2011 Urban & Rural Treatment Wetlands ManuaL

A New/Old Green Infrastructure

Table of Contents

Preface

Wetlands have always been part of the ecosystem within which we live. They were, and still are in some places, maligned as "useless" and "worthless." Now we know better as we attempt to "re-engineer" wetlands systems to solve our current runoff and water quality problems. This publication is an overview of some current research based guidance on how improved natural degraded wetlands and constructed wetlands can assist us by becoming "green infrastructure" to solve runoff and water quality problems.

Acknowledgements

This publication was written by Nidhi Pasi, a SUNY-ESF PhD candidate in Environmental and Natural Resources Policy under the direction of Richard Smardon, PhD Professor of Environmental Studies and co-major investigator for the CNY Watersheds Project. Further editorial and graphic assistance from the Environmental Finance Center at the Syracuse Center of Excellence is provided by Khris Dodson, Samantha Cremona and Jon Davis. Much of the content in this publication is based on two SUNY-ESF PhD dissertations. The agricultural waste treatment wetland work is based on Lauren Johnson's 2010 dissertation titled, *Restored Wetland-Treatment: A Potential Water Quality BMP*. The other source for the urban CSO treatment wetland guidance comes from Guihan Wu's 2008 dissertation titled, *A Case Study on Applying Subsurface Flow Constructed Wetlands (SFCWs) to Treat Combined Sewer Overflows (CSOs)*. The US Environmental Protection Agency should be acknowledged for supporting Guihan Wu's work through the CNY Watershed Project. Also the Atlantic States Legal Foundation should be acknowledged for supporting the early treatment wetland siting work as well as educational outreach work. Other individuals that should be individually acknowledged are Samuel Sage, President of Atlantic States Legal Foundation; Dr. John Ferrante who worked with us on early siting work and Mr. Steve Giarruso for his technical guidance.

Richard Smardon, PhD Professor of Environmental Studies SUNY-ESF

Introduction

This publication explores the potential roles of restored wetlands in rural settings and constructed wetlands in urban settings as water quality improvement best management practices (BMPs). With renewed emphasis on "green infrastructure" as opposed to gray infrastructure, such applications can reduce runoff and improve water quality in central New York. This publication summarizes more than 5 years of research in two SUNY-ESF PhD dissertation research projects (Johnson 2010 and Wu 2008) plus the CNY Watershed Project (Briggs and Smardon 2010). Based on this research, we believe that both enhanced and constructed wetlands can play a valuable role as water quality BMPs as well as restore multiple wetland functions.

What follows is a basic primer on what a wetland is, various types of wetlands, and how wetlands provide valuable hydrological services. This section is followed by an overview of types of water quality treatment wetlands, then restored wetlands for agricultural waste treatment and constructed wetlands for urban Combined Sewer Overflow treatment. For the last two sections, design and implementation steps are presented as well as detailed references for follow up.

Wetlands

What Is A Wetland?

The term wetland can be broadly understood. It is generally used by scientists to refer to areas that often include three main components:

1. Presence of standing water, either at the surface or within the root zone during all or part of the year,
2. Unique soil conditions (hydric soils), and
3. Presence of vegetation (and fauna) adapted to surviving under unique, saturated conditions (hydrophytes) and absence of flooding-intolerant vegetation.

Because of these characteristics it is difficult to formulate a precise definition. Also, since wetlands are at the margins of terrestrial and aquatic ecosystems exhibiting the characteristics of each—few definitions adequately describe all wetlands. The ecotone position they occupy has been suggested as evidence by some that they are mere extensions of either system (terrestrial or aquatic); and lack a separate identity.

However, in spite of these potential contradictions, there is need for some definition for scientists, regulators and managers. The different interests, objectives and needs of these groups have led to the development of many formal definitions. Relevant definitions for the purpose of this manual are listed below.

Wetland Definitions

U.S. Scientific Definition: Fish and Wildlife Service

This comprehensive definition was adopted in 1979, after several years of review. The definition was presented in a report titled, *Classification of Wetlands and Deepwater Habitats of United States*:

> Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water… wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during, the growing season of each year.
> (Cowardin et al., 1979)

This definition is widely accepted by wetland scientists in the U.S. and serves as the basis for a detail wetland classification and an updated and comprehensive inventory of wetlands in the U.S.

The International Definition

The International Union for the Conservation of Nature and Natural Resources (IUCN) in the Convention on Wetlands of International Importance Especially as Waterfowl Habitat, better known as the Ramsar Convention, adopted the following definition of wetlands as written in Articles 1.1 and 2.1:

Article 1.1:
"For the purpose of this Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."

Article 2.1 provides that wetlands:
"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands".

Legal Definition

This is the regulatory definition used by the U.S. Army Corps of Engineers to legally define wetlands for the purposes of the Section 404 of the 1977 Clean Water Act:

> *The term "wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.*
> *Corps of Engineers Wetlands Delineation Manual (U.S. Army Corps of Engineers 1987)*

Wetland Types

North America has a great abundance and a diversity of wetlands. A number of common terms have been used over the years to describe this assortment. Classification schemes have also been developed for wetlands in different regions of the country.

The classification scheme used in the U.S. as part of the National Wetlands Inventory is complex, formal and all-encompassing. A modified simpler version classifies seven major types of wetlands in the U.S. into two major groups: coastal and inland.

Table 1: *Types of Wetlands*

Wetland Types	
Coastal Wetland Ecosystems	**Inland Wetland Ecosystems**
• Tidal salt marshes	• Inland freshwater marshes
• Tidal freshwater marshes	• Northern peatlands
• Mangrove wetlands	• Southern deepwater swamps
	• Riparian wetlands

EPA classifies wetlands on the basis of four major types—marshes, swamps, bogs and fens—providing a basic but simplified scheme for understanding the diversity of wetland ecosystems *(see chart on following spread)*

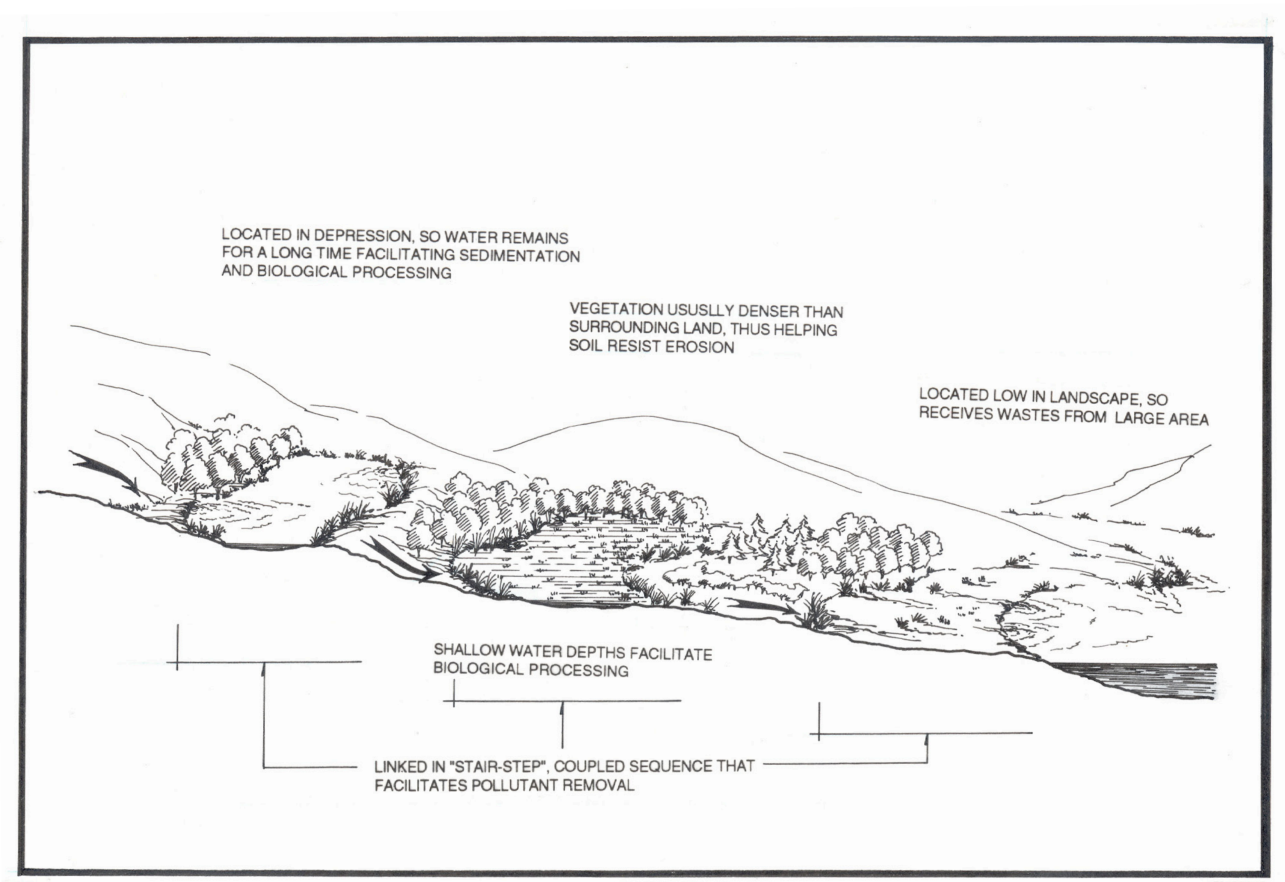


Table 2: *Types of Wetlands (EPA Classifications)*

Wetland Types	
Marshes	Periodically inundated, saturated or flooded by water and characterized by non-woody vegetation adapted to wet soil conditions
Tidal	Coastal; are influenced by tides and often freshwater from runoff, rivers or ground water. These types of wetlands maybe freshwater, brackish or saline. Salt marshes are the most prevalent, have highest rates of primary productivity, and are characterized by salt tolerant species like smooth cord-grass, saltgrass and glasswort. Tidal freshwater wetlands are located upstream from estuaries and lack of salt stress allows greater diversity (cattail, wild rice, pickerelweed which support diverse bird and fish species).
Non-tidal	Inland freshwater or brackish; dominated by herbaceous plants and occur in poorly drained depressions, floodplains and shallow water areas along the edge of rivers and lakes. Example: Great Lakes coastal marshes, Florida ever-glades, prairie pothole region.
Wet meadows	Poorly drained areas, waterlogged after precipitation events, dry up during the summer.
Wet prairies	Similar to wet meadows but remain saturated longer, receive water from streams along with precipitation and ground water.
Prairies potholes	Small shallow ponds developed by snowmelt and rain in glacial pockmarks, groundwater input also important; found in the Dakotas, Iowa, and the prai-ries of the central Canadian provinces.
Vernal pools	Shallow pools with a bedrock or hard clay layer, typically flooded in winter or early spring.
Playa lakes	Small shallow basins that collect rainfall and runoff from surrounding lands; these are the low-lying areas in the Southern High Plains of the U.S.

Table 2: *Types of Wetlands (EPA Classifications) Continued*

Wetland Types	
Swamps	Primarily fed by surface water and dominated by trees and shrubs; occur in either freshwater or saltwater; characterized by saturated soils during growing season and standing water at other times. Examples: Virginia's Great Dismal swamp, Georgia's Okefenokee swamp.
Forest Swamps	Found in broad floodplains of the NE, SE and south-central U.S.; receive floodwater, common deciduous trees include bald cypress, red maple, water tupelo, and swamp white oak.
Bottom land hardwoods	Found along river drainages in southeastern and central US where dominate vegetation is determined by river flooding. Dominant species include Bald Cypress, Water Tupelo, Black Willow, Silver Maple and Cottonwoods.
Shrub swamps	Similar to forested swamps except that shrubby species dominate; Example: buttonbush, swamp rose.
Mangrove swamps	Coastal wetlands characterized by salt-tolerant tress, shrubs, growing in brackish to saline tidal waters; extend from southern tip of Florida along the Gulf coast to Texas
Bogs	Freshwater wetlands characterized by peat deposits, acidic water, growth of evergreen trees and shrubs, and a floor covered with sphagnum moss; are also called precipitation-dominated wetlands as they receive most of their water inputs from precipitation.
Nothern Bogs	Found in the glaciated areas of NE and Great Lakes region of the U.S.
Pocosins	Evergreen-shrub bogs located in the SE coastal plains
Fens	Groundwater-fed peat-forming wetlands covered by grasses, sedges, reed and wildflowers. They are called groundwater-dominated wetlands and are characterized by less acidic water and higher nutrient levels. Tend to occur in the glaciated areas of the northern U.S.

How Do Wetlands Work?

Wetlands are among the most important ecosystems on the earth. The swampy environment of the Carboniferous period produced and preserved many of the fossil fuels on which we now depend. In more recent times, wetlands have been identified as valuable sources, sinks and transformers of a multitude of chemical, biological and genetic materials.

In addition to their value in fish and wildlife protection, other benefits are recognized. They have been called the "kidneys of the landscape" as they function as downstream receivers of water and waste from both natural and anthropogenic sources. They stabilize water supplies and thus ameliorate some flood and drought situations. They have been found to protect shorelines and recharge groundwater aquifers. They have been termed as "biological supermarkets" for the extensive food chain and rich biodiversity role they support. They provide unique habitat for a wide variety of flora and fauna. And most recently they have been described as carbon sinks and climate stabilizers. But how do wetlands work? What characteristics or features make them so unique and diverse in their uses?

Wetland Hydrology

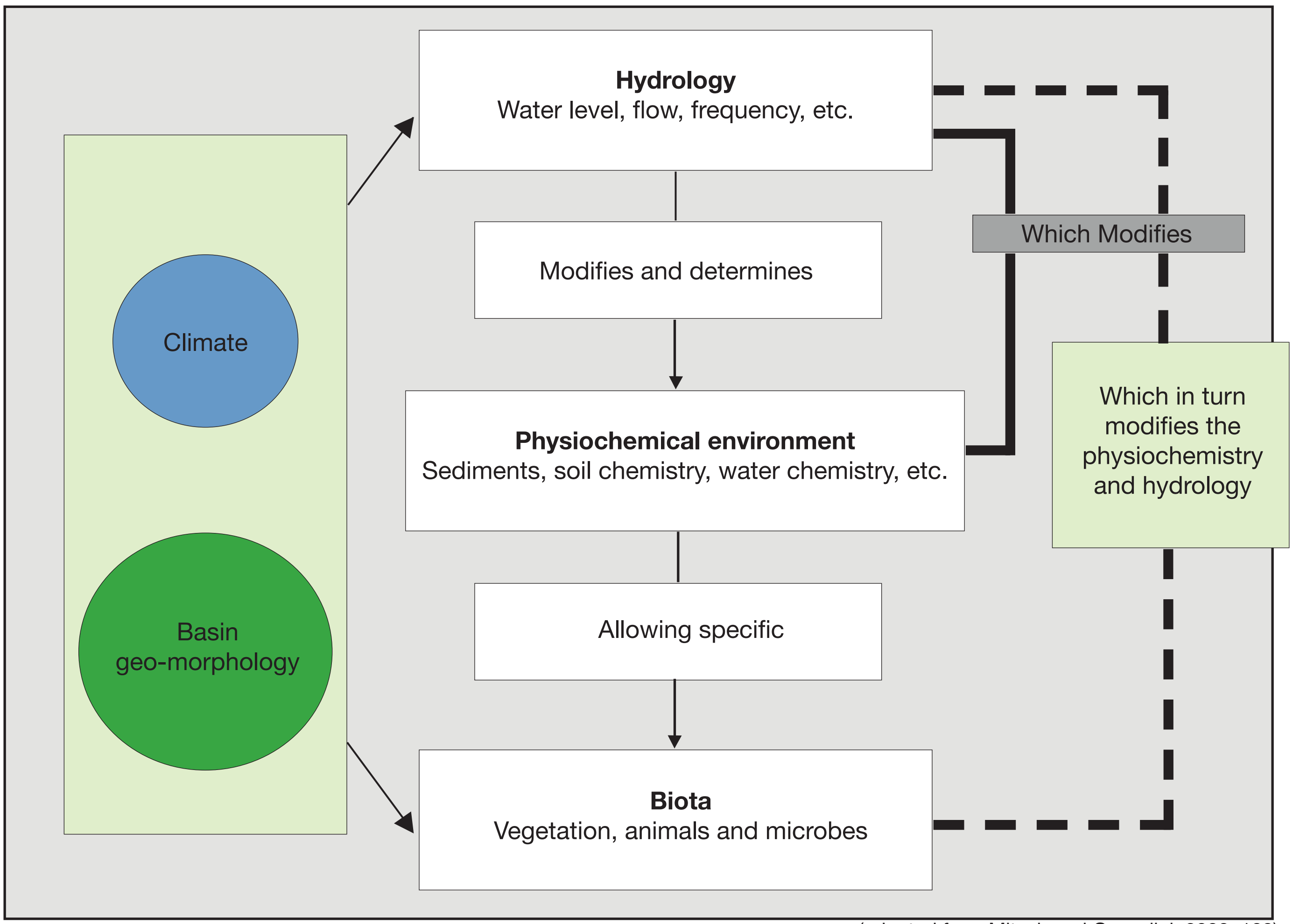
As previously mentioned, hydrologic conditions are extremely important for the maintenance of a wetlands structure and function. It is the hydrology of the wetland that creates the unique physiochemical conditions that make such an ecosystem different from both well-drained terrestrial systems and deepwater aquatic systems.

Precipitation, surface run-off, groundwater, tides and flooding rivers transport energy, sediments, organic matter and nutrients to, from and within wetlands. These hydrologic inputs and outputs also determine the water depth, flow patterns, and duration and frequency of flooding that, in turn, affects the biogeochemistry of soils and ultimately affects the selection of biota in the wetland.

Hydrology also affects species composition and richness, primary productivity, organic accumulation and nutrient cycling in wetlands. Generally, the productivity is higher in wetlands that have high flow-through of water and nutrients or in wetlands with pulsing water inflow/outflow (seasonal pattern of water flow). Wetlands in stagnant or continuously deep water have been observed to have low productivities, whereas wetlands that are in slowly flowing strands or are open to flooding rivers have high productivities. Many wetlands that sustain long flooding durations have lower species richness. Hydrology can limit or act as a stimulus to species richness. The richness increases as flow-through increases, as the flowing water will tend to renew minerals and reduce anaerobic conditions.

The effects of hydrology on wetland structure and function are a complicated series of cause-and-effect relationships. A simplified conceptual model of the general effects of hydrology in wetlands ecosystems is provided in Figure 1. The effects shown here are primarily on the chemical and physical aspects of the wetlands, which, in turn, influence the biotic components of the ecosystem. The biotic components then have a feedback effect on hydrology.

Figure 2: *Conceptual diagram illustrating the effects of hydrology on wetland establishment and function*



(adapted from Mitsch and Gosselink 2000: 109)

Functions and Values of Wetlands

For years wetlands have been viewed as wastelands (as the periodic standing water and waterlogged soils prevented their use for agriculture, forestry, or mineral production; for human habitation; or for commercial use), they are now being recognized as an important ecosystem that provides essential functions/ services (Table 3) which are valuable to humanity worldwide.

Table 3: *Ecosystem services provided by wetlands (natural and restored)*

Hydrology

- Water storage and flood reduction
- Barriers to waves and erosion
- Maintenance of groundwater table
- Maintenance of surface water levels
- Stable shores and storm protection

Wetlands function like natural sponges, storing water and slowly releasing it to downstream areas, lowering flood peaks. This reduces water's momentum and erosive potential, reduces flood heights, and allows for groundwater recharge, which contributes to base flow to surface water systems during dry periods. Also, coastal and inland wetlands adjoining rivers reduce the impact of tides and waves. This protects soil against erosion. Mangroves are particularly resistant.

Biogeochemistry

- Maintenance of overall water quality
- Cycling and transformation of nutrients and other elements
- Retention of sediments
- Retention and transformation of dissolved substances and pollutants
- Accumulation of carbon/ peat

As water gets slowed by the wetland, it moves around the plants allowing the suspended sediments to drop out and settle to the wetland floor. The reeds and grasses further increase this process. Retention of this sediment upstream can enhance the quality of ecosystems downstream along with lengthening the lifespan of downstream reservoirs and channels. This reduces the need for costly removal of accumulated sediments from dams, locks, etc.

Wetlands also retain nutrients (primarily nitrogen and phosphorous), through accumulation by microorganisms in the subsoil and/or absorption by vegetation. Hence we have nutrients from fertilizer application, manure, leaking septic tanks, and municipal sewage that are dissolved in water, filtered by the wetland leading to improved water quality and prevention in eutrophication.

Habitat and Food Web Support

- Maintenance of primary productivity
- Maintenance of characteristic plant communities that serve as habitat
- Sustaining anadromous fish and other wetland- dependent aquatic species
- Maintenance of biodiversity

(adapted from Spray and McGlothlin, 2004: 60, Kusler 1983)

As mentioned earlier wetland functions include water quality improvement, floodwater storage, fish and wildlife habitat, aesthetics, and biological productivity. These functions can be translated into values depending upon the estimation of the importance of its function(s) to society. In the recent past, humans have realized that the destruction of natural wetlands can (and has triggered) trigger a plethora of unpleasant and unproductive consequences ranging from periodic flooding to deteriorating water quality to loss of habitat and wildlife. Table 4) lists the ecological functions of the wetlands, the ecological effects of these functions (annual ecosystem goods and services obtained) and the societal/ economic values (including future ecosystem goods/services obtained) that are impacted.

Table 4: *Ecological functions to economic values of wetlands*

	Ecological Functions	Ecological Effects	Societal Economical Values		
			Intermediate Goods and Services	Final Goods and Services	Future Goods and Services
Hydrological	Short-term surface water storage; long-term surface water storage, maintenance of high water table	Reduced down-stream flood peaks; maintenance of base flows and seasonal flow distribution of hydrophytic plants	Flood control; water storage; irrigation and sub-irrigation water for agriculture	Flood damage security; reduced household utility costs; maintain sport fishing habitat in dry periods	Unique species, landscapes and ecosystems; bequest value; option value; undiscovered goods
Biogeochemical	Transformation and cycling of elements, retention and removal of dissolved substances, accumulation of peat, accumulation of inorganic sediments	Maintenance of nutrient stocks, reduced transport of nutrients, metals, etc; retention of sediments and some nutrients	Assimilation of wastes; pollution assimilation/ water purification	Higher water quality as an amenity	Unique species, landscapes and ecosystems; bequest value; option value; undiscovered goods
Habitat and Food Web	Maintenance of characteristic plant communities, maintenance of characteristic energy flow	Food, nesting, cover for animals; support for populations of vertebrates	Support for commercial fisheries and recreation; provision of commercially harvested natural resources (timber, fur-bearers, etc.)		Unique species, landscapes and ecosystems; bequest value; option value; undiscovered goods

(adapted from Spray and McGlothlin, 2004: 133)

Types Of Wetlands For Wastewater Quality Treatment

Natural wetlands have been used to treat wastewater for hundreds of years. Formal documentation of how these natural wetlands affected wastewater quality began in the 1960s and 1970s. Research found consistent reductions in the pollutant concentrations of wastewater as it passed through the microbial active wetlands. And by the late 1970s and early 1980s, this research led to the planning, development, and construction of discharges to natural wetlands at many locations in North America, as well as the implementation of constructed wetland technology for both habitat and water quality functions. Wetlands can be engineered and constructed for the following reasons:

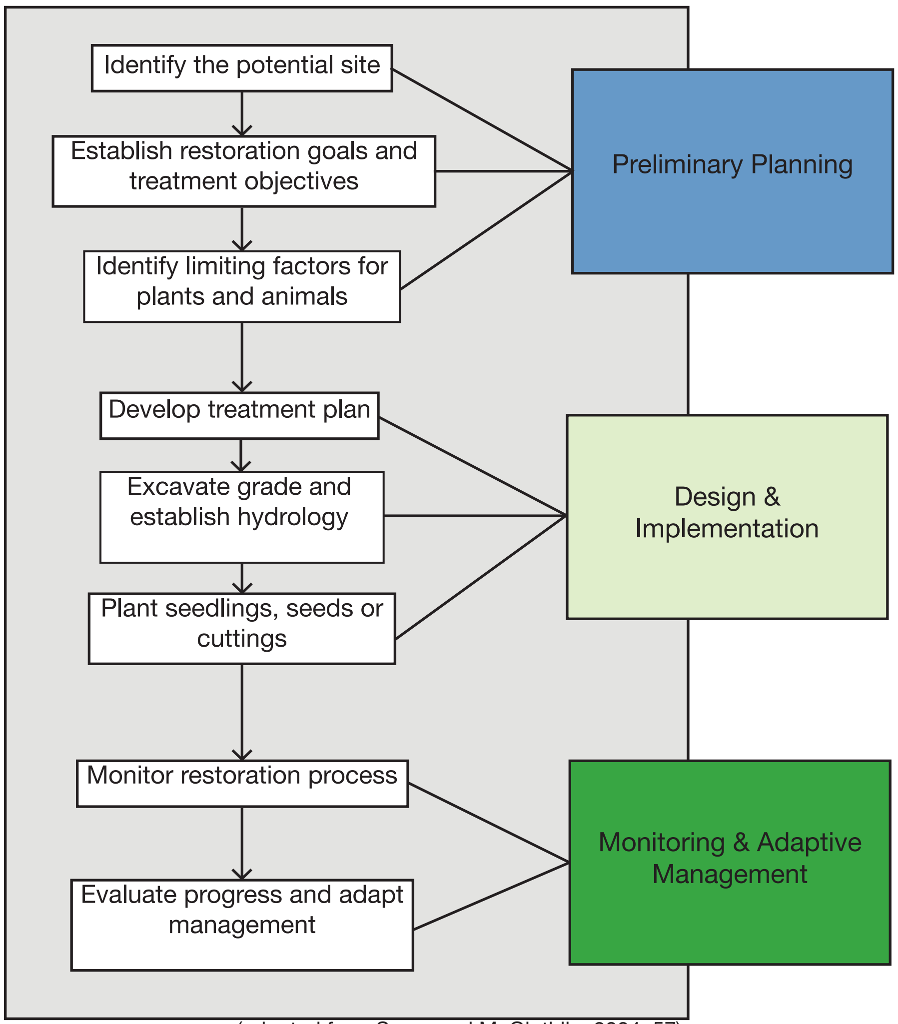
1. To compensate and offset the rate of existing wetland loss (constructed habitat wetlands),
2. To improve water quality (constructed treatment wetlands),
3. Provide flood control (constructed flood control wetlands),
4. To be used for the production of food and fiber (constructed aquaculture wetlands).

The wetland and the different treatment options can be grouped into the following three categories:

1. Natural wetlands
    a. Restored for habitat
    b. Restored for treatment with surface flow
2. Constructed wetlands
    a. Constructed to offset the historical and continuing losses of natural wetland functions
    b. **Constructed treatment wetlands** specifically engineered with water quality improvement
        i. **With surface flow**
        ii. **With sub-surface flow**

Selection of the appropriate treatment option is a critical aspect in project planning. For the selected alternative to be feasible and compliant it should satisfy technical, environmental, permitting and regulatory conditions. Alternative selection must be based on the best available information, including clear objectives, waste water source and flow characterization, site specific conditions (including information on soils, native flora and fauna, etc.), permitting feasibility, technical feasibility, cost of a particular alternative and so on. The alternative and design selection also has to be followed by careful monitoring evaluation. In cases where technical feasibility of a treatment option is not well-known due to unique characteristics of wastewater properties/flows; pilot projects need to implemented to ascertain regulatory feasibility and public acceptance. Figure 2 represents steps that should be followed where wetlands can be restored for treatment purposes.

Figure 2: Steps in the Process of Wetland Restoration



(adapted from Spray and McGlothlin, 2004: 57)

Use Of Restored Wetlands In Rural Areas

Introduction

Agricultural nitrogen (N) non-point source[1] (NPS) pollution can be effectively mitigated through strategies that increase the capacity and effectiveness of nutrient sinks that trap dissolved and particulate nutrients; and result in their conversion to the inert nitrogen (N2) gas. It has been estimated that through wetland sinks agricultural Nitrogen NPS pollution to the Chesapeake Bay can be reduced by 50%. These reductions are a direct result of the created physical, biological, and chemical environments promoting the biotransformation of ammonia and ammonium, into nitrite and nitrate, and finally into inert nitrogen gases, which are removed from the water through release into the atmosphere. This bioengineering approach to constructed wetlands; either through the sub-surface flow system (SSF) or the free water surface system (FWS)[2], is being implemented to treat Nitrogen NPS with great success. Data from more than two decades of extensive monitoring of Constructed Wetlands Practice Standard-657[3] (CW-656) has revealed significant reductions of NPS in treated runoff. However, recent studies have suggested that the potential of natural wetlands (including restored natural drained wetlands) to attenuate N loadings is high. Also, from an implementation standpoint, natural wetland treatment systems are simpler than constructed wetlands. The designer must collect and deliver the wastewater, but nature has provided the basin and vegetation.

Use of natural wetlands

Unlike constructed wetlands, no two natural wetlands are identical. Their N biotransformation function will depend upon various physical (basin dimensions); chemical (oxygen concentration gradient, pH, temperature); and biological (indigenous bacterial species) variables. In spite of this, there is considerable opportunity for not only treating N, but also additional pollutants along with the extra benefits natural wetlands provide. These include:

- Sedimentation of particulates leading to removal of suspended solids and attached pH
- Reduce pathogenic organisms: 99% effective in removal of coliform bacteria
- Additional benefits: habitat, recreation, education, environmental open space
- Terrestrial carbon sink

Wetlands have not been traditionally viewed by humans as beneficial, and have been converted to a variety of agricultural land uses such as pasture, hay land, cropland and farmsteads. These can be collectively termed as drained wetlands. Following the national trend, New York State has lost (drained or destroyed) approximately 50% of its natural swamps and marshes. A wetland inventory in Chenango county reveals that most of the farms in the county have wetlands (either farmed wetlands or converted wetlands). This means that hundreds of drained wetlands are found on the farms, leading to a high probability that many are hydrologically connected or located in close proximity to a source of agricultural Nitrogen NPS pollution. So, given that:

---

1. Non point sources (NPS): fertilizer spread on cropland ($N0_3^-$, mainly through leaching) and animal waste runoff from animal feedlot operations (AFO) (NH_3 and NH_4^+; surface runoff transports). It has been observed that growth in Nitrogen NPS pollution loads from agriculture has been found directly correlated to the expansion/intensification of animal agriculture, specifically expansion of confined AFOs.

2. Free water surface system wetlands are relatively inexpensive to manage and maintain when compared to the sub-surface flow wetlands and traditional water quality BMPs. FWS systems required the same amount of energy input for every kg of pollutant degraded in conventional treatment systems, but they use renewable energy. There might be some reduction of efficiency in winter, in colder climates

3 Constructed Wetland Practice Standard-656 is a constructed shallow water ecosystem designed to simulate natural wetlands, to reduce the pollution potential of runnoffs and waste water from agricultural lands to water resources.

- Most farms in NYS have drained wetlands,
- Many farms have significant Nitrogen NPS pollution sources,
- Constructed wetlands can significantly reduce agricultural N concentrations in runoff,
- There is incentive for farmers to restore wetlands, and
- Traditional water quality BMPs are expensive to construct and operate;

these drained wetlands can be potentially restored[4] for water quality treatment (**restored wetlands**); as a viable "alternative" water quality BMP.

The key aspect for success of restored natural wetlands to be utilized is the location with respect to NPS pollution, the wetland basin and its hydrology.

Science Behind The Restored Wetland Treatment BMP

Restored wetlands can be used to treat agricultural runoff via the nitrogen cycle. Organic nitrogen, which is the dominant form of N in the runoff from barnyards is readily converted to NH_3, NH_4^+ and NO_3^- in downstream water into N gases. Restored wetlands provide a favorable chemical, biological and physical environment for bacteria to bio-transform the agricultural NPS nitrogen pollutants into N gases.

The key sequential bacterial bio-transformation steps to remove N are **ammonification** followed by **nitrification** and concluding with **de-nitrification**. The chemo-heterotrophic[5] bacteria transform organic N into ammonium ions that are absorbed by plant roots; or taken up by anaerobic micro-organisms, or they can undergo nitrification into NO_3^-. In anaerobic conditions, this NO_3^- is then converted to gaseous N (N_2, NO, NO_2, N_2O; these can be harmlessly lost to the atmosphere) through the process of de-nitrification.

A restored wetlands N removal performance is dependent on several factors[6] such as **water depth** and **duration, area** and **volume.** Modification of these variables influences other factors (such as **population size, contact, N cycle continuity, kinetics** and **contact time**) which influences N cycle bio-transformation. These variables can be measured in a drained and restored wetland through the measures of **flooded vegetative area, conductivity distribution, O_2/ pH, water temperature** and **retention time**. Bacteria must be in contact with pollutants to bio-transform them. As most bacteria are sessile, unrestrained flows are essential to transport N pollutants to them. Wetlands are typically stratified vertically into both aerobic and anaerobic zones. This helps in maintaining the N cycle continuity which requires aerobic conditions (ammonification and nitrification) and anaerobic conditions (de-nitrification). Vegetation plays an important role in the N cycle for beneficial microbes to metabolize N through de-nitrification; and as been attributed as much as 90% of N removal in a constructed wetland. Additionally, the longer the bacteria remains in contact with N, the greater is its probability to trap and transform it.

Site-specific data is paramount to design an efficient restored wetland treatment (RW-T) system to treat agricultural NPS N polluted runoff due to the complex and highly variable mix of runoff contaminants, basin topography, basin flow patterns, and soil/vegetation characteristics. Operational efficiency of the restored wetland (RW) has

4. USEPA (2000) defines restoration as a return of an ecosystem to a close approximation of its condition prior to disturbance and reestablishment of previous functions and related physical, chemical and biological characteristics
5. Obtaining their nutrition and energy for growth from organic compounds
6. For further details refer to Kadlec and Knight (1996)

been found to increase as a direct result of additional retention time associated with the increased storage volume of the wetland. However, it has been found that the overriding design criteria for a RW-T ultimately depends on the contaminant of greatest local concern, that requires the longest retention time for its degradation, and the required percent reduction of this contaminant.

Application of the RW-T BMP in the Field

Functional capacity of a wetland to transform N pollution can be measured in terms of concentration or estimated to be high or low. This is determined by its internal and external characteristics. Studies have shown that NPS N polluted runoff from AFOs, flowing through RW is transformed into N gases, via N-cycle bio-transformation. Research indicates that N cycle operational efficiency is directly influenced by the following five N cycle variables:

1. Bacterial population size,
2. Bacteria and pollutant contact,
3. N cycle community,
4. Kinetics, and
5. Bacteria and pollutant contact time.

However, restoration's greatest influence is on the variables of population size and contact time, which can be quantified by **flooded vegetative area** and **retention time**.

Flooded vegetative area and retention time are dependent on the drained wetland's internal variables of depressional depth, surface area, and outlet shape; and the external variable of watershed runoff. Research shows that generally a **drained wetland with a flatter slope, larger surface area and more restrictive outlet has a greater restoration** potential for water surface area and storage volume. Also, the drained wetland's ability to treat NPS N pollution is significantly influenced by its watershed size: smaller watershed area to surface area ratios have a greater affect on retention time. However, the appropriate size for a RW-T wetland ultimately depends on the **contaminant of greatest local concern** that requires the **longest retention time** for degradation and on the **percentage reduction of the contaminant required by law and/or regulation**.

Given the increasing need to improve water quality in agricultural watersheds along with limited budgets, RW-T therefore, has significant potential. However, for RW-T to perform the bio-transformation potential, it must have both the **opportunity** (presence of the drained wetland in a physical location to perform bio-transformation function) and the **capacity** (effectiveness of the wetland to actually perform the bio-transformation function being considered).

NYS has sufficient number of drained wetlands that can serve as candidates for RW-T BMP projects. These drained wetlands are in adequate numbers[7] and in appropriate juxtaposition to the pollution sources to be feasible and cost-effective alternative water quality BMP. Suitability based on GIS spatial relationship analysis, construction

7. USFWS's National wetland inventory (NWI) and New York Sate Department of Environmental Conservation's (NYSDEC) Wetlands Conservation Law inventory exist, which have mapped the hydric soils in the state. USDA NRCS soil surveys has identified potential wetland restoration sites through aerial image interpretation or inventories. USDA, with National Technical Committee on Hydric Soils (NTCHS), has developed a list of the nation's hydric soils. States have adopted the list which identifies all map units that are hydric or have a potential of having hydric soil inclusions. The local county lists provide names of hydric soils, information on the composition and probable landscape position. This can be used in conjunction with local county soil survey maps to physically locate hydric soils in the field.

feasibility and cost variables can be used to determine which drained wetlands could and should be restored. These wetlands can then be ranked and rated to determine relative priority for implementation using additional variables like ratios of wetlands size to herd size and wetland surface water storage to watershed runoff.

Thus, the RW-T suitability model which:

1. Selects hydric soil[8] in close juxtaposition to dairy AFOs,
2. Rates each hydric soil/ wetland according to factors of operational efficiency, restoration costs, and environmental policy, and
3. Ranks wetlands for implementation prioritization or targeting has been developed which identifies, characterizes and estimates a drained-degraded hydric soil's potential biotransformation functional capacity to treat NPS N polluted runoff.

The RW-T suitability model's conceptual protocol is divided into three distinct sequential hierarchal models: selecting, rating and ranking the hydric soils. These selecting, rating and ranking protocol models have been operationalized by transforming them into a variety of GIS[9] and PC[10] spreadsheet process models, that are used to collect, organize, evaluate, manipulate and display data (Table 5).

Table 5: *Restored Wetland- Treatment Suitability Model*

Selection Process Model: Spatially located and selected hydric soils within a 305m radius		
Rating Process Model: Evaluated each hydric soil on three factors. These three factors are each divided into 2 variables each, which have been transformed into 6 quantifiable covariates.		
Factors	Variables	Covariates
1. Operational efficiency	• bacteria-pollutant contact time • bacterial population size	• surface water retention time • flooded vegetative area
2. Restoration costs	• reconstruction feasibility • utility to construct	• land use • relative position to pollution source (up or down slope)
3. National Wetland Policy	• agricultural pollution priority • wetland degradation status	• herd size • extent of degradation due to farming practices
Ranking Process Model: Prioritizes hydric soils by sorting the covariate values in the following order: 1. Herd size 2. Relative evaluation 3. Land use 4. Flooded vegetative area 5. Retention time		

8. Hydric soils have an accumulation of organic matter resulting from prolonged anaerobic soil conditions associated with long periods of submergence and/or soil saturation during the growing season
9. GIS process model—does geometric functions—to calculate distances, area and perimeter, and generate buffer; coincidence functions and adjacency functions
10. PC spreadsheet process model—empricial and theoretical formula computations, statistical analysis and data sorting functions

Steps In Setting Up a RW-T BMP

In order to site a restored wetland for a potential treatment BMP, the following steps need to be carried out in sequential order. These are based on the RW-T suitability model illustrated in Table 5.

- Identify hydric soils or restored wetlands located at a "convenient distance" of 305 m from the AFOs (animal feedlots) where the pollutant runoff needs to be treated.

The selected wetlands are then rated for their use based on efficiency, policy and cost factors:

- Natural undisturbed wetlands or restored wetlands for habitat are eliminated from the selection.
- Wetlands with a perennial river associated with a watershed greater than 80ha eliminated from selection.
- Wetlands with constructed utilities (roads, railways, pipelines and power line) eliminated from selection
- If multiple wetlands are selected in the buffer area of 305m around the pollution source, eliminate (based on relative vertical position) all but the lowest elevation wetland.
- Wetlands with watershed area to wetland water surface area greater than 10:1 are eliminated to allow higher retention time
- Wetlands with flooded vegetative area to herd size ratio smaller than 0.004ha:1 cow eliminated.
- Wetlands with retention times less than 1 day are eliminated.

The remaining rated wetlands from the total selection are now to be ranked or prioritized for targeted implementation using the following sorting protocol:

- Rated wetlands are ranked by associated herd size. More animals are associated with more pollution (manure), and hence demand higher priority.
- Wetlands with same herd size are then ranked by down slope position to the pollution source
- Wetlands with same pollution load and relative elevation are then ranked by land use from least to greatest restoration cost in the order of: pasture, hay land, cropland, and finally farmstead.
- Wetlands with same pollutant load, relative elevation and land use are then sorted by largest to smallest surface area
- Sort the remaining wetlands by longest to shortest retention time periods.

The final remaining wetland can now be successfully used for RW-T BMP. The details of these steps are provided in the following table which also explains the logic behind each selection, ranking and rating step.

For more details or questions regarding the following table (Table 6), please refer to Johnson (2010) or contact Dr. Lauren Locklin Johnson, (lauren.johnson@ny.usda.gov) District Conservationist, Chenango County Soil & Water Conservation District. [11]

11. Chenango County SWCD, 99 North Broad Street Norwich, NY 13815, 607.334.4632 ext

Table 6: *Sequential Steps for Citing and Identification of a Restored Wetland for Water Quality Treatment for BMP*

Steps	Criteria	What To Do	Why? / From Where?
I. "Selection"of Hydric Soils	1. Existence of N NPS pollution (e.g. a dairy AFO)	Identification of AFO using the SWCD localized definitions	County tax department (shapes files of county tax parcels) SWCD Cooperator files, USDA Farm Service Agency Producer Files, Produce shipping milk report published by NYS Agriculture and Market
	2. Juxtaposition or distance from NPS; located at a "convenient distance"	Convenient distance is based on cost of construction associated with gravity and pump manure transfer systems. Project requiring more than 305 m of plumbing are typically too costly or mechanically impossible based on present agricultural waste management engineering technology	USDA NRCS soil surveys and Hydric soils list
II. "Rate" the selected hydric soils according to 3 factors (efficiency, cost and policy) in 7 steps	1. Environmental Policy— wetland determination—impact of installed drainage practices	Hydric soils interpreted as undisturbed or restored for habitat are eliminated from further consideration	Undisturbed or restored wetlands for habitat cannot be considered for use as treatment wetlands as per USDA, EPA and US FWS policy. This is determined by the drainage practices in the hydric soils and can be reliably interpreted from its agricultural land use. Land use can be determined by direct field observations, aerial image land cover interpretation to crop reporting records.
	2. Efficiency—Contact time- retention use	Hydric soils with a 'blue line' stream flowing through eliminated	Blue line stream tool, used by USDA NRCS, indicates a perennial river and is associated with watershed greater than 80ha.
	3. Cost—Feasibility—land use	Hydric soils with a utility right of way, transportation corridor, or a developed area are eliminated.	Non-agricultural land uses used to gauge the degree of wetland drainage or conversion, to compare the cost of restoration to benefits received.
	4. Cost—utility—relative elevation (up slope/ down slope) of wetland to the pollution source	Buffer hydric soils are evaluated according to relative vertical position, with all but the lowest elevation wetland being eliminated	Waste treatment facilities upslope to a pollution source are typically more expensive.

Table 6: *Sequential Steps for Citing and Identification of a Restored Wetland for Water Quality Treatment for BMP: continued*

Steps	Criteria	What To Do	Why? / From Where?
(Continued from previous)	5. Efficiency—Contact time-retention time	Hydric soils with watershed area to wetland water surface area should not exceed a 10:1 ratio	USDA NRCS constructed wetland rule-of-thumb. Ratios greater than this do not have sufficient retention time to allow bacteria to adequately treat polluted runoff.
	6. Efficiency—population size—flooded vegetative area	Hydric soils with a flooded vegetative area to herd size ratio smaller than 0.004 ha:1 cow eliminated	USDA NRCS constructed wetland rule-of-thumb. With smaller fractional ratios, constructed wetlands perform poorly as they exceed their treatment loading capacity.
	7. Efficiency—Contact time-retention time	Hydric soils with retention time less than one day eliminated.	USDA NRCS constructed wetland rule-of-thumb. Retention time less than one day has no significant effect on NPS N pollution removal
III. “Rank” or target the rated hydric soils by sequential priority sorting. The protocol involves 5 steps arranged in the most significant water quality improving order:			Protocol is according to a guidance developed by USACE, USFWS and USDA NRCS
	4. Herd Size	Rank the rated hyrdic soils by associated herd size (largest to smallest)	Dairy herd is the most important factor in quantifying potential pollution risk
	5. Relative elevation (up/ down slope within same herd size)	Hydric soils with same herd sizes are sorted by down slope then upslope positions relative to pollution source	Costs of polluted runoff collection and transfer system construction to value of water quality improvement is used by agencies to calculate cost-benefit ratios to prioritize projects
	6. Land use	Hydric soils with same herd size and relative elevation are sorted by land use in the following order: pasture, hayland, cropland and farmstead (least to greatest modification or least to greatest restoration cost)	Construction costs are associated with collection, transfer system components and cost of restoration itself. The latter are related to degree of drainage or modification.
	7. Flooded vegetative area	Hydric soils with same herd size, relative elevation and land use are sorted by surface area (largest to smallest)	Greater the surface area, greater the N cycle bio-transformation capacity
	8. Retention Time	Hydric soils with same herd size, relative elevation, land use and surface area are sorted by retention time (longest to shortest)	The longer the pollutant is in contact with bacteria, greater is the probability for its assimilation

Use of Sub-Surface Wetlands in the Urban Setting

Introduction

Urbanization can drastically alter the natural hydrologic cycle, destroying natural areas like wetlands that are important for water quality and controlling urban storm water runoff. The urban pollutant loads increase with the imperviousness of the watershed. Urban and suburban runoff including storm water runoff non-point source pollution, contributes significantly to the pollution load of U.S. inland water surfaces (Kadlec and Knight 1998). Additionally, the stormwater flows and concentrations are episodic, changing rapidly in volume, duration and intensity. These flows can carry rural sediment/nutrient loads into urban settings where the pollutant loads are further augmented by increased runoff from impervious surfaces such as parking lots, roadways, rooftops, etc. The resultant runoff can include suspended particulate matter and nutrients (especially N and P) from vehicle exhaust and atmospheric deposition, trace metals from metal corrosion, materials from worn brake lining and tires, salts (deicing salts), and a wide array of complex hydrocarbons (such as motor additives, pesticides, rubber, oil and grease. In central New York (CNY), combined sewer overflows add raw sewage to this pollutant mix.

Urbanization around many watersheds in CNY, like Onondaga Lake and its contributing tributaries, has destroyed/ degraded vast areas of wetlands to such an extent that they can no longer provide their normal wetlands functions to the riparian system. The most prominent loss has been to the natural buffering capacity of the wetlands which in combination with the history of industrial, domestic and storm-water runoff pollution has led to the degradation of several water systems. An effective way to deal with this wetland loss along with water quality and quantity goals would be adoption of constructed wetlands as storm water and waste water management which can provide onsite solutions to water quantity/quality and restoring wetland habitat resources that have been lost to urban development activities.

Use of constructed wetlands

Constructed wetlands are planned systems designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands. The use of constructed wetlands for waste water treatment takes advantage of the same principles in a natural system, within a more controlled environment. They can be designed for a variety of treatment objectives, as influent ranges from raw wastewater to secondary effluent. As mentioned in the previous chapter, data from more than two decades of extensive monitoring of Constructed Wetlands Practice Standard- 657[12] (CW-656) has revealed significant reductions in the treated runoff. The use of constructed wetlands comes with several advantages and disadvantages.

Advantages include flexibility in site location, potential to treat more wastewater in smaller areas than with natural wetlands, optimal size can be designed for anticipated waste, and they cause no alteration to natural wetlands.

Disadvantages in using constructed wetlands over natural ones include cost and availability of suitable land, site grading, cost of construction (cost of gravel or other fill), cost of plant harvesting and disposal, breeding habitats for nuisance insects or disease vectors, may generate odors, pre-treatment maybe needed to avoid problems of bio-accumulation in wildlife, and so on.

Regulatory constraints, discharge standards and permit requirements

12. Constructed Wetland Practice Standard-656 is a constructed shallow water ecosystem designed to simulate natural wetlands, to reduce the pollution potential of runoff and wastewater from agricultural lands to water resources.

Municipal discharges to wetlands must meet minimum technology requirements and conform with state water quality standards. Clean Water Act and EPA regulations govern discharges of wastewater to waterbodies in the U.S., including any wetlands considered to be "waters of the USA." Section 402 of the Clean Water Act created the National Pollutant Discharge Elimination System (NPDES) permitting program. EPA regulates wastewater discharges to natural wetlands through this NPDES permit program. EPA uses a case by case approach to evaluate the use of natural wetlands for treatment purposes. It encourages the use of constructed wetlands through its innovative and alternative technology provisions. Projects that may result in any filling or other alteration of wetlands will generally need to obtain a Section 404 permit[13] and may have to address other federal requirements. Constructed wetlands designed, built, and operated as wastewater treatment systems are, in general, excluded from the definitions of "waters of the USA." However, in some cases, wetlands created to enhance wildlife and abandoned treatment lagoons that have developed dependent wildlife populations have been considered waters of the U.S.

Sub-Surface Flow Wetland Design

In subsurface flow treatment wetlands (SSW), the flows are fed to a gravel bed with pore spaces. Within these pores spaces, bacteria and algae do most of the treatment work in aerobic and anaerobic conditions year round. It has been shown that planted gravel beds achieved greater than 90% removal of chemicals. Several design recipes can be found in the literature for SSF wetlands. Some of these procedures are rules of thumb (as was the case with natural restored wetlands), based on intuition and analogs, and others are based on data analysis and application of physio-chemical principles. It is necessary for SSF wetland treatment to determine/ define the quantity and quality of water to be treated and the goals of the treatment.

Preliminary feasibility

The goal is to identify potential sites, estimate wetland size and determine if there is sufficient land available for a wetland. Cost estimates for the potential sites or projects would also be looked at at this stage.

Identification of potential sites proposed for creating wetlands

Sites identified for constructed wetlands need to be assessed for:

- Existing infrastructure to determine the ease of access,
- Ownership and availability of the site: if the land must be purchased, a significant cost is incurred, including the market price of land and ancillary acquisition costs,
- Engineering feasibility,
- Hydrology,
- Nature of soils on the site, and
- Topography: determines the amount of earth moving and the presence of large flat land area can influence potential costs. It also determines the need of pumps to move water to and from the site, which is an important cost consideration,
- Drainage area, and
- Upstream pollutant loading characteristics (including locations/ proximity of combined sewer overflows, if applicable).

13. Proposal to use natural wetlands for wastewater treatment involving some alteration of the wetlands, such as building dikes is generally neccessary to obtain a permit for the discharge of dredged or fill material from the Army Corps of Engineers (or appropriate state agency) under Section 404 of Clean Water Act before such construction will be allowed.

Sites which have large flat areas with presence of naturally wet areas are suitable for development of treatment sites. It is beneficial to identify wetland areas destroyed/lost due to urbanization within the drainage area to potentially locate the proposed constructed wetland site to derive the additional benefit of restoration of eco-system services provided by wetlands. The former wetlands areas can be estimated using National Wetland Inventory maps produced by the U.S. Fish and Wildlife Service.

Preliminary sizing

Each regulated water quality parameter requires its own particular wetland area for reduction to the desired level. Depending on regulations and retention time, the maximum size of the individual treatment areas is selected.

Preliminary economics

This includes the basic capital costs, operating and maintenance costs and comparison of costs for potential sites with those of conventional treatment options.

Engineering considerations and draft designs

The goal is to maximize treatment volume and efficacy. Typically there is a distribution box that distributes water based on the amount of flow and changes its distribution over time. Then there is a grit chamber in which the solids are dropped, and then the flow proceeds to the various buried gravel beds. Within these beds is a very course stone with pore spaces for bacteria and algae to do their work. The treated flow then moves towards the creek and is pumped back into the creek. Aquatic species can be planted on top of the gravel beds depending on whether the water levels in the beds and the frequency of flooding can support these species.

Stream (Hydrological) flow and stage calculations

To determine the quantity of water that will flow through SSW treatment it is essential to calculate both base-line and storm discharges. The amount and timing of the water to be treated is the first and foremost item to consider in design. This information should include the possible seasonality of flows and anticipated progres-sion of flows over the life of the design. This is more important for wetland design when compared with con-ventional water treatment plants because of the implied life cycle of the process and the nature of urban and industrial growth. Conventional water treatment plants are traditionally planned for a 20-year life expectancy, but wetlands can function for a far longer period.

Flows, whether municipal, industrial, or storm water, are often seasonal in character. It is necessary to antici-pate those patterns because the wetland must function appropriately under these variable hydraulic condi-tions. Monthly flow estimates are required for most point source projects, but storm water systems require a definition of frequencies of events and their magnitude and timing. The sampling and calculation for baseline flow should be done for at least one year or seasonal sampling should be done to capture the variations (or the different stages of flood flow) in the quantity of water entering SSW treatment. The frequency for this baseline sampling can be twice a month. A flow meter can be used to measure the velocity (V) of the CSO (storm water discharge). The discharge is then calculated using the following equation:

The information on water quantities and timing is then assembled into annual and monthly water budgets for design, including seasonal events that are important. Sometime this data may be available through the United States Geological Survey (USGS) gauging stations located at the water source.

Q = V x A

Q = discharge

V = velocity of the CSO discharge

A = area of the CSO channel transects.

Treatment potential

The treatment achieved in SSW systems depends on the volume and frequency of the inflow and also the characteristics of the inflow. Hence the treatment potential depends upon the following factors: hydraulic loading, retention, vegetation. However, the amount of water and the amounts of pollutants that reach the storm water treatment wetlands from contributing watersheds and/or urban surrounding are typically not known in advance. The number and duration of events that produce input are variable so it is difficult to define the retention time and hydraulic loading.

Nature of influx (Hydraulic loading): Water quality testing needs to be done for major pollutant sources for the SSW treatment system. To obtain better knowledge of the water quality aspects for the storm water or CSO discharge it is advisable to conduct at least a 1-year period of water quality data gathering. Major pollutant sources for the discharge is determined by assaying 5-day biological oxygen demand (BOD5), chemical oxygen demand (COD), total suspended solids (TSS), Total Kjeldahl Nitrogen (TKN), Ammonia (NH_3), total phosphorous, pH, salinity, alkalinity, fecal coliform, Iron, Mercury, Lead, hydrocarbons, Chromium, Benzene, pesticides, herbicides, polychlorinated biphenyls (PCBs), and arsenic.

Baseline sampling is done at the storm sewer outflow (SSO) (inflow) and upstream , however for an event sampling (when there is sever overflow), three samples should be taken; at the CSO, an upstream water sample and a downstream sample.

Retention (detention) time / Hydraulic Retention Time (HRT): This can be obtained using the water quality data for the baseline and CSO; total maximum daily loads and water quality-based effluent limits defined by policy (NYDEC) for effluent concentration data; maximum concentration measured in the last year's sample for influent data; and adopting the average rate constant from 14 operational sub-surface flow treatment wetland systems.

Vegetation in the system: The gravel bed will require planting because the media is not optimal for germination. The presence of macrophytes is important for pollutant removal functions. The three genera of wetland plants most frequently used are:

- *Phragmites australis* has remarkable growth rates, root development and tolerance to saturated soil conditions
- *Typha spp.*
- *Scirpus spp*.
- But in our own Research (Wu 2008) two species did quite well – Prairie Cordgrass (*Spartina pectinata*) and Sweet grass (*Hierochloe odorata*) and did much better in terms of survival as well as provide better habitat and aesthetic value.

Table 7: Sequential Steps for citing and identification of a Constructed Wetland for Water Quality Treatment for BMP

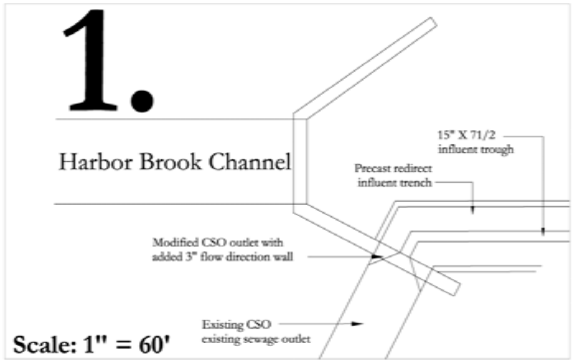
.

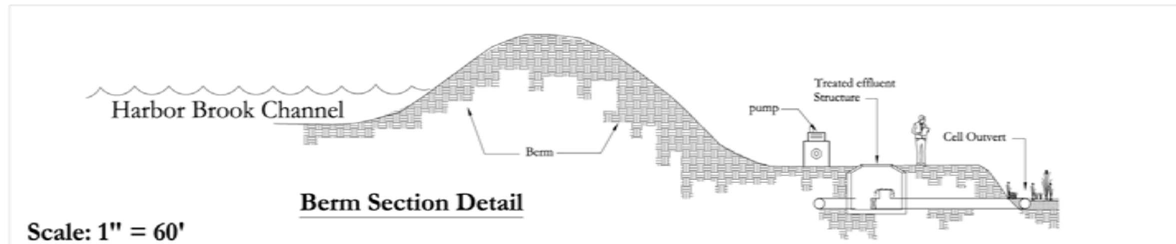
Steps	Criteria	What to do/ Why?	From Where?
1. Identification of potential sites	1. Existing infrastructure	This determines ease of access	
	2. Ownership and availablity of the site	If the land must be purchased, a significant cost is incurred, including the market price of the land and ancillary acquisition costs.	
	3. Engineering feasibility	location and costs	
	4. Hydrology	rate of flow	
	5. Nature of soils on the site	This can affect design and construction cost. For example, if the wetland is required to be relatively impermeable to protect groundwater, and the soils on site are permeable a liner may be required, adding to costs.	
	6. Topography	Determines the amount of earth moving, hence presence of large flat land area can influence costs. It also determines whether pumps will be needed to move water to/from the site, further adding cost considerations.	
	7. Drainage area	storm sewershed	
	8. Upstream pollutant loading characteristics	This will also include locations/proximity of combined sewer overflows	
2. Preliminary Sizing	Water quality regulations and retention time	Depending upon the regulated parameter and the retention time; the maximum of the individual treatment areas is selected as the final size	Refer to Chapter 20 & 21, Kadlec and Knight (1996). Regulatory parameters for treatment can be obtained by the NYSDEC

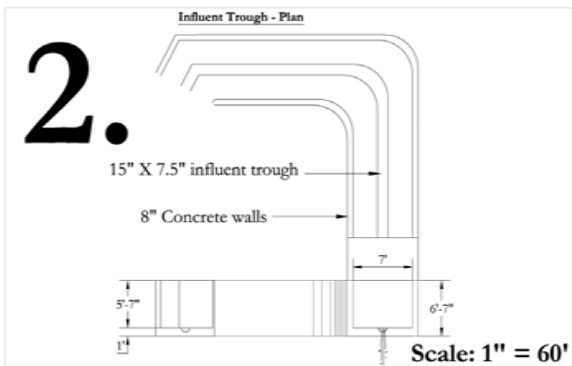
Table 7: *Sequential Steps for citing and identification of a Constructed Wetland for Water Quality Treatment for BMP; continued*

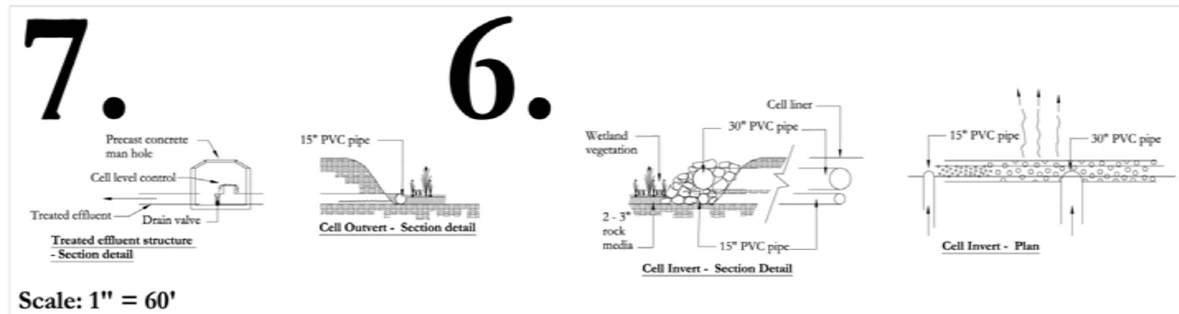
Steps	Criteria	What to do/ Why?	From Where?
3. Preliminary Economics	Costs of basic capital and operation/maintenance	These need to be compared for all potential sites identified and costs of conventional treatment facilities	
4. Stream Flow Calculations	Baseline flow and storm discharges	Amount and timing of the water to be treated is the key	Min. 1 year water quantity sampling or seasonal sampling to capture variations. Data may also be available through United States Geological Survey (USGS)
5. Nature of Influx (hydrolical loading)	BOD5, COD, TSS, TKN, NH3, total Ph, pH, salinity, alkalinity, fecal coliform, Iron, Mercury, Lead, hydrocarbons, Chromium, Benzene, pesticides, herbicides, PCB, arsenic	Concentrations of pollutants in the water to be treated are critical to the sizing process.	Minimum one year water quality sampling or seasonal sampling to capture variations.
6. Retention Time	1. Water quality data for the baseline and CSO	Calculations	Refer to Chapter 19, 20 and 21, Kadlec and Knight (1996)
	2. Total maximum daily loads	Calculations	
	3. Water quality-based effulent limits defined by policy for effluent concentration data	Calculations	Regulatory policy limits defined by NYSDEC
	4. Adopting the average rate constant from 14 operational sub-surface flow treatment wetland systems		
7. Vegetation in the System	Presence of macrophytes is important for pollutant removal functions	Three commonly planted species are: • *Phragmites australis* • *Typha spp.* • *Scirpus spp.*	Better species for habitat include: Prarie Cordgrass and Sweet Grass

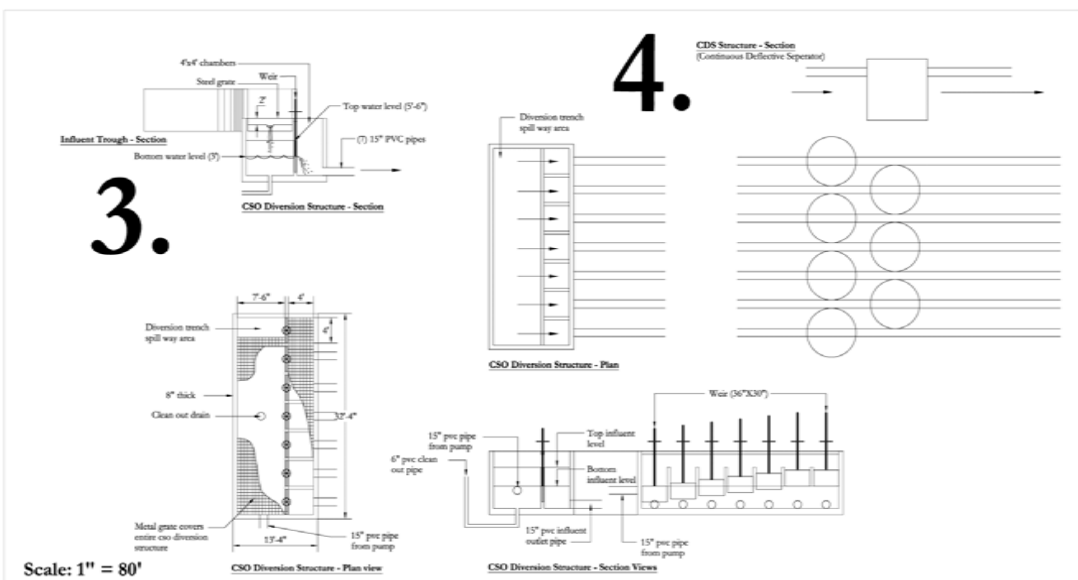
HARBOR BROOK SYRACUSE, NEW YORK
CSO WATER TREATMENT DEMONSTRATION PROJECT - DETAILS

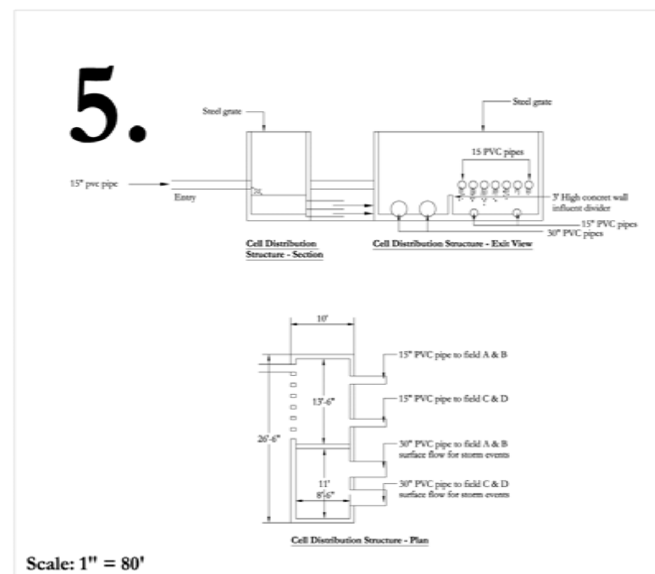












References

ASWM, Association of State Wetland Managers. 2000. Watershed- based wetland planning and evaluation. Proceedings of a Symposium at the Wetlands Millennium Event held August 6-12 in Quebec City, Quebec, Canada.

Bendoricchio, G., L.D. Cin, J. Persson. 2000. Guidelines for free water surface wetland design. Ecosystems Bd. 8:51-91

Brinson, M.M. 1993. Changes in function of wetlands along environmental gradients. Wetlands 13(2): 65-74.

Cedfeldt, P., M. Watzin, B. Richardson. 2000. Using GIS to identify functionally significant wetlands in the northeastern United States. Environmental Management 26: 13-24.

Cowardin, L. M., V. Carter, F. C. Golet, and E. D. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. US Department of Interior, Fish and Wildlife Service, Office of Biological Services, Washington, DC.

Dugan, Patrick (Ed). 2005. Guide to wetlands. Firefly Books Ltd.

EPA, Office of Water: Wetlands, oceans and watersheds - http://www.epa.gov/owow/wetlands/

Hammer, Donald A. (1989). Constructed wetlands for wastewater treatment- municipal, industrial and agricultural. Michigan: Lewis Publishers, Inc.

Johnson, Lauren Locklin. 2010. Restored Wetland- Treatment: A potential water quality BMP. Doctoral dissertation, State University of New York- College of Environmental Science and Forestry.

Kadlee, Robert H. and Robert L. Knight (1996). Treatment Wetlands. Boca Raton: Lewis Publishers.

Kusler, Jon. 1987. Our national wetland heritage- a protection guidebook. Washington D.C.: Environmental Law Institute.

Kusler, Jon . 2007. Wetland Assessment. Association of State Wetland Managers. P1-10.

Mitsch, William and James Gosselink. 2000. Wetlands, 3rd Edition. New York: John Wiley & Sons, Inc.

Palmeri, J.F. and M. Trepel 2002. A GIS based Score system for siting and sizing of created or restored wetlands: two case studies. Water Resources Management. 16: 307-328.

Ramsar Convention on Wetlands- http://www.ramsar.org/

Spray, Sharon L. and Karen L. McGlothlin (Eds). 2004. Wetlands. Lanham: Rowman & Littlefield Publishers, Inc.

USACE 1995a. United States Army Corps of Engineers. 1995. An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. Waterways Experiment Station, Vicksburg, MS.

USACE 1995b. United States Army Corps of Engineers. 1995. A guidebook for application of hydrogeomorphic assessment to ravine wetlands. Waterways Experiment Station, Vicksburg, MS.

USDA NRCS 2001. United States Department of Agriculture- Natural Resources Conservation Service. 2001. Hydric soil list of Chenango County, NY, Syracuse, NY.

USDA NRCS 2006. United States Department of Agriculture- Natural Resources Conservation Service. Indiana wetland mitigation policy. Technical reference- Wetland Science

USDA NRCS 2006. United States Department of Agriculture- Natural Resources Conservation Service. National Environmental Quality Incentive Program (EQIP) Evaluation procedure. Washington, DC.

USDA NRCS 2007. United States Department of Agriculture- Natural Resources Conservation Service. Resource management system quality criteria and guidance documents. http://policy.nrcs.usda.gov

USFWS 1980. United States Department of Interior- Fish and Wildlife Service. 1980. Habitat evaluation procedure. Washington, DC.

Welsch, David J.; Smart, David L.; Boyer, James N.; Minken, Paul; Smith, Howard C.; McCandless, Tamara L. 1995. Forested Wetlands. NA-PR-01-95. Radnor, PA: U.S. Dept. of Agriculture, Forest Service, Northern Area State & Private Forestry.

Woltemade, C.J. 2000. Ability of restored wetlands to reduce Nitrogen and Phosphorus concentrations in the agricultural drainage water. Journal of Soil and Water Conservation. 3: 303- 309.

Wu, Guihan. 2008. A Core Study on Applying Subsurface Flow Constructed Wetlands (SFEWS) to Treat Combined Sewer Overflows (CSOs) SUNY/ESF unpublished disseration, Syracuse NY. 177pp