THE **ROUGE RIVER** PROJECT
A WORLD CLASS EFFORT
BRINGING THE RIVER BACK TO LIFE

Rouge River National Wet Weather Demonstration Program

Wayne County, Michigan

TECHNICAL MEMORANDUM
Literature Review - Wetlands as a Nonpoint Source Pollution Control Measure

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MISSION STATEMENT

The mission of the Rouge River National Wet Weather Demonstration Program is to restore the water quality in the Rouge River as necessary to:

- provide a safe and healthy environment for ourselves and future generations,
- protect downriver water resources such as the Detroit River and Lake Erie, and
- re-establish a healthy and diverse ecosystem within the Rouge River watershed.

This will be accomplished through the development, implementation, and financial integration of a technical, social, and institutional framework leading to cost efficient, and innovative, watershed based solutions to control the wet weather problems in the Rouge River watershed.

PREFACE

The Rouge River has historically suffered and continues to suffer from the combined stress of pollutant loadings from various sources. The vast majority of continuous point sources have been eliminated through the issuance and enforcement of National Pollutant Discharge Elimination System (NPDES) permits for municipal and industrial dischargers. Yet, as established in the Rouge River Remedial Action Plan (RAP), the river remains polluted primarily because of sources associated with wet weather flow.

The Rouge River National Wet Weather Demonstration Program (Rouge Demo) is intended to evaluate each of the various sources of wet weather pollution; implement alternative remedial measures; investigate wet weather waste load allocations; establish associated pollutant load reductions; examine the financial and institutional impediments to wet weather pollution control; and recommend a plan and procedure for watershedwide pollution control which is "implementable" in the Rouge and can be readily transferred to similar urban watersheds throughout the country.

The effort is not being conducted in isolation. The Rouge RAP provides a baseline from which Rouge Demo efforts have begun. In fact, the Rouge Demo can be viewed as the key component of the initial implementation of the RAP. In addition, ongoing regulatory efforts aimed at controlling Combined Sewer Overflow (CSO) discharge have also been integrated into the Rouge Demo and all construction facilities will be in accordance to NPDES permits.

It is widely recognized, and reinforced by RAP recommendations, that CSO control by itself will not be sufficient to restore water quality to acceptable levels in the Rouge River and other similar urban rivers. The project has established a watershedwide concept as its focus. Within the Rouge River watershed, a range of pollution sources have been identified. They include: traditional urban runoff, illicit connections to drainage facilities, abandoned dumps within the river flood plain, wet fall and dry fall air deposition, and contaminated sediments within the river channel and impounded lakes.

The Rouge Demo has incorporated efforts to develop analysis tools, organize existing and future data, conduct field surveys, collect and analyze water quality samples, develop and implement water quality models, design and test structural and nonstructural best management practices (BMPs), and establish loadings from nontraditional wet weather sources. Additionally, it includes components that will involve watershed residents in pollution control planning, and will study the institutional structure and financial capabilities of those entities responsible for long term implementation of the recommended watershed plan.

To efficiently manage an effort with diverse objectives, the project has been divided into ten program elements. Each of these has a specifically defined technical or operational purpose. Within each of these elements, work plans are developed to define specific activities to be performed as part of the project. These work plans define the Tasks and level of effort.

The program elements that have been established are as follows:

Geographic Information System (GIS) and Mapping
Data Collection and Management
Sampling and Analytical Program
Modeling and Decision Support System (DSS)
Nonpoint Source Best Management Practices (BMPs)
CSO Design, Build and Test
Value Engineering
Public Information and Involvement
Financial and Institutional
Project Management, Coordination and Reporting

This document has been generated under the Nonpoint Source Program Element.

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1.0 INTRODUCTION.

The Rouge River National Wet Weather Demonstration Program has been initiated with the objective of developing a wet weather management plan for the Rouge River watershed. As part of this project, a literature review of the efficiency of wetlands systems for treatment of stormwater runoff has been conducted. This evaluation includes a review of the existing information on general wetland ecology, wetland ecosystem processes, and the use of wetlands for the water quantity/quality control of stormwater. Special emphasis was placed on those aspects of wetland ecology which pertain to nonpoint source (NPS) pollution control such as nutrient, toxics and sediment removal processes. The literature review focused on studies from Michigan and on nonpoint source pollution although additional sources from similar watersheds or other pollution sources were included where relevant.

The following is a summary of the literature reviewed with a list of references. This Technical Memorandum has been divided into several sections: Stormwater and Nonpoint Source Pollution, General Wetland Ecology, Nutrient Cycling, Wetland Systems for Wastewater Treatment and Nonpoint Source Pollution Control, and Natural versus Created Wetlands for Nonpoint Source Pollution Control. This technical memorandum completes Task 1 of Work Plan 7 of the Nonpoint Source Pollution Control Work Element. This technical memorandum completes Task 1.0 of Work Plan 7 of the Nonpoint Source Pollution Control Work Element.

2.0 STORMWATER AND NONPOINT SOURCE POLLUTION

2.1 ROUGE RIVER WATER QUALITY.

The Rouge River watershed encompasses 467-square miles with four watersheds which correspond to the four main branches of the river; Upper, Middle, Lower and Main (SEMCOG, 1978). The watershed contains numerous drains,tributaries and over 400 lakes and ponds. The watershed includes parts of Wayne, Oakland and Washtenaw Counties with a combined population of over 1.5 million. Most of the watershed is heavily developed for residential, commercial or industrial uses. The eastern portion of the watershed is intensely urbanized while the northern and western portions of the watershed contain more suburban and rural land and most of the remaining undeveloped land.

Water quality is assessed by physical and chemical parameters which are compared to standards set by the Water Resources Commission (P.A. 245, 1929). The severity of water pollution is evaluated based on the degree of impairment of the beneficial uses of a water body. Water quality problems in the Rouge River watershed are severe (SEMCOG, 1989). The Water Resources Commission has designated the beneficial uses of the Rouge River to include: water contact recreation, warm water fishery, industrial and agricultural water supply, navigation and general aesthetics. All of the four major sub-watersheds fail three of five designated beneficial uses (MDNR, 1992). In addition, the Rouge River has been designated a Great Lakes Area of Concern by the International Joint Commission.

The major sources of water pollution for the Rouge River have been identified as combined sewer overflows (CSOs), nonpoint source (NPS) runoff, sanitary sewer overflows and industrial and municipal discharges (MDNR, 1992; SEMCOG, 1978, 1989).
A Remedial Action Plan has been developed for the Rouge River (SEMCOG, 1989) which identifies the sources of pollution for the upper, middle and lower reaches of the Upper, Middle, Lower and Main branches of the Rouge River as follows:

- CSOs contribute nutrients, solids and pathogens. These pollutants impact the river in the vicinity of the discharge points, located along the middle and lower reaches of the four branches.

- Nonpoint source runoff is a major contributor to flow, suspended solids, biochemical oxygen demand (BOD), nutrients and trace contaminants. NPS pollution is a major concern in the upper and middle reaches of all branches of the Rouge River.

- Industrial and municipal discharges, controlled under National Pollution Discharge Elimination System (NPDES) regulations, are considered a minor source of pollution to the Rouge River, although in downstream reaches they are major contributors to flow. NPS runoff from industrial sites can have many times the concentration of toxicants as typical NPS runoff (Pitt, 1990).

- Sediment from portions of the Rouge River are a source of heavy metals (cadmium, chromium, copper, lead, mercury, nickel and zinc) and PCB contamination (MDNR, 1992). Sediment contamination increases from the headwaters to the downstream reaches to the heavily contaminated mouth of the river.

NPS runoff has significant impacts to the ecology of the Rouge River. The loss of wetlands, floodplains and the development of land with the accompanying increase in impervious surfaces results in extreme flow fluctuations. Drought flows are extremely low, some years to 0 cubic feet per second (cfs), which significantly restricts aquatic life (SEMCOG, 1989). High flows are also extreme, resulting in erosion and stream bed scour which impacts aquatic habitat and re-suspends contaminated sediments. NPS runoff contains high levels of nutrients, BOD, bacteria (measured as fecal coliform) and solids as well as heavy metals and organic contaminants. The nutrients, BOD and suspended solids contribute to low dissolved oxygen, especially during low- and high-flow conditions, which also restricts aquatic life and contributes to eutrophication of the river.

The diversity of aquatic life declines from the headwaters to the downstream reaches (MDNR, 1992). In the downstream reaches numerous fish kills have been reported and fish contamination has resulted in fish advisories for all branches of the river.

2.2 NONPOINT SOURCE RUNOFF CHARACTERISTICS.

The Nationwide Urban Runoff Program (NURP) studies (Athayde et. al., 1983) report highly variable quantity and quality of urban stormwater runoff. NPS runoff exhibits a 'first flush' discharge pattern where pollutants are concentrated in the initial portion of the discharge and typically are at peak concentrations for short durations (Barten, Lakatos and McNemar, 1987). Pollutants in NPS runoff include toxic components as well as sediments, nutrients and bacteria. The metals copper, lead and zinc constitute the most prevalent priority pollutants. These metals as well as other trace metals originate from tires, automobiles, paints, pipes, flashing, roof materials and catalytic converters (Tourbin and Westmacott, 1989). Organic priority pollutants have been identified in scans of NPS runoff, but are generally below relevant criteria or guideline levels. The typical organic pollutants include some pesticides, herbicides, phenols, cresols and phthalates. Oil and grease are also common components of NPS runoff. Oil and grease originate from sources such as automobile leaks on roads, parking lots and service stations. Chlorides are a component of NPS runoff common in the winter when roads are treated with salt deicers. After snow melt events, chlorides can exceed several thousand parts per million which is toxic to many freshwater organisms (Baker, 1993; O'Reilly, 1990).

Sediments, nutrients and bacteria in NPS runoff result from erosion, organic decomposition, fertilizers, pet and animals droppings. High levels of sediments increase turbidity and cover the substrate with silt. These factors severely restrict aquatic life by reducing visibility for prey capture, clogging of gills and filters and reduced spawning and juvenile habitat for fish (O'Reilly, 1990). Excess nutrients result in reduced diversity of aquatic plants and increased growth of algae. These factors contribute to increased BOD and low dissolved oxygen conditions. Bacteria is typically present at high levels in NPS runoff. High levels of bacteria restrict human body contact uses.

3.0 GENERAL WETLAND ECOLOGY.

Wetland ecosystems have traditionally been considered transition zones between open lakes and upland forests. Wetlands are integrally tied to the adjacent ecosystems and exhibit several similar characteristics. For example, similar to terrestrial and aquatic ecosystems, there are nutrient-high as well as nutrient-poor wetland systems. However, there are differences in the importance of the sediment storage of the nutrients and in the role of the vegetation in the nutrient cycle (Mitsch and Gosselink, 1986). Natural wetlands typically exhibit gradual hydroperiods, complex topographic structures, moderate to high wildlife habitat value, support few exotic species and are self maintaining.

Created stormwater wetlands, dependent on surface water runoff, are often described as "semi-tidal", being continually exposed to inundation and subsequent drawdown. According to Schueler (1992), no natural wetlands in the mid-Atlantic region exhibit this uncommon hydroperiod. The extent of the changes in water level impose severe physiological constraints on the plant community. The resulting created wetland systems typically have a larger standing open water component than natural wetlands (Schueler, 1992).

Wetlands are presently defined and classified by their hydrologic systems, vegetative communities, and soil conditions.

3.1 HYDROLOGY. The hydrologic character of a wetland is the single most important determinant for the establishment and maintenance of wetland processes and community structure. The hydroperiod of a wetland is generally defined by parameters such as water depth, flow patterns and duration and frequency of flooding and the hydroperiod affects the species composition and richness, primary productivity, organic accumulation, and nutrient cycling. The structure, shape and size of wetlands change over time, primarily as a result of changes in the hydrology. Long-term water level changes can drastically alter the extent and structure of a wetland (Keough, 1990). These system-wide effects stem from the hydrology's influence on the biochemistry of the soils (Mitsch and Gosselink, 1986).

While hydroperiods are unique to each type of wetland, it has been documented that productivity is highest in wetlands that exhibit flow-through water and nutrient regimes, and/or in wetlands with pulsing hydroperiods.

The most effective nonpoint source pollution abatement programs often rely on or enhance the existing hydrologic processes of wetland ecosystems. This generally means water level manipulation and adjustment to optimize retention time and contact between the litter-soil interface and stormwater. The degree of pollution abatement depends on the effectiveness of water level control.

3.2 VEGETATION. Wetland vegetation characteristically is tolerant of flooded conditions, being adapted to specific hydrologic regimes as well as soil compositions. Static hydrologic conditions tend towards emergent and wooded systems, each with relatively well-defined boundaries (Keddy, 1990). Greatly fluctuating hydrologic systems, such as estuaries, marshes, and flood plains exhibit a gradient of vegetative diversity that parallels the flooding regime.

Many wetlands with long flooding durations have lower species richness than do less frequently flooded areas. Wet meadows usually support the greatest diversity of vegetation (Keddy, 1990). Forested wetlands are dependent upon flooding frequent enough to control the impending competition of the understory and trend towards a shrub dominated system. Emergent systems are likewise dependent upon a continual flooded state to control the invasion of wooded species. The nature of wetland saturated soils and flooding serve to exclude terrestrial species (Keough, 1990).

3.3 SOIL. Soil represents a critical physical component in the determination of the vegetative as well as biotic communities which inhabit an area. The determining parameters include depth, mineral composition, organic matter content as well as chemical, moisture and temperature regimes (Cowardin et. al., 1979).

Chemical transformations as well as primary storage of available nutrients occur within the wetland soil medium. Newly created wetlands or existing wetlands designed to provide pollution abatement tend to act as nutrient sinks until an equilibrium is established. This seems to be due to availability of sorption sites in the soil in the early operation of such systems. As the soil sorption sites become saturated, biochemical and biological processes continue to remove nutrients from the water column.

The basic soil classification in the U.S. with regard to wetlands distinguishes between mineral and organic soils (Cowardin et. al., 1979). Organic soils (Histosols) are often saturated with water for prolonged periods of time and consist of between 12% and 20% organic carbon, dependent on the amount of clay present. Peat soils have significant pore spaces, allowing them to be approximately 80% water, by volume, when flooded (Mitsch and Gosselink, 1986).

Mineral soils are composed on less than 20% to 35% organic material. These soil conditions occur in many freshwater marshes and riparian forests. Distinct soil horizons, the upper layer often being organic peat composed of decayed plant material, are indicative of wetland mineral soils. Due to the physical properties of mineral soils, total nutrients are often more available to plants in mineral soils than in organic soils. Mineral soils, exhibiting only 45% - 55% total pore space, typically cannot absorb as high a volume of water as organic soils (Mitsch and Gosselink, 1986).

4.0 NUTRIENT CYCLING. Wetland systems have attracted attention as natural sinks for nutrients and contaminants and as potential components for nonpoint treatment of stormwater. Wetland vegetation provides biological uptake and sites for microbial transformation of nutrients in runoff. Wetland vegetation also represents high plant productivity and nutrient needs, slow decomposition activity, large adsorption potential, high microbial activity, etc. Studies have generally found that both natural and constructed wetland systems remove sediment, nitrogen and to a lesser extent phosphorus from wastewater and stormwater. However, attempts to quantify and compare the effectiveness of wetlands for nutrient removal have been met with mixed reviews.

Wetland vegetation possesses numerous mechanisms for assimilating nutrients and other elements through the interrelationship of the physical, chemical, and biological interactions with soil layers, water and air interfaces, biological and microbial activity. The primary mechanisms for nutrient removal involves adsorption onto particulate matter, physical sedimentation of particulates, plant uptake from sediments, chemical transformations, and microbiological metabolism. Nutrient cycling for wetland systems is fairly well understood. However, nutrient retention or removal effectiveness cannot be quantified between various components of the cycle because of the uniqueness and complexity of the environmental conditions of ecosystems. The major nutrients of study for Michigan wetlands are nitrogen and phosphorus, since they represent the limiting factor of productivity and are most frequently found in stormwater.

4.1 NITROGEN. The dominant forms of nitrogen entering wetlands through stormwater are ammonium-nitrogen, organic nitrogen, and nitrate-nitrogen. Within wetlands, the nitrogen cycle is complex and dependent upon input concentration and the rate of fixation, immonification, nitrification, volatilization, dentrification, uptake and release by vegetation, and wetland hydrology. Hydrologic factors are probably the most significant influences on the uptake and transformation of nitrogen in wetlands. Inundation of wetland systems provides anaerobic conditions which have a marked influence on several biochemical transformations unique to anaerobic conditions. Water movement and distribution influences the ability of wetlands to remove nutrients. Nitrogen uptake is most effective where water flows slowly and evenly over the wetland surface thus providing an increase in the effective area and detention time available for biological interactions (Simpson, 1978; Tilton, 1979). During high flow conditions, elevated nutrient levels in outflow waters have been reported and have been attributed to leaching and flushing of decomposing plant material (Lae, 1969). These results emphasize the need for properly designed hydrological systems for stormwater inflows.

In nearly every transformation of the nitrogen cycle, microorganisms play an important role. Organic nitrogen is broken down to primarily ammonium by microorganisms in the substrate and water column through a process called ammonification. A thin layer of oxidized soil, sometimes only a few millimeters thick, is very important in the chemical transformations and nutrient cycling that occur in wetlands (Mitsch, 1986). Because of the anaerobic conditions in wetland soils, ammonia would normally be restricted from further oxidation and would build up to excessive levels were it not for the thin oxidized layer at the surface of many wetland soils. This process may be the most significant rate-controlling reaction in the nitrogen cycle. Although nitrate is the preferred form of nitrogen for plant uptake, ammonium uptake by plants is known to occur particularly in anaerobic conditions where nitrate becomes less available for plant roots. In aerobic conditions ammonium is readily transformed to nitrate through oxidation, a process called nitrification.

Nitrification refers to the biological conversion of ammonium compounds to nitrite and nitrate-nitrogen by bacteria in the presence of oxygen where approximately 4.6 mg/l of dissolved oxygen is required to convert 1 mg/l of nitrogen (USEPA, 1975). Minimum nitrification occurs when dissolved oxygen is less than 2 mg/l (Chen, 1974). The bacteria, specifically Nitrosomonas and Nitrobacter, are dependent upon aquatic vegetation for appropriate habitat while the aquatic plants utilize the nitrates produced by the nitrifying bacteria. The nitrate produced during this process will either be taken up by plant roots or diffused into the anaerobic zone where dentrification proceeds.

A second pathway of ammonium loss from a wetlands system is through the process of volatilization at the air-atmosphere interface. Studies in Michigan (Kadlec, 1977) found that this process removed more ammonia than nitrification, vegetative uptake or sediment adsorption. Ammonia volatilization is significant only when the pH is greater than 8.0 and is therefore less significant means of ammonium removal in most Michigan wetlands. Wetlands present ideal conditions for the removal of nitrogen through a process called dentrification because they exhibit high organic matter, slow decomposition rates, and an aerobic-anaerobic interface at the sediment-water interface. Dentrification occurs as nitrate and nitrite are biochemically reduced to gaseous nitrogen at the anaerobic sediment-water interface. Dentrification has been documented as a significant path of nitrogen loss from some wetland systems (Kaplan, 1979) and has been documented as the most significant removal mechanism in some northeastern wetlands. In Massachusetts, 90 to 95% of the nitrate added to wetland soil-water suspensions was reduced to nitrogenous gases (USEPA, 1977). Dentrification is inhibited in acid soils and peat and is of less consequence in northern peatlands of Michigan.

Vegetative uptake of nitrogen in wetlands is complex and site specific relative to unique environmental conditions for individual wetlands. Interactions of water quantity and quality, sediment condition, plant diversity and density play an important role in plant uptake. Klopatek (1978) suggests that aquatic vegetation functions as a "nutrient pump", uptaking nitrogen from the sediment and water column and temporarily immobilizing it within plant tissues. However, nitrogen assimilated into wetland vegetation may be translocated and stored long-term in the roots of plants or returned to the litter component where it is eliminated from the system through other processes described above.

4.2 **PHOSPHORUS**. Phosphorus has been described as a major limiting nutrient in freshwater marshes (Klopatek, 1978) and various other wetland types. Phosphorus occurs as soluble and insoluble complexes in both organic and inorganic forms in wetland soils. The orthophosphate form is biologically available while dissolved organic phosphorus and insoluble phosphorus are generally not biologically available. The phosphorus cycle is generally less complex than the nitrogen cycle because there are fewer chemical transformations in wetlands. The major process for phosphorus removal is adsorption and precipitation reactions with aluminum, iron, and calcium in the soil (Nichols, 1983).

The sediment-water interface of wetland systems is the most important transformation site in the phosphorus cycle. In aerated conditions, inorganic phosphorus may develop complexes with various metals as oxidized forms and can effectively be removed from the water column through precipitation and incorporation into the bottom sediments. This phosphorus sink functions only under aerobic conditions; in wetland systems, however, the sediment-water interface is frequently anaerobic. Under reducing conditions, phosphorus and the associated ions can be released to overlying water.

In many studies, algae and bacteria were identified as important in phosphorus dynamics. Algae uptake was significant in Michigan (Kadlec, 1977; Tilton, 1976) where high productivity resulted in "luxury uptake" of phosphorus by algae. The majority of this phosphorus uptake by algae is temporary as phosphorus is slowly released through bacterial decomposition. It is transformed from organic phosphorus into inorganic phosphorus where it becomes available for adsorption, assimilation by vascular plants, or transported from the wetland.

It has been reported that seasons are an important factor when considering natural wetland systems with respect to nutrient retention. Northern wetlands have generally been found to release phosphorus during flushing flows in the fall, winter, and early spring. The best removal efficiencies are reported in the spring and summer growing seasons (Keenan, 1974; Sloey, 1978). Meanwhile, Sutherland (1979) reported that seepage wetlands provided nearly complete phosphorus removal through soil adsorption.

Uptake by vascular plants has been characterized by some studies as a "pump" where phosphorus is taken from the sediments, temporarily stored in plant tissues, and then released to the sediments through litter decomposition (Prentki, 1978). Plant uptake of phosphorus in wetland systems does increase the total phosphorus absorbing capacity, reducing the phosphorus loading and impacts to downstream receiving waters during the growing season. However, in general, wetland systems are not as effective for phosphorus removal as for nitrogen removal (Holley, 1966).

Unlike the nitrogen cycle, the only removal mechanisms for phosphorus from the water column is through sediment adsorption, removal of above-ground plant parts or phosphorus-laden sediments, or through seasonal hydrologic flushing. Studies of the yearly balances of phosphorus in some Wisconsin wetlands (Spangler, 1976; Spangler 1977) indicated overall minimal net phosphorus removal by wetland systems. However, Brix (1987) and Nichols (1983) found removal efficiencies as high as 95% and as low as 11%. Phosphorus eventually is bound to the substrate where it remains within the system or is flushed out into the receiving waters and bound to the substrate downstream.

4.3 SEDIMENTATION PROCESSES. Sedimentation is one of the most important mechanisms by which particulate pollutants are removed from stormwater. This removal of particulate matter is significant because the sediment itself seriously impacts water quality and aquatic resources. The pollutants which are adsorbed to the surface of particulate matter only supplement the degradation of water quality.

Sedimentation of pollutant particulates or pollutants adhering to the surface of particulate matter is the primary mechanism for the removal of these substances from stormwater. The process has been reported as significant for the removal of nitrogen (McElroy, 1978), oils (Gadbois, 1990; Gearing, 1980), hydrocarbons (Choi, 1976; Harper, 1985; Lakatos, 1987; Martell, 1978;) and metals, except for manganese and nickel (Knight, 1993; Cranston, 1980). The water quality and the physical composition of suspended solids determine the extent of pollutant adsorption and removal from the water column.

Sedimentation of pollutants is controlled by various physical and chemical mechanisms. Adsorption is the principal means of removal of dissolved pollutants in stormwater through electrostatic attraction, hydrogen bonding and chemical reactions. Under specific conditions of ionic strength, pH, temperature, redox potential and competing cations, adsorption can be particularly effective for the removal of certain heavy metals including: cadmium, copper, lead, mercury, and zinc. The greatest effectiveness occurs in wetland systems where the flow passes through vegetative and soil complexes prior to discharge. In wetlands, long residence times and shallow water promote greater contact with surface soils and increased pollutant removal efficiencies (Morris, 1979).

The nature of flow patterns through wetland systems has been found to influence the deposition of suspended solids and the overall pollutant removal effectiveness. Sheet flow and meandering channels provide the most effective deposition rates (Gosselink, 1978). Studies point to the importance of hydrological control, structural diversity and a combination of various wetland types. These factors in turn will promote circuitous flow, greater deposition, increase in the effective area and detention time, thereby improving the opportunity for biological interactions (Sloey, 1978; Tilton, 1979).

Various interrelated and complex chemical processes aid in the removal of pollutants from stormwater. Chelation is the chemical process by which metals are strongly bound to ionic molecules (ligands), either organic or inorganic. Wetland systems are high in organic material and provide many sources of ligands. Chelation competes with adsorption of the metals onto the surfaces of iron and manganese hydrous oxides (Kadlec, 1977) and is important in complexing certain metals from the water column. Sulfide is common in anaerobic soils of wetlands. In the presence of sulfide, metals form insoluble sulfides under reducing environments and precipitate out of the water column. Oxidation and reduction always occur simultaneously in wetland systems, chemically altering some pollutants to natural components.

Generally, wetlands act as detention areas and allow sedimentation of stormwater. Sedimentation is one of the most important mechanisms where pollutants can be removed thereby improving water quality. Within wetlands, however, high flow rates associated with storm runoff, seasonal runoff, human disturbances or unregulated discharges may seriously impact wetland vegetation. This may resuspend previously deposited and decomposing organic matter, flushing it out of the system and into the receiving water (Brezonik, 1968; Toetz, 1974; Hutchinson, 1974). The design of wetlands for the effective nonpoint source pollution control requires careful consideration of influent stormwater quality and quantity.

5.0 WETLAND SYSTEMS FOR WASTEWATER TREATMENT AND NONPOINT SOURCE POLLUTION CONTROL.

The use of wetlands for wastewater treatment has been a research topic for approximately 20 years. The results of this research represents a body of information that describes the limitations and opportunities for the use of constructed and natural wetlands for wastewater treatment. The purpose of this section is to summarize some of the relevant data from the wastewater field that is applicable to the use of wetlands for nonpoint source pollution (NPS) control.

5.1 APPLICABILITY OF DATA.

The information that has been developed in the wastewater treatment field regarding the effectiveness of wetlands in pollutant removal may not be directly applied to the use of wetlands for NPS treatment because of the differences between the two uses. Specifically, the systems are different in hydrology, pollutant loadings, pollutant characteristics, and operation and maintenance practices.

The hydrologic differences between the two systems are that wastewater treatment wetlands tend to receive a constant flow of water whereas NPS wetlands tend to receive pulse loadings of stormwater. The effect of this hydrologic characteristic is that some of the design criteria for wastewater treatment wetlands are not appropriate for NPS treatment systems.

Perhaps more important than the hydrologic aspects of these systems is the operation and maintenance aspects, especially as they relate to winter operation. Most wetland wastewater treatment systems in northern temperate regions discontinue treatment during winter months. Those systems that continue operation during the winter season must take special measures to assure that wastewater continues to remain in contact with the soil-litter interface. In the event that a layer of ice forms on top of the soil-litter complex, the wastewater treatment is severely reduced. NPS treatment systems in northern temperate regions are particularly prone to this problem and the likelihood of a storm event discharging to a wetland with a layer of ice in place is high. NPS control is reduced when this occurs; studies in Minnesota, however, indicate there is still significant removal of pollutants.

Although there are important distinctions between wetlands systems for wastewater treatment and those for NPS pollution control, there are some design criteria that can be transferred.

5.2 POLLUTANT REMOVAL RATES. Wastewater treatment in wetland systems is achieved through sedimentation and filtration, soil adsorption, chemical precipitation, biological uptake by plants, and microbial transformation of nutrients. Pollutant removal in wetland systems receiving stormwater is achieved through similar processes as described in the previous section. Summarized below are typical pollutant removal rates reported in the literature for both types of wetlands systems.

- Total Suspended Solids: The filtration and sedimentation processes active in wetlands produce high removal rates for suspended solids. In wastewater treatment systems, removal percentages of up to 93% and 91% have been reported in Bellaire, Michigan and Listowel, Ontario, respectively.

  Somewhat lower removal percentages have been reported for NPS wetlands, perhaps as a result of the hydrologic differences. For example, in the Washington, D.C. area 25 wetlands averaged 75% removal of total suspended solids.

- BOD: Wetlands are effective in reducing BOD from incoming waters at wastewater treatment plants. It is generally accepted that removal efficiency of 70-90% is possible in wetland systems. NPS wetlands tend to have a much lower BOD removal efficiency such as the 15% reported as an average for twenty five NPS wetlands in the Washington, D.C. area.

The reduced BOD removal efficiency in nonpoint source pollution control wetlands is in part due to the lower BOD concentration in stormwater compared to wastewater and the characteristic of wetlands to internally produce certain BOD substances.

- Total Phosphorus: Removal efficiencies for wetland wastewater treatment systems are variable but most operating systems are reporting between 30-50% removal. NPS wetlands also tend to produce variable removal efficiencies with most projects reporting similar to those for wetland wastewater treatment systems. In Washington, D.C. the removal efficiency for total phosphorus was 45%, but some investigators have reported removal efficiencies of 9%. However, in West Bloomfield, Michigan unpublished data from an NPS wetland system showed a total phosphorous removal efficiency of 85% during the growing season.

- Total Nitrogen: Total nitrogen removal in wastewater systems using wetlands is proportional to the loading rate. Removal efficiencies of 75 to 95% have been reported for high loading rates with lower efficiencies at lower loading rates. The lower removal efficiency at lower loading rates is in part due to the fact that nitrogen is naturally generated within wetland ecosystems. Wetland systems receiving stormwater tend to produce lower removal efficiencies because the nitrogen loading rate tends to be low. Removal efficiencies of 5-60% have been reported and the study in Washington, D.C. reported an average of 25%.

As with all pollution abatement systems, wetland systems may decrease in effectiveness over time. This may manifest itself as sediment accumulation in the basin or saturation of the cation exchange site in the soil. This tendency suggests that wetland management plans should include maintenance practices such as sediment removal and in certain cases replacing soil that has become saturated with nutrients. Some operators have discussed the option of vegetation harvesting as a means of prolonging the life of a treatment system. However, the nutrients in vegetation represent only about 10% of the total stored in a wetland system and given the difficulty associated with harvesting, implementing a harvesting program should be carefully evaluated.

5.3 DESIGN CRITERIA. As discussed earlier there are some differences between the design of wetland wastewater treatment systems and wetland NPS pollution control systems.

- Hydrology: The hydraulic loading rates of wastewater treatment systems is related to wastewater characteristics but the optimal loading rate is approximately 21,000 gpd/acre as reported from Listowel, Ontario. The range of loading rates reported in various studies is 16,000-54,000 gpd/acre. A detention time of 6-7 days has been reported as optimal for primary and secondary treatment of wastewater. However for phosphorus retention as much as 21 days of retention was necessary to achieve effective removal. Residence time is considered an important variable when designing wetlands and wastewater treatment systems (Hammer and Kadlec, 1983).

The hydraulic loading rates for NPS wetland systems vary with the characteristics of the stormwater to be treated. Perhaps more importantly, treatment effectiveness in wetland systems is dependent on more than treatment volume alone (Schueler, 1992). Agricultural runoff with high BOD and nutrient loadings require larger wetlands and greater retention time. However, retention time for stormwater calculations depends on the precipitation event, and the volume of water generated from the watershed. Therefore, for any given wetland the retention time will be greater for smaller storm events than for larger storm events.

Due to the variable nature of runoff, the sizing of NPS wetland systems is based on a ratio of wetland size to watershed area. In the mid-Atlantic region, a wetland to watershed ratio of 2.0% has been recommended for shallow marsh wetlands and 1.0% for wetlands with a pond incorporated into the design. Similarly, Hammer (1993) reports that the wetland to watershed ratio for nutrient and sediment removal from agricultural runoff be 0.6% for marsh systems. The size of the wetland should also reflect the anticipated pollutant load (Tourbier and Westmacott, 1989).

- Vegetation Cover Type: Wastewater investigators have studied the relative effectiveness of various wetland species. The NPS wetland systems seem to be less dependent on maintaining a monoculture of plant species and in some cases are designed to increase species diversity (Schueler, 1992). The filtering effectiveness of the vegetation depends on its roughness coefficient, the degree of slope present, and the length of the buffer strip (Tourbier and Westmacott, 1989). Emergent vegetation has been used much more extensively than forested systems because of the difficulty in establishing mature forested systems.

- Wetland Configuration: Schueler (1992) has published guidelines on the proportion of wetland types to be incorporated into an NPS wetland system. Key design factors include surface area/volume ratio, the nature and length of flow path, and deep water pools. Surface area may be increased by planting dense emergent vegetation or increasing the topographic diversity in a wetland. The flow path length should be maximized within the available wetland area. Deep water pools at the inlet are important in reducing inlet velocity, trapping coarse sediment and increasing habitat diversity. Length to width ratio of between 4 and 7 to 1.

- Maintenance: Maintenance activities vary with project design, geographic location, and wetland type. In Michigan, it will be necessary to perform periodic inspections to insure that inlets and outlets are operating properly, and that hydrologic flow patterns in the wetland are maintained for optimum performance. In situations where sediment traps are part of the design it will be necessary to monitor sediment accumulation and perform maintenance dredging as required. Depending on the wetland type and the manner of wetland system operation it may be necessary to harvest vegetation or replant vegetated areas damaged by muskrat grazing.

5.4 **ECOLOGICAL CONSIDERATIONS**. Several ecological considerations resulting from use of wetlands as treatment for NPS runoff have been addressed in the literature. These considerations include impact of frequent flooding on forested wetland vegetation, mobility of toxic contaminants in the food chain, nuisance plants and animals, and thermal impacts to streams.

5.5 **FLOODING OF FORESTED WETLANDS**. Historically, efforts to reclaim or create wetlands have been directed at marsh ecosystems. Restoration or creation of forested wetland systems (bottomland forests) has been both less researched and practiced as well as less successful. The restoration and creation techniques associated with these differing wetland systems contrast greatly in their scope and required approach. While marsh restorations can be accomplished within a few years, bottomland forest restoration requires decades. Marsh restoration techniques have been well documented and can be repeated with similar results. Bottomland forest restoration techniques have not yet advanced to that stage (Clewell and Lea, 1990).

A wide variety of bottomland forest establishment techniques have been attempted and include planting young whips within a newly created wetland hydrologic regime, extending existing bottomland systems and transplanting local vegetation, and reverting the hydrologic regime of previously drained bottomlands. Many of these projects have met initial success, however due to the recent nature of this work, the techniques are not yet proven. Apparent success has been determined by species composition and community structure, however functional equivalency and tenacity of natural bottomland systems have not been assessed or well documented (Clewell and Lea, 1990).

It has been found that, like marsh restoration projects, the development and maintenance of adequate hydrological conditions is the single most important parameter in the restoration of bottomland forest systems. Only as a supplement to the hydrology, and integrally tied to the creation of the appropriate regime, substrate stability, availability of adequate soil rooting volume and fertility must also be considered as influential factors. The long-term management of the created or restored system as a bottomland forest must address issues such as control of herbivores and competitive weeds. In natural bottomland forests, the understory system accounts for more than 90% of the species composition. Recent work in altering bottomland systems have not taken this dimension into account and the introduction of an understory has not yet been widely valued (Clewell and Lea, 1990).

Bottomland forest alteration is limited by the sensitivity of woody vegetation to flooding; extensive high water periods tend to stress woody species and encourage herbaceous systems (Keddy, 1990).

Vegetation diversity varies along flooding frequency gradients, however, the tolerance to varying water depth and flooding duration is species specific and has not been well documented (Mitsch and Gosselink, 1986). Many species have been classified by their relative flood tolerance (Mitsch and Gosselink, 1986; Schueler 1992; and Whitlow and Harris, 1979), however, this is not directly associated with the success of creating functional vegetative communities. If the flood timing, depth and water quality become asynchronous with the life cycles or growth requirements of the species being established, the vegetation will be subject to stress and mortality regardless of their original tolerance levels (Clewell and Lea, 1990).

5.6 TOXIC CONTAMINANT MOBILITY. The toxic components of NPS runoff include metals and organic and petroleum compounds. The metals lead, copper, cadmium and zinc are common in NPS runoff; other metals are present in lower concentrations as trace contaminants. Metals present in runoff follow one of two behaviors in wetlands: 1) Metals such as arsenic, cadmium, chromium, nickel and zinc adsorb onto clay particles and organic material (Knight, 1993); 2) Metals are also likely to accumulate in the roots or rhizomes which are the plant parts considered important wildlife food.

Wetlands act as sinks for metals adsorbed to particulates. If these metals remain in the water column of viable fishery habitat, they can become saturated in fish tissue. Fish tissues reach a constant body burden that is based on the concentration of metals in the water column. Some authors report that metals do not appear to magnify through the food chain; bioconcentration factors between water and fish were found to be less than 100 fold. Others note that heavy metals are found in lower food chain animals (Kraus, 1987).

Lead and mercury can become methylated by microbial activity. These compounds are toxic to aquatic fauna and can bioaccumulate and biomagnify in the food chain due to an affinity for lipids which results in an accumulation in fatty tissue. At low input levels of methylated lead and mercury, steady-state body burdens can be maintained which are not toxic to the biota.

Metals in the sediments can be either incorporated into plant tissue, permanently incorporated into the sediments or re-suspended into the water column. Hammer (1993) notes that plant uptake of metals is highly variable. High levels of iron, 5,000 mg/kg, and manganese, 4,100 mg/kg, were found in cattail tissue exposed to acid mine drainage; cattail exposed to wastewater contained 0.3 mg/kg lead while cattail in a natural, unexposed wetland contained 1.7 mg/kg lead. Kraus (1987) found the emergent vegetation (cordgrass, cattail and reed grass) accumulated heavy metals at levels above natural background. He suggests that wetlands may not act as sinks but as toxicant reservoirs. Some plants concentrate metals such as the salt tolerant cord grass, Spartina alternifolia (Gadbois, 1990). Strong sediment binding and rhizosphere oxygenation inhibit plant uptake in most cases. Metals which are incorporated into plant tissue can be released to the water column during plant senescence and decay.

Metals in the sediments typically form immobile complexes. Metals in the upper sediments become slowly incorporated in a stabile crystal lattice. Significant changes in the redox potential of pH could results in metal mobility. Metals are released from sediments at rates of less than one percent of the total metal content, although cadmium and manganese are less tightly bound and are released at less than five percent of total metal content (Harper, 1985). Concentration of metals in sediments were found to decrease with depth suggesting leaching of metals in deeper sediments.

The majority of organic and petroleum compounds discharged to wetlands are degraded, metabolized or deposited in the bottom sediments. Petroleum products are hydrophobic and therefore either form a thin film on the surface of the water or adsorb to particulates or organic debris (Gadbois, 1990). Petroleum products on the water surface can chemically or microbially decompose or volatilize (Lakatos and McNemar, 1987). The remaining refractory by-products typically bind to particulates and settle to the bottom sediments. Once in the sediments, refractory petroleum compounds are slowly decomposed by a combination of aerobic and anaerobic decomposition processes (Harper, 1985).

Organic constituents of NPS runoff include herbicides, pesticides, solvents and other organochlorine compounds. Studies indicate most toxics adsorb to sediments except zinc and 1,3-dichlorobenzene which remain in the water column (Pitt et. al, 1991). Microbial and chemical processes degrade most organic compounds.

Created wetlands can process moderate concentrations of toxic organic compounds in NPS runoff without deleterious effects on wetland flora or fauna (Gadbois, 1990). High levels of toxic organic compounds could negatively impact the functioning of the wetland system through impacts to the existing wetland flora and microbial fauna. Wetland vegetation can adsorb some pollutants through root uptake resulting biological assimilation of pollutants. Wetland vegetation also provides a surface for establishment of microbial communities for decomposition of pollutants (Lakatos and McNemar, 1987).

5.7 NUISANCE PLANTS AND ANIMALS. Nuisance plants and animals may develop in created wetlands used for treatment of NPS runoff. Many of the nuisance species are common to natural wetlands, especially in urban or disturbed areas. Wetlands may provide breeding ground for nuisance insects such as mosquitoes. Tourbin and Westmacott (1989) found that mosquitoes were managed when the wetland basin remains connected to an open water body. The open water body provides habitat necessary for natural propagation of natural predators such as stickleback minnows, damsel and dragon fly larvae, and a variety of water beetles (Kristof, 1993). These organisms need aerobic conditions to survive; therefore, wetlands should be designed to maintain aerobic conditions. These conditions are especially important at the influent point where mosquitoes are most likely to propagate. Created wetlands have been shown to effectively reduce pathogens in numerous studies.

Purple loosestrife (Lythrum salicaria) is an invasive plant common to many wetlands in southeastern Michigan. This plant provides minimal water quality treatment or wildlife habitat functions. Control of purple loosestrife may be accomplished through biological or cultural controls such as pulling, burning or water level control. Carp (Cyprinus carpio) can also be a problem in wetland systems (Barten, 1987). Carp can enter wetlands during high flow periods from adjacent waterways. Once in a wetland, carp remove vegetation and stir up the bottom sediments as part of spawning activity. These activities result in increased turbidity, re-suspension of sediments and removal of vegetation necessary for proper functioning of the wetland. Carp can be removed by chemical eradication or installation of fish barriers.

5.8 THERMAL EFFECTS FROM WETLAND TREATED NONPOINT SOURCE RUNOFF. Thermal impacts to urban streams are common due to the loss of cover vegetation and inputs from impervious areas. Water in stormwater treatment wetlands is typically shallow with small pool areas and minimal flow (Galli, 1991). These conditions result in an average increase of 3.2°F in water discharged from treatment wetlands and a maximum increase of 8.7°F. Discharge of warmed water to streams can result in a species shift from sensitive species such as mayflies and stoneflies to more tolerant species such as midge larvae. Coldwater fish like trout or sculpins may not survive. At temperatures above 86°F blue-green algae dominate the plant material and contribute to odor problems associated with a treatment wetland. Design of NPS treatment wetlands can incorporate features which would minimize the thermal impact to streams. These design features could include shading of inflow and outflow channels, modified outlet structures, and infiltration basins (Schueler, 1992).

5.9 SOCIOECONOMIC CONSIDERATIONS. It is well recognized that wetlands provide a vast variety of benefits to man A brief survey of benefits includes: food conveyance, shore protection, sediment control, water purification, fish and wildlife habitat, water supply, aquifer recharge, flood storage, recreational fishing, hunting and sport activities, and heritage and aesthetic values (Athayde et. al., 1983; Fish, 1989; Gadbois, 1990; Mitsch and Gosselink, 1986; Odum, 1979; and Simpson and Whigman, 1978). The multi-functional nature of wetlands, in combination with protective wetland regulations, have resulted in the development of methodologies for assessing wetland values.

Value estimates can be made regarding flood control, sediment retention, and water quality improvement; however, aspects such as aesthetics and recreation are more intangible. Many of the values represent concurrent and overlapping benefits. Valuation of such benefits are further complicated by the comparison of wetland values against economic systems, as well as comparing individual interests against values that benefit the general public.

Several methods for determining wetland values have been developed, including: Wetland Evaluation Technique (FHWA/COE), Wisconsin Wetland Evaluation Methodology, Hollands-Magee (IEP/Normandeau), Minnesota Wetland Evaluation Methodology for the North Central United States, and the Wisconsin Department of Natural Resources Rapid Assessment Method. These methodologies aid in presenting wetland values usable for decision-making processes. These methods, however, focus primarily on the environmental-based values, and do not attempt to measure other inherent values such as aesthetics or even the monetary value of clean water.

The recognition of wetland values has encouraged public agencies to emphasize wetland regulations which aim to protect the integrity of the entire system of wetland functions and benefits. The effectiveness of remediation activities such as using wetlands to treat runoff pollution must likewise address the apparent as well as the less discernible wetland values.

6.0 NATURAL VS. CREATED WETLANDS FOR NONPOINT SOURCE POLLUTION CONTROL. Under the Clean Water Act, the EPA has responsibilities for wetland protections and specifically for regulation of discharge of waterborne pollutants (Section 401 and 402) (Robb, 1993). Natural wetlands have been used for treatment of stormwater runoff and for secondary and tertiary treatment of wastewater discharge. Controversy has arisen, however, over the use of natural wetlands for treatment of stormwater runoff. The US Environmental Protection Agency (EPA) does not support the use of natural wetlands for water quality improvement of stormwater runoff due to the potential ecological and environmental degradation of the wetland (Hammer, 1993). Many believe that the use of wetlands to treat stormwater runoff should be limited to artificial wetlands where there are controlled conditions as well as periodic maintenance.

Kristof (1990) indicates that artificial wetlands are better candidates for treatment of NPS runoff primarily because wetland conditions can be designed, controlled and maintained without impacts to naturally-occurring systems. The advantages of artificial wetland systems include: 1) flexible site locations; 2) optimum size for watershed area; 3) design and construction of key treatment features; 4) exemption from rigorous influent criteria which would apply to natural wetlands; and 5) potential augmentation of existing wetlands. The disadvantages of using created wetlands include: 1) costs and availability of land; 2) construction costs; 3) potential reduced performance during establishment of vegetation; and 4) emergence of secondary problems such as mosquitoes or odor.

Schueler (1992) proposes to consider use of natural wetlands for treatment of stormwater when: 1) no other treatment options are available; 2) the existing wetland has low plant/animal diversity and no rare or threatened species; 3) the existing wetland is incidental, created by human activity; 4) the existing wetland is degraded; 5) the existing wetland is less than one percent of the watershed area or is small and isolated; 6) the existing wetland could be enhanced by increasing the amount of water flow through the wetland; and 7) the existing wetland is used as a polishing basin.

APPENDIX A

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