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Constructed Wetlands Technology Assessment and Design Guidance

Iowa Department of Natural Resources

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NOTICE

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Water Environment Research Foundation, 2006, Small – Scale Constructed Wetland Treatment Systems Feasibility, Design Criteria and Operation and Maintenance Requirements, Wallace and Knight, IWA Publications.

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Performance

Effluent quality from constructed wetlands is dependant upon numerous factors, but the most important of which is loading rates. The below table identifies specific loading rates required to achieve specific discharges from Constructed Wetlands.

Recommended loading rates for Constructed Wetlands			
Type of Wetland	Parameter	Assumed Discharge Criteria (mg/l)	Required Loading Rate (lb/acre-d)
SF	BOD	30.0	53.5
	TSS	30.0	44.5
	TKN	10.0	4.5
	Pathogen removal [1]	N/A	N/A
SSF	BOD	30.0	53.5
	TSS	30.0	89.2
	TKN [2]	N/A	N/A
	Pathogen removal [1]	N/A	N/A
NOTES	1: Pathogen removal data suggests a 3-day HRT for a 2-log reduction in fecal coliform. Consistent compliance with disinfection limits can only be achieved through other disinfection mechanisms. 2. SSF constructed wetlands are anaerobic in nature therefore limited TKN removal occurs.		

SF Recommended Design Criteria		
Parameter	Design Criteria	
Effluent Quality	BOD ≤ 30 mg/l TSS ≤ 30 mg/l TKN ≤ 10 mg/l (during warm weather)[1]	
Pretreatment	Septic tank	
Maximum BOD Loading	53.5 lb/acre-d	
Maximum TSS Loading	44.5 lb/acre-d	
Maximum TKN Loading	4.5 lb/acre-d	
Minimum Water Depth	1 foot	
Minimum HRT	Fully Vegetated Zone	2 days at AWW
Maximum HRT	Open Water Zone	2 days (or less) at AWW
Minimum # of Trains	2 (regardless of size)	
Minimum # of Cells/Train	Flow ≤ 10,000 gpd – 1 Flow ≥10,000 gpd - 2	
Aspect Ratio	Between 3:1 and 5:1	
Inlet / Outlet	Uniform distribution across cell	
Hydraulics	Handle 25-year, 24 hour storm Minimum 2 feet freeboard	
Cell Hydraulics	Each cell drainable	
	Capable of piping from one cell to multiple other cells	
Notes	1) Freezing conditions will dramatically impact TKN discharge. If necessary, thermal modeling should be performed.	

SF Design Process

1) Determine design requirements (Influent Flow and Load, Effluent Discharge)
2) Analyze for Water Balance
3) Size Pretreatment Unit
4) Determine Required area by loading rate
5) Determine Configuration and Redundancy Criteria
6) Determine Maximum Water Depth
7) Apply Aspect Ratio
8) Determine Hydraulic Retention Time and Hydraulic Design
9) Designate Open Water to Vegetation Ratios
10) Determine Depth and Gradation of Media
11) Layout Settling Zone, Inlet and Outlet Structures and Lining Systems

SSF Recommended Design Criteria		
Parameter	Design Criteria	
Effluent Quality	BOD ≤ 30 mg/l TSS ≤ 30 mg/l	
Pretreatment	Septic Tank	
Maximum BOD Loading	53.5 lb/acre-d	
Maximum TSS Loading	89.2 lb/acre-d	
Depth	Media	20 inches
	Water Depth	16 inches
Minimum Length	50 feet	
Maximum Width	200 feet	
Bottom Slope	0.5 to 1.0 Percent	
Top Slope	Level	
Minimum # of Trains	2	
Media	Inlet Zone	1.5" – 3.0" Gradation
	Treatment Zone	¾" – 1.0" Gradation
	Outlet Zone	1.5" – 3.0" Gradation
	Planting	¼" – ¾" Gradation
Inlet / Outlet	Uniform distribution across cell	
Planting Media	Minimum 4 inch layer	
Mulch Insulation	Minimum 6 inch layer	
Cell Hydraulics	Each cell drainable	
	Capable of piping from one cell to multiple other cells	
NOTES:	SSF wetlands should not be sized for TKN removal due to the anaerobic nature of the typical SSF wetland	

SSF Design Process

1) Determine design requirements (Influent Flow and Load, Effluent Discharge)
2) Analyze for Water Balance
3) Size Pretreatment Unit
4) Determine Required area by loading rate and apply redundancy criteria
5) Determine Media Depth and Gradation
6) Apply Maximum Water depth
7) Determine Hydraulic Conductivity
8) Determine Minimum Width of Construction for each cell
9) Determine Configuration and Incorporate Freezing Considerations
10) Layout Inlet and Outlet Structures and Lining Systems

I. INTRODUCTION

A. Scope

The Iowa Department of Natural Resources (DNR) has commissioned this manual in order to broaden the number of treatment options considered for managing wastewater within Iowa's small rural communities. Current rules and regulations do not recognize constructed wetlands as a viable wastewater treatment alternative. This manual is intended to expedite the design and review process for these technologies by:

- Summarizing existing research and performance data;
- Acting as a guide to determining the applicability of constructed wetlands;
- Advising the designer as to the selection and sensitivity of design parameters;
- Providing an overview of the design process; and
- Providing three example designs for populations of 25, 100, and 250 people.

The manual has application for:

- Treatment of Domestic Waste Only; and
- Population Equivalents from 25-250 people.

The following assumptions on waste quantity and strength have been used throughout the manual:

- Design influent BOD of 250 mg/l or less;
- Design influent TSS of 250 mg/l or less;
- Design influent TKN of 40 mg/l or less; and
- Design Hydraulic Loadings of 100 gpcpd

This manual is intended for use by Owners, Consulting Engineers, DNR review engineers and associated DNR personnel, as well as funding source personnel to provide guidance to the successful design for the use of constructed wetlands within Iowa. The design approach contained within this manual should be construed as a minimum basis of design. Nothing within this manual should be construed or viewed as eliminating additional alternative treatment systems, or alternative design approaches with respect to constructed wetlands, provided that adequate justification and data from actual installations is submitted.

B. Terminology

Definitions of some terms used in this evaluation report are as follows:

ADW	Average Dry Weather Flow Rate. ADW is average daily flow when groundwater is at or near normal and a runoff condition is not occurring. The period of measurement for this flow should extend for as long as favorable conditions exist up to 30 days, if possible
AWW	Average Wet Weather Flow Rate. AWW is the daily average flow for the wettest consecutive 30 days for mechanical plants, or for the wettest 180 consecutive days for controlled discharge lagoons
Anaerobic	Lack of molecular oxygen
Anoxic	Without free oxygen
Aspect Ratio	Ratio of Length to Width
Biochemical Oxygen Demand (BOD)	The biochemical oxygen demand (BOD) of domestic and industrial wastewater is the amount of molecular oxygen required to stabilize the decomposable matter present in water by aerobic biochemical action. Commonly expressed in terms of the measurable level over a 5 day testing regime.
Denitrification	The process of biologically converting nitrate/nitrite (NO_3^-/NO_2^-) to nitrogen gas.
Emergent Plant	A non-woody plant rooted in shallow water with most of the plant above the water surface
Emergent Wetland	A wetland dominated by emergent plants; marsh
Evapotranspiration	Loss of water to the atmosphere by evaporation from the water surface and by transpiration from plants
Exotic Plants	Non-native plant species, introduced
Hydric Soils	A soil that is saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part of the soil.
Infiltration	The water entering a sewer system (including service connections) from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include, and is distinguished from, inflow.

Infiltration/Inflow	The total quantity of water from both infiltration and inflow without distinguishing the source.
Inflow	The water discharged into a sewer system (including service connections) from such sources as, but not limited to, roof drains, cellar, yard and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross connections from storm sewers and combined sewers, catch basins, storm water, surface runoff, street wash waters, or drainage. It does not include, and is distinguished from, infiltration.
MWW	Maximum Wet Weather Flow. MWW is the total maximum flow received during any 24 hour period when the groundwater is high and a runoff condition is occurring.
Nitrification	The process of biologically oxidizing ammonia (NH_4^+/NH_3) to nitrate/nitrite (NO_3^-/NO_2^-).
Non-persistent plant	A plant that breaks down readily after the growing season
Non-vascular plant	A plant without differentiated tissues for the transport of fluids; for instance, algae
Pathogen	A disease producing microorganism
Perennial plant	A plant that lives for many years
PHWW	Peak Hourly Wet Weather Flow Rate. PHWW is the total maximum flow received during one hour when the groundwater is high, runoff is occurring and the domestic, commercial and industrial flows are at their peak.
Sanitary Sewer	A sewer intended to carry only sanitary or sanitary and industrial wastewater, from residences, commercial buildings, industrial plants, and institutions.
Suspended Solids	Those solids that either float to the surface of, or are suspended in water, sewage, or industrial waste, which are removable by a laboratory filtration device.
Total Kjeldahl Nitrogen	The sum of the organic and total ammonia nitrogen present.
Vector Organism	An organism, often an insect or rodent, that carries disease

Abbreviations of some terms used in this report are as follows:

BOD	five-day biochemical oxygen demand
$CBOD_5$	carbonaceous five-day biochemical oxygen demand
cfs	cubic feet per second
DNR	Department of Natural Resources (State of Iowa)
EPA	Environmental Protection Agency (Federal)
ET	Evapotranspiration
gpcd	gallons per capita per day
gpd	gallons per day
gpm	gallons per minute
HRT	hydraulic retention time
IAC	Iowa Administrative Code
I/I	infiltration/inflow
lb/day	pounds per day
lb/cap/d	pounds per capita per day
MGD	million gallons per day
mg/l	milligrams per liter
NH_4-N	ammonia nitrogen
NO_3-N	nitrate nitrogen
NPDES	National Pollution Discharge Elimination System
PHWW	peak hourly wet weather flow rate
scfm	standard cubic feet per minute
SF	Surface Flow Wetlands
SSF	Subsurface Flow Wetlands
STE	Septic Tank Effluent
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
TSS	Total suspended solids
WWTF	Wastewater Treatment Facility

C. Discharge Performance Capability

In general, constructed wetlands are capable of producing effluent compliant with secondary treatment levels. Discharges from well-designed, operated, maintained and constructed wetlands can consistently achieve compliance with a 30 mg/l BOD and 30 mg/l TSS discharge criteria. Nitrogen removal in SSF constructed wetlands is minimal due to its anaerobic design condition. Some reduction in nitrogen levels will occur with SSF constructed wetlands, but it is dependant upon temperatures in order to facilitate nitrification. Significant pathogen reduction can and will occur within constructed wetlands, as discussed within Chapter 3 of this manual.

It should be noted that regardless of constructed wetlands type, all wetlands have a limit of performance capability. Constructed wetlands contain plant and other deleterious matter, which when decay, produce "background concentrations" of each pollutant, including BOD, TSS and TKN.

Table 1-1
Typical Background Concentrations for Constructed Wetlands
(WERF, 2006)

Parameter	Typical Background Concentrations (mg/l)	
	Surface Flow Wetlands	Subsurface Flow Wetlands
BOD	3	18
TSS	8	19
TKN	2	19
NOTES:	Above concentrations are the 75th percentile of data reported	

II. PROCESS DESCRIPTION

Wetlands are defined as land where the water surface is near the ground surface long enough each year to maintain saturated soil conditions, along with related vegetation. Due to the inherent properties of natural wetlands, they play an extremely important role in removing pollutants from water systems throughout the world. Areas such as marshes or swamps all provide sufficient environments for biological and microbial activity for treatment and removal of pollutants.

Given this fact, natural wetlands have come to be viewed as integral to the overall health of the environment. As such, rules and regulations have been adopted to maintain the quality and quantity of such systems throughout the United States. Therefore, natural wetland systems should not be used for direct treatment of any wastewater. However, constructed wetlands can be created to mimic such systems in a controlled and regulated environment. Thereby using natures natural treatment system to treat wastewater without impacting existing wetlands.

"Constructed wetlands are artificial wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater. They typically have impervious clay or synthetic liners and engineered structures to control the flow direction, liquid detention time and water level." (US EPA, 2000)

In general, constructed wetlands consist of two separate categories classified by the location of the water surface. For purposes of this manual, these classifications are defined as subsurface flow (SSF) and free water surface flow (SF). Both types of wetlands use emergent aquatic vegetation in conjunction with the treatment of wastewater.

An SF system consists of a basin or channel with a liner system and soil to promote and support roots of emergent vegetation, with water that is exposed to the atmosphere. The water is typically at a relatively shallow depth and the intended flow path through the system is horizontal. SF type systems closely resemble natural wetlands and therefore attract a wide variety of wildlife, including insects, mollusks, fish, amphibians, reptiles, birds and mammals (Kadlec and Knight, 1996). Further, given the exposed water surface, they are susceptible to freezing in cold weather climates.

An SSF system consists of the same basin or channel with a liner system, but the bed consists of a suitable depth of porous media, in which roots of emergent plants are allowed to grow. The water surface of subsurface flow wetlands is designed to remain below the top of the porous media. Flow through this type of system can be either horizontal, vertical or both. Given the design constraint of a non-exposed water surface in an SSF wetland system, properly operated SSF system do not provide suitable habitat for mosquitoes or other vector organisms.

The treatment alternatives identified within this manual assume a discharge to a receiving stream on the surface. Alternative designs for constructed wetlands include a wetland system that provides for infiltration of treated effluent. These systems would then incorporate a drip irrigation system or other mechanism to dispose of the effluent wastewater. These design alternatives can be implemented at the readers choice.

A. Background of Constructed Wetlands

Constructed wetlands rely on chemical, physical and biological mechanisms to reduce pollutants within a waste stream. These processes are dependant upon size, shape, temperature, loading and vegetation used within the wetland process.

Figure 2-1
Constructed Wetlands Schematics
(US EPA, 2000)

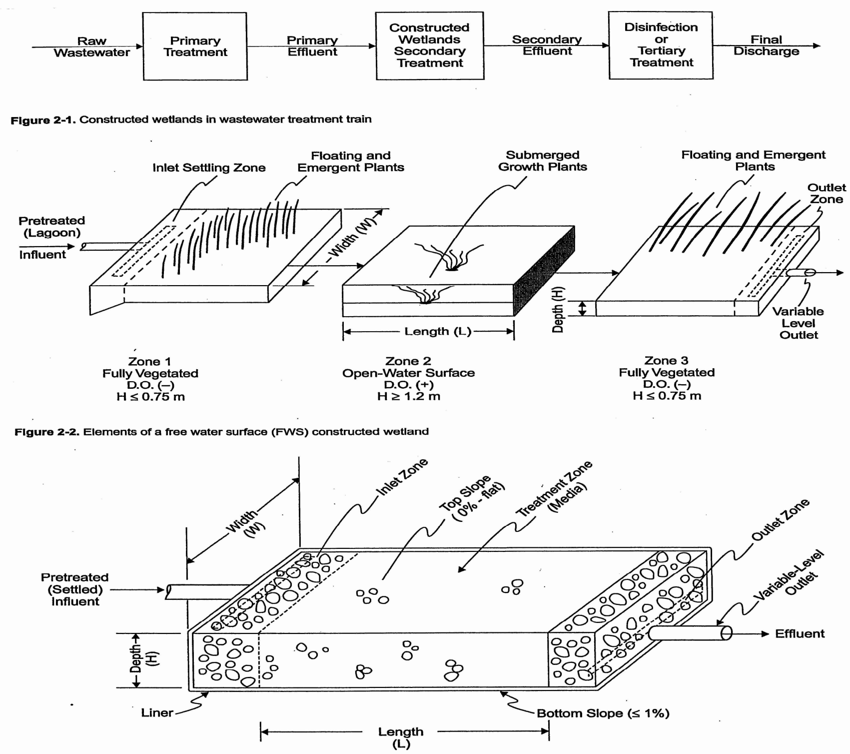

Figure 2-1. Constructed wetlands in wastewater treatment train

Figure 2-2. Elements of a free water surface (FWS) constructed wetland

Figure 2-3. Elements of a vegetated submerged bed (VSB) system

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Wetlands have been used for centuries to treat pollutant loads within waters; however it has only been over the past 50 to 60 years that these processes have been analyzed and evaluated. Further, the processes involved for treatment of wastewater within a wetland when viewed at first glance appear rather simplistic. However, published data does not currently have a consistent approach, nor full understanding of the complexities involved within a constructed wetland wastewater treatment system.

Further, the EPA has published some misconceptions about constructed wetlands (US EPA, 2000). The following statements can therefore be made concerning wetlands and their processes:

1) Wetland design has not been well characterized by published design equations.

   The design manual from the EPA was originally published in 2000. Additional data and design equations have been published since then, but given the complexity of treatment techniques within constructed wetlands and the lack of historical operational evidence this statement is still applicable.

2) Constructed wetlands do not have aerobic as well as anaerobic treatment zones.

   As stated within the EPA manual there is a belief that vegetation and other aquatic plants act as aerators by pumping oxygen into the constructed wetland environment. The EPA relates this misconception to the original design constraints of constructed wetlands acting as polishing reactors. Therefore, minimal loading occurred on the wetlands resulting in available free oxygen within the treatment process. With the increase in loading rates, a proportional decrease in available oxygen within the system is seen.

3) Constructed wetlands cannot remove significant amounts of nitrogen.

   Harvesting of plants and aquatic vegetation removes less than 20% of available nitrogen at conventional loading rates (according to Reed, et. al, 1995). According to the EPA's design manual, anaerobic processes dominate the vast majority of treatment through a constructed wetland. Due to this, nitrification, which requires the presence of oxygen does not occur in significant amounts to remove nitrogen. Further, SF type treatment systems can be designed with open water areas to promote oxygenation, but these open water areas are susceptible to freezing, which mitigates year round treatment.

Other frequently asked questions identified include (US EPA, 2000):

1) Are constructed wetlands reliable? What do they treat?

   Constructed wetlands are an effective and reliable water reclamation technology if they are properly designed, constructed, operated and maintained. They can remove most pollutants associated with municipal and industrial wastewater and storm water and are usually designed to remove contaminants such as BOD and suspended solids. Constructed wetlands have also been used to remove metals, including cadmium, chromium, iron, lead, manganese, selenium, zinc, and toxic organics from wastewater.

2) Can a constructed wetland be used to meet a secondary effluent standard?

Both SF and SSF constructed wetlands can be used to meet a 30/30 mg/l BOD and TSS discharge standard. It is not advisable to put raw wastewater into a constructed wetland.

3) Can constructed wetlands work in cold temperatures?

Constructed wetlands are found in a wide range of climatological settings, including cold climates where ice forms on the surface for four to six months of the year. For example, these systems are found in Canada, North Dakota, Montana, Vermont, Colorado and other cold-climate areas. Special considerations must be included within the design of these systems for the formation of an ice layer and the effect of cold temperatures on mechanical systems, such as the influent and effluent works. The absence of living plants that have died back for the winter and the presence of a layer of ice approximately 0.5 to 1.0 feet thick have not been shown to severely affect the secondary treatment capabilities of these systems. Nitrogen transformation and removal is, however, impaired during very cold periods.

The reader of this manual should well understand these limitations related to wetland systems prior to embarking on this type of treatment process. That being said, constructed wetlands do have a place within the treatment spectrum and can be implemented given these constraints.

B. Required Pretreatment

As discussed, two main categories of wetlands exist, SF and SSF. Both processes require a method of pretreatment in order to minimize the loading onto the wetland.

Subsurface flow constructed wetlands are extremely susceptible to plugging, due to the fact that water is made to move through the media pore space within the wetlands. In fact solids loading has a significant impact on the performance of SSF constructed wetlands (Sun, Thompson, et. al, 1998). When overloaded with solids, porosity is impacted in the gravel drainage bed which results in the flow path emerging on the surface of what should be a submerged flow constructed wetland. Both aerated and nonaerated lagoons have historically produced extremely high TSS discharges, which in turn lead to plugging within the SSF wetland. Therefore, only septic tanks have been evaluated for SSF wetland pretreatment regimes.

Surface flow constructed wetlands are not as susceptible to plugging, as the water will always have a preferential flow path on the surface of the wetland. However, surface flow constructed wetlands are extremely susceptible to algae growth. Algae, within a surface flow constructed wetland, will soon dominate all other vegetation within the wetland. In turn, this will result in extremely low dissolved oxygen contents, and reduction in overall performance. Nonaerated lagoons have shown limited capability of removing algae within the pretreatment regime (US EPA, 2000). Aerated lagoons have shown better capability of limiting algae growth (US EPA, 2000). However, for the sake of this manual, only septic tanks have been identified as approved pretreatment mechanisms. Alternative approached may be reviewed on a case-by-case basis.

1. Septic Tanks

Techniques for sizing of septic tanks are identified within the Appendix. The reader is strongly encouraged to read this particular appendix for design constraints and sizing guidance for septic tank installations for population equivalents of 25, 100 and 250 people. Septic tank systems may be effectively used for both the SF and SSF constructed wetlands.

2. Lagoons

Primary treatment through the use of Lagoons is above and beyond the scope of this manual. It has been assumed that all primary treatment within this manual shall be completed by the use of septic tanks.

SF constructed wetlands are susceptible to algae blooms. If algae is allowed into the SF constructed wetlands it will soon dominate all other vegetation within the wetland.

SSF constructed wetlands are susceptible to plugging by suspended solids overload. Lagoons have historically displayed poor suspended solids removal, therefore; lagoons are not recommended for use within SSF constructed wetlands (US EPA, 2000).

C. Macrophytes

Macrophytes are the types of plant species used within the wetland construction. Macrophytes are vascular type plants that have tissues that are readily seen. Macrophytes are further classified by the growth form (or location of the majority of growth). Emergent plants have the majority of growth and plant structure "emerging" from the water surface into the air. Floating plants have leaves and stems that are buoyant such that they "float" on the water surface. Submerged plants have both leaves and stems that are below the water surface.

Figure 2-2
Growth forms of Macrophytes
(Kadlec and Knight, 1995 p. 134)

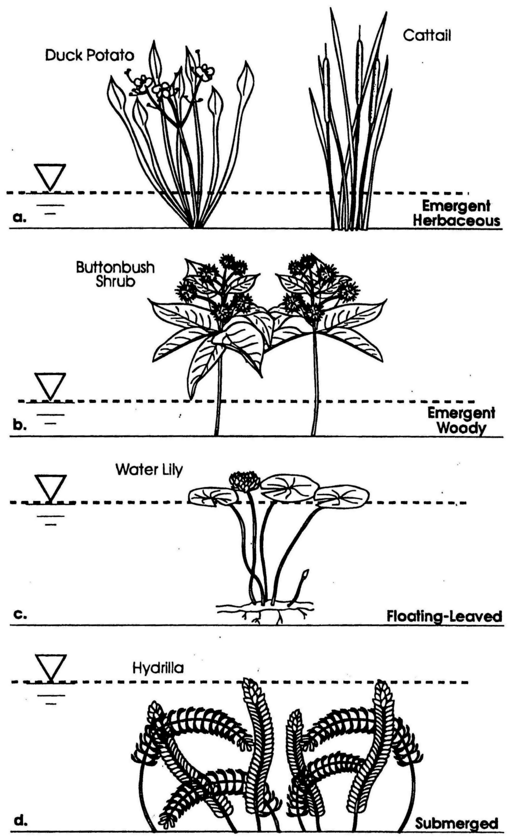


Figure 7-6 Growth forms of rooted wetland and aquatic vascular plants.

Due to no other reason than the classification of the system, floating and submerged plants may only be seen within SF constructed wetlands. SSF constructed wetlands can only have emergent type plants due to the location of the water surface at or below the root bed.

The following table has been summarized from the EPA's constructed wetlands treatment of municipal wastewater design manual. The table provides important information for each of the types of plants associated within a constructed wetland.

Table 2-1
Constructed Wetlands Macrophyte Information
(US EPA, 2000)

Type	Characteristics	Function	Design Considerations	Common Examples
Free – Floating	1) Will move with water currents 2) Will not stand erect out of water	1) Nutrient Uptake 2) Shading to retard algae growth	1) Duckweed is naturally invasive species	1) Common Duckweed 2) Big Duckweed
Submerged	1) Will not stand erect in air	1) Structure for Microbial attachment	1) Low retention time required to minimize algae which prevents submerged plant growth	1) Pond weed 2) Water weed
Emergent	1) Stand erect out of water 2) Tolerate flooded or saturated conditions	1) Structure to enhance settling 2) Shading retards algae growth 3) Insulation during winter months	1) Water depth must acceptable for plant used	1) Cattail 2) Bullrush 3) Common Reed

1. Free Floating

By definition, free-floating vegetation can only be seen within SF wetlands, which provide sufficient water depths for use of free-floating vegetation. The dominant form of free-floating fauna is Duckweed. Duckweed is extremely invasive and can and will grow in most environments (US EPA, 2000).

Floating plant species are not typically a design component of constructed wetlands (Crites, 2006). Free floating vegetation, including duckweed, experience a very high growth rate. This in turn can lead to a mat of duckweed across the entire wetland surface, dramatically limiting oxygen transfer capabilities.

Therefore inclusion of free floating vegetation within the constructed wetlands is not recommended. Further, inclusion of Open water zones is required in surface flow wetlands. These zones help to promote wind action to break up and move any duckweed mat that may develop.

2. Submerged

Submerged vegetation can only be used within SF wetlands, which provide sufficient water depths for use. The dominant form of submerged vegetation is Pond weed and water weed. Detention times and head losses through a constructed wetlands are greater when submerged vegetation is introduced. However, submerged vegetation also provides increase surface area for microbial attachment, thus increasing treatment capability (US EPA, 1999).

3. Emergent

Emergent wetland plants are very important structural components of wetlands (US EPA, 2000). In SSF wetlands, rooted emergent plant species interact with the wastewater at the root zone only. In SF wetlands, rooted emergent plants will again interact with the wastewater at the root zone, but will also provide an area for microbial attached growth (US EPA, 2000).

4. Recommended Plant Species

Due to the climatic variability and soil constraints across the state of Iowa, specific plant selection should correspond to use of indigenous plant species. Plants that are not indigenous may have lower survivability rates, as well as have potential invasive effects on the local environment. Recommendations for use of specific plant species are being made herein, but should be reviewed on a case-by-case basis.

Table 2-2 Recommended Constructed Wetlands Macrophytes			
Type of Constructed Wetlands	Macrophyte Type	Purpose	Recommended Macrophyte
Surface Flow (SF)	Free – Floating	Nutrient Uptake Shade to retard Algae Growth	Not Recommended for use due to oxygen transfer impacts
	Emergent	Provide structure to enhance flocculation and sedimentation.	Cattail Bullrush Common Reed
	Submerged	Provide structure for microbial attachment	Pondweed Water Weed
Subsurface Flow (SSF)	Free-Floating	NOT APPLICABLE	
	Emergent	Provide structure to enhance flocculation and sedimentation.	Cattail Bullrush Common Reed
	Submerged	NOT APPLICABLE	

D. Free Water Surface Wetlands

SF constructed wetlands providing wastewater treatment beyond the secondary level were built through the US and Canada during the 1980s and 1990s (US EPA, 1999). SF type constructed wetlands are typically shallow vegetated basins.

As stated previously, SF type constructed wetlands require primary treatment. Primary treatment should be accomplished through a septic tank. Sizing of septic tanks is discussed within the Alternative collection system manual.

SF wetlands are generally much larger than SSF wetlands due to their loading rates and associated requirements. As the water surface is exposed, freezing of the water surface in climates seen in Iowa is typical. Additional design constraints must be incorporated into a SF constructed wetland for proper operation.

SF type wetlands have aerobic conditions prevailing in the upper portion of the water column. Anaerobic conditions prevail at the base of the column (WERF, 2006). Nitrification potential is highest in SF type systems due to the increased presence of oxygen as compared to SSF type constructed wetlands.

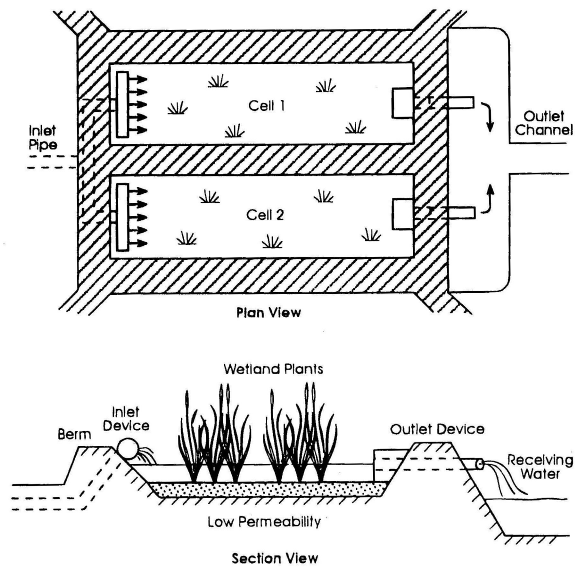
SF type constructed wetlands have been installed in cold weather climates. Additional considerations must be provided for the formation of the ice layer (i.e.

additional freeboard) and the effects on both influent and effluent structures. Regardless, nitrification is significantly hampered by cold weather operations in which freezing of the water surface may occur (US EPA, 1999).

1. Schematic Flow Paths

The following schematic flow path illustrates a potential flow regime through an SF type wetland. The vegetative and open water zones are not shown for clarity. Additional cells and trains can also be added to this design.

Figure 2-3
Schematic view of SF Wetlands
(Kadlec and Knight, 1995, p. 562)



E. Subsurface Flow Wetlands

SSF constructed wetlands can have variable levels of treatment performance that depend upon influent wastewater, hydraulic loading, climate and design. SSF systems provide isolation of the wastewater from vectors, animals and humans. Therefore concerns with mosquitoes and pathogen transmission are greatly reduced with an SSF constructed wetlands (U.S EPA, 2000).

While SF constructed wetlands typically require more land to achieve proper loading rates, an SSF constructed wetlands incorporates media and other materials that may result in increased costs over SF type systems.

As discussed previously, pretreatment is required for an SSF constructed wetlands. Primary treatment should be accomplished through the use of septic tanks.

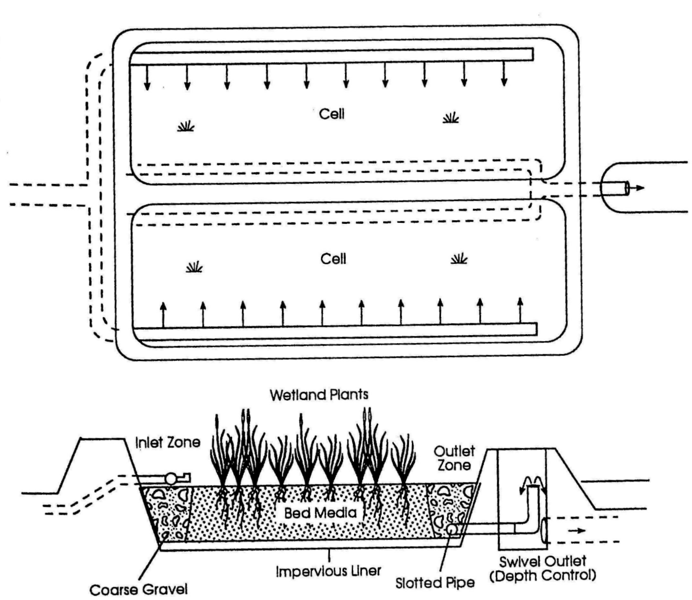
SSF constructed wetlands are mostly anaerobic in nature. That is due to the lack of atmospheric interaction with the water surface. Two factors influence the capability of oxygen transfer, the granular media impedes air movement to the water interface and decaying plant materials inhibit air transfer to the water interface (WERF, 2006).

Given this anaerobic condition, SSF type constructed wetlands have limited capability to assimilate and transform ammonia-nitrogen. However, they provide a readily available capability to denitrify a wastewater stream (U.S EPA, 2000).

1. Schematic Flow Paths

The following schematic flow path illustrates a potential flow regime through an SSF type wetland. The pretreatment option, which should be a septic tank is not shown for clarity. Additional cells and trains can also be added to this design.

Figure 2-4
Schematic view of SSF Wetlands
(Kadlec and Knight, 1995 p. 563)



III. PERFORMANCE

Constructed wetlands, when properly designed and operated can provide relatively reliable and effective treatment of wastewater to achieve a 30/30 mg/l BOD and TSS discharge standard. It is not advisable to put raw wastewater directly into a constructed wetland, as they require some level of preliminary treatment (U.S EPA, 2000).

The following sections identify potential performance capabilities of both SF and SSF constructed wetlands. Published data from operational constructed wetlands have been used to determine a range of effective performance.

A. Performance Data

Performance within both the SSF and SF constructed wetlands is related to the loading rates established within that system. Generally, the higher the load the higher the concentration on discharge. This statement does not apply to pathogen removal, which has additional factors associated with it.

As part of the completion of this manual, data was obtained from facilities throughout Iowa that currently have some form of constructed wetlands treatment system.

The following are the facilities that have been permitted by the IDNR:

Table 3-1
IDNR Constructed Wetlands Facilities

Facility Name	NPDES Number	Facility Type	Pretreatment	Note
Agency	69003001	SF	Aerated Lagoon	No Treatment Provided, Holding Only
Blencoe	66709001	SF	Aerated Lagoon	2 – Cell Wetlands, effluent testing only
Buchanan – Fontana Camp	61004001	SSF	Septic Tank	Limited flow – Plants dies every year, effluent testing only
Burr Oak Sewer Commission	69600301	SSF	Septic Tank and Sand Filter	Consistent Permit Compliance Effluent sampling data Only
Chelsea	68609001	SF	Aerated Lagoon	Plants did not establish. Administrative Order Issued
Dows	65225002	SF	Aerated Lagoon	Low Flow compared to Design Effluent Sampling Data only
Greenville	62133001	SSF	Septic Tank	Effluent Sampling Data only
Granger	62537001	SF	Aerated Lagoon	Effluent Sampling Data only
IAMU	67700502	SSF	Septic Tank	Effluent Sampling Data only
Iowa City	65225002	SF	Activated Sludge	Wetlands provides no treatment, Holding Only
Lake Park	63045001	SF	Aerated Lagoon	Effluent Sampling Data only
Laurel	66452001	SF	Aerated Lagoon	Effluent Sampling Data only
Neil Smith Wildlife Refuge	65000402	SSF	Septic Tank	Effluent Sampling Data only
Norway	60656001	SF	Aerated lagoon	Effluent Sampling Data only
Riverside	6926001	SF	Aerated lagoon	Wetlands provides no treatment, holding only
Springbrook State Park	63900900	SF	Aerated Lagoon	Effluent Sampling data only.

Significantly more SSF constructed wetlands have been constructed throughout the state for individual onsite treatment systems. Documentation for these systems concerning design and operational data is limited to nonexistent.

The majority of these systems installed within the state of Iowa do not have sufficient sample data to determine adequacy of design. While most systems provide effluent sampling, almost none have sufficient sampling prior to the constructed wetlands to document its performance.

Further, after evaluating multiple facilities throughout the state, four facilities were determined to be relevant to this manual: Burr Oak, Blencoe, Greenville and Norway.

1. Burr Oak Sewer System

Burr Oak sewer system has discharge data from 2004 to 2006 that indicates a CBOD average of 5 mg/l and TSS average of 2.1 mg/l. While this data indicates an overall acceptable performance of the constructed wetlands, further extrapolation of performance cannot be obtained due to insufficient influent sampling.

2. Blencoe Wastewater Treatment Facility

Blencoe monitors only influent flow and therefore has insufficient data to extrapolate a performance and design constraint from it.

3. Norway Wastewater Treatment Facility

Norway, Iowa is an SF wetland. Typical SF type wetlands should be sized for treatment and include a minimum of three zones, as shown on Figure 2-1. However, upon close inspection the facility in Norway has only an open water surface, without any fully vegetated zones. As a result, the facility has experienced multiple operational and performance related problems that are directly related to the undersized treatment processes. Given the fact that there are insufficient amounts of properly sized treatment units, the system has limited use in sizing of the treatment process.

4. Greenville Wastewater Treatment Facility

Greenville performance data between 2004 and 2006 indicates satisfactory discharge has historically been obtained, with less than 4.0 mg/l BOD and TSS discharge. There is a significant increase in ammonia-nitrogen discharge, showing an average of 32.3 mg/l, which can be attributed to decay of the biomass within the wetland. Given that this is the only wetland with sufficient influent and effluent data, design constraints should not be extrapolated from it.

Additional sources of data were consulted to determine adequacy of designs for both SF and SSF type constructed wetlands.

5. BOD Removal

In the case of BOD, there is a background concentration of BOD that neither type of constructed wetlands can go below. Background concentrations of BOD are caused by plant decomposition and previously settled influent TSS that has become resuspended. This background concentration can range from 2 to 12 mg/l, with a typical somewhere between 5 and 10 mg/l for an SF type constructed wetland (U.S EPA, 2000). For an SSF type constructed wetland, a background concentration will seasonally fluctuate due organic matter decomposition, but can range anywhere up to 18 to 45 mg/l (WERF, 2006).

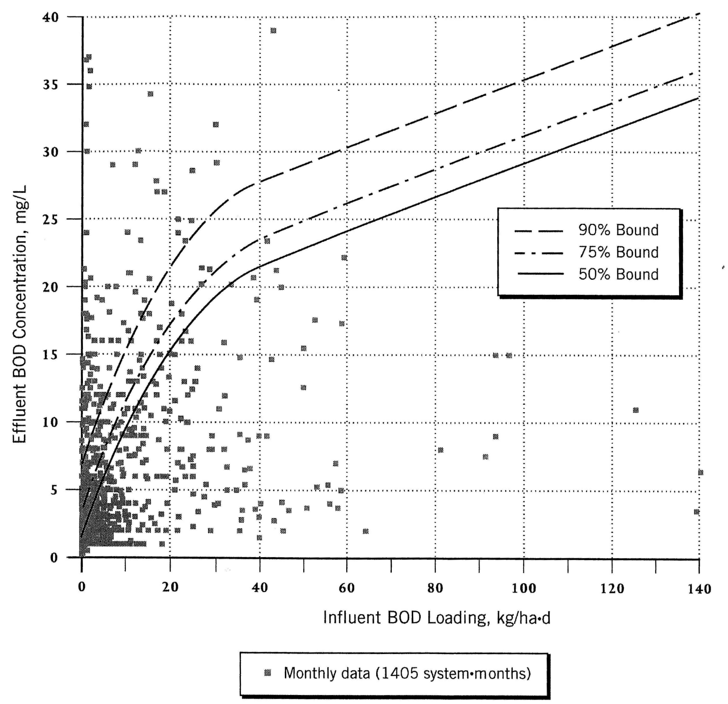
a) Surface Flow Wetlands

For SF constructed wetlands, there is a general trend of increased BOD discharge as compared to BOD loading rates. However, for facilities that display significantly lower loading rates, effluent BOD is controlled by the background BOD concentration (U.S EPA, 2000).

BOD loadings on an SF type constructed wetland should not be more than 53.5 lb/acre-d (US EPA, 2000). This level of loading has consistently achieved a discharge of not greater than 30 mg/l of BOD.

Constructed wetland treatment systems loading rates as compared to BOD discharge are also published (WERF, 2006). The chart indicates that an SF type constructed wetland loaded up to 53.5 lb/acre-d should be capable of achieving a monthly BOD discharge of not more than 30 mg/l, 90% of the time. This reference further indicates that one should not extrapolate the loading rates beyond 53.5 lb/acre-d due to the likelihood of anaerobic conditions being generated.

Figure 3-1
SF BOD Removal Data
(WERF, 2006 p. 6-4)



Given the above reported information, it is recommended that a BOD loading rate of 53.5 lb/acre-d be implemented when sizing SF constructed wetlands for BOD discharge of 30 mg/l or less.

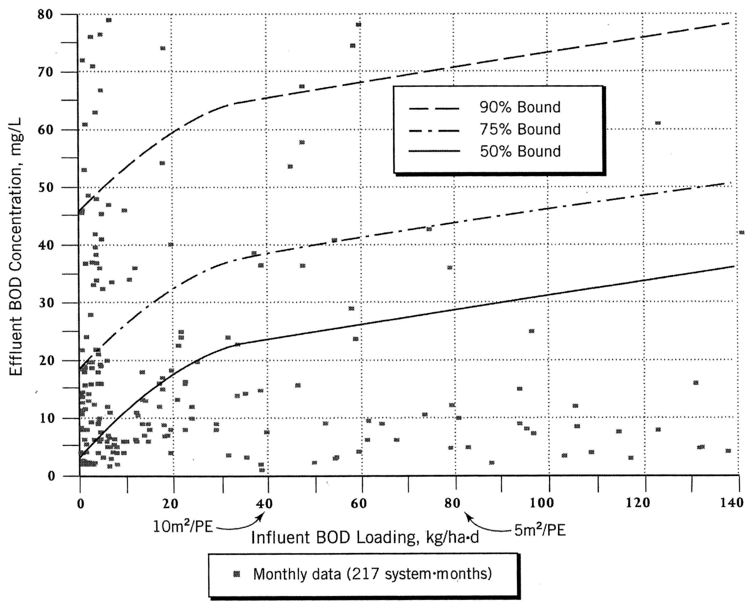
b) *Subsurface Flow Wetlands*

For SSF constructed wetlands, the primary mechanisms for BOD removal are flocculation, settling and filtration (U.S EPA, 2000). Background concentrations of BOD are also significant for SSF constructed wetlands.

BOD loadings on SSF constructed wetland should not be more than 53.5 lb/acre-d (US EPA, 2000). This level of loading has consistently achieved a discharge of not greater than 30 mg/l of BOD.

Alternative research provides confidence levels of loading rates as compared to BOD discharge (WERF, 2006). The figure indicates that an SSF type constructed wetland loaded up to 71.4 lb/acre-d should be capable of achieving a monthly BOD discharge of up not more than 30 mg/l, only 50% of the time. Please note that this reference further indicates that there is significant month-to-month variability of BOD discharge that is directly related to background BOD concentrations. Given this knowledge that significant variability is seen within the data set, a more conservative design approach is to apply the EPA loading rate of 53.5 lb/acre-d.

Figure 3-2
SSF BOD Removal Data
(WERF, 2006, p. 8-3)



6. <u>TSS Removal</u>

As in the case of BOD, there is a background concentration of TSS that neither type of constructed wetlands can go below. Background concentrations of TSS are similar in nature to background concentrations of BOD and are caused by plant decomposition and previously settled influent TSS that has become resuspended. This background concentration can range from between 2 and 5 mg/l, with a typical of approximately 3 mg/l for an SF type constructed wetland (U.S EPA, 2000). For SSF constructed wetland, a background concentration will also seasonally fluctuate due organic matter decomposition, but can range anywhere up to 19 to 39 mg/l (WERF, 2006).

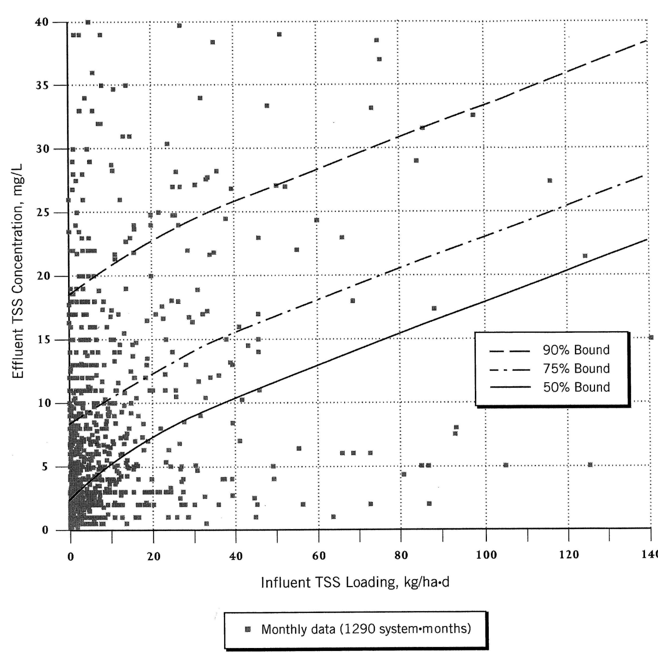
a) Surface Flow Wetlands

SF constructed wetlands are fairly effective at removing TSS (US EPA, 2000). Due to the relatively small background concentration of TSS associated with properly designed SF constructed wetlands, background concentrations of TSS typically do not impact the overall treatment process.

TSS loadings on an SF type constructed wetland should not be more than 44.5 lb/acre-d (US EPA, 2000). This level of loading has consistently achieved a discharge of not greater than 30 mg/l of TSS.

Alternative research provides confidence levels of loading rates as compared to TSS discharge (WERF, 2006). The figure indicates that an SF type constructed wetland loaded up to 64.2 lb/acre-d should be capable of achieving a monthly TSS discharge of up not more than 30 mg/l, 90% of the time.

Figure 3-3
SF TSS Removal Data
(WERF, 2006, p. 6-5)



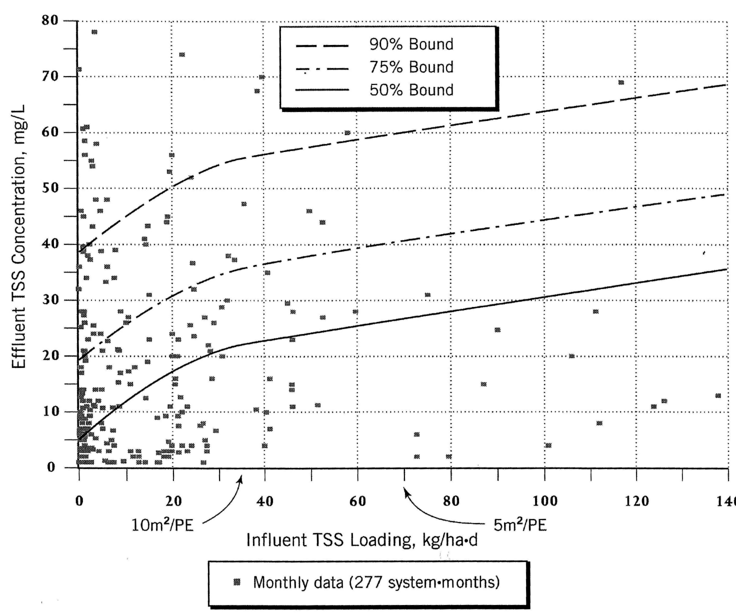
b) *Subsurface Flow Wetlands*

For SSF constructed wetlands, the primary mechanisms for TSS removal are flocculation, settling and filtration (U.S EPA, 2000).

TSS loadings on an SSF type constructed wetland should not be more than 178 lb/acre-d (US EPA, 2000). This level of loading has consistently achieved a discharge of not greater than 30 mg/l of TSS.

Alternative research provides confidence levels of loading rates as compared to TSS discharge (WERF, 2006). The figure indicates that an SSF constructed wetland loaded up to 89.2 lb/acre-d should be capable of achieving a monthly TSS discharge of up not more than 30 mg/l, only 50% of the time. Further the reference states that when sizing SSF constructed wetlands, BOD loading rates are invariably more restrictive than TSS loading rates. Therefore, an SSF constructed wetlands that are sized for BOD removal typically will achieve TSS removal. Only in the most extreme treatment cases should the designer be required to evaluate TSS loading rates for SSF constructed wetlands.

Figure 3-4
SSF TSS Removal Data
(WERF, 2006, p. 8-4)



7. Ammonia Nitrogen Removal

Ammonia nitrogen is a contaminant of particular interest as it relates to the effluent from a WWTP. Ammonia-nitrogen, when introduced into a receiving stream can deplete available dissolved oxygen, and can be toxic to aquatic life. Ammonia nitrogen however is only one component of a total Kjeldahl nitrogen (TKN) that is typically sampled for in the influent of WWTF. The other, organic nitrogen, represents nitrogen that will largely transform into ammonia nitrogen as it travels through the collection and treatment process.

Current monitoring regulations within Iowa require sampling for ammonia-nitrogen discharge. However, given the fact that the data obtained for this manual only identified TKN influent and effluent concentrations, TKN data is presented herein. The reader should be cognizant of the fact that ammonia-nitrogen is a component therein of TKN.

SF constructed wetlands typically do not contain the wastewater long enough to promote significant ammonia removal by nitrification (U.S EPA, 2000). TKN removal is believed to be temperature dependant (Kadlec and Knight, 1996). Given this, the majority of ammonia nitrogen removal occurs by sedimentation.

There is a background concentration of TKN that neither type of constructed wetlands can go below. This background concentration can range from 1 to 5 mg/l, with a typical around 2 mg/l for an SF type constructed wetland (WERF, 2006). For an SSF type constructed wetland, a background concentration will seasonally fluctuate, but can range anywhere up to 19 to 31 mg/l.

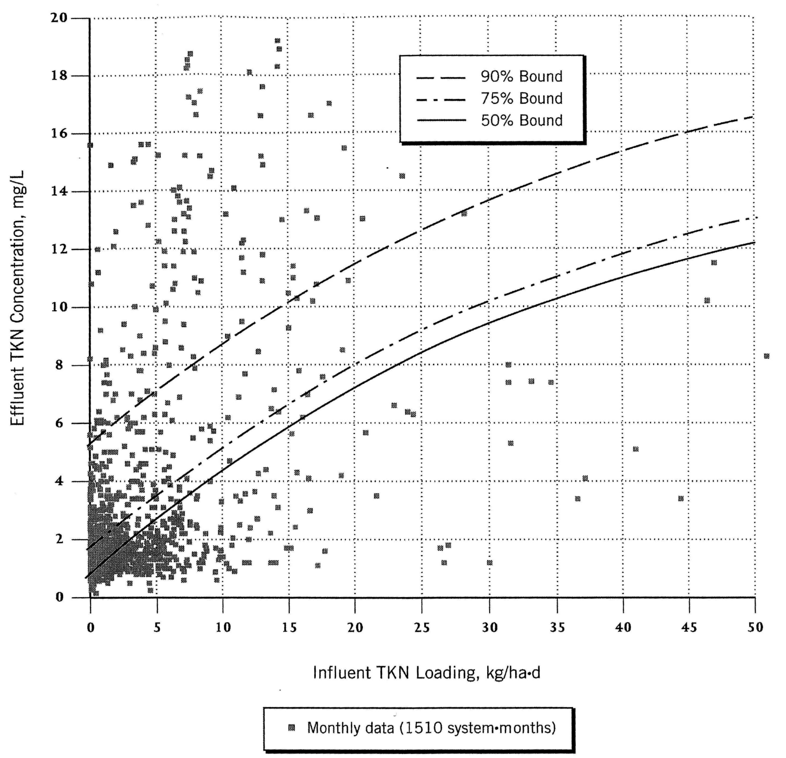
a) Surface Flow Wetlands

SF constructed wetlands have had varying degrees of success in removing TKN from a wastewater stream. In general, SF constructed wetlands that have open water spaces have a much greater chance of removal of TKN as compared to those SF type systems that are completely vegetated, without an open water space. This is due to the additional oxygen provided within the SF wetland at the open water space, which results in increases TKN removal performance (U.S EPA, 2000).

TKN loadings on an SF type constructed wetland with open water spaces should not be more than 4.5 lb/acre-d (US EPA, 2000). This level of loading has achieved some level of reduction in TKN.

Alternative research provides confidence levels of loading rates as compared to TKN discharge (WERF, 2006). The figure indicates that an SF constructed wetland loaded up to 13.3 lb/acre-d should be capable of achieving a monthly TKN discharge of up not more than 10 mg/l, 90% of the time. However, given the previously discussed constraints of temperature related to the effluent from SF type constructed wetlands, the reader of this manual should be cautioned against the assumption of consistently achieving this level of discharge due to limited nitrification capability in the winter months.

Figure 3-5
SF TKN Removal Data
(WERF, 2006, p. 6-6)



Given this information, the more conservative approach for designing TKN removal mechanisms within SF constructed wetlands with open water spaces is to use a 4.5 lb/acre-d loading rate, with specific caution and concerns addressed over the influence of freezing within the wetland itself.

b) *Subsurface Flow Wetlands*

For SSF type constructed wetlands the processes involved within the treatment bed are largely anaerobic. Little to no atmospheric oxygen is capable of being transmitted to the wastewater stream. Free oxygen is required to nitrify ammonia, which is the major constituent of TKN. Therefore, SSF constructed wetlands provide little to no TKN reduction, and should not be sized or used when TKN reduction is required.

8. Pathogen Reduction

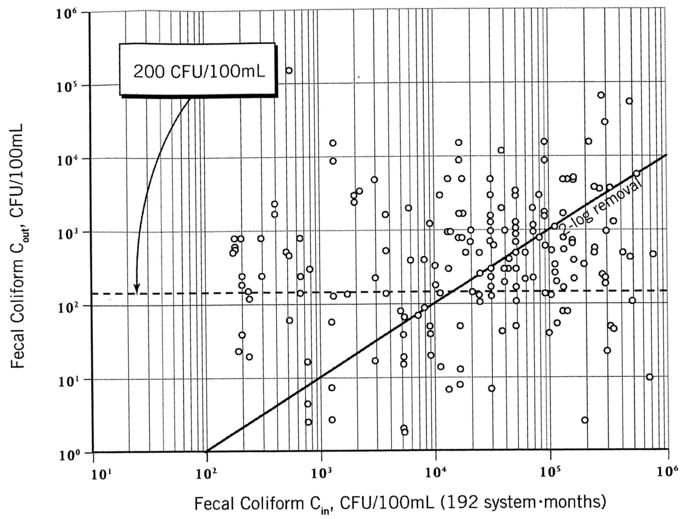
Pathogen reduction within constructed wetlands is accomplished through sedimentation, filtration and adsorption. Background concentrations of pathogens, in this case fecal coliform, are present in constructed wetland effluent due to vegetation cycles and wildlife activity. This background concentration can range from between 50 and 5,000 cfu/100 mL, with a typical of approximately 200 cfu/100 mL for an SF type constructed wetland (U.S EPA, 2000).

a) Surface Flow Wetlands

SF type constructed wetlands have had displayed extreme variability in their capability to remove fecal coliform, or other pathogens. Individual monthly values have been reported up to ten times larger than long term averages for the same treatment system (U.S EPA, 2000).

Fecal coliform readings on an SF type constructed wetland typically experience a 2-log reduction in influent versus effluent fecal coliform (US EPA, 2000). Should fecal coliform levels of less than 400 cfu/100 mL be required, additional disinfection mechanisms should be incorporated. EPA suggests that the inherent variability of pathogen reduction within a constructed wetland minimizes the level of assurance of achieving any consistent fecal coliform reduction. Given this information, alternative mechanisms for pathogen reduction should be implemented, if necessary, to consistently achieve an acceptable level of pathogen reduction.

Figure 3-6
SF Pathogen Reduction Data
(WERF, 2006, p 6-8)

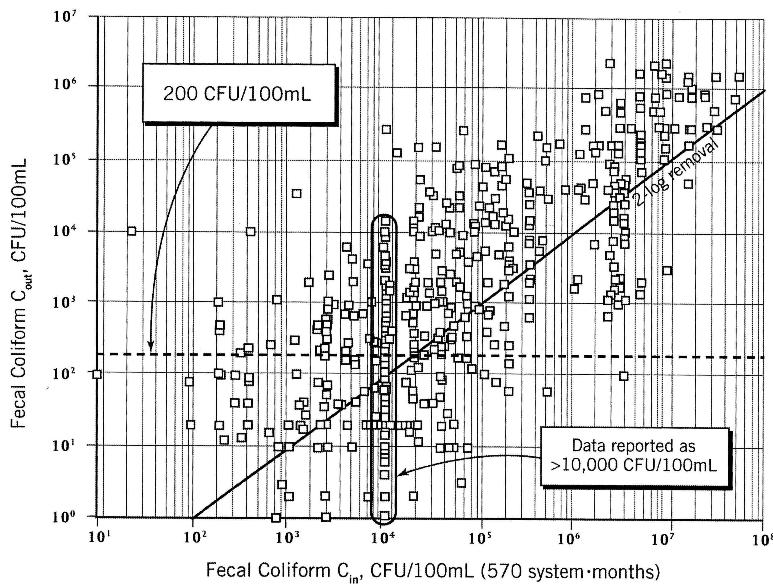


b) *Subsurface Flow Wetlands*

SSF constructed wetlands have also displayed great variability in their capability to remove fecal coliform, or other pathogens, similar to SF type systems.

Fecal coliform readings on SSF constructed wetland typically experience a 2-log reduction in influent versus effluent fecal coliform (US EPA, 2000). Should fecal coliform levels of less than 400 cfu/100 mL be required, additional disinfection mechanisms should be incorporated. EPA suggests that the inherent variability of pathogen reduction within a constructed wetland minimizes the level of assurance of achieving any consistent fecal coliform reduction. Given this information, alternative mechanisms for pathogen reduction should be implemented, if necessary, to consistently achieve an acceptable level of pathogen reduction.

Figure 3-7
SSF Pathogen Reduction Data
(WERF, 2006, p. 8-7)



B. Effluent Quality vs. Loading Rates

Areal loading rates specify a maximum loading rate per unit area for a given constituent. These loading rates have been previously defined in the last section. The loading rates have been determined using the following effluent concentration assumptions:

- BOD: 30 mg/l
- TSS: 30 mg/l
- TKN: 10 mg/l

The following table identifies the loading rates for both SF and SSF constructed wetlands that are applicable:

Table 3 -2 Recommended loading rates for Constructed Wetlands			
Type of Wetland	Parameter	Assumed Discharge Criteria (mg/l)	Required Loading Rate (lb/acre-d)
SF	BOD	30.0	53.5
	TSS	30.0	44.5
	TKN	10.0	4.5
	Pathogen removal [1]	N/A	N/A
SSF	BOD	30.0	53.5
	TSS	30.0	89.2
	TKN [2]	N/A	N/A
	Pathogen removal [1]	N/A	N/A
NOTES	1: Pathogen removal data suggests a 3-day HRT for a 2-log reduction in fecal coliform. Consistent compliance with disinfection limits can only be achieved through other disinfection mechanisms. 2. SSF constructed wetlands are anaerobic in nature therefore limited TKN removal occurs.		

C. Factors Effecting Performance

As with any wastewater treatment system, a properly functioning and operable constructed wetland depends on many factors that are specific to the location, type of wastewater treated, water balance, temperature and other factors. The reader of this manual is cautioned against only applying loading rates in determining applicable wetland treatment designs, without further investigating issues that could impact the performance of the proposed wetland system.

The following discussion surrounds some of the more common issues that have been found to impact wetland performance. The list herein should not be assumed to be comprehensive, as additional factors may be applicable. However, a short discussion concerning each of them is warranted as they have an impact on the selected treatment process.

1. <u>Surface Flow Wetlands</u>

SF constructed wetlands are typically shallow vegetated basins. They are designed to use physical, chemical and biological processes to remove organic material, total suspended solids, and pathogens. SF type constructed wetlands take advantage of these processes to provide a level of treatment that has already been discussed.

a) *Water balance*

The hydrology of an SF type constructed wetland is often considered to be the most important factor in maintaining wetland function (US EPA, 1999). In principle, the flow entering into a wetland is never equal to the flow exiting a wetland. Many additional factors affect the overall water balance within a wetland, including evapotranspiration, precipitation and infiltration.

Evapotranspiration (ET) is the combined loss of water from evaporation as well as plant transpiration. Because ET is diurnal, with its peak during the early afternoon, and it's minimum in the nighttime hours, discharge from a constructed wetlands can cease to occur during portions of the day (WERF, 2006).

For SF type constructed wetlands, specific ET rates have proven hard to quantify, therefore it is assumed to be a percentage of overall pan evaporation. A rate of 70 to 75% of pan evaporation, on average, has been assumed to be reasonable (U.S EPA, 2000).

Precipitation must also be included within an overall wetland hydraulic retention time calculation. A properly designed SF type wetland will limit water runoff from surrounding areas, but direct precipitation onto the exposed SF surface can have a direct impact on the overall size of the required treatment process (U.S EPA, 2000).

Without adequately accounting for all potential water sources the proposed wetland will invariably have operational and performance issues. Too much water into a system will limit settling and therefore increase discharge rates, while too little water into a wetland will stress vegetation resulting in potential loss of vegetative treatment capability.

b) *Hydraulic Retention Time*

SF type wetlands can be designed to operate over a wide range of depths, from 4 inches to 5 feet (US EPA, 1999). Further all zones within the SF constructed wetland must be designed to provide water depths compatible with the vegetation chosen.

Hydraulic detention time is equal to the volume of the wetland basin multiplied by the wetland porosity and then divided by the flow rate. The further complication within a hydraulic retention time evaluation is the potential for a wetland to short circuit. Should a short circuiting issue arise, it will impact effluent quality and overall treatment performance. Short-circuiting will be discussed later in this manual.

If proper design constraints are not included for addressing the water depth over varying water conditions, impacts will be seen in the vegetation, as well as the concentration of pollutants discharged. If an SF constructed wetland cannot handle all potential flows, significant backwater problems including flooding and overtopping of berms may result (US EPA, 1999).

c) *Aspect Ratio*

The aspect ratio is defined as the quotient of the average length of the major axis and the average width of the wetland. In general, SF type treatment wetlands with high length to width ratios are of greatest concern with respect to head-loss. However, treatment performance may improve with increased aspect ratios (US EPA, 1999).

SF constructed wetlands have been designed to have an aspect ratio from less than 1:1 to over 90:1. In general however, SF type constructed wetlands have been designed to incorporate an Aspect Ratio of greater than 1:1 (U.S EPA, 2000).

d) *Discrete Settling / Flocculation*

Dependent upon the type of pretreatment, a substantial portion of the incoming settleable solids may be removed by discrete settling within the inlet region of an SF constructed wetland. The use of inlet settling zones promotes the potential of discrete settling and mitigates the potential for plugging (U.S EPA, 2000).

The inlet settling zone should be designed and constructed across the entire width of the constructed wetlands. The settling zone should provide for a hydraulic retention time of 1 day, as the majority of settleable solids are removed during this time period. The recommended depth is approximately 3 feet (U.S EPA, 2000).

For wetland systems that receive pond effluent, the primary source of suspended solids is algal cells. These cells have a specific gravity close to water, such that they will remain suspended within the water column. It is likely that many of these cells will be removed by sedimentation in wetlands covered by emergent vegetation. However, attempts to settle algae in SF constructed wetlands with open areas have not been successful due to the presence of light and wind action (U.S EPA, 2000).

e) *Media Gradation*

Soils with high humic and sand components are easier for aquatic macrophytes to migrate through. The soil substrate for SF type constructed wetlands should be loam, well loosened and at least 6 inches deep. Should significant amounts of vegetation float to the surface during water changing events, denser soil substrates, such as a sandy loam or loam gravel mix should be used (U.S EPA, 2000).

f) *Resuspension*

In SF type constructed wetlands, velocity induced resuspension is minimal. Water velocities are too low to resuspend settled particles from the bottom sediments. Resuspension of settled particles may also occur through the slow degradation of particulate biomass, resulting in background concentrations of TSS and BOD (U.S EPA, 2000).

g) *Temperature*

The temperature of an SF type wetland influences both the physical and biological processes within the system. Ice formation may also alter wetland hydraulics and limit oxygen transfer. Decreased temperatures have been shown to reduce rates of biological reactions.

Predicting and understanding the influence of water temperatures within an SF type constructed wetlands is essential in defining the limits of its operation. Temperatures can be estimated using an energy balance that accounts for gains and losses of energy with respect to the wetland over time and space (US EPA, 1999). Temperature data is extremely site specific and therefore additional evaluations related to site constraints are warranted. In general Energy inputs (including solar radiation, energy within the entering wastewater, and ground heat) minus Energy outputs (including evapotranspiration, energy losses to the air and energy of the leaving water) equal the total change in energy storage within the system.

Excluding specific modeling, allowances within an SF constructed wetlands for the formation of an ice layer should be included within the design. After formation of the ice layer, the water level may be lowered 6 to 12 inches in order to facilitate an insulating air layer between the water surface and the ice layer. However, without the inclusion of a snow layer and air gap, the overall insulating capability of ice is limited (Wallace et. al, 2000).

2. Subsurface Flow Wetlands

SSF constructed wetlands are shallow gravel and soil beds planted with wetland macrophytes. They are designed to treat effluent from primary treatment mechanisms. SSF constructed wetlands have the water surface interface with the atmosphere contained within the rock bed. They are anaerobic in nature and therefore provided little to no nitrification capability.

They are designed to receive effluent from a septic tank, clarifier or other settling mechanism. SSF constructed wetlands should not be used when lagoons provide the primary treatment, as algae has a significant negative impact on their performance. If algae growth and its potential impact upon the downstream SSF constructed wetlands can be minimized, lagoon systems could be implemented (U.S EPA, 2000). Should the reader of this manual wish to implement that approach, additional research and quantitative data on performance should be provided to the DNR prior to implementation.

a) *Water balance*

As with SF constructed wetlands, SSF constructed wetlands must be adequately designed for all potential sources of water into and out of the system. Flows from precipitation events have a relatively small impact on the performance of the SSF constructed wetlands, due to it's inherently small surface area, as compared to SF type constructed wetlands (U.S EPA, 2000).

b) *Water Level Estimation*

In order to try and eliminate the potential for surfacing, that is water migrating to the surface of the SSF constructed wetlands, a proper design and estimation of water level should be performed. The water level in an SSF constructed wetlands is first controlled at the outlet structure. Hydraulic gradients and slopes control the level of water from the outlet structure through the SSF constructed wetlands.

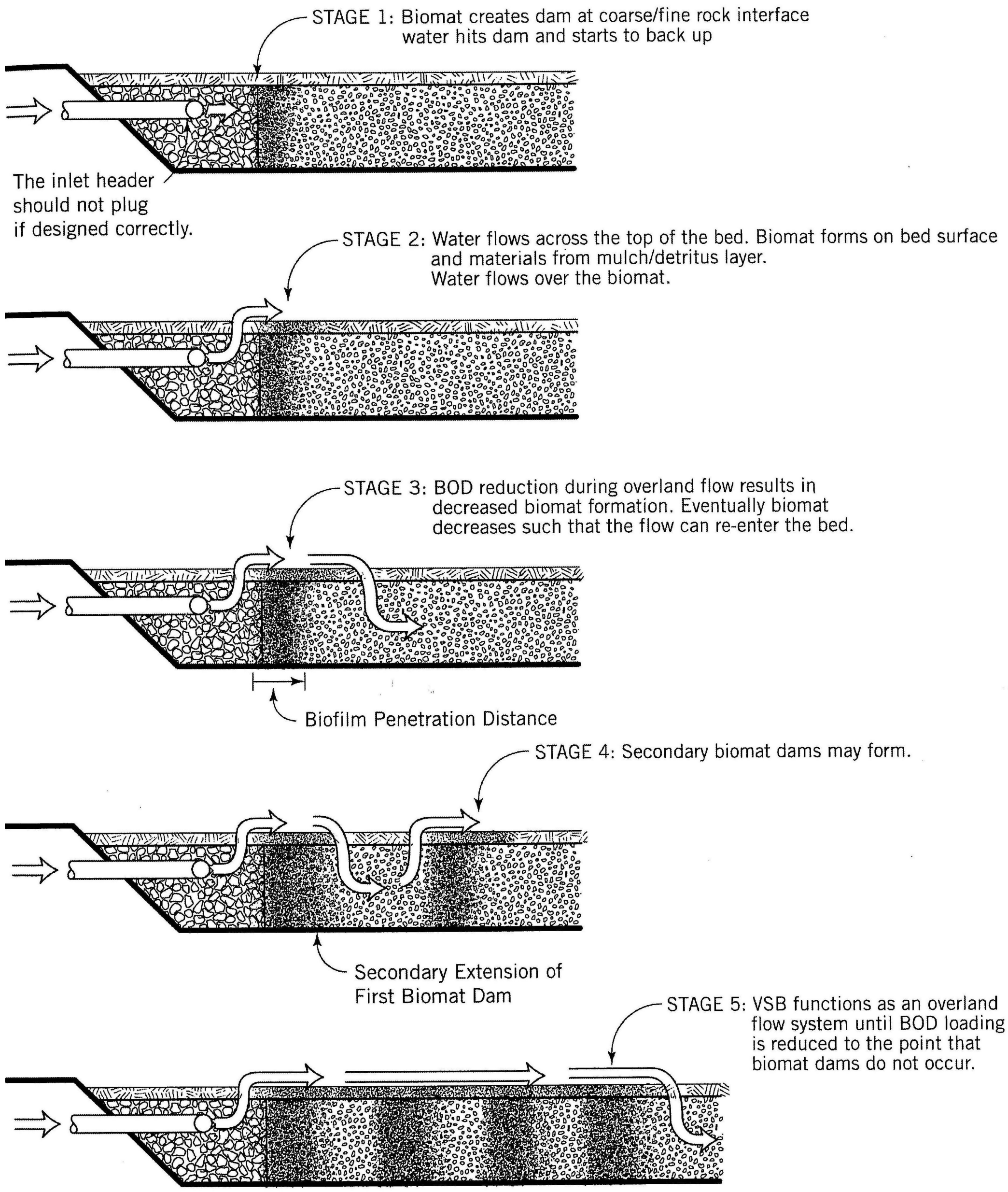
Darcy's law can be used to determine flow through an SSF constructed wetlands. With properly designed hydraulic conductivity of the gravel media, the effects and potential of surfacing can be minimized (U.S EPA, 2000).

However, biofilms or biomats will form within the annular spaces of the media. These biofilms are directly related to the loading of the proposed SSF constructed wetlands. Further, biomat generation is typically greatest closest to the inlet of the SSF constructed wetlands (WERF, 2006). A typical progression of clogging within an SSF type constructed wetlands can be seen below.

c) *Discrete Settling / Flocculation*

One of the primary mechanisms of removing suspended solids is flocculation and settling with an SSF type constructed wetland. SSF type constructed wetlands act in essence like large gravel filters, and therefore are susceptible to clogging. Clogging can lead to failure of the SSF constructed wetlands as shown in Figure 3-8.

Figure 3-8
Stages of Clogging in an SSF constructed wetlands
(WERF, 2006, p. 4-9)



d) *Filtration and Media Gradation*

Media within SSF constructed wetlands perform several functions, including: providing rooting material, providing even distribution of flow, allowing surface area for microbial growth and to filter and trap particulate matter. For successful plant establishment, the uppermost layer must be conducive to root growth. Inlet and outlet zones must provide sufficient free annular space to minimize clogging.

e) *Temperature*

The temperature of an SSF wetland influences both the physical and biological processes within the system. Ice formation may also alter wetland hydraulics and limit oxygen transfer. Decreased temperatures have been show to reduce rates of biological reactions.

Because an SSF constructed wetland does not have an open surface to the atmosphere, freezing effects are not as dramatic as in SF type constructed wetlands. Additional insulating mechanisms should be placed on the surface of the SF type constructed wetlands to help minimize heat loss. Insulating mulch, leaf litter, or other materials should be placed on the surface in sufficient depths based upon the local expected ambient air conditions (WERF, 2006). In fact, mulch was installed at the Indian Creek Nature Center in Cedar Rapids and proved to be highly effective in preventing the system from freezing (Wallace and Patterson, 1996).

IV. IDNR BACKGROUND AND REQUIREMENTS

Under the assumptions and constraints of this manual, the DNR is the jurisdictional entity that provides oversight and approval of wastewater treatment system design and operation. As defined within §567 IAC 64, the DNR provides that oversight through the issuance of permits to construct and NPDES operational discharge permits. These permits must be obtained and authorized before any wastewater treatment system can become operational.

The reader of this manual is directed to review the requirements, as outlined within §567 IAC 64, for the currently enforced rules and regulations regarding wastewater construction and operation in Iowa.

Criteria for monitoring of any discharge are statutorily identified within §567 IAC 63. This criterion is based upon method of discharge, either continuous or controlled and the size of the facility with respect to population.

As identified within §567 IAC 64, as well as the current wastewater treatment design standards, Constructed wetlands are not currently identified as a treatment process. Therefore, there is no current design standard. It is the intent of this manual to provide a non-codified standard of design and criteria for establishing constraints of implementation of constructed wetlands treatment systems.

V. DESIGN GUIDANCE

Constructed wetlands are treatment systems that provide for removal of pollutants through a variety of mechanisms. While at first glance, these mechanisms seem simplistic; the interaction between each mechanism can become complex. Models have been developed that try to identify how each mechanism interacts; however these models can become complex very quickly. Therefore, the design of constructed wetlands focuses on determining detention time, required surface area, loading rates and medium and water depth.

This manual is being written under the assumptions of design populations of 25, 100 or 250 people. Given these constraints, Influent wastewater flow and biological load can be determined.

According to current design standards, AWW flowrate can be assumed to be equal to 100 gpcpd. Further, a peaking factor of 4.4 can be applied to obtain the PHWW flowrates for the given populations. This flowrate is acceptable for use when determining sizes of both SF and SSF constructed wetlands. Table 5-1 identifies influent wastewater generation rates for the given populations.

Table 5-1
Influent Wastewater Flow Rates

Population Equivalents	AWW Flow (gallons/Day)	PHWW Flow (gallons/day)
25	2,500	11,000
100	10,000	44,000
250	25,000	110,000

Further, the constraints of this manual identify a standard residential influent BOD concentration of 250 mg/l, influent TSS of 250 mg/l and a TKN of 40 mg/l. The resultant design loads are as follows:

Table 5-2
Influent Wastewater Loading Rates

Population Equivalents	BOD Load (lb/day)	TSS Load (lb/day)	TKN Load (lb/day)
25	5.2	5.2	0.8
100	20.8	20.8	3.3
250	52.1	52.1	8.3

Specific issues regarding increased loads that may result from nonresidential higher strength wastewater are outside of the constraints of this manual. Should the reader of this manual wish to implement constructed wetlands for treatment of higher strength waste, additional research and documentation will be required to assure adequate design and performance.

The following sections of this manual will discuss the steps taken to complete a constructed wetlands design.

A. Design Process Overview

The general process used by this manual to design a constructed Wetland in accordance with the following steps:

1. Determine design requirements
   - a. Characterize design flow rates
   - b. Characterize influent wastewater makeup
   - c. Determine effluent discharge location and limits

2. Determine Water balance Limitations
   - a. Determine Precipitation (SF Wetlands)
   - b. Determine Evaporation (SF Wetlands)
   - c. Determine Outfall

3. Size Pretreatment Unit
   - a. Septic Tank Size, number and layout

4. Surface Flow Wetland Design
   - a. Select size by loading rate
   - b. Determine Configuration
   - c. Apply Safety Factor
   - d. Determine Water Depth
   - e. Integrate an Aspect Ratio
   - f. Determine Hydraulic Retention Time
   - g. Prepare Hydraulic Design
   - h. Apply Open Water/Vegetation Ratio
   - i. Determine Depth of Media and Gradation
   - j. Layout settling Zone
   - k. Design Inlet and Outlet Structures

5. Subsurface Flow Constructed Wetland Design
   a. Select Size by Loading Rate
   b. Determine Configuration
   c. Determine Media Depth and Gradation
   d. Apply Safety Factor
   e. Determine Maximum Water Depth
   f. Determine Hydraulic Conductivity
   g. Determine Minimum Cell Width
   h. Integrate Freezing Concerns
   i. Design Inlet and Outlet Structures

B. Siting Concerns

In general, constructed wetland systems can be constructed within most siting constraints. Good engineering practice dictates that a constructed wetland is sited such that no extraneous surface water runoff is allowed to flow into the constructed wetlands. Hydraulic overload is a prime failure mechanism for both SF and SSF constructed wetlands. Therefore, the constructed wetlands should be located and designed in conformance with the current Iowa DNR Wastewater Treatment Design Standards, including:

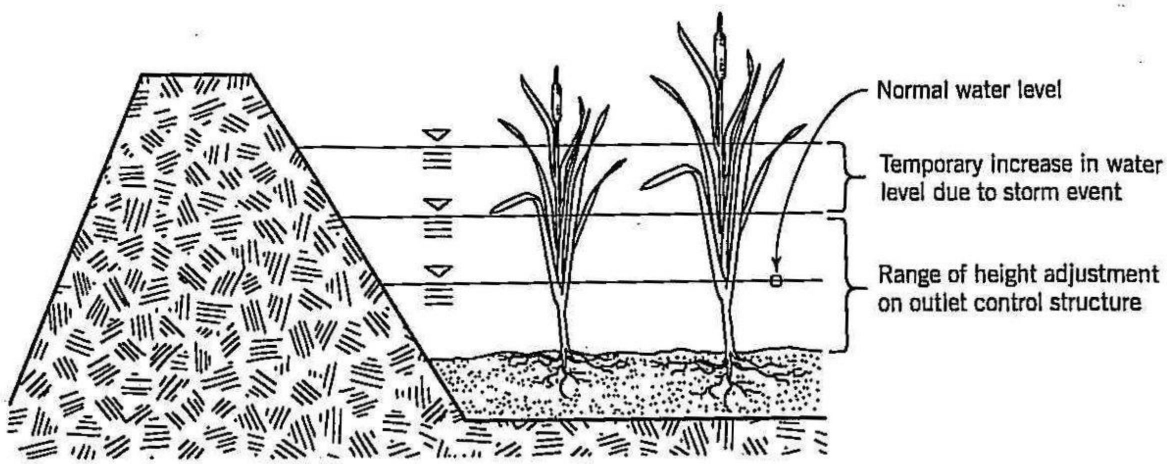
- Containment berms surrounding the constructed wetlands that do not allow surface water run-on into the treatment area, (in accordance with the wastewater facility design standards);
- Protection against 100-year flood events; (in accordance with the wastewater facility design standards);
- Vertical separation from maximum ground water and bedrock (in accordance with the wastewater facility design standards);
- Liner systems below the constructed wetlands should provide the same level of containment as Lagoon systems within Iowa (in accordance with the wastewater facility design standards).

C. Water Balance

Water balance is critical to the overall success or failure of a constructed wetlands system. The flow into a wetland is never equal to the flow out of a wetland system. Evapotranspiration, Precipitation, and infiltration all have an impact on the overall water balance within constructed wetlands. As such, they must be accounted for.

Without adequately accounting for all potential water sources the proposed wetland will invariably have operational and performance issues. Too much water into a system will limit settling and therefore increase discharge rates, while too little water into a wetland will stress vegetation resulting in potential loss of vegetative treatment capability.

Figure 5-1
Precipitation Effects on Freeboard Capacity – SF Constructed Wetlands
(WERF, 2006, p. 6-16)



1. <u>Inflow</u>

Inflow into a constructed wetlands has already been established to be equal to the wastewater generation rates identified. AWW flowrates should be used to evaluate average design constraints, while PHWW flowrates should be used to evaluate hydraulic conditions, in order to establish sufficient capacity within the constructed wetlands to contain the head required to move the wastewater through the wetlands.

2. <u>Precipitation</u>

Precipitation is the direct capture of rain or snow plus any runoff from surrounding earthen berms. All hydraulic control devises must be sized to accommodate a water generation from both the PHWW flowrate and the 25-year, 24-hour storm event.

According to Technical Release 55, from the NRCS, the average 25-year, 24-hour rainfall event throughout Iowa can be assumed to 5.5 inches of rain. While site-specific modifications to this value can be interpolated, it is reasonable to assume this value for precipitation throughout the state.

Further, given the geologic siting constraints of a containment berm surrounding any constructed wetland minimal water run-on should occur; therefore the overall precipitation component (P) is equal to 5.5 inches of rain times the area of the wetland.

3. Evaporation

For SF constructed wetlands, specific ET rates have proven hard to quantify, therefore it is assumed to be a percentage of the overall pan evaporation. SSF type constructed wetlands must be adequately designed for all potential sources of water into and out of the system. Evapotranspiration rates vary dependant upon the Macrophyte used.

ET estimates within the state are specific to each site location and therefore specific pan evaporation rate tests should be performed to determine actual evaporation rates, however, mean annual lake evaporation within the state of Iowa has been estimated to be upwards of 20 to 30 inches of water per year by the US Water resources council. Current estimates of annual precipitation range within 20 to 30 inches of water per year.

4. Outflow

If a constructed wetland is anticipated to receive large amounts of clear water, an overall water balance should be completed for either an SF or SSF type constructed wetland. The water balance should be performed to determine if the wetlands is sized properly for the potential water generation.

D. Primary Treatment Requirements

Primary Treatment is absolutely essential for proper SF and SSF constructed wetlands operation. Primary treatment should be achieved through the use of a septic tank properly sized to remove large solids and other deleterious materials.

For purposes of this manual, septic tanks have been assumed to be used for primary treatment. However, lagoons may also be used for removal of primary constituents prior to introduction of the wastewater into the SF constructed wetlands. For SF Type constructed wetlands, aerated lagoons are the preferred over facultative lagoons. This is due primarily to the fact that aerated lagoons have the capability of removing and limiting algae growth. Algae if present in the primary treatment system will impact and grow in the downstream constructed wetlands. For SSF type constructed wetlands, lagoons are not the preferred method for primary treatment (US EPA, 2000). This is primarily due to the fact that lagoon systems may produce effluent high in suspended solids, which in turn results in plugging and clogging of the constructed wetlands

Techniques for sizing of septic tanks are identified within the Appendix A. Septic tank systems may be effectively used for both the SF and SSF constructed wetlands.

1. Septic Tank

A septic tank is used to remove solids from the wastewater by settling and floatation. To a lesser degree, reducing influent BOD is needed prior to discharge to a treatment/dispersal component. Systems employing continuous, mechanical removal of primary sludge, such as a primary clarifier, are not considered feasible due to the cost of the mechanical equipment, and the degree of operational oversight needed. Specifics regarding septic tank sizing and implementation can be found within Appendix A of this manual.

a) Design Constraints

Given these septic tank design constraints, the following sizing may be seen for 25, 100 and 250 people:

Table 5-3
Septic Tank Sizing

Population Equivalents	AWW Flow (gallons/Day)	Resultant Septic Tank Volume*
25	2,500	5,000
100	10,000	20,000
250	25,000	50,000

Given the previous removal efficiencies and known loading rates, the following septic tank effluent loads may be determined:

Table 5-4 Septic Tank Effluent				
Population Equivalents	**Influent Parameter**	**Load (lb/day)**	**Assumed Septic Tank Removal Rate**	**Effluent Load (lb/day)**
25	BOD	5.2	50%	2.6
	TSS	5.2	50%	2.6
	TKN	0.8	0%	0.8
100	BOD	20.8	10%	10.4
	TSS	20.8	50%	10.4
	TKN	3.3	0%	3.3
250	BOD	52.1	10%	26.1
	TSS	52.1	50%	26.1
	TKN	8.3	0%	8.3

E. Surface Flow Wetlands (SF)

SF constructed wetlands are sized based upon loading rates and other factors. The first component of design is to assign loading rates to determine adequate sizes of the SF constructed wetlands. After determining an appropriate size, a configuration and aspect ratio are assigned. Finally hydraulic considerations are evaluated.

SF wetlands have open water surfaces that are subject to freezing. This freezing action limits the nitrification of ammonia nitrogen, as cold temperatures limit this process. Ammonia nitrogen removal should not be counted on during these cold weather months. However, temperature effects including dynamic modeling of thermal changes through the constructed wetlands can be performed to demonstrate capabilities of ammonia removal. These modeling efforts are outside of the limits of this manual.

1. <u>Loading Rates</u>

Given the BOD loading rate of 53.5 lb/acre/day, a TSS loading rate of 44.5 lb/acre/day, and TKN loading rate of 4.5 lb/acre/day the following minimum sizes for SF constructed wetlands treating 25, 100 and 250 population equivalents are applicable:

Table 5-5 Minimum SF Size by Loading rates				
Population Equivalents	**Parameter**	**Influent Load (lb/d)**	**Loading Rate (lb/acre/day)**	**Minimum Size (acres)**
25	BOD	2.6	53.5	0.05
	TSS	2.6	44.5	0.06
	TKN	0.8	4.5	**0.18**
100	BOD	10.4	53.5	0.19
	TSS	10.4	44.5	0.23
	TKN	3.3	4.5	**0.74**
250	BOD	26.1	53.5	0.49
	TSS	26.1	44.5	0.59
	TKN	8.3	4.5	**1.85**

In all cases, the limiting condition is the TKN loading rate in order to obtain a discharge of 30 BOD, 30 TSS and 10 TKN from the SF constructed wetland.

2. <u>Configuration</u>

The configuration of the SF constructed wetlands should provide for redundancy and backup so as to assure adequate discharge during potential upsets. Documentation shows that the design of SF type constructed wetlands that include a number of cells in series will consistently produce a higher quality effluent (US EPA, 2000).

Operational flexibility is greatly increased with multiple cells having appropriate piping between them in order to route wastewater around a cell that needs to be taken off line.

Therefore, it is recommended that a minimum of two trains should be constructed for any SF type constructed wetlands. For those influent flows that are higher than 10,000 gpd, each train should have a minimum of two cells.

a) Design Constraints

Given the design constraints of this manual of 25, 100 and 250 people the following minimum number of cells is applicable.

Table 5-6					
Minimum Size Per Cell					
Population Equivalents	**Minimum Total Size (Acres)**	**Minimum Number of Trains**	**Minimum Cells per Train**	**Minimum number of Cells**	**Minimum Size per Cell (acres)**
25	0.18	2	1	2	0.09
100	0.74	2	2	4	0.18
250	1.85	2	2	4	0.46

3. Safety Factor / Redundancy

Prudent design constraints also mandate the inclusion of a safety factor within all design. This safety factor will provide for a level of redundancy within the operation of each cell. A safety factor of between 15 and 25% is prudent (Crites and Tchobanoglous, 1998).

a) Design Constraints

Applying the safety factor to the design reveals the following table:

Table 5-7					
Minimum Size per Cell with Reliability					
Minimum Size per Cell (acres	**Safety Factor (%)**	**Minimum Size per cell (Acres)**	**Total Acreage with One Train out of Service**	**Table 5-5 Required Minimum Size (Acres)**	**Resultant Level of Reliability (%)**
0.09	15	0.10	0.10	0.18	55
0.18	15	0.21	0.42	0.74	57
0.46	15	0.46	1.06	1.85	57

The above design including a 15% safety factor results in a reliability level of a minimum of 58%, as calculated by the use of the current Iowa DNR standards. Reliability is defined as the minimum size of the remaining treatment units, with one train of treatment units out of service. Unit Process Reliability Criteria B (as identified within 14.5.2.2 of the design standards) has been assumed for the purposes of this manual. According to Reliability Criteria B, there shall be a sufficient number of units such that, with the largest unit out of service, the remaining units shall have a design load capacity of 50% of the total design loading to that unit. Reliability criteria can change dependant upon the discharge location and therefore the DNR should be contacted to determine specific criteria to be implemented.

4. Minimum Depth of Water

SF constructed wetlands must be designed to be compatible with the macrophytes that are contained within the wetland. As such, most emergent type wetland plants cannot tolerate more than 2 feet of submergence when subjected to wastewater loadings (WERF, 2006). Therefore, in order to assure that the plants are not subjected to excessive amounts of water depth, the design water depth should be one foot for all emergent vegetation.

5. Aspect Ratio

The aspect ration of an SF constructed wetlands is defined as the length to width ratio. Historical documents identify that SF constructed wetlands have been designed with aspect ratios between 1:1 to 90:1.

Aspect ratio's between 3:1 and 5:1 are optimal (US EPA, 2000). Should the designer wish to use aspect ratios greater than 10:1, additional hydraulic headloss considerations should be examined.

For purposes of this manual an aspect ratio of 3:1 has been implemented.

a) Design Constraints

Given the previously calculated minimum cell size for each design population, and an aspect ratio of 3:1, the following dimensions can be seen.

Table 5-8
Resultant Cell Dimensions

Population Equivalents	Minimum Size per Cell (acres)	Aspect Ratio (length to Width)	Width (feet)	Length (feet)
25	0.10	3:1	40	120
100	0.21	3:1	60	180
250	0.46	3:1	85	255

6. Hydraulic Retention Time

The nominal hydraulic retention time is defined as the ratio of the useable wetland water volume to the average flowrate (AWW). While water is contained within the pore space of all wetland soils, for SF type constructed wetlands, a simplifying assumption ignoring the porosity of the soils can be made for the hydraulic retention time calculation.

Therefore; the hydraulic retention time is equal to:

$$t = (V\varepsilon)/Q$$

Where: V = Wetland volume neglecting vegetation
ε = Porosity, Assumed 0.85 (WERF, 2006)
Q = Flow (AWW) cfd

a) *Design Constraints*

Given the previously determined length and width for each population equivalent, the following hydraulic retention time for each cell can be found:

Table 5-9
Hydraulic Retention Time

Population Equivalents	Total Volume (Cubic Feet)	AWW Flow (cf/d)	Porosity	Hydraulic Retention Time (Days)
25	9,600	334	0.85	24.4
100	43,200	1,337	0.85	27.4
250	86,700	3,342	0.85	22.1

7. Hydraulic Design

The water level within an SF constructed wetlands is controlled at the effluent control structure. Each cell should have a separate control structure to allow for water levels to be adjusted independently (WERF, 2006). Each hydraulic control structure should have enough vertical adjustment to allow adjustment through the full range of water levels through the entire facility.

A headloss evaluation should be completed for each outlet structure under both design peak flows and the addition of the 25-year, 24-hour storm flow event. Headloss calculations are required to be performed so that sufficient freeboard is contained within each cell.

Each cell should contain the maximum amount of headloss plus an additional 2 feet of freeboard. This design constraint will result in assurances that all influent wastewater is contained within the constructed wetlands.

a) Design Constraints

For purposes of this manual, it has been assumed that the discharge structure for each cell is an adjustable 60-degree V-notch weir. Head over a V-notch weir is defined by the following equation.

$$Q = 1.443H^{2.5}$$

Where: Q = Flow (cfs)
H = Weir Height (feet)

A 25-year, 24-hour storm event is on average throughout the state equal to 5.5 inches. Further, assumptions have been made that no additional storm water is being routed into the SF constructed wetlands. If additional storm water (besides that falling onto wetland footprint), additional storm water calculations must be completed. Also note, that the PHWW flowrate is split in half due to multiple trains being constructed for each SF constructed wetlands.

Table 5-10
Headloss Calculations

Population Equivalents	Minimum Size per Cell (square feet)	Flow Rate of 25-year, 24-hour Hour Storm (cfs)	PHWW Flowrate (cfs)	Total Peak Flowrate to Cell (cfs)	Resultant Maximum Head over discharge weir (feet)
25	4,800	0.03	0.01	0.04	0.24
100	10,800	0.06	0.07	0.13	0.38
250	21,675	0.11	0.17	0.28	0.52

8. Open Water / Vegetation Ratio

Open water is defined as a wetland surface that is not populated by emergent vegetation, but may contain submerged aquatic plants. If an SF constructed wetland is designed and built as a fully vegetated wetland surface, the resultant water column within the wetland will produce extremely low Dissolved oxygen and result in high odor production (US EPA, 2000).

A properly designed SF constructed wetlands should incorporate a fully vegetated zone where influent wastewater is initially introduced into the wetlands. This is to promote emergent vegetation growth and subsequently increase solids flocculation and separation. Emergent vegetation should be installed within this zone. The size of this zone should be equal to a 2-day retention time at the AWW flowrate (US EPA, 2000).

After entering the fully vegetated zone, the wastewater should be allowed to enter an open water surface area. This open water zone facilitates production of Dissolved oxygen to meet CBOD demands. Floating vegetation may be installed within this zone. The size of this zone should be equal to approximately 2 days retention time at AWW flowrate (US EPA, 2000). The final zone within the SF type constructed wetlands is a fully vegetated zone, similar in nature to the first zone. Again emergent vegetation may be installed within this zone.

Figure 5-2
Open Water Areas – SF Constructed Wetlands
(WERF, 2006, p. 6-16)

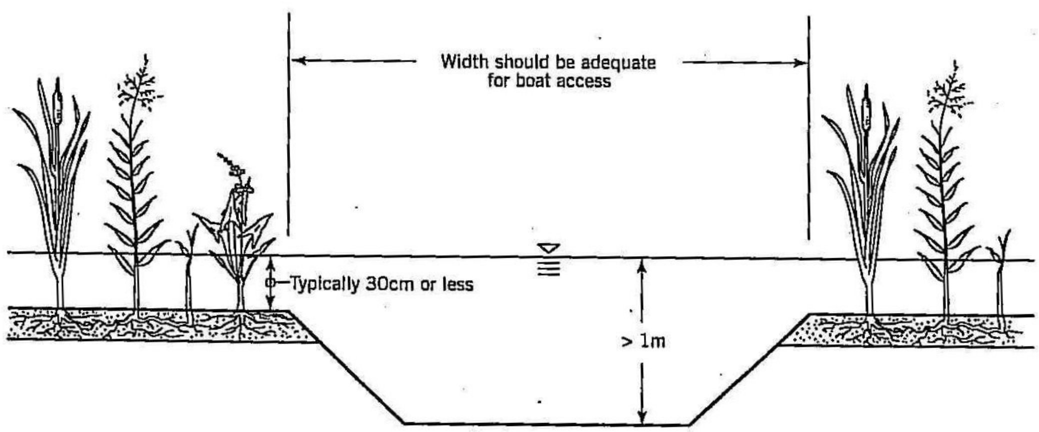


Table 5-11			
Length of Zones in SF Wetland			
Population Equivalents	**Zone of SF Wetland**	**Required Hydraulic Retention time (days)**	**Required Length (feet)**
25	Vegetative	2 (Minimum)	20 (min)
	Open Water	2 (Maximum)	20 (max)
100	Vegetative	2 (Minimum)	52 (min)
	Open Water	2 (Maximum)	52 (max)
250	Vegetative	2 (Minimum)	93 (min)
	Open Water	2 (Maximum)	93 (max)

9. Depth and Gradation of Media

After the wetland basin, berms and liner material are constructed; a soil substrate media of a minimum of 12 inches in depth should be installed. The soil substrate should be a sandy loam material, and not compacted. Lesser dimensions of rooting material have been used throughout the US, but all SF constructed wetlands are susceptible to freezing, which mandates the minimum depth of 12 inches.

10. Settling Zone

Settling zones are areas at the inlet of an SF type constructed wetlands. They are installed to promote settling prior to the wastewater entering into the first vegetative zone of the SF Constructed wetlands. Settling zones should only be constructed if there is a high amount of influent solids discharged into the SF constructed wetland (US EPA, 2000).

Given the fact that all SF type constructed wetlands are mandated to have some sort of pretreatment, a settling zone is only necessary when there is significant concern over TSS discharge from the pretreatment mechanism. Within the constraints of this manual, the TSS is being significantly reduced by a septic tank, which therefore means a settling zone is not necessary.

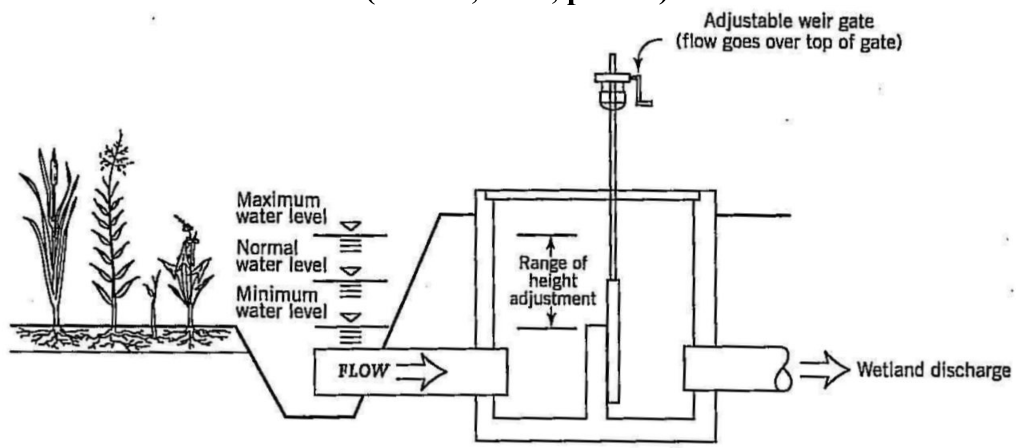
Should an SF constructed wetlands be installed where high solid content waste is anticipated, specific attention should be given to construction of a settling zone.

11. Inlet and Outlet Structures

Inlet and Outlet control structures are critical to the overall success or failure of a constructed wetland system. The inlet control structure should uniformly distribute the inflow across the entire width of the wetland. The outlet control structure should uniformly collect wastewater effluent across the entire width of the wetland.

Two types of inlet/outlet control structures are commonly used in SF constructed wetlands (US EPA, 2000). For small systems, a perforated PVC pipe can be used. For larger systems a moveable weir can be installed within a structure. The determining factor is hydraulics in order to obtain uniform distribution.

Figure 5-3
Outlet Control Structure - SF Constructed Wetlands
(WERF, 2006, p. 6-14)



12. <u>Lining Systems</u>

All constructed wetlands within the State of Iowa, should be constructed with an impervious lining system. As such, the current design standards for lagoon-based systems identify the constraints for installation of such lining systems. These design regulations should be enforced for the SF constructed wetland.

13. Summary of SF Design Parameters

The following table provides a summary of the recommended design constraints for SF constructed wetlands within Iowa.

Table 5 – 12		
SF Recommended Design Criteria		
Parameter	Design Criteria	
Effluent Quality	BOD ≤ 30 mg/l TSS ≤ 30 mg/l TKN ≤ 10 mg/l (during warm weather)[1]	
Pretreatment	Septic tank or Aerated Lagoon	
Maximum BOD Loading	53.5 lb/acre-d	
Maximum TSS Loading	44.5 lb/acre-d	
Maximum TKN Loading	4.5 lb/acre-d	
Minimum Water Depth	1 foot	
Minimum HRT	Fully Vegetated Zone	2 days at AWW
Maximum HRT	Open Water Zone	2 days (or less) at AWW
Minimum # of Trains	2 (regardless of size)	
Minimum # of Cells/Train	Flow ≤ 10,000 gpd – 1 Flow ≥10,000 gpd - 2	
Aspect Ratio	Between 3:1 and 5:1	
Inlet	Uniform distribution across cell	
Outlet	Uniform collection across cell	
Hydraulics	Handle 25-year, 24 hour storm Minimum 2 feet freeboard	
Cell Hydraulics	Each cell drainable	
	Capable of piping from one cell to multiple other cells	
Notes	1) Freezing conditions will dramatically impact TKN discharge. If necessary, thermal modeling should be performed.	

F. Subsurface Flow Wetlands (SSF)

SSF constructed wetlands are also sized primarily based upon loading rates. The first step of design is to assign loading rates to determine sizes of the constructed wetlands. After determining an appropriate size, a configuration and aspect ratio are assigned. Finally, hydraulic considerations are evaluated. Special attention needs to be paid to the hydraulic design. As the wastewater is flowing through a gravel medium, frictional losses are larger than in SF constructed wetlands.

Research has shown that SSF wetlands are also subject to freezing considerations (US EPA, 2000). If freezing occurs within an SSF type wetland, plugging and ponding will result in failure of the system. Therefore special consideration to freezing conditions will be discussed herein.

Finally, ammoniafication of influent nitrogen does not readily occur within an SSF constructed wetland. Because SSF constructed wetlands are predominately anaerobic in nature and that the nitrogen removal mechanism within an SSF constructed wetland is microbial, limited ammoniafication occurs within an SSF constructed wetlands. Operational modifications, including a fill and draw mechanism have been shown to increase available oxygen, but this modification is not being evaluated herein. Should the reader of this manual wish to implement this concept, additional thermal and design considerations need to be considered and presented to the review authority.

1. Loading Rates

Given the BOD Loading rate of 53.5 lb/acre/day and a TSS loading rate of 89.2 lb/acre/day the following minimum sizes of SSF wetlands are applicable for populations of 25, 100 and 250 people.

Table 5-13				
Minimum SSF Size by Loading rates				
Population Equivalents	**Influent Parameter**	**SF Influent Load (lb/d)**	**Loading Rate (lb/acre/day)**	**Minimum Size (acres)**
25	BOD	2.6	53.5	**0.05**
	TSS	2.6	89.2	0.03
100	BOD	10.4	53.5	**0.19**
	TSS	10.4	89.2	0.14
250	BOD	26.1	53.5	**0.49**
	TSS	26.1	89.2	0.29

The limiting condition is BOD load; in order to obtain a discharge of 30 mg/l BOD, 30 mg/l TSS from the SF type constructed wetland.

2. Media Depth and Gradation

All wastewater flow within an SSF type constructed wetlands, is by definition, contained within the media. As shown on Figure 3-8, clogging of the media is a major potential source of failure, and proceeds along in stages. Media depth, size and hardness than play an important factor in the overall performance of a SSF type constructed wetlands.

a) Media Depth

Media depth within an SSF type constructed wetlands has historically been set at between 1 to 2 feet. All wastewater should be contained within the media of a SSF type constructed wetlands. There are significant frictional losses as the wastewater passes through the pore spaces of the media.

there are two methodologies for determining media depth (US EPA, 2000). The first is to maintain a constant depth to the water surface. This would imply that the top elevation of the media generally slopes towards the outlet. However, given constructability concerns this approach is not recommended.

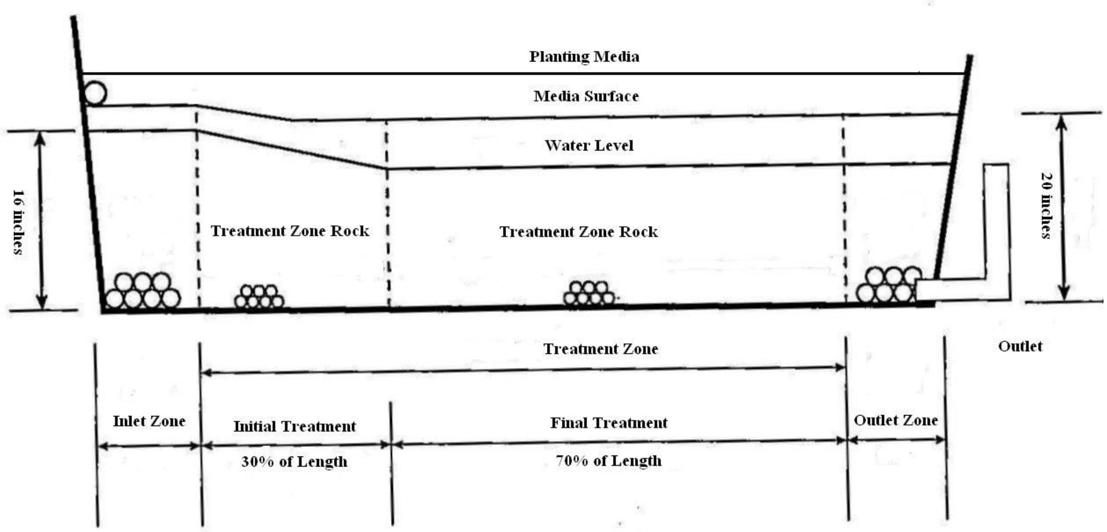
The media is recommended to have a flat, level, top surface with a consistent depth. Increasing media depth beyond 12 inches does not appear to increase treatment efficiency due to limited root bed penetration (WERF, 2006). Wastewater will typically find a preferential flow path below the root system of the wetland plants.

SSF Constructed Wetlands should have 20 inches of media, because a shallower depth may require increased area of constructed wetlands to achieve an acceptable hydraulic retention time (US EPA, 2000). Therefore, it is recommended that the media depth be set at 20 inches, and checked for adequacy after completion of the hydraulic calculations.

b) *Media Gradation*

Different gradations of media should be used for different locations within the SSF constructed wetlands, as they will provide different functions. The inlet area will require coarser media so as to provide an area for solids deposition. This in turn will help mitigate the potential for plugging. The majority of the media is within the treatment zone. At the outlet, a coarser media is recommended to help mitigate plugging potential.

Figure 5-4
Cross Section - SSF Constructed Wetlands
(US EPA, 2000, pg. 113)



The media at the inlet and outlet should be between 1 ½ inch to 3 inch in average diameter. The treatment zone media should have an average diameter of ¾ inch to 1 inch in diameter. Rounded media is recommended in order to minimize the effects of settlement (US EPA, 2000). As such, there may not be an Iowa Department of Transportation gradation that is readily available. The following table identifies the constraints of the media.

Table 5-14		
SSF Media Criteria		
Location	Average Particle Size (inches)	Media Depth (inches)
Inlet Zone	1 ½ inch to 3 inch	20
Treatment Zone	¾ inch to 1 inch	20
Outlet Zone	1 ½ inch to 3 inch	20
Planting Media	Maximum Size ¾”	4

3. Configuration

The configuration of the SSF constructed wetlands should provide for amounts of redundancy and backup so as to assure adequate discharge during potential upsets. SSF constructed wetlands that include a number of cells in series will consistently produce a higher quality effluent (US EPA, 2000).

Operational flexibility is greatly increased with multiple cells having piping between them that allows for routing of wastewater around a cell that needs to be taken off line. It is recommended that a minimum two trains should be constructed for SSF constructed wetlands. For those influent flows that are higher than 10,000 gpd, each train should have a minimum of two cells. SSF Treatment systems designed for population equivalents of 250 should have a minimum of four trains with two cells each.

a) Design Constraints

Given the design constraints of this manual of 25, 100 and 250 people the following minimum number of cells is applicable.

Table 5-15					
Minimum Size Per Cell					
Population Equivalents	**Total Minimum Size (Acres)**	**Minimum Number of Trains**	**Minimum Cells per Train**	**Minimum number of Cells**	**Minimum Size per Cell (acres)**
25	0.05	2	1	2	0.025
100	0.19	2	2	4	0.049
250	0.49	4	2	8	0.061

4. Safety Factor / Redundancy

Prudent design constraints also mandate the inclusion of a safety factor within all design. This safety factor will provide for a level of redundancy within the operation of each cell. A safety factor of between 15 and 25% is prudent (Crites and Tchobanoglous, 1998).

a) Design Constraints

Applying the safety factor to the design reveals the following table:

Table 5-16
Minimum Size per Cell with Reliability

Minimum Size per Cell (acres)	Safety Factor (%)	Minimum Size per cell (Acres)	Total Acreage with One Train out of Service	Total Required Minimum Size (Acres)	Resultant Level of Reliability (%)
0.025	15	0.03	0.03	0.05	60
0.049	15	0.06	0.12	0.19	63
0.061	15	0.07	0.42	0.49	85

The above design including a 15% safety factor results in a reliability level of a minimum of between 60 and 85% as calculated by the use of the current Iowa DNR standards. Reliability is defined as the minimum size of the remaining treatment units, with one train of treatment units out of service. Unit Process Reliability Criteria B (as identified within the design standards) has been assumed for the purposes of this manual. According to Reliability Criteria B, there shall be a sufficient number of units such that, with the largest unit out of service, the remaining units shall have a design load capacity of 50% of the total design loading to that unit. Reliability criteria can change dependant upon the discharge location and therefore the DNR should be contacted to determine specific criteria to be implemented.

5. Maximum Depth of Water

SSF constructed wetlands must be designed so that the water is contained within the entire media bed. As stated previously, the depth of the media has been set at 20 inches. Therefore, a maximum depth of water can be initially set at 16 inches.

6. Estimate Hydraulic Conductivity

Hydraulic conductivity is a method of describing the ability of a soil substrate to allow any liquid to move through it. Hydraulic conductivity can be dramatically impacted by degradation and solids accumulation within the soil substrate. The below table identifies clean versus dirty hydraulic conductivity rates for various gradations of media.

Table 5-17
Hydraulic Conductivity Clean vs. Dirty - SSF Constructed Wetlands
From US EPA Manual – Constructed Wetlands Treatment, pg. 103

Size and Type of Media	"Clean"/"Dirty" K (m/d)	Type of Wastewater (Typical TSS, mg/l)	Length of Operation	Notes and References
5-10mm Gravel	34,000/12,000	Secondary Effluent (100)	2 years	K=12,000 is for downstream portion (last 80m) of VSB
5-10mm Gravel	34,000/900	Secondary Effluent (100)	2 years	K=900 for inlet zone (first 20m) of VSB Bavor et al (1989), Fisher (1990), Bavor and Schulz (1993)
17mm Creek Rock	100,000/44,000	nutriet solution (neg)	4 months	neg = negligible TSS
6mm Pea Gravel	21,000/9,000	nutriet solution (neg)	4 months	Macmanus et al (1992), DeShon et al (1995)
30-40mm Coarse Gravel	NR/1,000	Secondary Effluent (30 w/a)	2 years	w/a = with algae, pond effluent, gravel bed only, no plants
5-14mm Fine Gravel	NR/12,000	Secondary Effluent (30 w/a)	2 years	coarse gravel is first 6m of bed, fine is last 9m of bed Sapkota and Bavor (1994)
20-40mm Coarse Gravel	NR/NR	Landfill Leachate (neg)	26 months	for coarse gravel, headloss controlled by outlet, not K
5mm Pea Gravel	6,200/600	Landfill Leachate (neg)	26 months	Sanford et al (1995a&b), Sanford (1999), Surface et al (1993)
19mm Rock	120,000/3,000	Septic Tank Effluent (50)	7 months	George et al (2000)
14mm Fine Gravel	15,000/see note	aerated pond (60 w/a)	2 years	K of combined gravel (fine overlaid coarse) was 2,000 at 50m
22mm Coarse Gravel	64,000/see note	aerated pond (60 w/a)	2 years	from inlet; 27,000 at 300m from inlet Kadlec and Watson (1993), Watson et al (1990)

Conservative estimates as to the amount of clogging that could occur within the wetland have been published (US EPA, 2006). In order to account for the amount of clogging, the following hydraulic conductivity rates should be used:

Initial 30% of SSF Wetlands: K = 1% of Clean K
Final 70% of SSF Wetlands: K = 10% of Clean K

a) *Design Constraints*

Based upon Table 5-17, a clean hydraulic conductivity rate of the substrate can be estimated to be 100,000 m/d (30,500 ft/day). Applying the assumptions of 30% and 70% the following hydraulic conductivities can be obtained.

Table 5-18
Determined Hydraulic Conductivities

Clean Hydraulic Conductivity (ft/d)	Initial Treatment Zone Hydraulic Conductivity (ft/d)	Final Treatment Zone Hydraulic Conductivity (ft/d)
30,500	305	3,050

Further, Initial and Final Treatment zone areas can be defined by the following:

Table 5-19
Treatment Zone Areas

Population Equivalents	Minimum Size per Cell (Acres)	Initial Treatment Zone Size (Acres)	Final Treatment Zone Size (Acres)
25	0.03	0.009	0.021
100	0.06	0.018	0.042
250	0.07	0.021	0.049

7. Determine Minimum Width

While aspect ratios provide a good rule of thumb for SSF type constructed wetlands, the overall width is more controlled by the hydraulic loading rates. The important design parameter for an SSF constructed wetland is that it maintain all flow within the media. Therefore, an estimate of the minimum width of the constructed wetlands can be determined using Darcy’s law.

Darcy's law states:

$$Q = KWD_W \left(\frac{d_h}{L}\right)$$

Where:

L = Length of Treatment Zone = Area /width

Therefore:

$$W^2 = \frac{QA_{si}}{KD_w d_h}$$

A_{si} = Surface area of the Treatment Zone (ft^2)
D_w = Depth of Water (ft)
W = Width of cell (ft)
Q = Flow into Cell (ft^3/day)
K = Hydraulic Conductivity (ft/day)
d_h = Maximum Permissible Headloss (ft)
Assume = 50% of difference between depth of media and depth of water

For the given design conditions, the influent storm event of 25-year, 24-hour is neglected due to its relevant small impact on the overall size of the treatment cell. Should there be a significant amount of storm water present for the SSF constructed wetlands, additional considerations should be given to this constraint.

Finally, the minimum cell width should be computed for both the initial treatment zone and the final treatment zone. As both zones are within the same cell, both must be computed, with the maximum cell width computed being used. This is the only method that can assure that water is being contained within the media for all zones of the cell.

a) *<u>Design Constraints</u>*

For the design constraints identified herein; the maximum depth of water has been established at 16 inches (1.33 feet). The media depth is equal to 20 inches (1.67 feet), which in turn means the maximum permissible headloss is equal to 0.167 feet. Therefore the following minimum widths of cells can be computed:

Table 5-20							
Minimum Cell Dimensions							
Population Equivalents	Number of Cells	Min Size Per Cell (Acres)	Influent Flow per train (ft^3/day)	Minimum Cell Widths (feet)		Required Cell Length	
				Initial Zone (Feet)	Final Zone (Feet)	Initial Zone (Feet)	Final Zone (Feet)
25	2	0.03	167	**30**	15	12	59
100	4	0.06	668	**85**	9	41	42
250	8	0.07	836	**106**	9	51	42

8. Determine Configuration

Based upon the determined minimum cell width and cell area, an overall configuration can be computed. Given the fact that short circuiting caused by plugging is a common cause of failures, a length to width ratio of between 1:1 to 1:2 is common (US EPA, 2000), but even higher ratios can be seen.

a) Design Constraints

The minimum width is determined by applying the larger of the initial or final treatment zone widths. The minimum length of the cell is determined by summing the minimum lengths of both the initial and final treatment zones.

The following designs are then computed for each population equivalent:

Table 5-21					
SSF Wetland Configuration					
Population Equivalents	Number of Cells	Required Area per Cell (ft^2)	Width (ft)	Length (ft)	Media Depth (in)
25	2	2,130	42*	50*	20
100	4	7,055	85	83	20
250	8	9,858	106	93	20
*	Recomputed for Minimum Length				

9. Freezing Considerations

In cold climates like Iowa, SSF constructed wetlands are prone to freezing concerns. Heat entering with the water will dissipate in an exponential decay pattern (Kadlec and Knight, 1996), until an energy balance point condition is reached. A minimum of 6 inches of mulch insulation has generally been sufficient to keep the wetland from freezing in Minnesota (WERF, 2006). It is recommended that this level of insulation be used within the design of all SSF constructed wetlands within Iowa.

Further considerations with the inclusion of a mulch layer include the selection of the proper mulching material. Mulch material should include the following (Wallace et al., 2000):

- Be substantially decomposed and not exert a secondary organic loading on the system;
- Have a balanced nutrient distribution and a circumneutral pH;
- Have a fluffy structure to provide good thermal insulation and not wash into the underlying rock material;
- Have good moisture holding capability so that seedlings are not subject to stress.

Mulch material that is chipped (instead of ground) packs tightly and limits plant root penetration. Mulch such as wood chips or popular bark degrade the overall treatment performance due to increased background BOD concentrations as they decompose (Wallace et al, 2000).

10. Inlet and Outlet Structures

Inlet and outlet control structures are critical to the overall success or failure of a constructed wetland system. The inlet control structure should uniformly distribute the inflow across the entire width of the wetland. The outlet control structure should uniformly collect wastewater effluent across the entire width of the wetland.

Figure 5-5
Constructed Wetlands Inlet Control Structures
(US EPA, 2000, pg. 125)

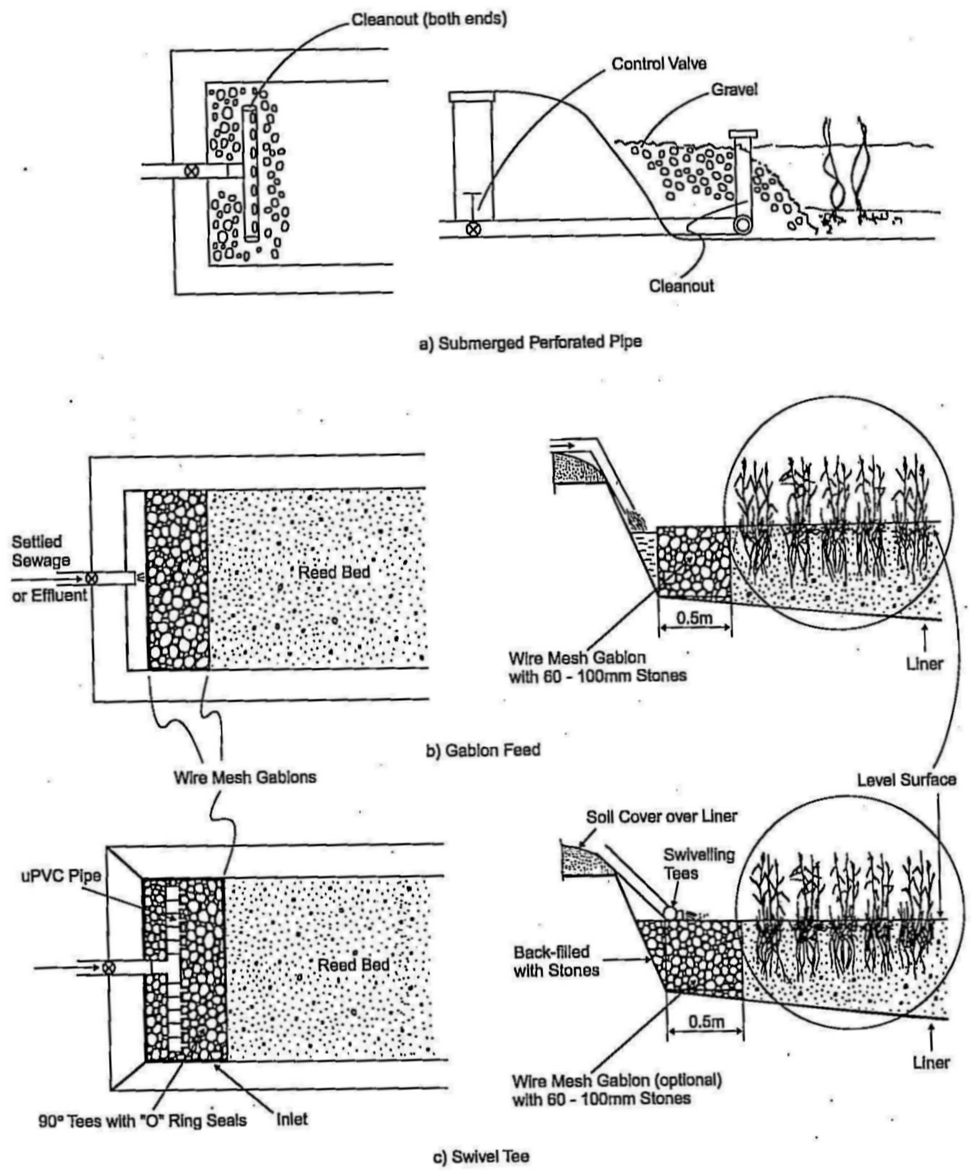
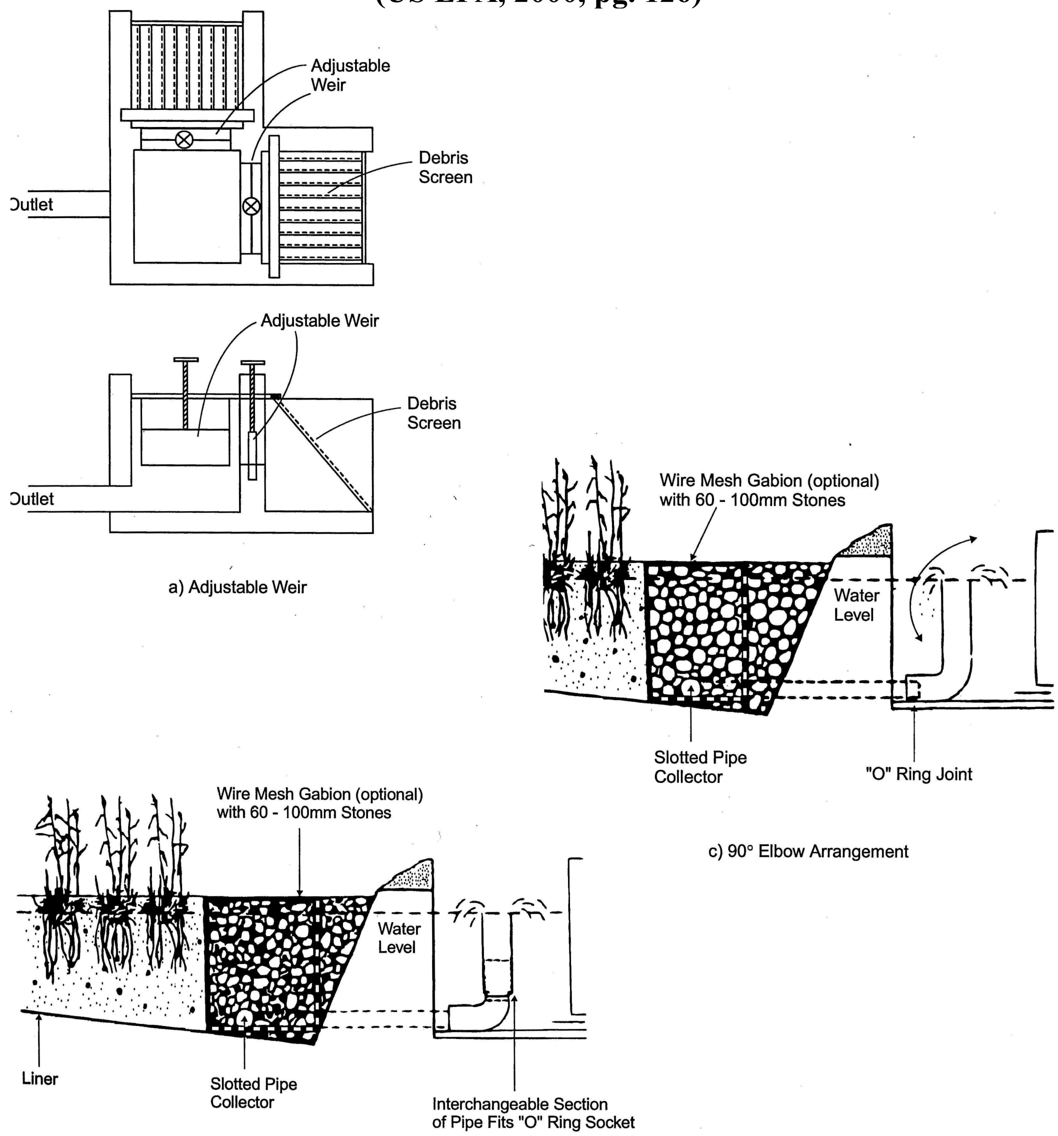


Figure 5-6
Constructed Wetlands Outlet Control Structures
(US EPA, 2000, pg. 126)



11. Lining Systems

All constructed wetlands within the state of Iowa, should be constructed with an impervious lining system. As such, the current design standards for lagoon-based systems identify the constraints for installation of such lining systems. These design regulations should be enforced for the SSF constructed wetland.

12. Summary of SSF Design Parameters

The following table provides a summary of the recommended design constraints for SSF Constructed Wetlands within Iowa.

<table>
<tr><th colspan="3">Table 5 – 22</th></tr>
<tr><th colspan="3">SSF Recommended Design Criteria</th></tr>
<tr><td>Parameter</td><td colspan="2">Design Criteria</td></tr>
<tr><td>Effluent Quality</td><td colspan="2">BOD ≤ 30 mg/l
TSS ≤ 30 mg/l</td></tr>
<tr><td>Pretreatment</td><td colspan="2">Septic Tanks</td></tr>
<tr><td>Maximum BOD Loading</td><td colspan="2">53.5 lb/acre-d</td></tr>
<tr><td>Maximum TSS Loading</td><td colspan="2">89.2 lb/acre-d</td></tr>
<tr><td rowspan="2">Depth</td><td>Media</td><td>20 inches</td></tr>
<tr><td>Water Depth</td><td>16 inches</td></tr>
<tr><td>Minimum Length</td><td colspan="2">50 feet</td></tr>
<tr><td>Maximum Width</td><td colspan="2">200 feet</td></tr>
<tr><td>Bottom Slope</td><td colspan="2">0.5 to 1.0 Percent</td></tr>
<tr><td>Top Slope</td><td colspan="2">Level</td></tr>
<tr><td>Minimum # of Trains</td><td colspan="2">2</td></tr>
<tr><td rowspan="4">Media</td><td>Inlet Zone</td><td>1.5” – 3.0” Gradation</td></tr>
<tr><td>Treatment Zone</td><td>¾” – 1.0” Gradation</td></tr>
<tr><td>Outlet Zone</td><td>1.5” – 3.0” Gradation</td></tr>
<tr><td>Planting</td><td>¼” – ¾” Gradation</td></tr>
<tr><td>Inlet</td><td colspan="2">Uniform distribution across cell</td></tr>
<tr><td>Outlet</td><td colspan="2">Uniform collection across cell</td></tr>
<tr><td>Planting Media</td><td colspan="2">Minimum 4 inch layer</td></tr>
<tr><td>Mulch Insulation</td><td colspan="2">Minimum 6 inch layer</td></tr>
<tr><td rowspan="2">Cell Hydraulics</td><td colspan="2">Each cell drainable</td></tr>
<tr><td colspan="2">Capable of piping from one cell to multiple other cells</td></tr>
<tr><td>NOTES:</td><td colspan="2">SSF wetlands should not be sized for TKN removal due to the anaerobic nature of the typical SSF wetland</td></tr>
</table>

VI. OPERATION AND MAINTENANCE INFORMATION

A constructed wetland has a limited number of operational controls compared to mechanical treatment systems. Wetland systems respond to system changes much more slowly than other mechanical wastewater treatment systems. In some instances if poor operational decisions kill all of the emergent plants in an SF constructed wetlands, it may take one or more growing seasons (after replanting) to reestablish a plant canopy (WERF, 2006).

Proper operation and maintenance can dramatically prolong the life of and affect the performance of a constructed wetland system.

A. Operation and Maintenance Concerns

Operation of a constructed wetlands is mostly passive and therefore requires little operator input. Operational concerns are similar in nature to a controlled discharge lagoon. The following are the most critical items in which operator input is necessary (US EPA, 2000):

- Adjustment of water levels
- Maintaining uniformity of flow
- Management of Vegetation
- Odor Control
- Control of nuisance pests and insects

1. <u>Water level adjustment</u>

Changes in water level will effect hydraulic retention time, atmospheric oxygen diffusion into the water and plant cover. Observed changes in the water level should be investigated immediately, as they may be due to leaks, clogging or other issues (US EPA, 2000).

For SF Type constructed wetlands, the water depth is directly related to the outlet hydraulic control structure, as there are little friction losses through the wetland. A well-designed SF constructed wetland system should provide the operator with the ability to adjust the water level through the entire range of potential water level (minimum to maximum).

a) *Freezing*

Seasonal water level adjustment can help to prevent freezing conditions in the winter. Water levels can be raised prior to freezing and then lowered after the top water level has frozen. This increase in water level will increase the retention time, which can partially offset the reduced biological activity during colder weather. Further leaving an air gap with ice above it will help insulate the wetland, which in turn can help to maintain higher temperatures within the wetland (Kadlec and Knight, 1995).

Should this operational mechanism of increased water level during winter months be implemented, operators should pay close attention during spring months. Rapid water level increases when an ice cover is present can result in plants being pulled from rooting media (WERF, 2006).

Further, it has been recommended within this manual that a minimum of 6 inches of mulch be installed on top of an SSF constructed wetland to help insulate the wetland against freezing concerns.

2. Uniformity of Flow

Water is introduced into a wetland system through the inlet control device and removed through the outlet control device. Short-circuiting of a wetland system occurs when clogging or other issues create non-uniform preferential flow paths. To help mitigate against this potential, the inlet and outlet control devices should be inspected routinely. Debris removal and bacterial slime from weir and screen surfaces will be necessary. If the inlet and/or outlet manifolds are submerged, they should be flushed regularly. If short-circuiting occurs due to media fowling and solids accumulation in an SSF constructed wetlands, the media must be removed and replaced.

3. Vegetation Management

Establishing vegetation within a constructed wetland involves the planting of suitable vegetative materials at the appropriate time. Species selection for different types of constructed wetlands has been previously established.

Planting densities can be anywhere from 1 to 3 feet on center. The higher the density, the more rapid the development of the system, but with an increased construction cost. If planted 3 feet on center, a wetland will take at least 2 growing seasons to approach equilibrium (US EPA, 2000).

Only a small fraction of the ultimate plant density is required to be planted, depending on the rate of plant reproduction and the acceptable timeframe for plant establishment.

a) *Start-up*

For plant establishment within a constructed wetlands to be successful, the following must occur (WERF, 2006)

- Plant Species must be matched to the regime of the wetland;
- Plant material must be viable at the time of the planting;
- Water level management during startup must be compatible with the needs of plants.

For SF type constructed wetlands, the water level should just cover the top of the rooting material. Emergent plants need access to air, and if the new plants are inundated for extended periods they will drown. As the plants grown taller the water level may be raised (WERF, 2006).

For SSF type constructed wetlands, the water level should be just above the gravel bed, but not above the mulch. The goal is to provide a continuous source of water to the plant root zone during establishment (WERF, 2006).

Plants may be obtained from the following sources:

- Commercially available planting stocks;
- Donor plants from another treatment wetland;
- Onsite plant nursery; or
- Natural wetlands.

b) *Vegetation harvesting*

Routine maintenance of wetland vegetation is not required for systems operating within their design parameters. Wetland plant communities are self-maintaining and will grow, die and regrow every year. Should plants naturally spread to areas not intended for vegetation, the plants should be harvested (US EPA, 2000).

Harvesting will affect hydraulic performance, so the harvested cell should be taken out of service before and after harvesting. Harvested vegetation can be burned, chopped and composted, chopped and used as mulch or digested (Crites and Tchobanoglous, 1998). Special attention should be paid to land application of any harvested rhizomes, as unwanted propagation of plant material may occur on resultant fields.

4. Odor Control

SF constructed wetlands may contain anaerobic zones that release hydrogen sulfide or other compounds. Decreasing the water depth, thus increasing the overall amount of dissolved oxygen within the water column may help reduce the anaerobic conditions that lead to these odors.

Turbulent flow patterns at the inlet or outlet will generate additional sources of odor. Removal of turbulent flow paths, including splashing, may help to reduce this source of odor.

5. Algae Control

In SF Type constructed wetlands, filamentous algae mats may displace emergent vegetation. Low dissolved oxygen conditions under the algae mat, and lack of access to sunlight, may prevent emergent plants from growing. When this occurs, the water level can be lowered to expose the rooting media and oxidize the algae. Once the algae has been removed, the areas may be replanted (WERF, 2006).

6. Mosquito Habitat

Mosquito control is required in SF constructed wetlands. Some provisions for mosquito control within an SF constructed wetland include: stocking with mosquito fish, maintenance of aerobic conditions, biological controls and encouragement of predators (Crites and Tchobanoglous, 1998).

It is not possible to exclude egg-laying mosquitoes from SF constructed wetlands (WERF, 2006). Therefore the goal of the system is to minimize the number of larvae that survive to become adult mosquitoes.

7. Nuisance Pests

Other nuisance pests within an SF type constructed wetlands include burrowing animals such as muskrats. These animals can seriously damage the vegetation and surrounding berms and dikes within the constructed wetlands. Some design consideration to help control the impact of these animals include 5:1 slopes and the use of a coarse riprap, or wire mesh.

The common carp is another nuisance species that can affect treatment performance. Carp will uproot vegetation and disturb sediment within the wetland (WERF, 2006).

8. Bed Clogging

Bed clogging within an SSF type constructed wetland is generally a common cause of failure. High levels of suspended solids, grease or biofilms generation in the bed media will result in clogging. Bed clogging can be checked by lowering the outlet structure water level to the minimum, if the water level within the SSF wetlands does not drop accordingly, the wetland is most probably plugged.

9. Recommended Minimum Operational staffing

Operational staffing should be sufficient to maintain compliance with the resultant discharge permit and monitoring requirements established therein. Further, additional monitoring of the system should be performed to assure overall satisfactory operation of the construction wetland system. These include the following:

Table 6-1
Operation & Monitoring Schedule

System Component	Frequency								Comment
	W	M	Q	S	A	2YR	3YR	OTHER	
Primary Component									
Septic Tank									
Sludge Depth				X					
Pump Contents					X				
Baffles (all tanks)			X						
Outlet Filter(s)			X						
Wastewater Sampling			X						
Constructed Wetland Component									
Process Operation	X								
Alarms & Meters	X								
Wastewater Sampling	X								
Remove Solids							X		Dependent upon solids accumulation
Inspect Plant Coverage		X							

W - Weekly, M - Monthly, Q - Quarterly, S - Semi-Annually, A - Annually

10. Record Keeping

The maintenance record keeping system for a constructed wetland treatment facility can be effective while being kept fairly simple, due to the facility's size. The operation, monitoring and maintenance record keeping system should include the following features:

Equipment Maintenance & Replacement Records
Calendar Schedule of Maintenance
Pretreatment Component Monitoring
Septic Tank Pump Outs including volumes and dates
Sludge Depth Measurements
Effluent Filter Cleaning Frequency
Constructed wetlands plant coverage
Wastewater Sampling Results

The maintenance record keeping system may be modified to best suit the needs of the facility. It is very important that the operator keeps the record system up-to-date by recording and filing in an orderly manner any information pertaining to the operation and maintenance of the facility.

B. Cost of Operation

As discussed, a constructed wetland system is by definition a passive operational system. The treatment components do not require additional costs for operation. Every wastewater treatment system that discharges to a receiving stream in Iowa requires a certified operator to assure adequate operation. This is also true for a constructed wetland system.

1. <u>Electricity</u>

As there are no moving parts within either the pretreatment septic tank or the constructed wetlands, no electricity costs are present for operation of a construction wetlands system. Due to topographic constraints, some installations may require pumping either prior to or after preliminary treatment. These installations are not standard, and therefore costs have not be developed for them.

2. <u>Maintenance</u>

Sludge and solids removals within a constructed wetland must be performed on a regular basis. As solids accumulate they will dramatically impact the overall hydraulic performance of the constructed wetland. As such, the solids must be removed.

For SF type constructed wetlands, this involves isolation and draining of the wetland, removal of the accumulated solids and replanting appropriate vegetation. For SSF type constructed wetlands, this involves the removal and replacement of the solids laden media.

Wetlands can become clogged with vegetation and or debris. In some instances this can result in hydraulic failure. This vegetation or debris must be removed.

3. <u>Staffing</u>

Staffing levels within a constructed wetlands system should be sufficient to maintain compliance with the discharge permit. Staffing is therefore dependant upon the criteria of the specific installation.

VII. Cost Estimates

Due to the extreme variably of local markets for labor and materials, it is not possible to estimate universally the cost of construction and operation of constructed wetlands. Cost differentials are significant across local geographies and economies. Therefore the reader of this manual is advised to consult local markets for specific data.

A. Capital Costs

A major determinant in the overall cost of a project is its size. The larger the project, the greater the benefit from economies of scale. Therefore the reader of this manual is advised to consult with knowledgeable individuals for specifics relating to costs of construction for a particular project.

1. Capital Cost estimating Spreadsheet

The next page details a typical cost estimating spreadsheet for estimating overall capital costs for a constructed wetlands treatment system. The spreadsheet identifies major components of the proposed construction and allocates units for each component. Upon completion of a standard design, actual units of installation may be inputted into the spreadsheet. Costs per unit must be obtained from local sources due to the aforementioned extreme variability in local markets.

Table 7-1

Constructed Wetland System Capital Cost Estimating Sheet

Capital Costs

Item	Quantity	Units	Unit Cost	Total Cost
Land		Ac.		
Site Work (Treatment Tank Area)		L.S.		
Primary Treatment Component				
Septic Tanks, Complete w/Bypass Valves		Ea.		
Effluent Filter(s)		Ea.		
Constructed Wetland System				
Gravel		C.Y.		
Drainfield Rock		C.Y.		
Mulch		C.Y.		
Wetland Plants		Ea.		
Synthetic Liner		S.F.		
Geotextile Fabric under Liner		S.F.		
Geotextile Fabric over Liner		S.F.		
Inlet Structure		Ea.		
Outlet Structure		Ea.		
Inlet Structure - PVC Pipe		L.F.		
Outlet Structure - PVC Pipe		L.F.		
Observation Ports		Ea.		
Control Building (incl. Elec and HVAC)		L.S.		
Fencing		L.F.		
Yard Piping		L.S.		
Electrical (10%)		L.S.		
Mob./Demob., Bonding/Ins. (7%)		L.S.		
Subtotal				-
Capital Contingencies (25%)				25.00%
Subtotal				
Engineering (20%)				20.00%
Legal and Administative (5%)				5.00%
Total Estimated Capital Cost				

Table 7-2

Constructed Wetland System Annual Cost Estimating Sheet

Operation and Maintenance Costs	Quantity	Units	Unit Cost	Annual Cost
Labor		hours/yr		
Electric Power		kWh		
Supplies		L.S.		
Maintenance and Repair		L.S.		
Laboratory Testing		L.S.		
Sludge Disposal		Gal.		
Annual O & M Cost				

B. Annualized Costs

Constructed wetland systems are mechanically simple wastewater treatment systems, and therefore operation and maintenance costs are reflective of that.

1. Operations and Maintenance Cost Estimating Spreadsheet

A spreadsheet showing the major operations and maintenance cost line items and unit costs that could be anticipated is shown in Table 7-2.

2. Significant Assumptions

a) Sludge Removal

Bi-annual sludge removal should be assumed, with an annual amount built into the budget equal to one-half the cost. Accumulation of sludge to one-day's average forward flow would be a conservative assumption. A contract hauling rate of $0.07 per gallon of sludge removed is a reasonable estimate. The annual sludge hauling set aside should then be for one-half day's forward flow times $0.07 per gallon.

b) Power

Power costs will vary across the state, but a rate of $0.10 per kWh should be used to estimate annual power costs for the use of any mechanical components. As stated previously, properly designed constructed wetland systems have little to no power requirements, however should site constraints or other issues warrant the inclusion of pumps, power costs should be accounted for. Power cost for potential pumping systems can be done by multiplying the total number of pumps times the average running time, and converting horsepower into kilowatts as per the following formula:

$$\text{Annual Power Cost} = (N_p)(T_{\%})(24\ \text{hours})(HP)(0.75)(\$0.10)(365)$$

Where:

Np	=	Number of pumps
T%	=	Percent daily run time
HP	=	Horsepower of each pump

c) Maintenance

Maintenance requirements for constructed wetlands systems are simple and straight forward. Maintenance activities should include maintenance of berms and dikes (mowing, erosion control, etc..), maintenance of the liner system (e.g. monitoring for burrowing animals and tree growth on berms) and control of nuisance pests and vectors (e.g. muskrats and mosquitos) (Natural Wastewater Treatment Systems, Crites, et. al.).

(1) Equipment Maintenance and Replacement

An annual set-aside for equipment replacement should be built into the budget. The amount set aside should be based on the original cost of the equipment, and prorated out over the expected design life of the equipment.

(2) Site Maintenance

The annual cost should account for site maintenance such as grass mowing and snow removal.

d) Labor

The estimated cost for labor should be based on the total compensation for the operating staff, including any benefits, plus any administrative salaries for meetings, billing, etc. The estimated hours needed should consider the monitoring and sampling requirements of the particular facility, and include provision for periodic maintenance such as vegetation removal, flushing of laterals and regular pump maintenance.

e) Sampling and Analysis

The cost for a facility's sampling and analysis program will vary from one facility to another based on the permit. Larger facilities with surface water discharges will require more frequent and comprehensive sampling than a small facility with a subsurface discharge. The cost should be based on the total number of samples expected in a year, and include the cost of analysis by a certified laboratory, plus the costs of sample delivery.

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