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Project Summary

The Use of Wetlands for Water Pollution Control

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An investigation was made of the use of wetlands as treatment mechanisms for urban stormwater runoff. **Application of municipal wastewaters and polluted urban runoff to wetlands may potentially provide low-cost water quality protection for many communities. Though the cost of coventional treatment facilities may be difficult to support, development of wetlands for runoff treatment is easy to justify because it meets many community needs (recreation, wildlife and fishery enhancement, recharge of groundwater, and water quality renovation, for example). This report summarizes current kowledge about the use of wetlands for treating urban stormwater runoff.**

Wetlands such as marshes, swamps and artificial wetlands, have been shown to remove selected pollutants from urban stormwater runoff and treated municipal wastewaters. Wetlands have produced reduction in BOD, pathogens, and some hydrocarbons, and they excel in nitrogen removal. They have been reported to act as sinks for trace metals, phosphorus, and suspended solids.

Physical/chemical pollutant removal mechanisms in wetlands include sedimentation, coagulation, chemical filtration, volatilization, adsorption, and chelation. Vegetative mechanisms include filtration, adsorption through roots, stems, and leaves, and chemical transformations in the plants. Chemical transformations of some waterborne pollutants also occur in the sediment layers or the water column as a result of anaerobic or aerobic conditions, the presence of catalysts and reactive substances, and microbial action.

Though individual plant species have been studied for their pollutant removal properties in a wetland, the interaction of numerous plant and animal species is not well understood. Management of wetland vegetative systems to optimize pollutant removal requires further investigation.

Further research needs to be conducted on long-term impacts to wetlands, bioaccumulation of trace metals, the interaction of individual pollutant removal mechanisms in various wetland systems, and management techniques for wetlands used as treatment systems.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Strong evidence suggests that wetland and upland vegetative systems can degrade and eliminate various waterborne pollutants. But information on the subject, is scattered over a wide range of technical disciplines, and much of it results from investigations undertaken only within the last 5 to 10 years. Consequently, technical guidance is lacking on potentially useful management practices for wetlands Before policies are adopted for using the natural treatment functions of vegetative systems, the current state of knowledge on the subject should be defined. This study was undertaken to address this need. The object was to summarize relevant findings on the use of wetlands as treatment mechanisms for urban stormwater runoff and to guide users to more detailed sources of information in the literature.

The technology and management tools for controlling surface stormwater runoff pollutants have advanced considerably as a result of various EPA and other research activities. But for a variety of reasons (principally financial), local control of nonpoint pollution sources probably will not occur unless it can be related to other enviromental issues and public needs.

One way to achieve this goal is to tie solutions to stormwater runoff to a framework of other community needs such as flood control, recreation enhancement, food and fiber production, etc. This concept leads to active consideration of wetlands and upland vegetated areas for their potential in removing pollutants from stormwater runoff. These areas are highly valued for their ecological, agricultural, and hydrological significance. Preservation and artificial creation of wetlands are of great current interest because of their importance as nesting, feeding, and nursery areas for birds, fish, invertebrates, and wildlife, and as natural runoff detention areas for flood storage and water quality enhancement. Water quality objectives may also be combined with the agricultural open space and landscapig needs of upland pastures and cropland.

This study describes what is and is not known about the use of wetlands as treatment mechanisms for urban stormwater runoff. The report is based on a survey of scientific investigations and basic literature sources related to nutrient and pollutant cycling in wetland ecosystems. The survey includes a review of fundamental research regarding plant morphology processes and physical and hydrological relationships, and the growing number of site-specific investigations of pollution impacts and treatment capabilities of vegetative systems. Most investigative work to date has been related to the treatment of municipal wastewater by vegetative systems. This report describes the implications for the evaluation of stormwater runoff treatment. Also incorporated are recent findings from a handful of studies concerned specifically with stormwater runoff, including work by the study team at the Palo Alto Marsh/Flood Basin in California.

Literature and Practices

Wetland and upland vegetative systems have attracted attention as natural sinks for containments and as potential components of treatment systems for wastewater and stormwater. The greatest number of investigations and data in the literature pertain to the treatment of municipal wastewaters. Promising results have fostered scientific interest and a handful of investigations into the effectiveness of vegetative systems for the control of stormwater pollutants.

Wetlands Treatment of Wastewater

Wetlands Treatment of Municipal Wastewater

Wetlands occur in a wide range of physical settings at the interface of terrestrial and aquatic ecosystems. Because of this position, some wetlands have been subjected to inadvertent municipal and industrial wastewater discharges for many years. But only in the past 10 to 15 years has attention been focused on their planned use for wastewater treatment. Promising results have been obtained with experimental applications in various natural wetlands, including:

- northern peatlands
- cattail marshes
- southeastern swamplands
- cypress domes
- freshwater/tidal marshes

Consolidation of results indicates that in nearly all instances, wetlands act to renovate or improve water quality to some extent. Pollutant removal efficiencies are extremely variable, and questions of treatment capacity and long-term impacts on wetlands are unanswered. Indiscriminant discharge of wastewaters to wetland ecosystems is not advised.

Artificial Wetlands for Treatment of Municipal Wastewater

Artificial wetlands for treating wastewaters have been created for both small- and large-scale applications in Europe and the United States using different types of vegetation and substrates. These systems offer controlled environments for testing and studying vegetative treatment of wastewaters. The resulting data establish hydrologic and constituent balances and assess pollutant removal capabilities for these systems. Examples of artificial systems include·

- meadow-marsh-pond system (New York)
- ponds with reeds or rushes (Germany and Holland)
- peat filters (Minnesota)
- marsh-pond system (California)
- seepage wetland (Michigan)
- water hyacinth ponds (Florida and Texas)

Many researchers favor continued work with artificial wetland systems because of the high degree of control and reliability. The environmental enhancement they provide is an added incentive.

Wetlands Treatment of Stormwater

Field investigation and research on using wetlands to treat stormwater runoff have been extremely limited. The few studies undertaken (a) exhibit great dissimilarities in the type of wetland and stormwater characteristics examined, (b) contain a very slim data base from which to draw conclusions, and (c) encounter numerous complications in determining hydrologic components. Key investigations include studies of:

- northern peatland (Minnesota)
- cypress wetland (Florida)
- brackish marsh (California)
- high altitude meadows (Lake Tahoe)
- wetland detention basins (Maryland)

In general, these studies revealed the following:

(1) A wide disparity exists in the ability of wetlands to remove nonpoint source pollution, particularly with regard to nutrients;

(2) The greatest consistency in pollutant reduction appears to be for biological oxygen demand (BOD), suspended solids, and heavy metals;

(3) The nature of flow and seasonal factors are major influences on polluant removal capabilities in certain wetlands.

Physical and Chemical Removal Mechanisms in Wetlands

Some investigations of the physical and chemical removal mechanisms of wetlands have been undertaken. Several removal processes that occur in natural waters are likely to occur in wetlands, but not many have been documented in marsh environments. Studies of rivers, lakes, and oceans have dominated research. Nevertheless, a few general conclusions can be drawn:

(1) A wide variety of physical/chemical pollutant removal mechanisms occur in wetlands. Most common are evaporation, sedimentation, adsorption, filtration, chelation, precipitation, decomposition, and adsorption.
(2) Wetlands exhibit large variations in type, climate, and ecosystem. The interaction and relative importance of physical/chemical pollutant removal mechanisms vary significantly among and within wetlands.
(3) Studies of pollutant removal mechanisms in wetlands have generally been piecemeal. Sufficient data have not been collected to formulate a comprehensive theory of pollutant transport and fate within a wetland system.

Vegetative Treatment Systems

Though the initial pollutant removal mechanisms in wetlands are physical and chemical processes, plants can increase the overall capacity of a system to retain or remove pollutants through interactions with various anaerobic and aerobic soil layers, water, and interfaces. In particular, plant root uptake of pollutants from the sediments frees more exchange sites in the sediments for further pollutant interaction and accumulation. The primary biochemical pollutant uptake and removal processes in vegetative systems are:

(1) Uptake through the plant/soil interface by means of below-ground roots, rhizomes, holdfasts, and buried shoots and leaves;
(2) Uptake through the plant/water interface by means of submerged roots, stems, shoots, and leaves;
(3) Translocation through the plant vascular system from roots to stems, shoots, leaves, and seeds during growing season;
(4) Differential pollutant uptake such as preferential storage of trace contaminants in specific plant parts and preferential uptake/accumulation of certain trace elements;
(5) Nonspecific pollutant uptake occurring primarily as plants absorb large quantities of nutrients from water and sediments;
(6) Uptake and immobilization by plant litter zones, where dead but not decomposed plant litter sequesters pollutants through chemical interactions.

Nutrient Removal through Wetlands

Wetland environments present ideal conditions for nutrient cycling and removal, particularly for ntirogen. The aerated water column and aerobic upper sediment layer promote nitrification and the formation of insoluble phosphorus-metal complexes. Reducing (anaerobic) sediment conditions and the interface between the aerobic and anaerobic sediment layers promote ammonification and denitrification.

Wetland vegetation can function as nutrient pumps to take up nitirogen (in the ammonium as well as nitrate form) and phosphorus (in the orthophosphate form). The highest observed nitrogen removal potentials were 300 to 800 kg/ha for the above-ground parts of cattails and reeds, and up to 1,290 kg/ha for the below-ground parts of rushes and cordgrass. Nitrogen assimilated into wetland vegetation can be translocated back to the roots and stored during the plant dormancy season, or it can be returned to the litter component during senescence of above-ground parts. The highest observed phosphorus removal potentials were 30 to 80 kg/ha for the above-ground parts of cattails, reeds, and sedges. Phosphorus assimilated into vegetation is not translocated back to the roots, but remains in the plants or plant litter. Hydrologic variables are crucial (particularly during the high runoff season) because particulate matter and organic nitrogen and phosphorus from the litter zone can be flushed. Plant uptake and storage of phosphorus is highly variable and is not a reliable mechanism for phosphorus removal. But phosphorus-metal interactions can form insoluble complexes that can accumulate in long-term sediment deposits.

Uptake and Removal of Trace Elements

Wetland systems can function as sinks for heavy metals and other trace elements, either through vegetative uptake and storage or through immobilization in the sediment layers. The observed heavy metal removal potentials range from:

(1) 0.001 to 0.38 kg/ha of cadmium, with highest levels effected by *Potamogeton crispus* and *Salicornia pacifica;*
(2) 0.007 to 1.58 kg/ha of copper, with highest levels occurring in *Justicia americana* and *Salicornia pacifica;*
(3) 0.13 to 103.4 kg/ha of iron, with highest levels occurring in *Carex stricta;*
(4) 0.026 to 1.01 kg/ha of lead, with the highest levels occurring in *Salicornia pacifica* and *Phalaris arundinacea;*
(5) 0.001 to 1.714 kg/ha of zinc, with the highest levels occurring in *Phragmites communis, Carex stricta,* and *Scirpus lacustris.*

Though pollutant removal potentials for floating aquatic vegetation are not reported in kg/ha, observed uptakes and concentrations in water hyacinth (Eichhornia crassipes) are significant for some heavy metals, particularly cadmium, chromium, copper, lead, nickel, gold, and strontium.

Hydrologic Practices

A clear knowledge of the hydrogeology of an area is crucial for understanding the wetland environment and assessing its potential for assimilating waterborne pollutants. The lack of adequate hydrologic information has hampered numerous researchers in quantifying and evaluating the pollutant removal efficiencies of wetlands.

The relationships between hydrology and ecosystem characteristics need to be recognized when considering the application of stormwaters and wastewaters to wetlands. Factors such as source of water, velocity, flowrate, renewal rate, and frequency of inundation have a major bearing on chemical and physical properties of the wetland substrate. These properties in turn influence the character and health of the ecosystem as reflected by (a) species composition and richness, (b) primary productivity, (c) organic deposition and flux, and (d) nutrient cycling. In general, water movement through wetlands tends to have a positive impact on the ecosystem.

Hydrology controls pollutant removal in wetlands through its influence on the processes of sedimentation, aeration, biological transformation, and soil adsorption. Critical hydrologic factors are:

- velocity and flowrate
- water depth and fluctuation
- detention time
- circulation and distribution patterns

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- turbulence and wave action
- seasonal and climatic influences
- groundwater conditions
- soil permeability and groundwater movement

Various criteria and practices can be identified for hydrologic management of wetlands for improved wastewater and stormwater treatment:

(1) Flow routing - Initial introduction and subsequent distribution of flow should attempt to maximize effective contact between water and wetland soils and vegetation.

(2) Water level maintenance - Manipulation of water levels is a useful means of enhancing pollutant removal by vegetation and soil. Regulation of levels must take into account competing ecosystem needs and the additional nuisance problem of mosquitos.

(3) Inflow/outflow regulation - Possible techniques for regulation of inflow/outflow containment of the first flush of runoff or retention storage during spring runoff until marsh communities are functioning at higher uptake rates.

(4) Seasonal application - Where possible, seasonal applications of wastewaters and stormwaters might be used for specific treatment or flushing purposes, taking into consideration biological activity in the wetlands, availability of dilution flows, and seasonal uses and quality of downstream receiving waters.

(5) Infiltration - Maximum soil contact should be emphasized, with attention given to routing and/or ponding wastewaters in areas of highest soil permeability.

Conclusions

This study reviews numerous reports of vegetative removals of waterborne pollutants and several studies of wetlands. Because of the nature of the available literature, the conclusions that can be drawn here reflect only an initial interpretation of the reported literature. Synthesis of this study results into a theory of wetland pollutant removal systems is beyond the scope of this report, and perhaps it is beyond the presently available information. Conclusions drawn from this literature survey may therefore have to be revised as further research results and operating information are collected.

The conclusions are as follows:

(1) Most wetlands studied were able to receive treated municipal wastewater and/or stormwater runoff, remove certain pollutants, and produce satisfactory plant growth. Pollutants removed or decreased included organic wastes (as measured by BOD), nutrients, suspended and volatile solids, and trace metals.

(2) The application of hydraulic controls and vegetation management has the potential for improving wetlands removal of pollutants.

(3) Wetlands remove waterborne pollutants principally through physical and chemical processes that are substantially augmented by biological processes associated with wetland vegetation.

(4) Wetland system stress was reported only in laboratory studies and certain field studies below municipal and industrial discharges where plants were exposed to excessive pollutant concentrations. Abatement or reduction of pollutant loadings usually led to recovery of wetland vegetation.

(5) Further research should be directed at improving our understanding of how wetland systems assimilate pollutants after initial removal.

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The complete report, entitled "The Use of Wetlands for Water Pollution Control," (Order No. PB 83-107 466; Cost: $23.50, subject to change) will be available only from:

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