lb N/d})(365\ \text{d/yr}) \\ &= 47{,}632\ \text{lb N/yr} \end{aligned}$$

Steps 3 through 6



Step 3 Determine cropland requirement to utilize the annual total N loading:

$$\text{Cropland requirement} = \frac{TN_a}{\text{Crop TN requirement} \times \dfrac{\%\ \text{TN remaining after losses}}{100}}$$

$$= \frac{47{,}632\,\text{lb N/yr}}{\left[\dfrac{(150\,\text{lb N/acre/yr})}{\left\{\left(\dfrac{75}{100}\right)\left(\dfrac{95}{100}\right)\right\}}\right]}$$

Step 4 Estimate daily total N required for the available cropland:

$$N_1 = \frac{\text{Available cropland} \times \text{Crop TN requirement}}{365\ \text{d/yr} \times \dfrac{\%\ \text{TN remaining after losses}}{100}}$$

$$= \frac{(80\ \text{acres})(150\ \text{lb N/yr})}{(365\ \text{d/yr})\left(\dfrac{75}{100}\right)\left(\dfrac{95}{100}\right)\left(\dfrac{90}{100}\right)}$$

$$= 51.3\ \text{lb N/d}$$

Step 5 Calculate the average daily total N effluent concentration needed from the wetland to satisfy daily input on the available acreage:

$$C_e = \frac{(N_1)(119{,}826)}{(Q_d)}$$

$$= \frac{(51.3\ \text{lb N/d})(119{,}826)}{(37{,}970\ \text{gal/d})}$$

$$= 162\ \text{mg/L}$$

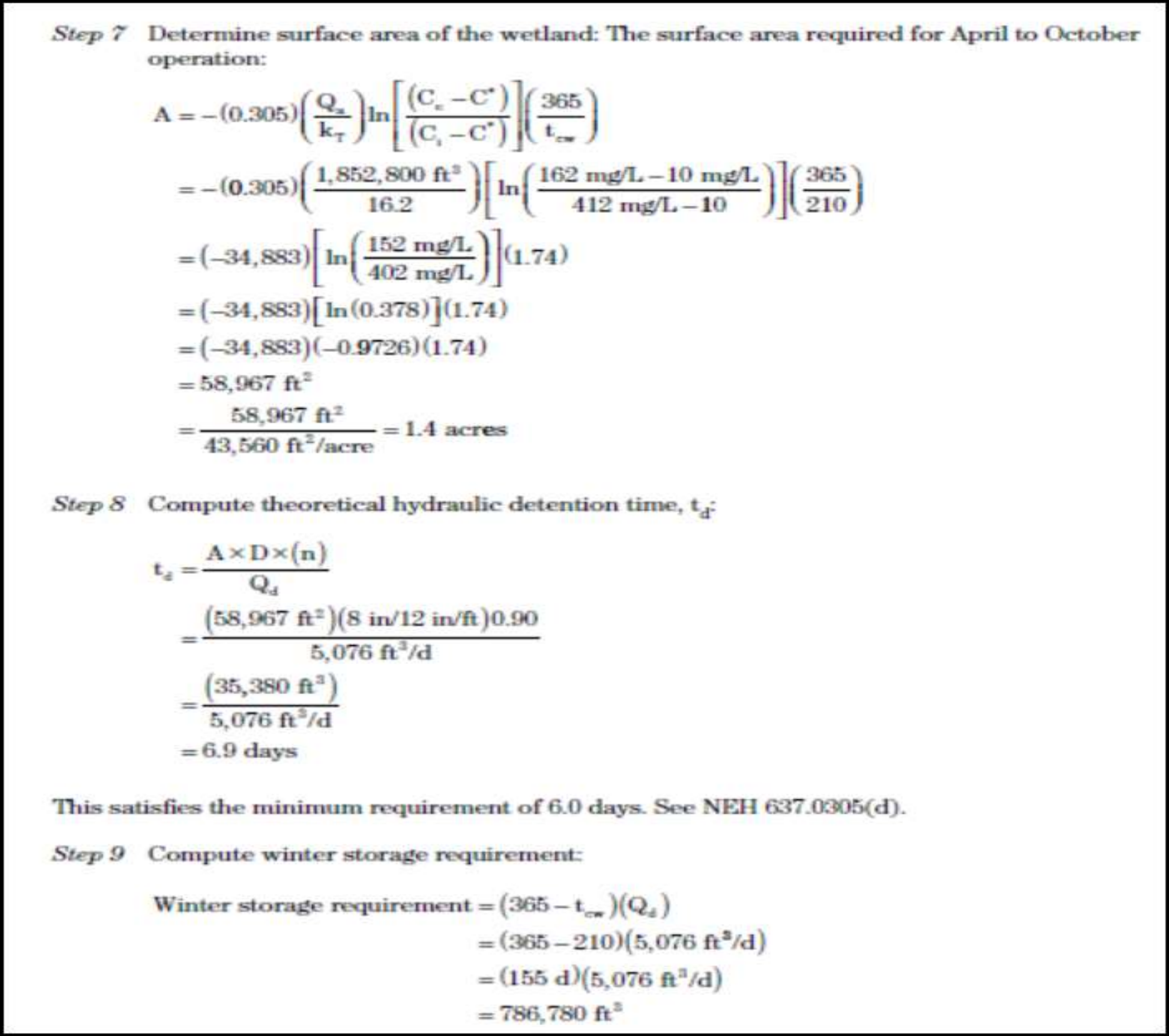
Step 6 Calculate k_T: For April to October

$$k_T = k_{20}\theta^{T-20}$$

$$= (14)(1.06)^{(22.5-20)}$$

$$= 16.2$$

Step 7 through 9



Step 7 Determine surface area of the wetland: The surface area required for April to October operation:

$$A = -(0.305)\left(\frac{Q_a}{k_T}\right)\ln\left[\frac{(C_e - C^*)}{(C_i - C^*)}\right]\left(\frac{365}{t_{cw}}\right)$$

$$= -(0.305)\left(\frac{1{,}852{,}800\ \text{ft}^3}{16.2}\right)\left[\ln\left(\frac{162\ \text{mg/L} - 10\ \text{mg/L}}{412\ \text{mg/L} - 10}\right)\right]\left(\frac{365}{210}\right)$$

$$= (-34{,}883)\left[\ln\left(\frac{152\ \text{mg/L}}{402\ \text{mg/L}}\right)\right](1.74)$$

$$= (-34{,}883)\left[\ln(0.378)\right](1.74)$$

$$= (-34{,}883)(-0.9726)(1.74)$$

$$= 58{,}967\ \text{ft}^2$$

$$= \frac{58{,}967\ \text{ft}^2}{43{,}560\ \text{ft}^2/\text{acre}} = 1.4\ \text{acres}$$

Step 8 Compute theoretical hydraulic detention time, t_d:

$$t_d = \frac{A \times D \times (n)}{Q_d}$$

$$= \frac{(58{,}967\ \text{ft}^2)(8\ \text{in}/12\ \text{in/ft})0.90}{5{,}076\ \text{ft}^3/\text{d}}$$

$$= \frac{(35{,}380\ \text{ft}^3)}{5{,}076\ \text{ft}^3/\text{d}}$$

$$= 6.9\ \text{days}$$

This satisfies the minimum requirement of 6.0 days. See NEH 637.0305(d).

Step 9 Compute winter storage requirement:

$$\text{Winter storage requirement} = (365 - t_{cw})(Q_d)$$

$$= (365 - 210)(5{,}076\ \text{ft}^3/\text{d})$$

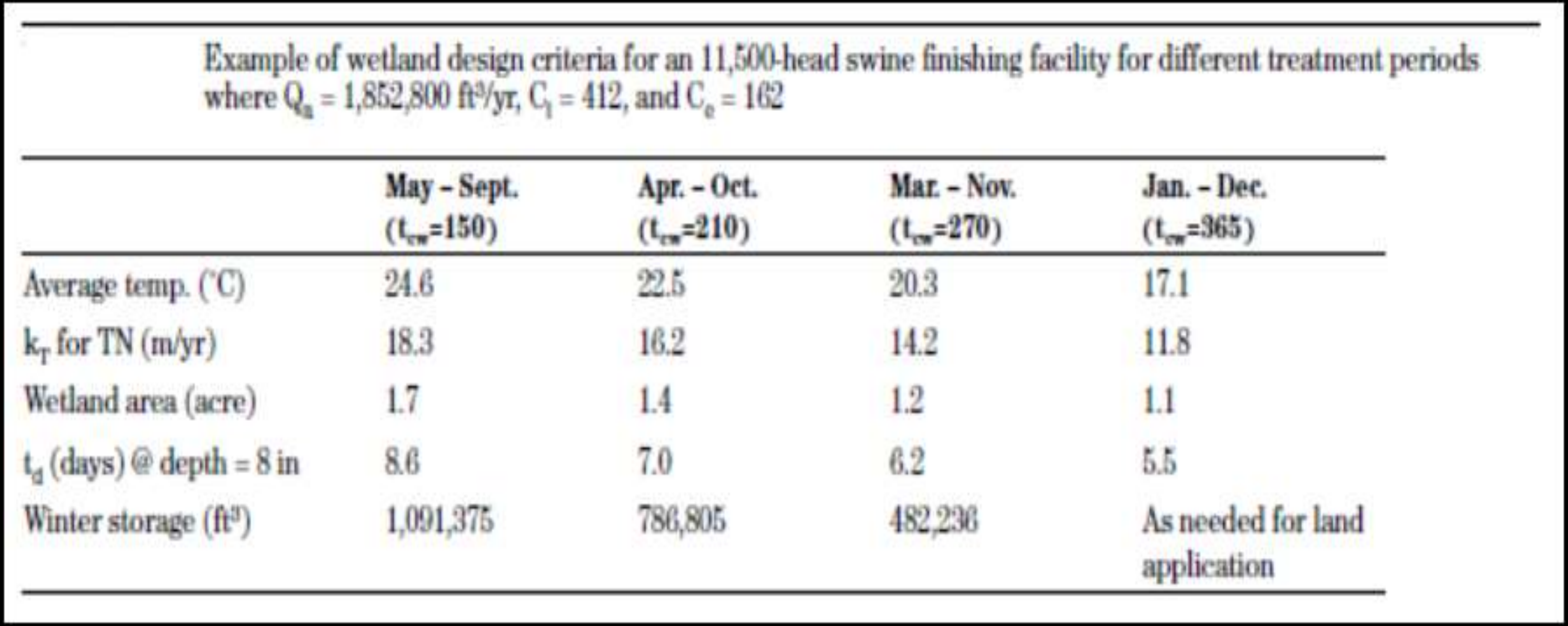
$$= (155\ \text{d})(5{,}076\ \text{ft}^3/\text{d})$$

$$= 786{,}780\ \text{ft}^3$$

Summary of Field Test Method

Example of wetland design criteria

The table below shows how different treatment periods used in the field test method affect wetland size for a given set of inflow and outflow concentrations of total nitrogen.



Example of wetland design criteria for an 11,500-head swine finishing facility for different treatment periods where $Q_a = 1{,}852{,}800$ ft³/yr, $C_i = 412$, and $C_e = 162$

	May – Sept. (t_{cw}=150)	Apr. – Oct. (t_{cw}=210)	Mar. – Nov. (t_{cw}=270)	Jan. – Dec. (t_{cw}=365)
Average temp. (°C)	24.6	22.5	20.3	17.1
k_T for TN (m/yr)	18.3	16.2	14.2	11.8
Wetland area (acre)	1.7	1.4	1.2	1.1
t_d (days) @ depth = 8 in	8.6	7.0	6.2	5.5
Winter storage (ft³)	1,091,375	786,805	482,236	As needed for land application

Hydraulic detention time and Wetland porosity

Values for hydraulic detention time (dt) shown in this table are based on a wetland porosity (n) of 0.90, an average water depth of 8 inches, and a daily flow of 5,076 cubic feet per day.

The wetland porosity is the volume of water not occupied by wetland plants and was originally assumed to be between 0.65 and 0.75.

These values, from Reed et al. (1988), were used in the earlier NRCS field test method.

Plant fill rates

However, TVA researchers found in one study that plant fill rates for:

- Cattails (Typha spp.) - 10 percent
- Bulrush (Scirpus validus) - 14 percent
- Reeds (Phragmites) - 2 percent
- Woolgrass (S. cyperinus) - 6 percent

In addition, Rogers et al. (1995) reported fill rates of 10 percent for Sagittaria lancifolia and 7 percent for Phragmites australis.

This data indicates that fill rates presented in the earlier NRCS Technical Requirements (USDA 1991) were probably too high and, consequently, the values for wetland porosity were too low.

The earlier field test method (a volumetric method) required a determination of dt, which meant that an accurate measure of water volume within the wetland be known.

However, its value can be estimated with only a limited degree of accuracy.

This is because mats of vegetation, growth habit of various plants, and other factors can reduce volume and either impedes flow or causes short-circuiting.

Estimates of dt can be quite different from measurements using more sophisticated approaches, such as dye testing.

For the field test example, the wetland surface area or wetted area ranges from 1.1 to 1.7 acres, with treatment period and associated changes in temperature significantly affecting size.

Of interest is that the area determined with the presumptive model, using the same number of animals with average weight of 135 pounds, was about 1.4 acres.

This is the same as that calculated for a 210-day operating period for the field test model shown on the previous (example - field test method.)

Presumptive method and field test method variations

This does not mean that the presumptive method and field test methods are considered comparable for any wetland with a 210-day storage period; it happens to be the same only because of the influent concentration selected for the field test example.

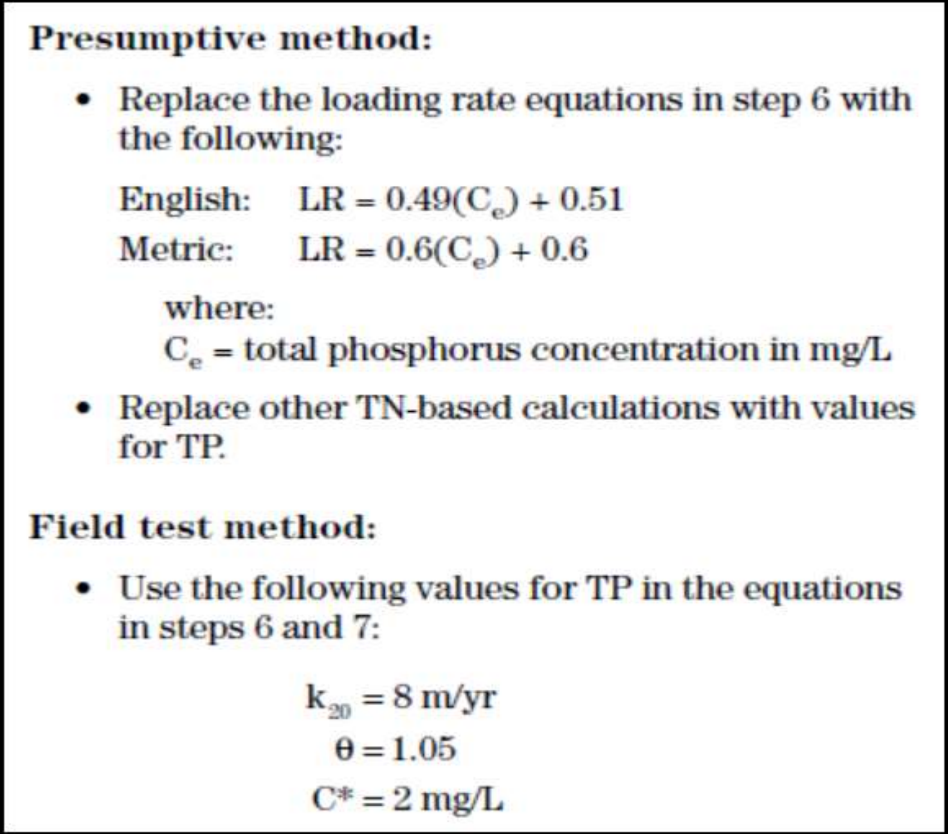
If, for example, Ci for the field example had been 380 mg/L instead of 412 mg/L, with all other factors the same, the wetland surface area would have been 1.2 acres, while the presumptive method acres would remain at 1.4 acres.

Section 27: Designing for Phosphorus Removal

Designing for Phosphorus removal

The presumptive method and the field test method can be used to design for P removal.

The changes needed in the two models are as follows:



Presumptive method:

- Replace the loading rate equations in step 6 with the following:

  English: $LR = 0.49(C_e) + 0.51$

  Metric: $LR = 0.6(C_e) + 0.6$

  where:
  C_e = total phosphorus concentration in mg/L

- Replace other TN-based calculations with values for TP.

Field test method:

- Use the following values for TP in the equations in steps 6 and 7:

$$k_{20} = 8 \text{ m/yr}$$
$$\theta = 1.05$$
$$C^* = 2 \text{ mg/L}$$

Section 28: Wetland Configuration – Bottom Gradient/Maximum Length

Bottom gradient/maximum length

Early guidance on constructed wetlands indicated that a gradient in the lengthwise direction is beneficial to facilitate emptying the wetland for repairs or maintenance.

While providing a gradient can facilitate emptying, the effect it will have on water depth should be considered.

Gradient has effect on allowable water depth

For instance, a wetland cell with a 0.5 percent grade and a water depth of 6 inches at the upstream end will have a water depth of 12 inches at a length of 100 feet and 15 inches at 150 feet.

Therefore, if a bottom gradient is used, either by choice or out of necessity because of the site conditions, the maximum length is dependent on the allowable water depth for the wetland plants that will be used.

Level-bottom wetland

If a level-bottom wetland is used, length is not an important consideration for most animal waste treatment wetlands.

However, if large volumes of water are used and this water is pumped to a long, narrow wetland cell, resistance of the vegetation to the flowing water could cause incoming water to back up.

At one municipal wetland having a 20:1 length-to-width ratio, flow was so restricted that wastewater overflowed the embankment at the inlet end of the system (Reed et al. 1995).

Use of a “deep zone” as opposed to gradient

An acceptable alternative to providing a bottom gradient to facilitate emptying is a flat bottom with a deep zone that acts as a sump.

The deep zone provides the submergence on the suction pipe necessary for the pump to transfer the wetland effluent to land application, to a downstream holding storage facility, or to an upstream waste treatment lagoon.

Intermediate deep zones for long level bottomed wetlands

If an exceptionally long, level bottom wetland is planned, intermediate deep zones should be used.

This not only facilitates draining the wetland, but also allows effective lateral distribution of flow during normal operation.

Section 29: Wetland configuration - Layout of the Wetland

Layout of the wetland

The layout or configuration of a constructed wetland may be affected by site conditions.

Shape of the site, area available and lay of the land can influence how a constructed wetland is configured. Surface-flow wetlands are generally designed to have more than one cell.

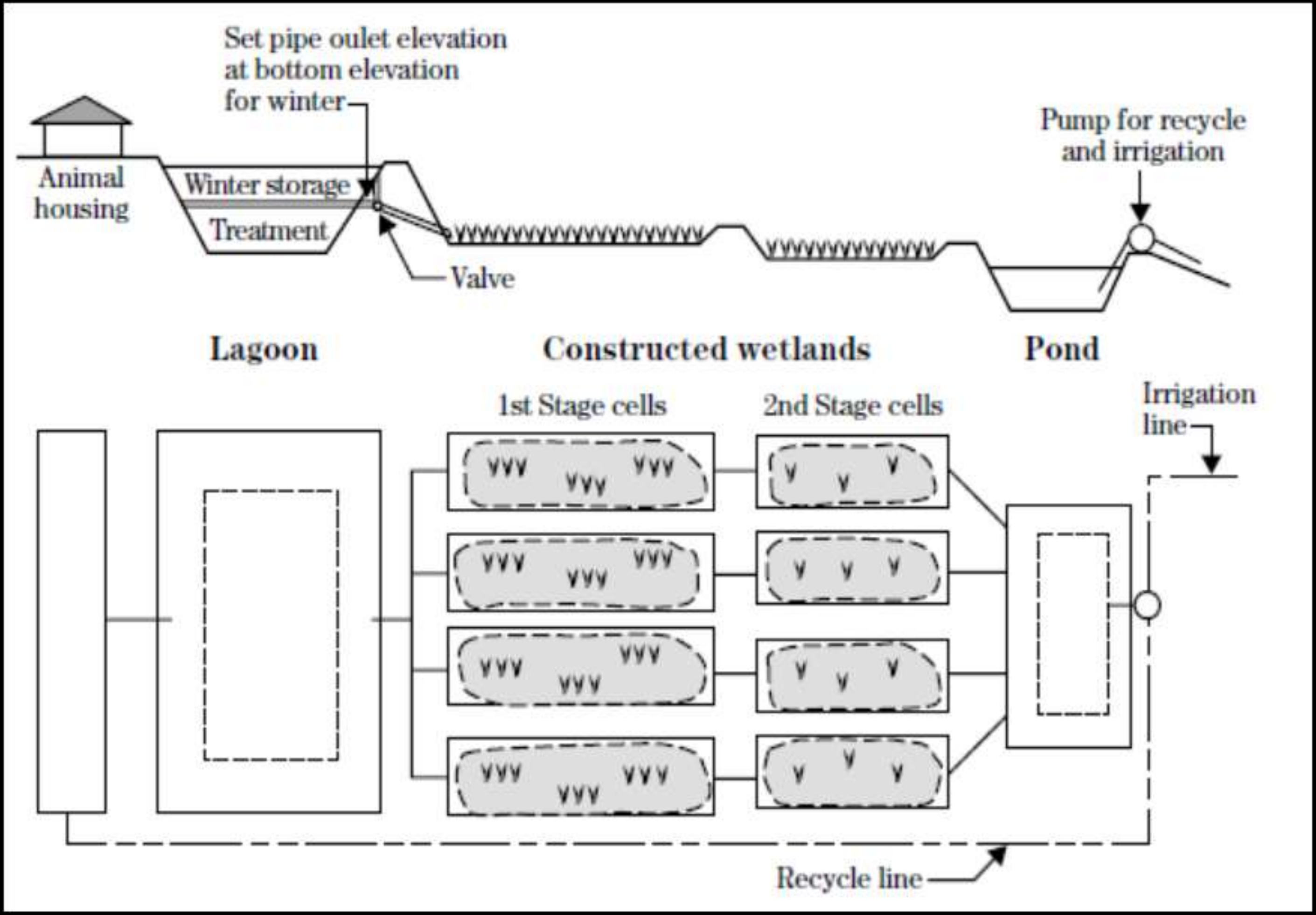
For these multi-celled wetlands, the cells are typically arranged in series (end-to-end) or in parallel (side-by-side).

The parallel arrangement allows two or more cells to receive influent at the same time; thus, if the inlet on one cell plugs or if a cell is closed for maintenance, the other cell(s) can keep operating.

The parallel arrangement can also be used for alternating treatment, allowing wetting and drying of cells and, thereby, enhancing treatment performance. However, this method of treatment requires a higher level of management.

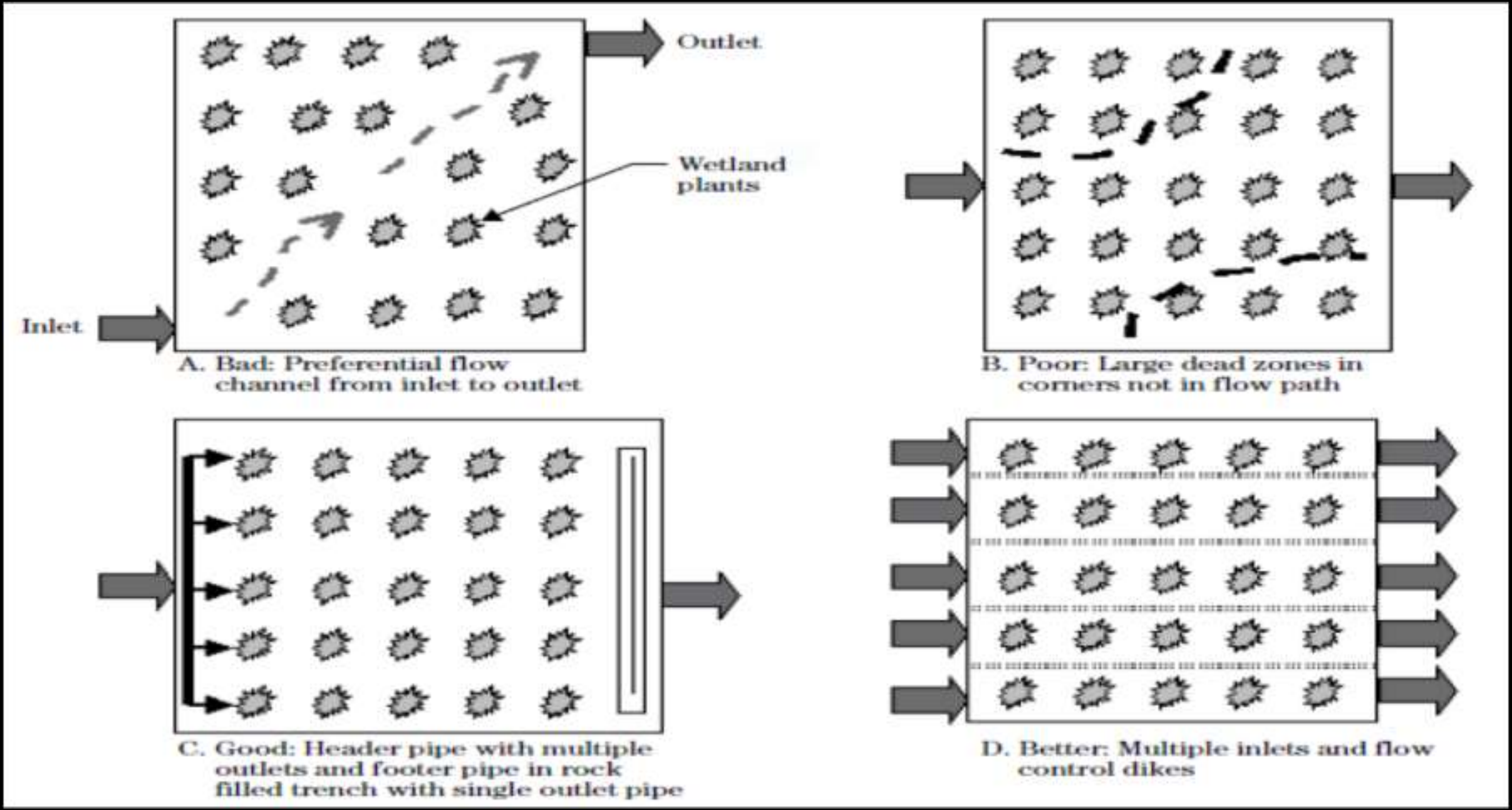
Layout of cells

The image below, shows a typical layout of cells in parallel. An efficiently designed system has limited short circuiting of wastewater between inlets and outlets. In the ideal system, wastewater flows evenly across the wetland cell throughout its entire length with no stagnant pools.



Efficient and inefficient layouts

An inlet consisting of a gated or slotted pipe across the upstream end helps to ensure initial distribution of flow. The image below, shows efficient and inefficient layouts as related to inlet and outlet structures. As water moves through the plants and detritus, however, channelization of water may occur as a result of the buildup of islands of roots, rhizomes, and dead vegetation.



A. Bad: Preferential flow channel from inlet to outlet

B. Poor: Large dead zones in corners not in flow path

C. Good: Header pipe with multiple outlets and footer pipe in rock filled trench with single outlet pipe

D. Better: Multiple inlets and flow control dikes

Long, wide wetland cells

For long, wide wetland cells, uneven distribution is more apt to occur; resulting in a need to redistribute flow.

This can be accomplished by using shorter cells in series and discharging the effluent of one into a distribution header pipe or deep trench at the upstream end of a receiving cell.

Long cells that have a flat bottom

For long cells with a flat bottom, flow can be redistributed laterally along the flow path by installing deep zones or trenches across the width of the cell at appropriate points.

Inlet trenches and redistribution sumps should be at least 3 feet deeper than the constructed bottom of the cell to inhibit growth of rooted vegetation.

As a rule, the length-to-width ratio for the system should be in the range of 1:1 to 4:1. Individual cells within this overall system may have ratios as high as 10:1. In fact, 20:1 length-to-width ratios have been used successfully.

Most efficient wetland

From the standpoint of construction costs, however, the square (1:1) wetland is most efficient.

The cost advantage of the square wetland is offset by the critical need to provide for distribution of flow to prevent short-circuiting.

Section 30: Embankments

Design embankment height

Wetland embankments are often the same height. However, a distinction can be made between the outer embankments, which surround the entire system, and inner embankments or dikes that divide the system into cells.

The outer embankment must be high enough to protect the system from overtopping during a specific design storm (i.e., 25-year, 24-hour).

These embankments must have an ungated overflow device set at an elevation such that any precipitation that exceeds the design will pass through it.

Design height

Design height for the outer embankment should be based on the following increments of depth:

- normal design flow - based on type of vegetation; typically 8 to 12 inches
- accretion - based on buildup during the design life of the system; allow 0.5 inch per year
- design storm - includes direct precipitation on the wetlands plus runoff from embankments and, if inflow to the wetland is unrestricted, precipitation on the pretreatment surface, including embankments
- ice cover - If the system will operate under ice cover in winter, allow depth equal to ice thickness expected during some design period (i.e., once in 25 years)
- freeboard - A safety factor of at least 12 inches is recommended
- overflow device - As required by type (i.e., pipe, earthen spillway)

Design height for interior divider embankments must include at least the first three items listed for design height for outer embankment.

Top width

The top width of dikes used to surround and divide the constructed wetland must be wide enough to accommodate the requirements of construction and operation and maintenance.

Outer embankments should be at least 15 feet at the top to prevent burrowing animals from draining the system to the surrounding area.

The recommended top width for inside dikes is 8 to 10 feet. This width allows grass to be mowed with tractor-driven equipment and reduces the potential for animals burrowing through the dikes.

Narrower dikes or embankments must be cut with a hand mower and are easily breached by muskrats.

Side slopes

Side slopes should not be steeper than 2 horizontal to 1 vertical.

Consideration should be given to flatter slopes if needed for slope stability or to accommodate maintenance.

Section 31: Liners

Bottom of cells

The bottom of all wetland cells should be lined with either a compacted clay liner or with a fabricated liner, if there is the potential for groundwater to become contaminated.

Although the wetland operates under a low hydraulic head environment, seepage is still possible. A liner can help to prevent groundwater contamination by nitrates.

Detailed information on the evaluation of soils to protect groundwater is in the NRCS Agricultural Waste Management Field Handbook, appendix 10D.

Installation of the liner

If a fabricated liner is needed, the top 12 inches of soil from the construction site should be removed and stockpiled.

After the liner has been installed, the stockpiled soil is placed on top of the liner to serve as the rooting medium for the wetland plants.

Protecting the liner from puncture

To prevent puncture of the liner during construction, consideration should be given to placing 6 to 8 inches of sand on top of the liner prior to installing the stockpiled soil.

Over-excavating, additional fill height, or a combination of both, will be needed to accommodate the sand layer.

Where a liner is installed, care must be taken to ensure that it ties in vertically at the embankments, thus preventing any lateral movement under or through the embankments. This requirement is the same for soil and fabricated liners.

Section 32: Inlet Structures

Inlet structures

A variety of inlet control structures can be used at constructed wetlands used to treat animal waste.

These would come directly from the pretreatment facility to the first cells of the constructed wetland.

They may include:

- an ungated gravity flow overflow pipe
- pipes with orifice controls
- swivel pipes
- valves

Inlet discharge

Inlets may discharge at a point centered on the width of the upstream end of the cell if the cells are relatively narrow and dead zones will not be a problem in the adjacent corners.

Gated pipe that spans the width of the cell can ensure even distribution and eliminate dead zones in the corners.

This pipe has precut holes or slots, or it may have gated openings so flow can be more accurately distributed.

Plugging is sometimes a problem at the inlet to the first cell where influent wastewater is from the pretreatment facility. If this is a concern, an alternative to a gated pipe is a deep trench across the width of the upper end of the cell.

An elbow can be placed on the inlet pipe so that influent water is discharged downward into the middle of the trench; wastewater should then discharge into the vegetation across the width of the cell.

If the cell is wide, a shallow dam with multiple slots or weirs across the top can be placed immediately downstream of the trench.

When winter storage is needed

If wastewater will be stored in the pretreatment facility during winter, the invert elevation at the entrance to the effluent pipe leading to the wetland should be in line with the bottom elevation of winter storage.

If the design calls for winter storage in the upstream pretreatment facility, some positive control is needed to prevent discharge to the wetland during this period (i.e., a closed valve).

In addition, some positive control is also needed to ensure that stored wastewater is released to the wetland according to a water budget for the system.

This may mean manually opening and closing of valves on a daily basis or using a properly sized orifice control based on daily requirements of the water budget.

Note: Reliance on manually opening and closing valves can be a dangerous option because the operator may forget to close a valve, which could result in a discharge from the system.

Plugging prevention measures

All control devices should be checked daily since plugging of pipes and controls can be a problem. A buildup of a crystalline substance on pipe walls is a problem in some orifice-control devices.

An inlet screen or box screen used around the inlet pipes to the first cell can prevent floating debris from entering the line.

Small turtles have been known to enter an unprotected inlet and clog the pipe. For these reasons, large diameter pipe is preferred over smaller diameter pipe.

Section 33: Outlet Structures

Outlet structure

The outlet structure is used to maintain the proper water level in the upstream cell and to control flow rate.

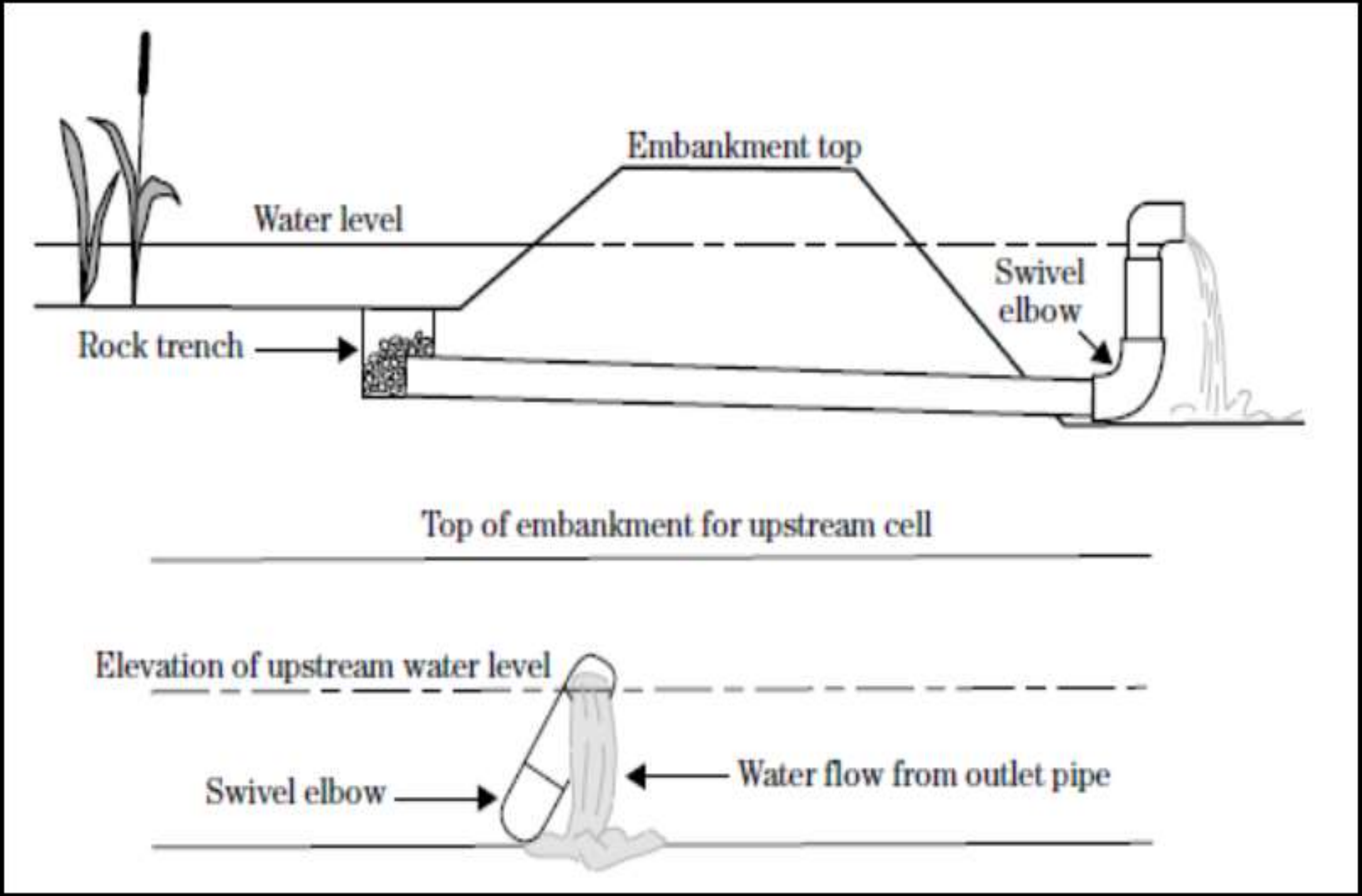
Several types of outlet controls are possible.

They include slotted pipes laid across the downstream end of the cell or slotted pipes buried in a shallow trench of gravel.

In each case a T-section is placed in the middle of the pipe to carry water through the embankment to a water-level control structure.

Most common water-level control structure

The most common water-level control structure used on wetlands for treating animal waste is an elbow attached with a swivel joint located downstream of the cell for which water level is being controlled (image).



In other words, water level in the upstream cell will be at the same elevation as the invert of the downstream outlet pipe.

As the pipe is turned on the swivel, the invert of the pipe is raised or lowered, thus setting water depth in the upstream cell.

Water can be discharged to a point centered on the width of the upstream end of the next cell if the cell is relatively narrow.

If it is wider and there is concern for dead zones in the corners, the swivel pipe can be attached to a header pipe, forming a U between the pipe that exits the embankment and the header.

Flashboard dam

Another water level control device is a flashboard dam. This provides a simple way to control upstream water level without the problem of plugging pipes.

However, the embankment on the downstream side must be adequately protected from erosion, and a deep-zone distribution trench may be needed if the downstream cell is wide.

Section 34: Water Budget

Water budget

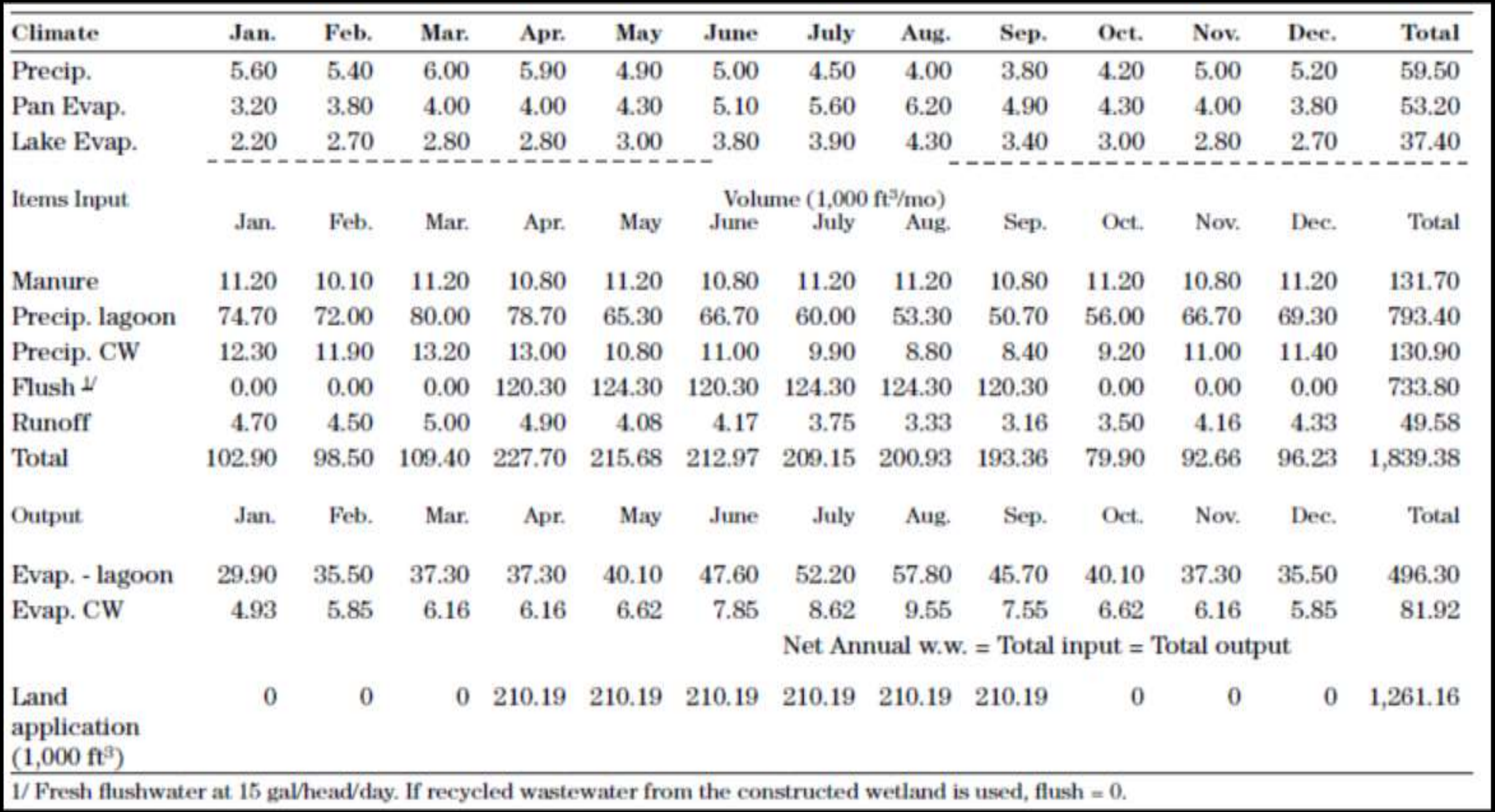
A water budget is essential as it is used in:

- determining annual and daily flow rates needed to determine wetland surface area using the presumptive and field test design equations
- sizing the embankments
- scheduling land application
- determining release rates or pumping rates to the wetland for the in-use period, and sizing pipes, pumps, orifice controls, and other devices accordingly
- sizing the downstream storage pond
- sizing storage for the upstream pretreatment facility
- determining detention time in the wetland

If several treatment wetlands will be designed, a computer spreadsheet is recommended to speed repetitive calculations and assist with accuracy in design.

Sample water balance

A sample water balance spreadsheet is shown below for 2,000 finisher swine (125 lbs. to market weight), with a 400 x 400 foot waste treatment lagoon and 26,400-square foot constructed wetland.



Climate	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Precip.	5.60	5.40	6.00	5.90	4.90	5.00	4.50	4.00	3.80	4.20	5.00	5.20	59.50
Pan Evap.	3.20	3.80	4.00	4.00	4.30	5.10	5.60	6.20	4.90	4.30	4.00	3.80	53.20
Lake Evap.	2.20	2.70	2.80	2.80	3.00	3.80	3.90	4.30	3.40	3.00	2.80	2.70	37.40
Items Input						Volume (1,000 ft³/mo)							
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Manure	11.20	10.10	11.20	10.80	11.20	10.80	11.20	11.20	10.80	11.20	10.80	11.20	131.70
Precip. lagoon	74.70	72.00	80.00	78.70	65.30	66.70	60.00	53.30	50.70	56.00	66.70	69.30	793.40
Precip. CW	12.30	11.90	13.20	13.00	10.80	11.00	9.90	8.80	8.40	9.20	11.00	11.40	130.90
Flush [1/]	0.00	0.00	0.00	120.30	124.30	120.30	124.30	124.30	120.30	0.00	0.00	0.00	733.80
Runoff	4.70	4.50	5.00	4.90	4.08	4.17	3.75	3.33	3.16	3.50	4.16	4.33	49.58
Total	102.90	98.50	109.40	227.70	215.68	212.97	209.15	200.93	193.36	79.90	92.66	96.23	1,839.38
Output	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Evap. - lagoon	29.90	35.50	37.30	37.30	40.10	47.60	52.20	57.80	45.70	40.10	37.30	35.50	496.30
Evap. CW	4.93	5.85	6.16	6.16	6.62	7.85	8.62	9.55	7.55	6.62	6.16	5.85	81.92
							Net Annual w.w. = Total input = Total output						
Land application (1,000 ft³)	0	0	0	210.19	210.19	210.19	210.19	210.19	210.19	0	0	0	1,261.16

1/ Fresh flushwater at 15 gal/head/day. If recycled wastewater from the constructed wetland is used, flush = 0.

Section 35: Operation and Maintenance

Incorporating into the AWMS plan

Written operation and maintenance (O&M) requirements for a constructed wetland must be incorporated into the AWMS plan to which the wetland becomes a component.

In addition to the O&M requirement for the wetland itself, coordination of its operation with other components of the AWMS must also be described.

For further information on developing a AWMS plan, consult the AWMFH, Chapter 13, Operation, Maintenance, and Safety.

Recommended requirements to be included in the AWMS plan for a constructed wetland are described in this section.

Operation

Operation of a constructed wetland includes the administration, management, and performance of non-maintenance actions needed to keep the wetland safe and functioning as planned.

Annual operational requirements are dictated by the water budget, by visual inspection, by wastewater testing, and by common sense.

Some key operational requirements include:

- Maintaining water levels in the wetland cells as appropriate for the vegetation. In cold climates where continuous winter operation is involved, increase water levels as needed prior to the first freeze.
- Controlling flows into the wetland in accordance with water budget requirements. Adjust as needed for drought periods, increasing inflow rates to ensure vegetation at the downstream end of the wetland is kept wet during dry times.
- Ensuring that water levels in the pretreatment facility and downstream storage pond are lowered to appropriate levels in preparation for winter storage.
- Monitoring treatment performance. Collect samples and measure flow rates into and out of the wetland regularly. Determine treatment efficiencies and nutrient mass loadings for use in adjusting application rates.

Analyze samples

Typically, samples should be analyzed for total Kjeldahl nitrogen (TKN), total ammonia nitrogen ($NH3 + NH4–N$), combined nitrite plus nitrate nitrogen ($NO2 + NO3–N$), total phosphorus (TP), and ortho-phosphorus (ortho-PO4–P).

If a wastewater discharge is being considered or if additional information on water quality improvement is sought, the following criteria may be required by the State regulatory agency:

- 5-day biochemical oxygen (BOD5)
- chemical oxygen demand (COD)
- total suspended solids (TSS)
- temperature, and pH

Maintenance

Maintenance of a constructed wetland includes actions taken to prevent deterioration of the wetland components and to repair damage. Regular maintenance of the wetland system is essential.

If frequent inspections are ignored, rodents can destroy vegetation and embankments, pipes can become clogged, wastewater can short circuit through the cells and the system can become nonoperational in a short time.

A short list of important maintenance items follows, (not intended to be an all-inclusive list):

- Inspect inlet and outlet structures daily for plugging and damage.
- Inspect embankments at least weekly for damage, and make repairs as needed. Control rodent pests through removal or deterrents, such as electric fences.
- Mow embankments regularly to allow for inspections and to enhance visual appeal.
- Inspect and repair fences as needed.
- Inspect vegetation throughout the growing season, and replace plants that are not performing as expected.
- Inspect and repair pumps and piping systems as needed.

Section 36: Plant Establishment and Maintenance

Plant establishment

Successful plant establishment requires:

- adequate soil preparation
- intact plant materials
- appropriate plant spacing
- proper planting methods
- good timing
- sufficient soil moisture
- proper water depth

The failure to meet any of the above requirements can be problematic when establishing a successful wetland plant base.

Maintenance

Wetland vegetation maintenance is not nearly as straightforward as the initial establishment of the plant base.

The following are complex and problematic maintenance goals that cannot always be achieved:

- Ensuring the dominance of certain desired species
- Maintaining the desired plant cover density
- The exclusion or control of undesirable plant species

Plant sources

The commercial supply of wetland plant material has become fairly commonplace.

Regulations requiring entities that remove or manipulate wetlands to mitigate the wetland losses have created a high demand for live, healthy plants for revegetation.

Most commonly used plants for treatment wetlands can be purchased for planting or can be harvested locally from existing roadside ditches or pond margins.

Depending on the morphology of individual plants, plants can be purchased in the following means:

- as a bare-root seedling
- a sterile propagule from a micro-propagation laboratory
- a senesced root or rhizome
- a potted seedling
- an individual taken from an established stand
- Some wetland plants can be established from seed by hand or automated broadcasting

Transplanting an existing soil layer from another wetland site

Most constructed treatment wetlands require some type of organic soil augmentation for successful plant establishment.

Removing a layer of soil from another existing wetland and evenly distributing the soil throughout the newly constructed wetland allow the natural seed bank in the existing soil to germinate and establish the vegetation in the new treatment wetland.

The most common form of plant seedlings is bare-root propagules.

Bare-root seedlings

These are easily planted in the field using a small shovel, trowel, or dibble.

The survival rate of bare-root seedlings is significantly higher than that for field germinated seeds and generally can be maintained at 80 percent or higher with healthy plant stock and an adequate moisture regime.

Since bare-root stock has already had a sufficient period of initial growth, successful planting can lead to a rapid plant cover.

Field-harvested plants

In some cases, these offer the most successful option for planting treatment wetlands.

These plants can be collected in nearby retention ponds, roadside ditches, and canals and then planted in suitable substrate in the newly constructed wetland.

Planting of field-harvested plants may be more difficult than planting bare-root propagules because of the size differences of the plants.

Planting

Planting can be accomplished by using a shovel or post-hole digger to bury all roots and associated below ground structures.

Stresses to the plants, such as extreme shifts in temperature, moisture, and light, should be limited where possible.

The advantages of field-harvested plants over nursery grown stock include:

- Larger roots, rhizomes, and/or corms for energy storage allow the plant to produce above ground structures faster once they are planted
- They are adapted to local environmental conditions.
- Additional volunteer plant species are introduced with the harvested plant species.

Plant Establishment

Environmental adaptations

Wetland plants have various environmental adaptations as part of their normal routines of:

- germination
- growth
- reproduction
- senescence (biological ageing)
- decay

Wet but not flooded conditions

A general understanding of the above components of plant biology is important in planning and operating constructed wetlands.

Most emergent wetland plants produce seeds that germinate and initially develop best in wet, but unflooded loamy soil.

Excessive flooding kills most wetland plant seedlings.

Poor soil conditions:

- Tight, clayey soil may be inhospitable for root development and aeration.
- Highly drained sandy soil and gravel may not provide adequate moisture for initial plant development.

Good soil and growing conditions

Rapid development of herbaceous wetland plants in many constructed wetlands is normally accomplished through adequate spacing of healthy plants into moist, loamy to sandy soil, followed by gradual increases in the water level during plant establishment.

Rapid increases in water level within newly planted treatment wetlands may kill the plantings.

Nutrients

Plants require nutrients in proper proportions for healthy growth.

The two major nutrients most likely to limit plant growth in wetlands are *phosphorus* and *nitrogen*, respectively.

Other nutrients especially important for plant growth are carbon (typically supplied from atmospheric or dissolved carbon dioxide), potassium, calcium, and sulfur.

In addition, wetland plants require several minor nutrients for normal growth and development.

Essential micronutrients

Some essential plant micronutrients are magnesium, iron, manganese, boron, zinc, copper, and molybdenum.

While livestock wastewater supplies adequate quantities of these nutrients, some industrial wastewater and agricultural runoff water do not provide ample nutrition for productive wetland plant growth.

In such cases nutrient supplements may be required for rapid plant development and for sustained wetland plant growth.

Soil tests during predesign can identify fertilization requirements for rapid plant establishment.

In a relatively few instances, supplements of plant micronutrients must be added to wetlands to provide adequate plant growth.

Plant Maintenance

Growth strategies

Wetland plant species have a variety of growth strategies that provide a competitive advantage in their natural habitats.

Senesced biomass provides attachment sites for microbial species and root viability.

Emergent herbaceous marsh species in temperate climates generally grow within a single growing season, to a maximum total standing live biomass, in late summer or early fall.

This biomass may represent multiple growth and senescence periods for individual plants during the course of the growing season, or a single emergence of plant structures.

Standing senesced biomass provides attachment sites for microbial species important in wetland treatment performance throughout the annual cycle. It is also important for maintaining root viability under flooded, winter conditions.

Excess solids

These can stress or kill wetland plants. Since untreated livestock wastewater typically contains high concentrations of solids, adequate pretreatment of the wastewater is important.

This can be accomplished by settling solids in lagoons or storage ponds or by using special solids separators.

Other environmental factors

Other environmental factors that may stress the wetland plants include:

- excessive water depth (any constant depth over about 12 to 18 inches is stressful to emergent wetland plants)
- excessive drought conditions
- extremely hot or cold conditions
- insect pests
- plant pathogens

Some emergent wetland plant species, such as cattails, can quickly recover from pest outbreaks and excessive water levels if their roots remain alive and healthy and conditions become more favorable.

Healthy wetland plant communities that senesce during freezing winter conditions quickly regrow from below ground structures during the next growing season as long as their standing dead stems remain above the water level during the non-growing season.

Section 37: Suitability for Treatment Wetlands

Not all wetland plants are suitable for treatment wetlands

The U.S. Fish and Wildlife Service (USFWS) lists more than 6,700 plant species that are identified with wetlands.

These include the obligate species that are exclusively in wetland habitats and facultative species that are in either wetland or upland areas.

Only a fraction of this number is suitable for use in treatment wetlands, and fewer still would be suitable for use in treating high-strength wastewater, such as that from most confined livestock facilities.

Nonetheless, a variety of wetland plant species has been used in the treatment of wastewater. Some have been purposefully introduced, and some are natural invaders.

Plant species

Guntenspergen et al. (1989) listed 17 emergent species, 4 submergent species, and 11 floating species that have been used in wetlands for treating municipal wastewater.

Kadlec and Knight (1996) listed 37 families of vascular plants that have been used in water quality treatment.

Be alert to using any plant species that may be considered invasive.

These can pose a serious risk of causing ecological damage to other nearby wetlands, and bodies of water.

Section 38: Aquatic and Wetland Plant Types

Groups of macrophytic plants

The four major groups of macrophytic plants associated with wetlands in general are:

- mosses
- ferns
- conifers
- flowering plants

However, the vast majority of plants used in wastewater treatment wetlands are flowering plants.

This page describes plants within the flowering plant group. The emergent herbaceous plants are used extensively in municipal waste treatment systems throughout the world and are the most widely used plants in animal waste constructed wetlands.

Although floating plants, such as duckweed, often fill open areas of surface flow wetlands, their contribution to the overall treatment process in this type system is incidental to that provided by the emergent herbaceous plants.

Therefore, the focus in this course is on the emergent herbaceous varieties.

Rooted plants

Submerged - Main vegetative structure is completely underwater. Flowers or inflorescence generally extend above the water.

Through photosynthesis, these plants produce volumes of dissolved oxygen, which facilitates aerobic decomposition.

They may be shaded out where free floating plants are plentiful. These are best adapted to deep water zones.

Species:

- hydrilla (Hydrilla)
- egeria (Egeria elodea)
- frog’s-bit (Limnobium)
- pondweed (Potamogeton spp.)

Floating (stems and leaves)

Roots extend into the bottom soil or may be attached at the shoreline. Plants may cover large areas in shallow water regimes. The shade they provide may affect water temperature.

Such coverage may also reduce the population of algae and, thereby, reduce suspended solids concentrations in wetland effluent.

Pennywort, attached at the shoreline, has spread profusely in open areas between emergent plants in some treatment wetlands.

Species:

- water lily (Nymphaea spp.)
- spatterdock (Nuphar spp.)
- pondweed (Potamogeton spp.)
- pennywort (Hydrocotyle spp.)

Emergent herbaceous

Plants are rooted in the soil and have structures (stems and leaves) that emerge or stand upright above the water surface.

As herbaceous plants, their structures are nonwoody, yet they stand erect above the water surface.

They are the primary plants used in constructed wetlands for treating animal waste.

Species:

- bulrush (Scirpus spp.)
- cattail (Typha spp.)
- common reed (Phragmites)
- duckpotato arrowhead
- (Sagittaria spp.)
- giant cutgrass
- (Zizaniopsis spp.)
- southern wild rice (Zizania)
- rush (Juncus spp.)

Emergent woody

This group includes shrubs, trees, and woody vines. Distinguishing characteristics include bark, non-leafy vascular structure, decay-resistant tissues, and relatively long life.

Their effectiveness in treating wastewater from confined livestock operations is uncertain.

Species:

- cypress (Taxodium spp.)
- willow (Salix spp.)
- ash (Fraxinus spp.)
- gum (Nyssa spp.)
- birch (Betula spp.)
- alder (Alnus spp.)

Free-floating plants (free-floating to partly submerged)

Plants may be rootless (Wolffia spp.) or have a root system that ranges from a single hair-like root (Lemna spp.) to roots that are several feet long (Eichhornia spp.).

Roots, when present, are not attached to the soil, but extend into the water column. Plants reproduce rapidly, especially in a nutrient-rich environment.

When used for wastewater treatment, harvesting is essential.

Species:

- duckweed (Lemna spp.)
- water meal (Wolffia spp.)
- water hyacinth
- (Eichhornia crassipes)

Section 39: Emergent Herbaceous Plants

Emergent herbaceous plants

Emergent herbaceous plants (EHPs) are the dominant type of vegetation used in wetland treatment systems, mainly because most treatment wetlands are surface flow systems and the shallow water of these systems is ideal for this type vegetation.

EHPs are also the dominant type vegetation in SSF wetlands.

While floating plants (free-floating or attached) frequently enter SF wetlands through natural means, their presence is usually of little important.

Reasons that emergent wetland plants are important for use in treatment wetlands are:

- special structural properties that allow these plants to survive in an otherwise hostile environment
- plants' special ability to facilitate the treatment process
- they function in cold and hot climates, unlike some major floating plants
- the most versatile of the wetland plants (cattails and bulrushes) are often available locally

Structural Functionality

Root zone activity

All plants require oxygen, nutrients, and water for various metabolic processes. When plant roots remain in saturated soil, the normal diffusion of gases to and from the plant roots is inhibited.

Such gas transfers can still take place within the root zone if the water is oxygenated, but the process is much slower than in well aerated, but unsaturated soils. If the soils are saturated and also enriched with organic matter, anaerobic condition undoubtedly exists.

In this case the roots are in competition with local microbial communities for any meager supplies of dissolved oxygen (DO) available; for most terrestrial plant species, the result is certain death.

Many emergent wetland plants have adaptations that allow life to go on even in soil that is both continuously flooded and saturated with a high level of oxygen-demanding organic material, more specifically, wastewater.

These adaptations ensure that oxygen is transported to the roots and rhizomes to satisfy the plant’s respiratory demands.

Vascular wetland plants

Vascular wetland plants are equipped with aerenchyma or aerenchymous tissues containing lacunae, or a network of tiny hollow tubes that traverse the length of the plant allowing gases to move from the above- water portion of the plant to the roots and rhizomes, and vice versa.

In addition, these plants have lenticels, or small openings along the plant stems that facilitate the flow of gases in and out.

Lenticels may also be located on adventitious roots that develop from the stalk or stem of the plant within the water column.

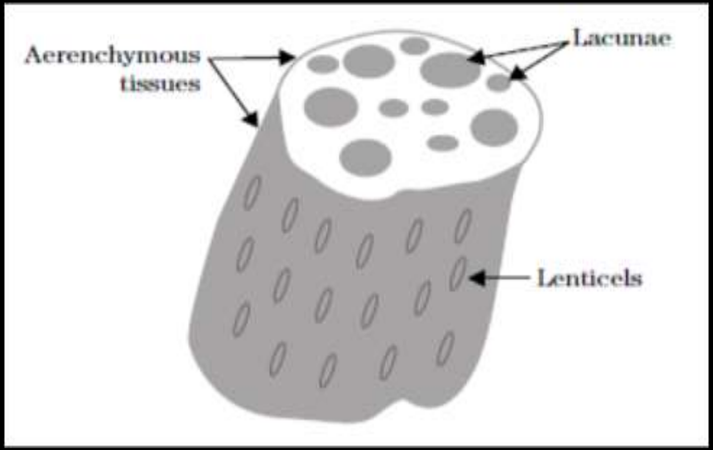
Other structural components include “knees” on cypress trees (an emergent woody plant) and buttresses, also on certain woody species.

Features of an emergent-hydrophytic plant stem

The image below shows features of an emergent-hydrophytic plant stem that allow movement of gases to and from the root zone.

The transfer of gases and in particular of oxygen from the above water part of the emergent herbaceous plants to the root zone can occur in two basic ways:

- passive molecular (gas-phase) diffusion
- bulk flow of air through internal gas spaces of the plant, resulting from internal pressurization



Molecular diffusion

Diffusion within the emergent herbaceous plants involves reverse gradients of O_2 and CO_2 partial pressures in the lacunae.

Researchers have shown that in some plants a large decrease in O_2 concentration occurs between the aerial parts of the plants and the root zone, while gradients of CO_2 and CH_4 occur in the reverse direction.

The decrease in O_2 concentration was shown to range from 20.7 percent in the aerial stems to 3.6 percent in the lacunal air of the deepest-growing rhizomes, with the drop resulting from O_2 extracted for respiration (Brix 1993).

In the same manner, CO_2 produced by respiration in the roots and rhizomes and CH_4 produced in the anoxic sediment diffuse along a reverse path with an increasing concentration gradient until these gases are expelled from the aerial part of the plant.

Pressurized ventilation

The bulk flow of air into and through a plant can result from differences in temperature and water vapor pressure across porous partitions (i.e., plant leaves).

Pressure is higher on the warm side and on the humid side of a partition, which can result in pressurization and airflow within the plant.

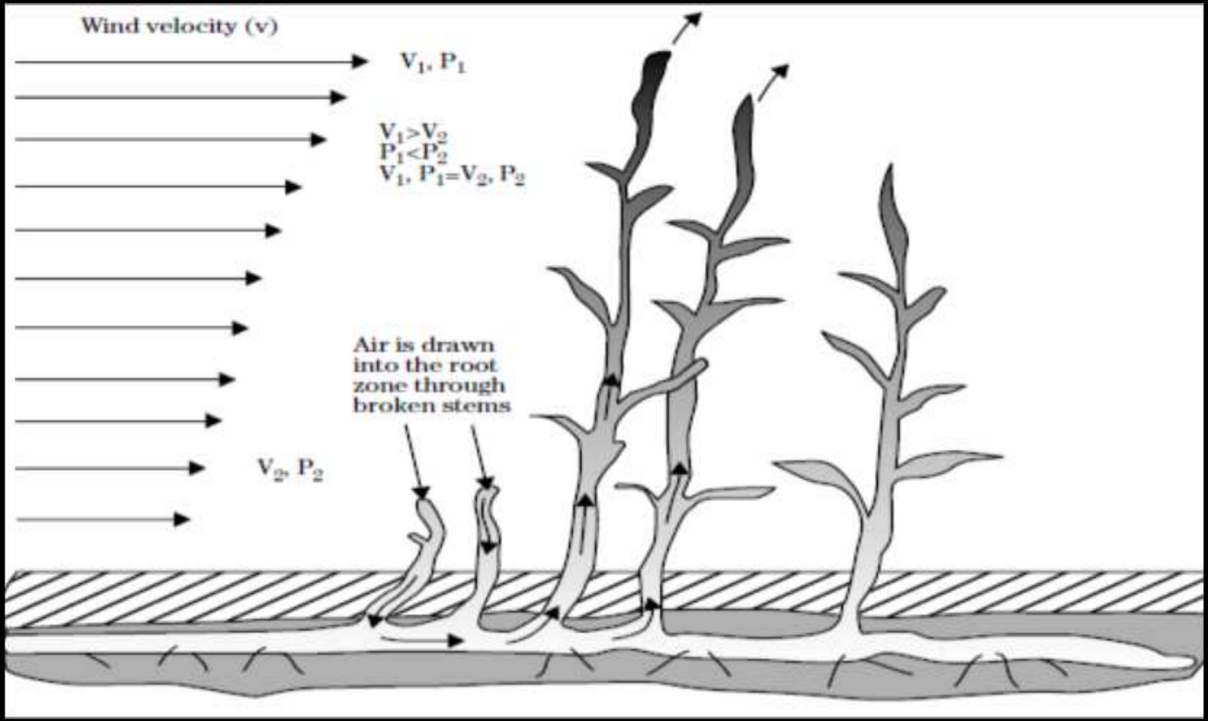
In a study of water lilies, the external pressure was greatest in the youngest leaves, causing airflow into the leaves, down the petioles to the rhizomes, and back up to the older leaves where the air was vented back to the atmosphere.

Internal pressurization and convective through-flow driven by gradients in temperature and water vapor pressure seem to be common attributes of a wide range of wetland plants, including species with cylindrical and linear leaves (such as Typha, Schoenoplectus, Eleocharis).

Venturi-induced convection

Another type of pressurization is called *venturi-induced convection*. Wind passing over the wetland flows at different velocities, with lower velocities occurring near the water surface because of drag.

At lower wind speeds, the pressure is greater. Thus, air is drawn into broken stems and culms closest to the water, circulated within the root system, and moved through the lacunae to points of lower pressure in the upper leaves and shoots. From there it is exhausted to the surrounding atmosphere (image).



Respiratory requirements

The special structural features noted here do more than provide a means of respiration in the roots and rhizomes.

In some cases an amount of O2 exceeding the respiratory requirements of the roots and rhizomes occurs, resulting in O2 exuding into the adjacent soil and creating microscopic aerated zones amid otherwise anaerobic conditions.

The amount of O2 leakage from diffusion has been reported to be in the range of 0.02 to 12 grams of O2 per square meter per day, although higher values have been reported.

Wetland plants that have a pressurized flow-through mechanism for transporting oxygen to the roots and rhizomes have a greater potential for leakage and rhizosphere oxidation than those based on passive diffusion or pressurized mechanisms without flow through.

Primary Functions of EHPs

Role of emergent macrophytes in the treatment process

The primary function of emergent herbaceous vegetation is not to remove nutrients and other pollutants through plant uptake; rather, it is to facilitate waste treatment.

As facilitators, these plants play several roles in the treatment process:

- source of microbial substrate
- facilitator of nitrification/denitrification
- water and pollutant transporter
- users of nutrients
- filter
- source of shade
- source of new soils and sediment

Source of microbial substrate

Wetland plants provide solid surfaces or substrate on which bacteria and fungi grow. Fallen leaves, stems, flowers, and other residue from aging plants provide a large amount of surface area on which the treatment organisms thrive.

The populations of organisms that inhabit the substrate are the driving force in the treatment process, causing pollutant concentrations to dramatically decrease as wastewater passes through the wetland.

Microorganism activity in the substrate

Reed et al. (1995) indicates that the microorganisms that populate the submerged plant stems, fallen leaves, roots, and rhizomes are responsible for much of the treatment within the wetland.

Kadlec and Knight (1996) state the complex mixture of plant litter in various stages of decomposition and its highly productive biological communities are responsible for 90 percent of the overall treatment within surface flow wetlands.

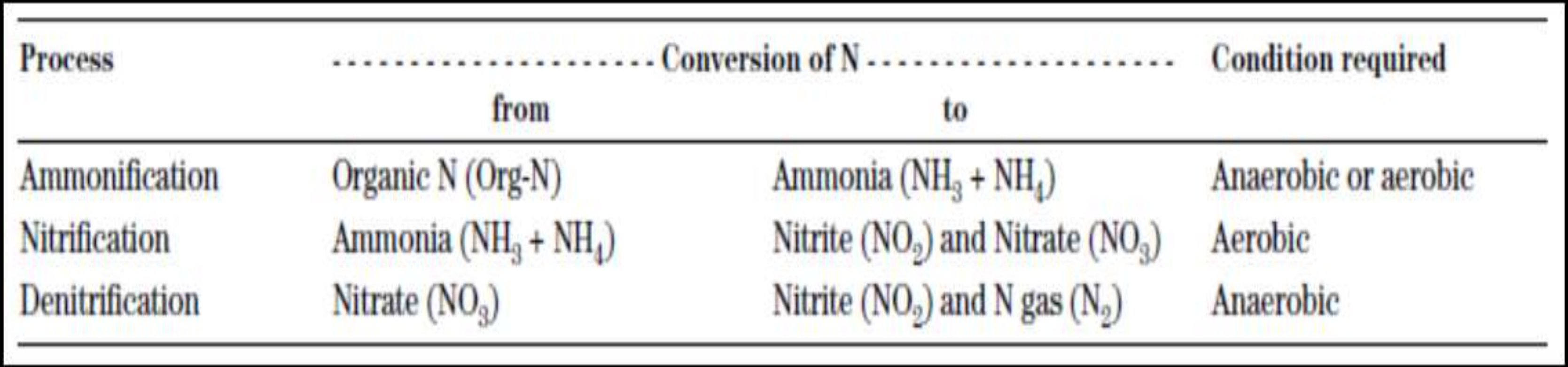
Thus, the principal function of the emergent herbaceous vegetation is to provide substrate for the microorganisms essential to the treatment process.

It becomes evident that the greater the surface area of the wetland, the greater amount of substrate present and, hence, the greater the effectiveness of the wetland.

This assumes complete submergence of the litter and adequate contact time between wastewater and attached microorganisms.

Facilitator of nitrification/denitrification

An important function of the treatment wetland is to remove nitrogen. A large fraction of the nitrogen in animal waste treatment wetlands is lost through volatilization. However, nitrogen can also be lost through a series of processes that lead to nitrate (NO3) being converted to N2 gas, which is liberated to the atmosphere.



Process	Conversion of N		Condition required
	from	to	
Ammonification	Organic N (Org-N)	Ammonia ($NH_3 + NH_4$)	Anaerobic or aerobic
Nitrification	Ammonia ($NH_3 + NH_4$)	Nitrite (NO_2) and Nitrate (NO_3)	Aerobic
Denitrification	Nitrate (NO_3)	Nitrite (NO_2) and N gas (N_2)	Anaerobic

Shown above are processes involved in the conversion of organic and ammonia N to nitrogen gas.

Wastewater entering a surface flow wetland from a waste treatment lagoon or waste storage pond generally has little or no dissolved oxygen. Therefore, the nitrogen entering the wetland is either in the form of organic N or ammonia. The conversion from ammonia to nitrate is impossible unless the wastewater is somehow aerated, since aerobic bacteria are needed to make this conversion. Here is where the unique properties of the wetland plants become important, as explained in the conceptual model that follows.

Aerobic and anaerobic zones

As wastewater is drawn into the soil profile to satisfy the water requirements of the plants, it enters a zone that is basically devoid of oxygen (anaerobic), thus prohibiting the oxidation of ammonia to the nitrate form (NO3).

However, some O2 seeps from the roots and rhizomes of the plants to form microscopic zones of aeration within the root complex.

Within these aerobic zones, conditions are conducive for the growth of aerobic, nitrifying organisms that convert ammonia to NO3.

Some of this soluble form of nitrogen is used by the plants, but some migrates back into the surrounding anaerobic environment.

Denitrifiers

Within the anaerobic zone, special types of bacteria called *denitrifiers* use NO3 as a source of oxygen for respiration and, in the process, convert the NO3 to N2 gas, which then passes from the soil to the water column and then to the atmosphere.

Field-scale research to determine the actual amounts of O2 exuded into the root zone and the extent to which nitrifying and denitrifying organisms make the conversions is still limited.

Kadlec and Knight 1996

Wetland systems are so complex in terms of types of plants, soils, and a host of other related factors that could influence oxygen transfer and biological activity, that the loss of N, however it occurs, is currently explained in terms of general rate constants based on influent and effluent sampling rather than on kinetics of individual microbial processes.

Excerpt from Kadlec and Knight 1996 study

Water and pollutant transporter

As plants draw water into the soil profile to satisfy their normal water requirements, they also bring various ionized pollutants into the matrix.

As noted in NEH 637.0303, treatment process, these potential pollutants can be inactivated through ion exchange, adsorption and precipitation, complexation, and oxidation and reduction.

Without the plants serving as pumps to draw the wastewater into the soil, these reactions would not occur.

Users of nutrients

Plants use nitrogen, phosphorus, and the full range of minor nutrients.

The amount taken up by the plants is generally small in relation to the full nutrient load in animal waste constructed wetlands. Nutrient utilization becomes especially important if plants are harvested.

Otherwise, a high percentage of nutrients taken up by the plants are returned to the system as leaves and stems die and decay during senescence.

A small percentage becomes stored in the accretion, some is stored within the roots and rhizomes, and some escapes the wetland in the effluent.

Filter

The matrix of plant stems and litter traps and retains a large fraction of the solids that enter the wetland.

In addition, the plant/litter matrix slows the movement of water as it passes through the wetland, causing solids to settle.

Thus, the plants facilitate the breakdown of organic matter by allowing more time for biochemical conversions to take place.

Source of shade

By shading the water, plants help regulate water temperature and reduce algal populations.

The reduced concentration of algae prevents large daily swings in pH and dissolved oxygen concentrations.

It also results in a lower concentration of suspended solids in the wetland effluent.

This is especially important if the wetland has a permitted discharge.

If the effluent is land applied using sprinkler irrigation equipment, the reduction of algae, especially the filamentous varieties, will reduce problems related to clogged pumps and nozzles.

Source of new soils and sediment

Over time, a layer of peat-like material gradually builds up on the floor of the wetland through a process called *accretion.*

This material, sometimes referred to as new soil or deposited sediment, consists of plant residue, the remnants of the microbial organisms that were part of the treatment process, and non-degradable or slowly degradable solids trapped by the plants.

Accretion rates and TSS concentrations

The accretion rate is typically 0.08 to 0.39 inch per year for lightly loaded surface flow wetlands for municipal wastewater treatment (US EPA 1999).

While TSS concentrations in pretreated influent to animal waste SF wetlands are typically higher than those for most municipal systems, the total annual sediment load to municipal wetlands is expected to be higher because of a much greater annual influent volume.

Although no data are available on long-term accretion rates for animal waste constructed wetlands, a rate of 0.5 inch per year appears ample based on a comparison of data from municipal and animal waste systems.

Some of the phosphorus, non-degradable solids, and metals are permanently trapped in this layer.

Embankment heights and accretion rates

Accretion should be considered when designing embankment heights.

It may be necessary to raise the embankments after a number of years to maintain the effectiveness or increase the effective life of the wetland.

Section 40: Glossary of Related Terms

Accretion
Refers to the long-term buildup of a peat-like material consisting of settleable solids from the waste stream, the remnants of decayed plant litter, and microbial biomass on the floor of a surface flow wetland or on top of the filter bed of a subsurface flow wetland.

Adsorption
The process by which chemicals are held on a solid surface, such as the positively charged ammonium ion (NH4+) bonding with negatively charged clay particles.

Aerobic
Living, active, or occurring only in the presence of free oxygen. A condition of having free oxygen.

(AWMS) Agricultural waste management system
A combination of conservation practices formulated to appropriately manage a waste product that, when implemented, will recycle waste constituents to the fullest extent possible and protect the resource base in a nonpolluting manner.

Agricultural waste
Waste normally associated with the production and processing of food and fiber on farms, feedlots, ranches, and forests that may include animal manure, crop and food processing residue, agricultural chemicals, and animal carcasses.

Algae
Photosynthetic organisms that occur in most habitats, ranging from marine and freshwater to desert sands and from hot boiling springs to snow and ice. They vary from small, single-celled forms to complex, multicellular forms, such as the giant kelps of the eastern Pacific that grow to more than 60 meters in length and form dense marine forests. Ambient Environmental or surrounding conditions.

Ammonification
The production of ammonia by microorganisms through the decomposition of organic matter.

Anaerobic
Living, active, or occurring only in the absence of free oxygen. A condition of being without free oxygen.

Anoxic sediment
Sediment devoid of oxygen.

Biochemical oxygen demand (BOD)
The amount of oxygen (measured in mg/L) required in the oxidation of organic matter by biological action under specific standard test conditions. Widely used to measure the amount of organic pollution in wastewater and streams.

Biomass
The total mass of living tissue of both plants and animals.

BOD5
Biochemical oxygen demand measured over a standard 5-day test period; distinguished from BODN (nitrogenous oxygen demand) and BODU (ultimate oxygen demand). See Biochemical oxygen demand.

Cation exchange
The interchange between a cation in solution and another cation in the boundary layer between the solution and surface of negatively charged material, such as clay or organic matter.

Center pivot
An automated irrigation system consisting of a sprinkler line rotating about a pivot point at one end and supported by a number of self-propelled towers. The water is supplied at the pivot point and flows outward through the line supplying the individual outlets.

Chelation
A chemical complexing (forming or joining together) of metallic cations with certain organic compounds.

Class A pan evaporation

Evaporation as measured using a standard U.S. Weather Bureau Class A evaporation pan that has a depth of 10 inches and a diameter of 48 inches. The depth of water that evaporates is measured, and coefficients can be applied to estimate evaporation amounts from waterbodies. A typical coefficient for lakes is 0.7.

Complexation

A reaction in which a metal ion and one or more anionic ligands chemically bond. Complexes often prevent the precipitation of metals.

Composting

A facilitated process of aerobic biological decomposition of organic material characterized by elevated temperature that, when complete, results in a relatively stable product suitable for a variety of agricultural and horticultural uses.

Culm

An aerial stem bearing the inflorescence, in grasses, rushes, and other such plants.

Deciduous
Plants that shed all their leaves annually, generally in the fall.

Denitrification
Reduction of nitrogen oxides (usually nitrate and nitrite) to molecular nitrogen or nitrogen oxides with a lower oxidation state of nitrogen by bacterial activity (denitrification) or by chemical reactions involving nitrite (chemo-denitrification). Nitrogen oxides are used by bacteria as terminal electron acceptors in place of oxygen in anaerobic or microaerophilic respiratory metabolism.

Diffusion
The process by which matter, typically a gas, is transported from one part of a system to another as the result of random molecular movement; movement is from areas of high concentration to areas of low concentration influenced by temperature and the nature of the medium.

Dissolved oxygen (DO)
The molecular oxygen dissolved in water, wastewater, or other liquid; generally expressed in milligrams per liter, parts per million, or percent of saturation.

Effluent
Water or some other liquid, (raw, partially or completely treated), flowing from a waste storage or treatment facility.

Emergent plant
An aquatic or wetland plant with its lower part submerged and its upper part extending upright above the water.

Evapotranspiration (ET)
The combination of water transpired from vegetation and evaporation from soil and plant surfaces. Sometimes called consumptive use.

Facultative species
In the context of wetland plants, the term refers to species of plants that can grow under natural conditions in both wetlands and uplands. See Obligate species.

Field test method
An approach to sizing constructed wetlands based on loading determined from laboratory test results of the influent proposed for the wetland.

Floating aquatic plants
Aquatic plants that are not attached to the soil, but rather float freely on or near the water surface, such as duckweed and water hyacinths.

Floating aquatic plant (FAP) systems
Consists of a pond or series of ponds in which floating aquatic plants are grown for the purpose of treating wastewater.

Flushwater
Water used to clean or rinse surfaces.

Free-floating plants
Plants that float at or beneath the water surface without attachment to the substrate. Free-floating aquatics are transported freely by wind and currents, so they are normally found in abundance only in calm, sheltered water.

Gated pipe
Portable pipe that has small gates installed along one side for distributing water across the width of the inlet end of a constructed wetland cell or to surface irrigation corrugations or furrows.

Groundwater
Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper level of the saturated zone is called the water table. Water stored underground in rock crevices and in the pores of geologic material that makes up the Earth's crust. That part of the subsurface water that is in the zone of saturation; phreatic water.

Herbaceous vegetation
Plants that are herbs with soft, non-woody stems and no secondary growth.

Hydraulic detention time
The period that wastewater flow is retained in the constructed wetland for completion of physical, chemical, or biological reaction. The theoretical detention time is equal to the volume of water in the constructed wetland divided by the flow rate.

Hydraulic gradient
The slope of the surface of open or under groundwater.

Hydrophytic vegetation
Any plant that can grow in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content.

Influent
Water or other liquid, raw or partly treated, flowing into a reservoir, basin, treatment process or treatment plant.

Ion
An electrically charged atom, radical, or molecule formed by the loss or gain of one or more electrons.

Ion exchange
A process that involves substitution of one ion, either cation or anion, for another of the same charge when a solution containing ions is passed into a molecular network having either acidic or basic substituent groups that can be readily ionized. The ions in the solution attach themselves to the network, replacing the acidic or basic groups.

Jurisdictional wetlands
Those wetlands defined as water of the United States.

Kjeldahl nitrogen
Nitrogen in the form of organic proteins or their decomposition product ammonia, as measured by the Kjeldahl Method.

Lacuna
A gap or cavity.

Lake evaporation
The rate of evaporation from a water surface like that of a lake too large to be much affected by the additional evaporation that occurs at the edge.

Land application
Application of manure, sewage sludge, municipal wastewater, and industrial wastewater to land for reuse of the nutrients and organic matter for their fertilizer and soil conditioning value.

Leaching
The removal of soluble material from one zone in soil to another via water movement in the profile.

Lenticel
A small, raised, corky spot or line appearing on young bark, through which gaseous exchange occurs.

Liner
A relatively impermeable barrier designed to prevent seepage into the soil below. Liner material includes plastic and dense clay.

Loading
The quantity of a substance entering the environment or facility, such as the quantity of a nutrient to a constructed wetland.

Macrophyte
Macroscopic vascular plant; a multicellular aquatic plant, either free floating or attached to a surface.

Non-persistent plant
A plant that breaks down readily after the growing season.

Nonpoint source
Pollution sources that are diffuse and do not have a single point of origin or are not introduced into a receiving stream from a specific outlet.

Nutria
Aquatic, plant-eating rodent, Myocastor coypus, native of South America, resembling a small beaver with a ratlike tail. These rodents inhabit wetlands throughout the continental United States and are considered destructive pests.

Nutrient
Elements or compounds essential as raw material for organism growth and development.

Obligate species
Species that in nature can grow and multiply in only specific environment. Organic matter Mass of matter that contains living organisms or nonliving material derived from organisms. Sometime refers to the organic constituents of soil.

Oxidation
The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances.

Pathogen
Microorganisms that can cause disease in other organisms or in humans, animals, and plants. They may be bacteria, viruses, fungi, or parasites.

Perennial plant
A plant that lives through several growing seasons.

Point source
A stationary location or fixed facility from which pollutants are discharged or emitted.

Presumptive method
An approach to sizing a constructed wetlands based on estimates of influent loadings.

Pretreatment
Treatment of waste or wastewater to reduce the concentrations of solids and other constituents of waste and wastewater before discharge to a facility for further management.

Propagules
Any of various portions of a plant, such as a bud or other offshoot, that aid in dispersal of the species and from which a new individual may develop.

Rhizome
A root-like stem that produces roots from the lower surface and leaves, and stems from the upper surface.

Seepage
The loss of water by percolation into the soil from a canal, ditch, lateral, watercourse, reservoir, storage facility, or other body of water, or from a field.

Senescence
The plant growth phase from full maturity to death that is characterized by an accumulation of metabolic products, increase in respiratory rate, and loss in dry weight, especially in leaves and fruit.

Settleable solids
Solids in a liquid that can be removed by stilling a liquid. Settling times of at least 1 hour are generally used.

Short circuiting
When water finds a more direct course from inlet to outlet than was intended. This is generally undesirable because it may result in short contact, reaction, or settling time in comparison with the theoretical or presumed detention times.

Sludge
The accumulation of solids resulting from chemical coagulation, flocculation, and sedimentation after water or wastewater treatment.

Solid set system
An irrigation system that covers the complete field with pipes and sprinklers in such a manner that the entire field can be irrigated without moving any of the system.

Sorption
The removal of an ion or molecule from solution by adsorption and absorption. It is often used when the exact nature of the mechanism of removal is not known.

Stolon
A trailing aboveground stem or shoot, often rooting at the nodes and forming new plants.

Substrate
A supporting surface on which organisms grow. The substrate may simply provide structural support, or may provide water and nutrients. A substrate may be inorganic, such as rock or soil, or it may be organic, such as vegetation surfaces.

Supernatant
The liquid fraction in a waste impoundment, such as a waste treatment lagoon or waste storage pond, that overlies the sludge or settled solids.

Suspended solids
Organic or inorganic particles that are suspended in and carried by the water. The term includes sand, mud, and clay particles, as well as solids in wastewater.

Total maximum daily load (TMDL)
The sum of the individual waste load allocations for point sources and load allocations for nonpoint sources and natural background.

Total solids (TS)
The weight of all solids, dissolved and suspended, organic and inorganic, per unit of volume of water or wastewater. It is the residue remaining after all water has been removed by evaporation.

Traveling gun
An irrigation system using a high volume, high pressure sprinkler (gun) mounted on a trailer, with water being supplied through a flexible hose or from an open ditch along which the trailer passes.

Treatment
Chemical, biological, or mechanical procedures applied to sources of contamination to remove, reduce, or neutralize contaminants. Tuber An enlarged, fleshy, underground stem with buds capable of producing new plants.

Vascular plants
Plants that possess a well-developed system of specialized tissues that conduct water, mineral nutrients, and products of photosynthesis through the plant, consisting of the xylem and phloem.

Venn diagram
A diagram where sets are represented as simple geometric figures, with intersections and unions of sets represented by intersections and unions of the figures.

Volatile solids
That part of total solids driven off as volatile (combustible) gases when heated to 1,112 degrees Fahrenheit.

Volatilization
Loss of gaseous components, such as ammonium nitrogen, from animal manure.

Waste storage facility
A waste storage impoundment made by constructing an embankment and/ or excavating a pit or dugout or by fabricating a structure for the temporary storage of animal or other agricultural waste.

Waste treatment lagoon
A waste treatment impoundment made by constructing an embankment and/or excavating a pit or dugout for the biological treatment of animal and other agricultural waste.

Wastewater
The used water and solids from a confined livestock or aquaculture facility that is usually not suitable for reuse unless it is treated.

Water budget
An accounting of the inflow to, outflow from, and storage changes of water in a hydrologic unit.

Water table
The upper surface of groundwater in the zone of saturation.

Wetland porosity
The amount of wetland water volume not occupied by plants, expressed as a decimal.

Wetlands
Land transitional between terrestrial and aquatic systems that has a water table at or near the surface or a shallow covering of water, hydric soil, and a prevalence of hydrophytic vegetation.

Bibliography:

1) Much of this course is based on the USDA Natural Resources Conservation Services, “Part 637 Environmental Engineering National Engineering Handbook, Chapter 3, “Constructed Wetlands”, Pub. # 210–VI–NEH; amended release date: Nov 2009

2) Various excerpts in this course are based on Wikipedia sources

This concludes our course on “Constructing Wetlands for Water Purification”.
You may now proceed to the final exam.

Thank you for taking this Flashcard course!

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