# CONSTRUCTED WETLANDS:

# A GROWING OPPORTUNITY FOR THE CONSTRUCTION INDUSTRY


by

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ABSTRACT

Constructed wetlands are being used in treating various types of wastewaters; municipal, industrial, and agricultural; in controlling and treating stormwater run-offs; and in the creation and restoration of wetlands for wildlife sanctuaries or as mitigation for development projects. Each application is analyzed regarding constructability issues and technological understanding of the processes at work. Potential market size and demand are analyzed along with associated regulatory and public policy issues and their impacts. Risks are evaluated considering the perspective of a firm interested in entering constructed wetland markets.

Analysis shows the most promising market is constructed wetlands for municipal wastewater treatment. Their low-cost advantage over traditional sewage treatment plants combined with reductions in federal funding make wetland systems an attractive option for small communities. Wetland systems also make sense for developing countries having plentiful land resources but limited funds. The mining industry's use of wetlands for acid mine drainage treatment is a low-cost alternative technology that is currently in widespread use and will continue to grow. Drawbacks for acid mine drainage treatment principally concern the wetland's long-term capacity to immobilize metals. Other industrial applications have not yet gained widespread use. Agricultural and urban run-off markets are highly dependent on regulatory forces. Creation and restoration of wetlands involve high risks due to scientific uncertainty over replication of complex natural wetland functions and due to uncertainty regarding political and regulatory issues.

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## Biographical Note

Kevin L. Griffith is a graduate of the United States Military Academy at West Point, New York where he received a Bachelor of Science Degree in 1982. He served eight years as a commissioned Regular Army officer in the United States Army Corps of Engineers. Assignments included Combat Engineer Battalions in Germany from 1982 to 1985 and at Fort Benning, Georgia from 1986 to 1990 where he served as a company commander for eighteen months. He is a Registered Professional Engineer in the Commonwealth of Virginia.

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## 1. Introduction

The need for various types of wetlands is increasing both in the United States and around the world. Today, wetlands are being used in numerous wastewater treatment systems and in restoration or creation projects. As alternatives to conventional wastewater treatment facilities, constructed wetlands are being used to treat point sources such as acid mine drainage, municipal sewage, and various types of industrial wastewaters; and to treat non-point sources such as urban stormwater and agricultural run-offs.

Markets have developed for wetland restoration to attract wildlife and restore vital ecosystems and for creation of new wetlands in upland areas as mitigation for natural wetland losses due to real estate development. Losses in the United States during the 1980's were as high as 500,000 acres annually. Draining of agricultural wetlands accounted for the majority with real estate development accounting for ten percent.[1,2] Forestry and elimination of natural flooding cycles along the Mississippi River contributed also. More recent estimates say annual losses are between 30,000 and

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[1]David Salveson, Wetlands: Mitigating and Regulating Development Impacts (Washington D.C.: Urban Land Institute, 1990), p.109.

[2]Philip X. Masciantonio, "Increasing Our Wetland Resources: Looking to the Future," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington D.C.: National Wildlife Federation, 1988), p. 237.

400,000 acres annually depending on wetland definitions that are used.[3,4]

The concept of wetland creation has stirred great debate within the scientific community concerning the value and functionality of a created wetland as compared to a natural wetland. While it is definitely possible to construct or create a wetland that has plant life, animal life, and hyrdrological similarities with a natural wetland, it is scientifically questionable whether the created wetland will ever achieve the natural wetland's degree of complexity and functional ability that has developed naturally over many centuries.

For the purposes of this thesis constructed wetlands will be defined as wetlands that are built for wastewater treatment plus those that are created or restored for wildlife or as a mitigation for lost natural wetlands. Natural wetlands that are used for wastewater treatments are not considered constructed wetlands herein. Risks associated with using natural wetlands for wastewater treatment are discussed in the section pertaining to municipal wastewater treatment.

First, the forces which are creating the need for all types of constructed wetlands are investigated. Each application of constructed wetlands is then examined from the

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[3]"EPA May End Dumping of Corps Spoils in Gulf," Engineering News-Record, 18 March 1991, p. 15.

[4]William K. Stevens, "Restoring Lost Wetlands: It's Possible But Not Easy," New York Times, 29 Oct. 1991, p. C9.

perspective of a construction industry firm that sees constructed wetlands as a market opportunity. In this examination, issues of ease of constructability and siting, technological effectiveness, and regulatory stability are evaluated. Market size and the forces that drive demand are also examined. Finally, an evaluation of risk is made which shows relative market risks of each application. The evaluation of risk can be used as a decision-making aid for firms interested in constructed wetlands.

## 2. <u>Forces</u>

In analyzing constructed wetlands as a potential market for the construction industry it is necessary first to examine the social, economic, political, and technological forces which are creating the interest in constructed wetlands. Four primary forces are regulation, heightened environmental consciousness, cost advantage, and the inability of developing countries to afford traditional wastewater treatment plants.

### 2.1. <u>Regulation</u>

#### 2.1.1. Agricultural conversion

The leading cause of wetland loss in the United States is conversion of wetlands into arable land. The Food Security Act of 1985 (Farm Bill) provides opportunities for wetlands restoration. The most widely known aspect of the Farm Bill is the "swampbuster" provision. This law protects wetlands by denying beneficial federal programs to farmers who convert wetlands into arable land. Since passage of the law, land that was once wetland can be restored, and farmers can regain their subsidies and price supports.

A second provision of the Farm Bill is the Conservation Reserve Program. This program pays farmers to set aside highly erodible cropland for not less than ten years. In the program, previously drained wetlands can be restored. Partial federal funding is provided.

The Farm Bill also will provide another source of land for wetland restoration. The inventory of properties taken over by the Farmers Home Administration as a result of farm foreclosures contain extensive amounts of previously converted wetlands that can be restored. Federal, state and/or private funding is still needed to realize the full potential of these opportunities.[1]

### 2.1.2. Nonpoint source run-offs from agriculture and stormwater

Agriculture needs a cost effective means to treat nonpoint source pollution caused by pesticides and fertilizers. States are requiring agriculture to control discharges into water supplies. Florida is spending $400 million to control and cleanup farm run-offs into the Everglades that have high phosphorous concentrations. Part of the clean-up is a $16 million artificial marsh consisting of 17,700 acres which filter run-off.[2] The money for the clean-up is being raised by taxation of farmers.[3]

Treatment of nonpoint source run-offs require a macro approach that considers an entire watershed as is the case in

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[1]Frank Dunkle and Bob Misso, "Farm Bill-Related Wetland Protection and Restoration Opportunities," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington D.C.: National Wildlife Federation, 1988), pp. 244-246.

[2]"U.S. and Florida Sign New Everglades Pact," Engineering News-Record, 11 March 1991, p. 11.

[3]"Everglades Law Signed, But Feds Decry Cleanup," Engineering News-Record, 27 May 1991, p. 13.

Florida. There is little incentive for individual farmers to control run-off from their own land other than incentives that come from regulation and enforcement. The Florida example of imposition of taxes on the polluters creates that incentive for farmers to minimize and control pollution. Low cost and effective solutions will be demanded.

Increasing regulation of stormwater run-offs require developers to adequately provide for stormwater control and treatment. Developers and expanding communities have found that constructed wetlands can be used to effectively attenuate and treat storm run-offs. New developments such as shopping malls, office parks, or residential subdivisions have integrated constructed wetlands into stormwater management plans. Constructed wetlands act as buffers slowing run-off and preventing flooding. Also, a wetland can remove sediments, adsorb and precipitate metals, filter contaminants, and provide biochemical processes to remove nutrients.

### 2.1.3. Mining Industry

Effluent from coal mines commonly contain contaminants that do not meet discharge regulations. Commonly referred to as acid mine drainage, the effluent is usually acidic and contains high concentrations of metal contaminants. Pollutant-laden run-off usually continues decades after a mine is inactivated, and the industry is searching for ways to control the long-term operation and maintenance cost of run-off treatment.

Mining companies are required to reclaim land disturbed by mining operations. Wetlands are being integrated into land reclamation projects.[4] Phosphate mining reclamation projects in North Carolina and Florida are recent examples of wetland creation. Costs for these two projects are approximately equal to that required by upland reclamation.[5]

### 2.1.4. Other Industries

Other industries also face regulation of effluent. Regulatory requirements combined with the cost advantages of wetland technology and the public relations benefits of wetland use, provide incentive for industry to innovate in treating effluent. Fish canneries, geothermal drilling operations, textile mills, landfill leachate treatment, oil refineries, pulp and paper mills, and hazardous waste leachate treatment have used wetland treatment systems.[6,7,8,9,10]

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[4]William L. Branch, "Design and Construction of Replacement Wetlands on Lands Mined for Sand and Gravel," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington D.C.: National Wildlife Federation, 1988), pp. 168-172.

[5]Rusty Walker, Phosphate Mining and Wetlands Creation: A Company Perspective," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington D.C.: National Wildlife Federation, 1988), p. 37.

[6]Norman N. Hantzsche, "Wetland Systems for Wastewater Treatment: Engineering Applications," in Ecological Considerations in Wetlands Treatment of Municipal Wastewater, ed. Paul J. Godfrey et al. (New York: Van Nostrand Reinhold, 1985), p. 9.

[7]Margarita Winter and Reinhold Kickuth, "Elimination of Sulphur Compounds from Wastewater by the Root Zone Process-I. Performance of a Large-Scale Purification Plant at a Textile

### 2.1.5. Mitigation of wetland losses due to urban development

In the United States the nation's natural wetland resources are being lost due to urban development for public and private constructed facilities such as highways, airports, commercial and residential buildings, resorts, marinas, and industrial development. The Urban Land Institute and the National Fish and Wildlife Foundation estimate that ten percent of annual wetland losses are due to real estate development with the remainder due to agriculture, forestry, and elimination of natural flooding cycles along the Mississippi River.[11,12,13] Most coastal wetland losses are

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Finishing Industry," Water Resources, 23 (May 1989), pp. 535-546.

[8]James N. Dornbush, "Natural Renovation of Leachate: Degraded Groundwater in Excavated Ponds at a Refuse Landfill," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), pp. 743-752.

[9]V.W. Kaczynski, "Considerations for Wetland Treatment of Spent Geothermal Fluids," in Ecological Considerations in Wetlands Treatment of Municipal Wastewaters, ed. Paul J. Godfrey et al. (New York: Van Nostrand Reinhold, 1985), pp. 48-65.

[10]U.S. Environmental Protection Agency, Superfund Record of Decision (EPA Region 3): Palmerton Zinc Pile, EPA/ROD/R03-88/063 (Washington D.C.: U.S. Government Printing Office, 1988).

[11]Salveson, p. 3.

[12]Charles H. Collins, "Remarks to the National Wildlife Federation Wetlands Conference," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington D.C.: National Wildlife Federation, 1988), p. 247.

[13]"EPA May End Dumping of Corps Spoils in Gulf," Engineering News-Record, 18 March 1991, p. 15.

from development of marina and port facilities where fewer good building sites lead to pressure to build on natural wetlands.

To reduce losses of wetlands the trend of federal, state and local legislators is to increase regulation of wetlands destruction. This trend has led to wetland mitigation laws which require reduction of proposed losses, restoration of degraded wetlands, and creation of compensatory wetlands. Some compensation laws require up to five acres of wetland for each acre that is lost due to development. In effect, a market for restoration and/or creation of wetlands is being created by lawmakers.

Highway construction regulations are an example. In many states new construction through wetlands is permitted only with wetland restoration or creation. California's Department of Transportation is involved in several wetland restoration projects, one of which has a seven million dollar budget.[14]

A long-term trend toward more regulation of wetlands can be expected to continue despite a Bush Administration proposal in August 1991 to relax the definition of a wetland in the federal government's updated policy manual. According to environmental interest groups the relaxed definition opens

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[14] F. Housley Carr and Debra K. Rubin, "Wetlands: Picking Up Where Nature Left Off," Engineering News-Record, 29 March 1990, p. 82.

heretofore protected land to development.[15] If in fact more land is open to development because that land no longer meets the wetland definition, demand for restoration and/or creation would diminish. This assumes developers must be forced to mitigate by legislation. There are other forces which may force developers to mitigate; such as, public pressure and economics.

## 2.2. **Heightened Environmental Consciousness**

Developers may also be forced to mitigate wetland losses because of pressure from the public and environmental interest groups to protect the natural environment. Public pressure to build without environmental degradation may force developers to mitigate voluntarily. They may be viewed by the public as being destructive to the natural environment with profit as the sole motive.

A logical response by developers is to voluntarily integrate wetlands into their projects; thereby, giving them an opportunity to be seen as environmentally concerned. There may be a profit motivation for this as well. For example, an office park with an integrated wetland may add aesthetic and commercial value to the property and actually attract businesses that want also to be identified as being environmentally concerned. Residential land values also may

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[15]"Looser Standards Coming," Engineering News-Record, 12 Aug. 12, 1991, p. 21.

increase if wetlands are integrated into subdivision developments to create an aesthetically pleasing natural environment that attracts wildlife.

The future impact of public environmental concern should not be underestimated. With the increasing number of communities adopting recycling programs, manufacturers marketing "green" products and a "green" image to the consuming public, the force of public environmental concern is strong and only going to increase with time. As environmental concern at all levels of society grows, so will interest in the construction of wetlands.

## 2.3. Cost advantage of wetland technology

### 2.3.1. Municipal wastewater treatment

The third primary force generating interest in constructed wetlands is the cost advantage over traditional secondary and tertiary municipal wastewater treatment facilities. Constructed wetlands systems are less expensive to build and maintain on a per capita basis than traditional systems. This cost advantage is the major factor spurring small communities to consider constructed wetlands.

Costs for sewage treatment plants are increasing, and municipalities are finding it harder to pay for them. The hardest hit are small communities under 10,000 in population. Small communities in need of upgraded or expanded municipal sewage treatment systems bear disproportionate costs for the equivalent treatment levels that larger communities and cities can achieve because of economies of scale.[16]

Legislation has not favored small communities regarding funding. The 1987 Water Quality Act Amendments to the Clean Water Act phased out federal funding grants for municipal treatment in 1990. The State Revolving Loan Program which is often used for wastewater treatment systems ends in 1994.[17] In addition, proposed legislation before the United States Senate ends any federal funding for wastewater treatment plants after fiscal year 1996.[18] Phasing out of federal and state funding is creating the need for lower cost solutions.

**2.3.2. Industrial effluent treatment**

Cost advantage is the major incentive for industry to innovate using wetland technology. Industry will use wetland technology if it functions effectively and offers a cost savings over other alternatives.

As mentioned previously, the mining industry requires long-term effluent treatment that is low-cost. Chemical treatment systems are expensive to build, operate and maintain. Constructed wetlands offer a possible alternative. Numerous treatment systems are currently operating and

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[16]Hantzsche, p. 7.

[17]A.J. Smith, "Wastewaters: A Perspective," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), p. 3.

[18]Hazel Bradford and Debra K. Rubin, "New Definitions Prompt Whole New Controversy," Engineering News-Record, 27 May 1991, p. 12.

producing favorable water quality results at significantly lower annual operating costs. Long-term performance; however, is not proven.

The greatest need for a low-cost solution to treat acid mine drainage is at closed or abandoned mines. These mines are generating no income that could be used to fund expensive treatment systems.

## 2.4. Inability of developing countries to afford traditional wastewater treatment plants

Developing countries are not able to afford highly technological wastewater treatment systems designed in industrialized countries. Costs of construction, operation, and maintenance are prohibitive considering the number of facilities that would be needed to serve entire populations.

A modern approach to wastewater treatment that is appropriate for the budgets of developing countries is needed. The approach must rely on minimization of water use by the population and industrial processes. Treatment facilities must be simple, small scale, and affordable. Treatment facilities should be decentralized and close to the source. Large, centralized treatment facilities that require extensive sewer collection systems are too costly.

Wetland treatment systems can play a major role meeting this need. They can be built by local labor using materials that are available and with methods that are simple. An example is using a wetland to treat sewage from a cluster of residential dwellings. The transfer of wetland technology to developing countries is the key to providing treatment systems that are effective and sustainable.[19]

Each of the above mentioned constructed wetland applications and their advantages and disadvantages will be discussed with respect to other wastewater treatment systems. Each will be examined and evaluated based on their constructability, their technological and scientific basis, the market size and demand, and the risks associated with each. The impacts of regulatory policies on each application of constructed wetlands will also be considered in the evaluation.

[19]The concept of a modern approach is from Janusz Niemczynowicz, "Environmental Impact of Urban Areas: The Need for Paradigm Change," Water International, 16 (1991), pp. 83-95.

### 3. **Municipal Wastewater Treatment**

Constructed wetlands have been successfully used to treat municipal wastewater at many locations in the United States and in other regions of the world. The natural biological, chemical, and mechanical processes operating in wetlands have the ability to reduce concentrations of the common pollutants found in municipal wastewater to secondary and advanced level treatment standards. Treatment systems have been constructed and have been in operation at locations throughout the United States and Europe for as long as fifteen years. The United States Environmental Protection Agency's Risk Reduction Environmental Laboratory (US EPA RREL) has determined that over 150 wetland treatment systems are in operation in the United States as of September 1990.[1] Scientific research, field testing of pilot projects, and full scale operating systems have shown municipal wastewater treatment systems to be effective in meeting discharge limits at many different locations and climates.

Constructed wetlands can be classified as either free water surface (FWS) or subsurface flow (SF) systems. FWS systems maintain a shallow depth of wastewater flowing through emergent vegetation. SF systems have wastewater flowing through the substrate and the root zone of the wetland vegetation. SF systems are also known as the root-zone

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[1]Sherwood C. Reed, "Constructed Wetlands for Wastewater Treatment," Biocycle, 32 (Jan. 1991), pp. 45-46.

method, reed bed, or vegetated submerged bed systems and have been researched, tested, and used in Europe.

Common wetland plants that have been used in both types of systems are: woolgrass (Scripus cyperinus), cattail (Typha latifolia, Typha angustifolia), common reed (Phragmites communis), and bulrush (Scripus validus).

### 3.1. Advantages

Constructed wetlands for municipal wastewater treatment offer several advantages over conventional wastewater treatment systems. The most compelling reason is that constructed wetland treatment systems generally cost one tenth as much in capital and annual maintenance expenses.[2] Lower construction costs result from the use of simple construction techniques with little need for concrete, steel or other permanent structures. For a FWS system the mean capital cost per acre (sample of nineteen constructed facilities) was $22,200. For SF systems the cost was $87,218 per acre (sample of 18).[3] In terms of treating a million gallon per day wastewater flow which is generated by a community with a population of ten thousand, loading rates indicate that 20 acres at a $1.74 million capital cost is required for a SF

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[2]Donald A. Hammer, "Water Improvement Functions of Natural and Constructed Wetlands," in Teleconference Proceedings: Protection and Management Issues for South Carolina Wetlands (Clemson University, South Carolina: The Strom Thurmond Institute, 1990), p. 137.

[3]Reed, pp. 45-46.

system and 50 acres at a $1.10 million capital cost is required for a FWS system. This example excludes the cost of land.

Annual operating expenses are also significantly lower due to the relative ease of maintaining a constructed wetland once it is properly functioning. Maintenance generally consists of periodically harvesting the vegetation. If vegetation becomes too dense, flow becomes restricted enabling algal growth and the possibility of anaerobic conditions. It may also be necessary to make adjustments to avoid short circuiting and channelization of the flow.

The treatment provided by constructed wetlands is effective and reliable. High removal efficiencies for pollutants have been demonstrated.[4] Numerous pilot projects and studies have shown their ability to reduce biochemical oxygen demand and pollutants such as suspended solids to acceptable secondary and advanced level treatment standards. A treatment system at Listowel, Ontario has been receiving raw aerated sewage since 1979. The marsh system has effluent quality that is better than secondary standards year-round and

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[4]Robert K. Bastian, Peter E. Shanaghan, and Brian P. Thompson, "Use of Wetlands for Municipal Wastewater Treatment and Disposal - Regulatory Issues and EPA Policies," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), p. 271.

often reaches advanced level standards during ice-free periods.[5]

Established constructed wetland treatment systems have proven to be relatively tolerant of fluctuating hydrologic and contaminant loading rates.[6] Alternating flooding and dry periods have not caused significant problems at many sites provided that periods are not prolongated. In addition, it has been shown that effective wastewater treatment continues even during cold climatic conditions with only marginally reduced efficiency.

Advantages that are becoming increasingly significant to society are indirect benefits gained from constructed wetlands adding to the natural environment. Increased wildlife habitats along with additional recreational and educational opportunities add value that is difficult to measure but is surely a factor in favor of constructed wetlands when considering the type of wastewater treatment facility a community needs and can afford. Birdwatchers, naturalists, and educational institutions value constructed wetlands as natural resources. As a result, siting of wastewater

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[5]I. Wile, G. Miller, and S. Black, "Design and Use of Artificial Wetlands," in Ecological Considerations in Wetlands Treatment of Municipal Wastewater, ed. Paul J. Godfrey et al (New York: Van Nostrand Reinhold, 1985), p. 26.

[6]Donald A. Hammer and Robert K. Bastian, " Wetland Ecosystems: Natural Water Purifiers," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), p. 16.

treatment facilities may meet less public resistance than the siting of a conventional sewage treatment plant.

### 3.2. Disadvantages

A major disadvantage for constructed wetlands for municipal wastewater treatment is the relatively large land area required. The land area required is four to ten times more than for a conventional wastewater treatment plant. This can be prohibitive for a community that doesn't have the required land. It also indicates that constructed wetlands are not feasible for large, densely-populated metropolitan areas with limited land availability. A city such as northeast Philadelphia with a population of 1.24 million has a design wastewater flow of 175 mgd and would require between 3500 and 8750 acres of wetlands.[7] Tracts of land this large are likely not available for large cities.

Another disadvantage is that current constructed wetland design and operating criteria are imprecise.[8] Many treatment systems are designed empirically. Often adjustments must be made to the physical size, the flow rates, and retention times until monitoring reveals acceptable standards have been achieved. This is due to the biological and hydrological

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[7]Design flow figures from William T. Ingram, "Environmental Engineering," in Standard Handbook for Civil Engineers, ed. Frederick S. Merritt, 3rd ed. (New York: McGraw-Hill, 1983), p. 22.6.

[8]Hammer and Bastian, p. 16.

complexities in an active wetland system. There is a significant lack of understanding of important process dynamics.

Constructed wetlands require several growing seasons to develop before they can be fully loaded to design specifications.[9] Research in Germany has shown that the root system reaches full depth penetration (60 cm) into the substrate after three growing seasons.[10] The treatment facility is not able to immediately start receiving high loading of wastewaters after it is constructed. The facility can be seriously damaged and become septic with plant die-off if it is loaded too highly too soon.

Lastly, pests and odors can be a problem for constructed wetlands. Burrowing animals can destroy dikes, and mosquitos can be a nuisance. Mosquitofish (Gambusia affinis) are a natural predator of larvae and have proven effective in mosquito control.[11] Remedies such as trapping may become necessary.

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[9]Hammer, "Water Inprovement Functions of Natural and Constructed Wetlands," p. 139.

[10]James T. Watson et al, "Performance Expectations and Loading Rates for Constructed Wetlands," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), p. 343.

[11]R.Kelman Wieder, George Tchobanoglous, and Ronald W. Tuttle," Preliminary Considerations regarding Constructed Wetlands for Wastewater Treatment,"in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), p. 299.

### 3.3. **Constructability**

Wetlands designed and built for municipal wastewater treatment have been the most common application of constructed wetlands. Although there is continued disagreement among scientists and engineers concerning what works best, design parameters have been researched and empirically tested to determine effective contaminant removal mechanisms. This makes construction more predictable than for other types. Municipal wastewater composition and design flow rates for a given population are known or can be reliably estimated, and required wetland dimensions, water depths, retention times, plantlife, and other variables can be designed with relative reliability. Effective construction techniques have been learned and documented from the many systems that have been built.

Since most municipal wastewaters are similar the construction of wetlands treatment systems is not necessarily site specific. Wetlands can be economically constructed and established in uplands given that adequate level land is available. If extensive earthwork in hilly terrain is required, wetland construction costs rise and the technology loses its key advantage. The flexibility to locate constructed wetlands in uplands or lowlands is important because the large land requirement can make it difficult to find a site.

Although municipal wastewaters are generally similar, site location characteristics and constraints are invariably different causing unique construction problems at each site. Differences in soils, climatic effects, hydrologic patterns and vegetation require consideration in wetland design. Some of these can be minimized. The substrate can be lined with clay or impermeable membranes to reduce exfiltration. The substrate itself can be imported. Standard treatment cells can be designed to handle specific loads and volumes. These steps at reducing design differences between sites come at additional construction cost.

### 3.4. Technology

There is no consensus on the most appropriate design parameters for municipal wastewaters treatment with wetlands. Studies and pilot projects have found that different approaches have been successful. SF and FWS systems each have advantages and disadvantages. Also different length to width ratios, substrates, and plants have all been used with successful results. First, SF systems will be discussed.

SF systems have several advantages over FWS systems. There is less risk of odors, mosquitos, and other insect vectors. Substrates with rock or gravel media are more effective at removing algae from lagoon effluent than a FWS system. An important advantage of SF systems is that more surface area for microbial activity is available on the substrate and root zone media and hence SF systems require less acreage than comparable FWS systems. Where there is limited land area on a site a SF system may be more feasible.

A disadvantage is that SF system may get clogged and subsurface flow becomes restricted. For this reason most municipal wastewater treatment systems in the United States have been FWS systems.[12]

FWS systems maintain a shallow water depth and rely on naturally occurring microbial consumption of nutrients, sedimentation, ultraviolet radiation, and chemical reactions for water purification. Microbes attach to sites on vegetation and debris in the water column and in the root zone. Wetland plants transport oxygen through their vascular system to the root zone allowing reduction of organic nutrients by microbes and chemical reactions in the substrate.[13] Wetland plants also enhance sedimentation by slowing water flow. Pathogenic organisms are consumed by microbes and neutralized by ultraviolet radiation.

Common pollutants found in municipal wastewater include ammonia, nitrates, phosphorous, pathogenic bacteria, suspended solids, organic material, and traces of metals. The removal process for each will be described.

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[12]Hammer, "Water Inprovement Functions of Natural and Constructed Wetlands," p. 136.

[13]G. R. Guntenspergen, F. Stearns, and J.A. Kadlec, "Wetland Vegetation," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publisher's, 1989), p. 80.

### 3.4.1. Phosphorous removal processes

Phosphorous is removed from wastewaters by soil sorption processes and by plant uptake. There is a finite capacity of the substrate to retain phosphorous with maximum soil capacity varying widely depending on the soil. Soils high in calcium, iron, and aluminum are best for phosphorous removal, and selecting a proper substrate is critical.

Removal percentage is strongly dependent on loading rate with the highest efficiencies (65 - 95%) achieved at loading rates less than 5 kg of phosphorous per hectare per year (2kg/acre/yr). Removal efficiencies of 30-40% have been measured at loading rates between 10 and 15 kg per hectare per year.[14]

Studies have shown that initial removal efficiencies of 90% can decline sharply after four to five years.[15] One way to allow greater phosphorous removal is to alternate oxidizing and reducing conditions by periodically allowing the water level to drop, letting oxygen more easily enter the substrate. Sorption sites can be recharged and phosphorous removal can last longer than would be possible under only reducing conditions.[16]

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[14]S.P. Faulkner and C.J. Richardson, "Physical and Chemical Characteristics of Freshwater Wetlands," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), p. 57.

[15]Ibid.

[16]Ibid, p. 64.

A percentage of phosphorous is absorbed by plants and can be permanently removed from the system by harvesting. Uptake of phosphorous by plants is generally regarded as less than 10%; however, a one year study has shown that a marsh retained a total of 48 kg of phosphorous per hectare, of which 10 kg was taken up by plant life and able to be harvested.[17] Harvesting is an added maintenance expense and may not be economical; but, if plants are not harvested phosphorous can return to solution during die-back and decomposition.

### 3.4.2. Nitrogen removal process

Nitrogen is usually in the form of ammonium, nitrites, and nitrates. The principal removal process is known as nitrification-denitrification. $NH_3$ is oxidized to $NO_3$ by chemoautotrophic denitrifying bacteria, followed by reduction to $N_2$ and $NO_2$ gas and release to the atmosphere. Denitrification usually occurs in the substrate. The water can not be too deep or too aerobic or gases will be oxidized before release into the atmosphere.[18]

The removal percentage at a high hydraulic loading rate of 16.8 cm/day of wastewater has been measured at up to 95% for total nitrogen (TN) when methanol was added to act as a carbon source to enhance the process. When mulch was applied as a

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[17] William E. Sloey, Frederick L. Spangler, and C. W. Fetter Jr., "Management of Freshwater Wetlands for Nutrient Assimilation," in Freshwater Wetlands: Ecological Processes and Management Potential, ed. Ralph E. Good et al (New York, NY: Academic Press, 1978), p. 325.

[18] Ibid, p. 324.

carbon source the removal efficiency was measured at 87% at the loading rate of 8.4 cm/day.[19] Other results have measured TN removal between 55% and 79%.[20]

Operational procedures to increase nitrogen and phosphorous removal are compatible. Alternating oxidizing and reducing conditions by alternating hydrologic cycles enhances denitrification and release of gases into the atmosphere.[21]

**3.4.3. Suspended Solids (SS) removal process**

SS are removed by sedimentation and depend primarily on retention times. Well designed and operated constructed wetland treatment systems have produced SS effluent concentrations below the common discharge limit of 10 mg/l. An optimal hydraulic retention time is seven days.[22] Evapotranspiration and precipitation are the two major factors which influence retention time. High evapotranspiration rates during unusually hot weather will increase retention time and possibly cause stagnation and anaerobic conditions. Precipitation will tend to decrease retention time. The ability to decrease flow during periods of precipitation is necessary to maintain retention times. Ice formation will reduce available volume and tend to also decrease retention

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[19]R.M. Gersberg, B.V. Elkins, and C.R. Goldman, "Nitrogen Removal in Artificial Wetlands," Water Resources, 17 (1983), p. 1009.

[20]Watson, et al, p. 329.

[21]Faulkner and Richardson, p. 64.

[22]Wile, Miller, and Black, p. 30.

time. A possible solution is to raise the water level before the onset of winter.[23] A common fault of many systems is short-circuiting and channelization of flow within the wetland which decreases retention time.

### 3.4.4. Organic material removal processes

Five day biochemical oxygen demand ($BOD_5$) removal efficiencies of 70% to 95% have been observed with loads ranging from 18 to 116 kg/ha/day $BOD_5$.[24] The recommended loading rate is 70 kg/ha/day or less.[25]

In FWS systems microbial growth on plant life removes soluble BOD with the oxygen from the water surface as the oxygen source. If ice forms and persists for more than a few days this process is restricted.[26] In SF systems the oxygen source comes through the plant's vascular system into the roots and oxidation reactions occur in the root zone.[27]

Retention time is also important to allow bacteria enough time to come into contact with organic material.

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[23]Ibid.

[24]Watson et al, p. 341.

[25]Donald A. Hammer, "Designing Constructed Wetlands Systems to Treat Agricultural Nonpoint Pollution" (unpublished draft paper presented at USEPA Region VIII Constructed Wetlands Workshop, 5 September 1991), p. 21.

[26]Watson et al, pp. 327-328.

[27]Ibid, p. 320.

### 3.4.5. Pathogen removal

Pathogenic bacteria are removed by sedimentation, ultraviolet radiation, chemical reactions, natural die-off and predation by zooplankton. Coliform is the most common type and removal efficiencies are generally around 82% to 100% in wetlands that have adequate retention times.

### 3.4.6. Design

Design considerations are operating water depths, loading rates, process kinetics, temperature effects, climatic effects, and physical configuration.[28] Retention time design and bed depth have been derived empirically from a limited database and assume steady state conditions.

FWS and SF system design of flow, bed width, and length is presented by Watson, et al.[29] and Knight.[30] Flow through the system can be described by Darcy's Law with temperature-dependent first order reaction rate kinetics. Bed length is determined by hydraulic residence time required for biological reactions to remove the desired level of contaminants. Bed depth should not exceed 60-74 cm for bulrushes and reeds and 30 cm for cattails.[31] Experience has also shown that it

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[28]Wieder, Tchobanoglous, and Tuttle, p. 299.

[29]Watson et al, pp. 339-345.

[30]Robert L. Knight, "Wetland Systems," in Natural Systems for Wastewater Treatment: Manual of Practice, FD-16, ed. Sherwood C. Reed (Alexandria, VA: Water Pollution Control Federation, 1990), pp. 241-248.

[31]Watson et al, p. 342.

takes about three growth seasons to fully establish the root zone to a depth of 60 cm for bulrushes and reeds. Downward root penetration can be stimulated by draining the wetland in the early fall of the first two growing seasons.[32] Gravel bed slope should be between 0% and 2%.[33] Flow through gravel and rock substrate can become plugged as mentioned previously.

For subsurface flow the hydraulic conductivity of the substrate and the hydraulic gradient must be known. Subsurface flow velocity should be limited to less than 8.6 meters per day to allow adequate contact time with bacteria.

Water gain or loss due to evapotranspiration, infiltration, exfiltration, or precipitation must be factored into design. Evapotranspiration is known to strongly increase residence time to a greater extent than precipitation which has the opposite effect.

Another important feature of a constructed wetland is the need for sufficient oxygen in the subsurface bed. As a safety factor, available oxygen should be twice the required oxygen of the $BOD_5$ load. The oxygen balance check is described in Watson et al.

### 3.4.7. Loading

The design load should be based on treatment level objectives and can be expressed as a mass loading per unit area or as a hydraulic loading rate. Recent data suggests

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[32]Ibid, p. 343.

[33]Ibid.

that mass loading rate is more highly correlated with treatment efficiency than hydraulic loading rate, or retention time.[34]

The loading rate will determine the land requirement for the wetland. Based on the mass loading rate of 70kg/ha/day a community of 10,000 population would require at least 32 acres of wetlands in treating primary effluent to at least secondary levels. This assumes .2 lb $BOD_5$ per capita per day.[35]

Hydraulic loading rates have been found to be 4.7cm/day for SF systems and 2cm/day for FWS systems.[36,37] At the above loading rates and a flow rate of 100 gallon per capita per day the 10,000 person SF system would require 20 acres to treat the one million gallon per day flow. The FWS would require 50 acres. Additional land would be required for pretreatment facilities.

### 3.4.8. Physical design features

The constructed wetland should be segmented so that there is flexibility in the system for maintenance activities.[38] Treatment cells in a combination of series and parallel paths provide flexibility for draining while continuing operation of

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[34]Hammer, "Designing Constructed Wetlands Systems to Treat Agricultural Nonpoint Pollution," p. 22.

[35]Ingram, p. 22.26.

[36]Watson et al, p. 337.

[37]Knight, p. 232.

[38]Wieder, Tchobanoglous, and Tuttle, p. 299.

the overall system. Effluent also can be recycled to reduce the overall size of the wetland. Empirical results with high aspect ratios (length to width) have been more effective because they limit the tendency for short-circuiting. At Listowel, Ontario an aspect ratio of 75:1 out-performed a wetland with an aspect ratio of 4.5:1.[39] Higher aspect ratios require higher construction and maintenance costs due to greater earthwork requirements. Performance data and construction cost considerations suggest that the optimum aspect ratio is 2:1.[40]

Statistics of average designs have been collected by the US EPA's Risk Reduction Environmental Laboratory.[41] Tables 1 and 2 show the results as of mid-1991. Table 1 shows designs which are based on those developed by the Tennessee Valley Authority, the EPA's Region VI, and by independent designers. Table 2 shows design data for FWS systems based on designed treatment level.

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[39]Wile, Miller, and Black, p. 30.

[40]Knight, p. 242.

[41]Reed, p. 48.

**TABLE 1**
DESIGN CHARACTERISTICS OF SUBSURFACE FLOW SYSTEMS[42]

| Design Type | Flow (mgd) | Area (ac) | Hydraulic Surface Area (ac/mgd) | Organic Load (lb/ac/d) | Time (days) |
|---|---|---|---|---|---|
| Type I (TVA) | 0.125 | 1.16 | 16.0 | 27 | 2.6 |
| Type II (EPA Region VI) | 0.402 | 0.40 | 5.8 | 61 | 1.1 |
| Independent Designs | 0.224 | 2.15 | 12.0 | 37 | 2.4 |
| All Types | 0.295 | 1.83 | 11.0 | 54 | 2.0 |

**TABLE 2**
DESIGN CHARACTERISTICS OF FREE WATER SURFACE SYSTEMS[43]

| Design Type | Flow (mgd) | Area (ac) | Hydraulic Surface Area (ac/mgd) | Organic Load (lb/ac/d) | Time (days) |
|---|---|---|---|---|---|
| Removal of BOD & TSS | 1.85 | 14.35 | 26.5 | 29 | 8.4 |
| BOD, TSS, $NH_3$ | 0.97 | 16.49 | 23.36 | 20 | 6.8 |
| Advanced & Total Retention | 2.76 | 253.65 | 146.93 | 2 | 243.1 |
| Total Retention | 1.80 | 88.48 | 62.10 | 17 | 68.9 |

### 3.5. Market Size and Demand

The constructed wetlands market for municipal wastewater treatment is shaped largely by two opposing forces: the cost

[42]Ibid, p. 47.

[43]Ibid, p. 48.

advantage favoring such systems and the required land area per capita which is their primary disadvantage. This type of treatment system is best suited to small, rural communities that have land resources available. Currently over 150 wastewater treatment facilities using wetlands are now in operation in the United States and Canada. Most densely populated cities do not have adequate land area available for the population to be served by a constructed wetland. Multiple localized sites would be necessary. It is much more economical for cities to construct a conventional wastewater treatment plant due to the economies of scale gained.

It is estimated that small communities (under 10,000 population) require wastewater treatment construction totalling between $10-15 billion nationwide.[44] Aging systems that are in need of replacement or expansion combined with service to new communities make up this total. While the combined need and dollar value is great, it is spread out all across the nation in thousands of small scale projects that are constructed by thousands of construction firms.

The 1987 Water Quality Act Amendments to the CWA phase out federal grant money available to states and local governments for water pollution control. The federal grants program for municipal wastewater treatment was phased out in 1990 and the State Revolving Loan Program for municipal wastewater

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[44]Smith, p. 3.

treatment projects ends in 1994.[45] This hurts the small communities more than larger communities because smaller communities do not have as many options to generate funding for their projects. Small communities do not have as large a tax base for example. In addition, larger conventional wastewater treatment plants are more cost efficient because of their size and the associated economies of scale. Smaller communities pay a disproportionate amount to achieve a similar level of treatment.[46] The low-cost advantage of constructed wetlands for municipal wastewater treatment is the strongest indicator that the demand for them will rise in the next few years.

As mentioned earlier communities with specific objectives concerning future development may find constructed wetland treatment systems attractive. The advantage of an ecologically sound and natural treatment system will gain appeal to expanding communities. Constructed wetlands can be used in subdivision developments, clusters of homes or single family homes. On the Mayo Peninsula of Maryland decentralized treatment systems such as this are installed and working effectively. Designs for single family homes have been devised, constructed, and are in operation. These systems are similar to the traditional septic tank followed by a leach field. Cattail filled trenches with gravel substrates have

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[45]Ibid.

[46]Hantzsche, p. 7.

been used. The size for a single family home is about $150m^2$ of marsh. That size can be reduced to $50m^2$ with use of low phosphate detergents in the home.[47]

The very large potential market in undeveloped countries is as yet largely untapped. Constructed wetlands for wastewater treatment suit the needs of developing countries due to low-cost, simplicity of construction, readily available materials, and ease of operation. Significant politically-based problems must be overcome however. For instance, the perception must be overcome that a developing country needs to emulate developed countries and their infrastructure intensive wastewater treatment plants to modernize the country and climb out of third world rank. As discussed earlier the developing country's approach to modernization must be altered.

### 3.6. Regulations

An important distinction between using a natural wetland and a constructed wetland built solely as a municipal wastewater treatment facility is the fact that the natural wetland requires a permit under Section 404 of the Clean Water Act; whereas, the constructed wetland generally does not. The exception is when a constructed wetland is designed to be a multi-purpose facility that is used for things in addition to wastewater treatment such as recreation and a wildlife sanctuary.

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[47]Sloey, Spangler, and Fetter, p. 337.

As a wastewater treatment facility, discharges from constructed wetlands must meet standard and known regulatory federal, state, and local requirements based on secondary or advanced treatment standards. These regulatory requirements are not likely to change significantly due to the relative constancy of municipal wastewaters.

### 3.7. Risk

Relative risks for constructed wetlands are low when compared to many of the other applications of constructed wetlands. The most important risk is the difficulty in siting the relatively large treatment system. High real estate costs and limited land availability favor a conventional wastewater treatment system. Wetland treatment systems have an advantage over conventional systems in siting considerations and the not-in-my-back-yard syndrome because of the outwardly benign and natural appearance of wetlands.

Risks are present in constructing the wetland to meet the specified design effectiveness. Often, the same design will not achieve similar results at different sites. This is due to variations in plant life, hydrology, soil, or other climatic factors. After the constructed wetland is initially built an adjustment period of up to several years is required to make the system operate to designed specifications. Knowing initially inadequate treatment may occur and planning for an adjustment period of several growing seasons is important in handling this risk.

Another risk that must be recognized is the possible reduced efficiency of the system over time. As mentioned earlier phosphorous removal efficiency degrades over time. Also channelization may occur within the wetland reducing residence time. A facility that has built-in operational flexibility with treatment cells that can be shut down for maintenance can reduce this risk.

The risk due to changes in regulations is minimal since regulatory agencies will probably not change the standards for secondary and advanced wastewater treatment.

Risk of a wildly fluctuating demand is low. Long-term demand for small scale wastewater treatment systems should hold steady or grow based on low cost and increased popular acceptance of an ecologically sound wastewater treatment solution.

## 4. **Industrial Applications**

Industrial wastewaters of many types have been treated with constructed wetlands. The mining industry has conducted the most research and has put into practice numerous wetland treatment systems for mine drainage treatment.

### 4.1. **Mine drainage treatment**

Acid mine drainage is now realized to be a much bigger problem than previously thought. Throughout Appalachia it is estimated that acid mine drainage affects over 11,800 miles of streams.[1] Much of this comes from abandoned or inactive mines. Conventional treatment consists mainly of chemical additives such as hydrated lime, sodium hydroxide, sodium carbonate, and other neutralizing and oxidizing chemicals which elevate pH and precipitate metals. Chemical treatment can be expensive as demonstrated by the $1 million per day that is spent in the Appalachia coal mining region.[2] As a less expensive alternative, constructed wetlands are being used to treat contaminated run-offs. In Maryland, Ohio, Pennsylvania, and West Virginia several hundred wetland-based systems have been constructed and are now in operation.[3]

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[1]Smith, p. 4.

[2]"Wetlands," Impact, 11 (March/June 1988), p. 13.

[3]Ronald L. Kolbash and Thomas L. Romanoski, "Windsor Coal Company Wetland: An Overview," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), p. 788.

### 4.1.1. Advantages

Treatment of acid mine drainage using constructed wetlands has several advantages over other treatment systems. The major advantage is cost savings due to lower construction cost and lower operating and maintenance expense.

An example of potential cost savings is the treatment system in operation at the Flat Rock, Alabama inactive coal mine. Prior to the constructed wetland system treatment construction costs for a chemical treatment system totalled $500,000 over ten years with annual operating and maintenance expenses averaging $28,500 per year. The cost for construction of a wetland totalled $41,200 with annual operating and maintenance costs at $3,700.

Another mine in Dunka Minnesota had high concentrations of nickel, copper, cobalt, and zinc. Estimates for a treatment plant totalled $8.5 million capital cost with $1.2 million annual operating and maintenance expenses. The estimate for a constructed wetland treatment system is $4.0 million capital cost with $40,000 annual operating and maintenance expenses.[4]

Smaller projects have also achieved similar savings. At the several hundred constructed wetlands in the Appalachian coal mining region the average annual conventional treatment

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[4]P.Eger and K. Lapakko, "Use of Wetlands to Remove Nickel and Copper from Mine Drainage," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), pp. 780-787.

costs alone were $60,000. Many of these constructed wetlands had construction costs in the $10,000 to $20,000 range.[5]

The wide variance in costs shows the difference in sophistication between a more conventional treatment system and one which relies on passive measures and natural biological processes to achieve similar results.

The figures for reduced operating and maintenance costs are related to the passive nature of the constructed wetland treatment system. The operating maintenance costs depend on many factors. More stringent effluent standards may require additional treatment steps. Also, advanced influent distribution systems using sophisticated piping and flow control valves require more capital cost and upkeep.

The effectiveness of the constructed wetland system for treating acid mine drainage effluent has been demonstrated. At the same Flat Rock mine iron concentrations were reduced from 14.3 mg/l to 0.8 mg/l, manganese concentrations from 4.8 mg/l to 1.1 mg/l, and suspended solids concentrations from 24 mg/l to 7 mg/l. Average pH increased from 6.1 to 6.9.[6]

Like wetlands for municipal wastewater treatment, wetlands for acid mine drainage treatment provide other

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[5]Kolbash and Romanoski, p. 788.

[6]Gregory A. Brodie, Donald A. Hammer, and David A. Tomljanovich, "Treatment of Acid Drainage with a Constructed Wetland at the Tennessee Valley Authority 950 Coal Mine'" in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), pp. 201-209.

ancillary benefits such as wildlife enhancement, aesthetic appeal, recreational, and educational opportunities.

Recycling of minerals such as iron, phosphate, or manganese from the detritus material deposited in the wetland is a possibility.[7] "Bog iron" was once a valuable source of iron ore in this country and is still mined in parts of northern Europe.[8]

**4.1.2. Disadvantages**

Although, constructed wetlands seem very promising as an acid mine drainage treatment alternative there are several important drawbacks that must be considered. Foremost is the fact that these treatment systems have not been tested over a long span of time to determine if contaminant removal efficiencies decline over time or if the wetland reaches a finite capacity to retain metals.[9] Polluted discharges from mines will continue for many decades or perpetuity and the treatment system must have longevity. Very few constructed wetland systems treating acid mine drainage have been operating for more than 10-15 years. Mixed results regarding sustained treatment effectiveness have been observed. Some results have reported poorer removal rates from mine discharges as time passes. If it is found that removal

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[7]Donald A. Hammer, "Constructed Wetlands for Acid Water Treatment: An Overview of Emerging Technology," (unpublished paper, Tennessee Valley Authority, 1990), p. 5.

[8]Impact, p. 13.

[9]Wieder, Tchobanoglous, and Tuttle, p. 301.

efficiencies do not decline appreciably, or decline at a rate that can be predicted, this knowledge can be incorporated into design and the wetland can function to meet standards over the life of the pollutant discharge. At present, there is simply no long-term data to verify the continued removal efficiency over many decades with enough certainty for long-term design.

The conventional treatment system also faces the problem of long-term treatment. The treatment facility may require renovation or periodic equipment replacement after several decades -- an equally unattractive consequence.

Pollutant removal mechanisms for metallic ions in acid mine drainage are not well understood. Some studies have shown effective removal and some have not been as effective.[10] Many variables and their interactions remain a mystery and in need of further study. Most studies have been input/output or "black box" studies where the internal mechanism operating in the system is difficult to understand because of the many variables.[11,12]

Further, nearly all mine discharges vary in chemistry of pollutants, in hydrologic conditions, in climate, and in physical site characteristics. This variance requires unique

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[10]Ibid, p. 300.

[11]Watson et al, p. 332.

[12] R.K. Wieder, and G.E. Lang, "Influence of Wetlands and Coal Mining on Stream Water Chemistry," Water, Air, Soil Pollution, 23 (1984), 381.

study and design to develop an effective treatment system tailored to the set of conditions present.[13]

Indications are that a wetland system has a finite capacity to retain metals. It is important to consider what happens after the treatment system ceases to function effectively.[14] In some cases capacity may be reached after decades have passed. Responsibility for continued treatment must be identified. A likely scenario may be that a mining company committed to long-term treatment over the span of many decades constructs and operates a wetland treatment system and then goes out of business. The same problem would arise with a conventional treatment to acid mine drainages and a wetland system may indeed be the safest long-term solution because of the limited amount of maintenance and capital expenditure required.

Questions regarding the ultimate fate of toxic metals after decades of operation have been raised. Does the wetland turn into a toxic waste dump after many years of absorbing metals? When does the wetland reach its metal absorption capacity and need to have the substrate replaced? More research needs to be done on these issues.

### 4.1.3. Constructability

Several constructability issues are important when treating acid mine drainage with constructed wetlands. The

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[13]Faulkner and Richardson, p. 63.

[14]Wieder, Tchobanoglous, and Tuttle, p. 301.

foremost issue is wetland site availability. Abandoned or inactive coal mines requiring acid mine drainage treatment are often in rugged country with difficult topography on which to site a wetland. Most drainages have low flow volumes where extensive piping is neither feasible nor economical; and, as a result the wetland must be constructed at or close to the mine seepage. The many constructed wetlands studies and pilot projects treating mine drainage at these sites have used the existing topography by siting the wetland along streambeds minimizing cut and fill operations. Topography usually favors high length to width ratio wetlands.

Construction of treatment systems for mine drainage are necessarily site specific. This is due both to the unique site geomorphology and the chemical composition of the effluent. Both of these factors mean that each acid mine drainage treatment system requires a unique design. Extensive study and testing must be done to design the system.

Construction costs, as has already been stated, are low compared to conventional treatment systems. Two separate design approaches empirically derived by the Bureau of Mines (BOM) approach and the Tennessee Valley Authority (TVA) have found that construction costs range from $2.96/m$^2$ (BOM) to between $3.58/m$^2$ and $32.03/m$^2$ (TVA).

All evidence to date shows that constructed wetland treatment systems offer a cost advantage of between 1/10 to 1/2 of the cost of conventional treatment systems.[15]

Key questions that must be answered are: Do constructed wetlands provide an equivalent level of treatment? Is the treatment reliable under varying weather and hydrological conditions? Is the treatment effective on a long-term basis? An understanding of the processes involved in treating acid mine drainage is essential in determining answers to these questions.

#### 4.1.4. Technology

The state of knowledge of the removal processes and design considerations will be reviewed.

The composition of mine drainage is varied. It can contain many different metals, has varying degrees of acidity, and varying concentrations of suspended solids and dissolved oxygen. Depending on the mine type the drainage could contain high concentrations of nickel, copper, lead, zinc, silver, iron, cobalt, sulphur, and manganese. Processes to remove all of these metals are not well understood.

Metal removal processes operating are sedimentation, filtration, adsorption, complexation, precipitation, plant uptake, and microbially mediated reactions.[16] Plant uptake

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[15]Hammer, "Constructed Wetlands for Acid Water Treatment," p. 4.

[16]Watson et al, p. 331.

has been shown to be of little significance in metal removal (less than one percent).[17]

Removal of iron, manganese, and sulphur from coal mine drainage is the best understood circumstance because many of these systems have been put into practice. Studies of their effectiveness have been mixed. Some have been effective; but, many have not, with the causes not well understood.[18,19,20]

Formation of metal oxides in the substrate is the principal removal mechanism for iron, manganese and zinc. Oxygen is transported to the substrate through the root system of emergent plants. Bacteria act as catalysts in forming residual compounds of sulfates, sulfides, oxyhydroxides and carbonates which become immobilized in the substrate.[21]

Iron is known to be oxidized in cattail ponds at their roots and rhizomes. Manganese concentrates in cattail leaves

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[17]R.P. Brooks et al, Bureau of Mines Report OFR-24(1)-90: Long-term Removal and Retention of Iron and Manganese from Acidic Mine Drainage by Wetlands (Washington D.C.: Bureau of Mines, 1990), p. 11.

[18]Jacqueline Henrot, et al, "Wetland Treatment of Coal Mine Drainage: Controlled Studies of Iron Retention in Model Wetland Systems," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), 793-800.

[19]Wieder, Tchobanoglous, and Tuttle, p. 300.

[20] Michelle A. Girts and Robert L. P. Kleinmann, "Constructed Wetlands for Treatment of Acid Mine Drainage: A Preliminary Review," in University of Kentucky, Office of Engineering Services, (Bulletin) UKY BU 1986 (Lexington, KY: University of Kentucky, 1986), pp. 165-171.

[21]Brooks et al, p. 12.

with only small percentages in the roots and rhizomes. In addition manganese concentrations are lowered due to uptake by algae. Abandoned mine ponds containing algae have been observed to effectively remove manganese from acid mine drainage.[22] Sulfate is known to be reduced in anaerobic substrates with bacteria acting as a catalyst.

A highly effective design for acid mine drainage treatment is an iron removing wetland populated with cattails followed by cells designed for subsurface reducing of sulfates, followed by algae ponds to remove manganese followed by filtration through sand to elevate pH and remove algae and any suspended manganese.[23]

For aluminum and copper, complexation with organic compounds is dominant in lowering concentrations. 100% of Cu and 40% of Al formed complexes with organic compounds in the substrate in a greenhouse study.[24] Various substrates were used in the study. Pine needle and hay substrate effectively reduced acidity and total Al levels.

The capacity of cation exchange and sorption of metal ions occurring in the substrate is finite. In a wetland

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[22]D.A. Kepler, "Acid Mine Drainage Treatment Using Blue-green Algae" (unpublished study, EADS Group, 1989), p. 46.

[23]Ibid, p. 47.

[24]A.D. Karathanasis and Y.L. Thompson, "Metal Speciation and Immobilzation Reactions Affecting the True Efficiency of Artificial Wetlands to Treat Acid Mine Drainage," (unpublished research report, Kentucky Water Resources Research Institute, 1990.

system the sites which metal ions can attach to get used up and the wetland's ability to remove more metal ions from solution is reduced.[25] The processes get more complicated when the hydologic conditions vary between aerobic and anaerobic conditions. For example, when a flooding event occurs previously retained metals may be washed out. Alternatively, when a dry period predominates, the anaerobic condition becomes aerobic in the low water levels permitting oxidation of sulfates to occur and releasing them back into the water to be flushed from the system.[26]

For metal concentration discharges that are near neutral in pH, wetland treatments have been successful. Where discharges are highly acidic and the metal load is high wetlands have not been as successful.[27] Performance of these processes in constructed wetland systems for periods longer than about ten years is unknown.[28]

The specificity of each site requires a separately designed treatment system to treat the unique water chemistry. Generic guidelines that can be applied indicate that wetlands

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[25]Edward A. Howard, Martin C. Hestmark, and Todd D. Margulies, "Determining Reliability of Using Forest Products or On-Site Materials in the Treatment of Acid Mine Drainage in Colorado," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989) p. 774.

[26]Faulkner and Richardson, p. 57.

[27]Brooks et al, p. 84.

[28] Watson, p. 332.

should be shallow (15 to 30 centimeters) to allow oxygenation and should include a few deeper areas to permit species diversification.

The Tennessee Valley Authority's empirically derived wetland sizing criteria is based on pH and metallic concentrations. As an example, for pH of less than 5.5, $2m^2$ of wetland is needed for each mg/min of Fe in the flow. For pH greater than 5.5, $.75m^2$ is required. This area will theoretically achieve an effluent Fe concentration of 3 mg/l. An effluent flow of 10 l/min containing 30 mg/l Fe would require 600 $m^2$ of wetland. The Bureau of Mines design approach (also empirically derived) results in smaller sized treatment areas.[29]

### 4.1.5. Market Size and Demand

There are over 150 treatment systems currently operating in the Appalachian coal mining region with 50 to 60 more being built each year.[30] Other mining regions such as the Rocky Mountain and the phosphate mining region of Florida are also experimenting with wetlands as treatment for run-offs and as part of land reclamation projects. Wetland applications for mining of minerals other than coal require research and

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[29]Wieder, Tchobanoglous, and Tuttle, p. 300.

[30]Hammer, "Constructed Wetlands for Acid Water Treatment", p. 5.

testing based on the particular chemical composition of mine seepages.

The market is growing as mining companies recognize that the treatment systems demonstrate compliance with discharge permit limits at an initial cost and annual maintenance cost that may be only a tenth of the conventional chemical treatment systems. Based on economics, a constructed wetland treatment system should be more favorable to mining companies than other more sophisticated technologies. Other factors such as pressure from environmental interest groups, political agendas, and increased public demand for environmentally safe industry will also increase to some extent the desire for mining companies to choose the constructed wetlands alternative which offers a potentially long-term, low-maintenance treatment system satisfying the requirement for long-term treatment of mine effluent.

Owners of abandoned mines on either private or public lands have no cash in-flow from the mine with which to construct and operate an expensive chemical treatment system and are particularly in need of a low-cost alternative. Regulation of mine outflows and cost effectiveness will make the constructed wetlands market for acid mine drainage grow.

#### 4.1.6. Regulations

Regulatory agencies involved with the mining industry in regard to acid mine drainage are the Bureau of Mines, Environmental Protection Agency, US Army Corps of Engineers, and state and local governments. States impose varying discharge concentration limits for contaminants from mining operations. Discharge limits may change based on political motive, changes in socially acceptable health risk, or on new scientific knowledge about ecology -- concerning concentration of heavy metals in the food chain for example. Changes will likely be in the more strict direction which may negatively impact the use of constructed wetlands. Wetland systems do not possess the degree of process control that chemical treatment systems can attain and are not as flexible to changing effluent requirements. Without the ability to improve the treatment process by chemical means the wetland size would either have to be increased or an "end-of-marsh" type chemical treatment added.

**4.1.7. Risk**

The biggest risk associated with wetland treatment of acid mine drainage is that unique technology will be required for many sites. At present it is difficult to predict if a constructed wetland will perform as designed. Often design parameters such as; size, loading rates, flow rate, retention time, depth, type of plant life, etc. must be altered to find a workable system which will meet specified discharge limits. The long establishment period for the plant life which sometimes lasts three growing seasons, combined with an adjustment period to reach acceptable efficiency can create a long, drawn-out period in which the design/constructor is at risk. Specialization in one particular type of wetland; such as only constructing wetlands for coal seepages, is the best way to limit the risks associated with treatment of widely different water chemistries from all types of mines. Experience constructing many wetlands treating discharge from the same type of mine will develop knowledge about what works and what does not.

Firms face the risk of wetland systems declining in efficiency with age and reaching their metal immobilization capacity before anticipated. Liability for fixing a treatment system that doesn't work can be high. Additionally, with the unknowns about the fate of heavy and trace metals in wetlands or in the foodchain, liability also exists for creation of as yet unknown health risks.

As mentioned above regulatory agencies or lawmakers may change the laws governing acceptable discharge limits. This creates the risk that additional area or facilities may have to be added to the wetland treatment system.

The risks associated with siting constructed wetlands for acid mine drainage are relatively low. Land is generally privately owned by the same party that needs the drainage treatment. Usually the major siting problem is that drainages can be located in rugged terrain making for very high construction costs to level a large enough treatment area.

## 4.2. Other Industries

Other industrial applications of constructed wetlands for wastewater treatment include treating wastewaters from pulp and paper mills, oil refineries, fish canneries, geothermal drilling operations, textile mills, livestock and poultry, landfill leachate, and hazardous waste leachate.[31] Each of these produce particular wastewater compositions that have been treated with wetland systems. These varied uses show the versatility and adaptability that wetland systems have to neutralize wastewaters using the naturally occurring processes which have been discussed for municipal wastewater and acid mine drainage treatments -- sedimentation, biological reactions, chemical complexation of metals with organic and inorganic compounds, nitrification-denitrification, and ultraviolet radiation.

### 4.2.1. Risk

A firm constructing wetlands for industrial clients faces risk in applying wetland technology to the specific wastewater type generated by the industry. Developing one-of-a-kind treatment systems can be risky because of the unknowns

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[31]There have been at least two Superfund hazardous waste sites which have used wetlands to treat leachate. See Environmental Protection Agency, Superfund Record of Decision (EPA Region 3): Palmerton Zinc Pile, Pennsylvania, EPA/ROD/R03-88/063 (Washinton D.C.: U.S. Government Printing Office, 1988); and E.A. Howard, J.C. Emerick, and T.R. Wildeman, "Design and Construction of a Research Site for Passive Mine Drainage Treatment in Idaho Springs, Colorado," in Constructed Wetlands for Wastewater Treatment, ed. Donald A. Hammer (Chelsea, MI: Lewis Publishers, 1989), pp. 761-764.

involved with how the wetland systems will react to specific loading of contaminants. As discussed with acid mine drainage this risk can be limited by focusing on providing wetlands for one specific industry.

The risk of market demand disappearing is partly a function of the cost advantage wetland treatment systems hold. Wetlands will in all likelihood continue to maintain this cost advantage and demand will continue to increase as industry seeks innovative ways to reduce costs.

Market demand is also a function of the "greening" of industries. As industries seek to be perceived by the public as being environmentally conscious, the use of wetlands as an alternative wastewater treatment technology is more attractive. Constructing wetlands can be a highly visible public relations vehicle for showing environmental concern.

Regulatory risks are uncertain for industrial applications of wetland treatment systems. Discharge limits may be very stable for some applications like poultry wastes but may be variable regarding removal and fate of trace metals or non-biodegradable organic compounds that are discharged in oil refinery wastewaters.

Risks associated with technology are likewise uncertain and depend on the particular application. Wetland applications which have not been attempted before or which depend on some of the untested pollutant removal mechanisms are risky. The firm constructing such wetlands would need significant research and development capability.

Along with risks from untested wetland technology come associated liability risks regarding the ultimate fate of contaminants removed from toxic wastewaters. Landfill or hazardous waste leachate treatments are examples where liability risks can be very high.

## 5. Agricultural Run-offs

Nonpoint source run-offs from agricultural practices are a major contributor to nonpoint source pollution in the United States. Wetlands can be used for control of nonpoint source pollution and erosion together with the already widely used best management practices (BMP); such as, lagoons, crop rotation, land application, etc. Wetland applications can be used in four levels of control. First order control includes wetland treatment of wastewaters from concentrated livestock areas; such as around dairy barns or feedlots. Second order control uses wetlands to treat run-off from a variety of sources on individual farms including fertilized fields and grassy areas. Third order control may use ponds, natural, created or restored wetlands which trap sediments and nutrients from many farms. Fourth order control entails the use of large wetlands situated lower in the watershed which act as nutrient buffers and as flood and erosion control mechanisms.[1]

### 5.1. Advantages

Ponds, marshes and constructed wetlands provide numerous benefits to agriculture. Erosion control, wastewater treatment and purification, recreational opportunities, ecosystem balance and aesthetic improvements can be gained by

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[1]Levels of control are described in Hammer, "Designing Constructed Wetlands Systems to Treat Agricultural Nonpoint Pollution," p. 6.

integrating wetlands into BMP's. These benefits can be gained at a reasonable cost. Wastewater treatment costs for farms must be kept low. Farms may produce an organic load which is equivalent to a small community's; and the farmer can not be expected to expend the capital or take on the debt required for a conventional wastewater treatment plant. A properly designed wetland treatment system will provide the necessary treatment at a cost that does not burden the farmer with more unaffordable capital costs.

### 5.2. **Disadvantages**

The primary disadvantage to using a wetland treatment system is that a farmer must relinquish profitable land. The size of the wetland may be significant for controlling large areas of fertilized row crops or for large feedlots. Wetland acreage can be minimized by using pretreatment with lagoons or settling tanks which are more efficient on a per acre basis in handling concentrated organic loadings.

### 5.3. **Constructability and Technology**

First and second order control systems will be discussed here. Third and fourth order control requires wetland systems that resemble natural, created, and restored wetlands which will be discussed in section 7.1.

Constructability and technology involved in treating agricultural wastewaters and run-offs are similar to those for municipal wastewater treatment systems. The same contaminant removal mechanisms apply. There are several important differences however.

The major difference is that wastewaters from livestock yards or feedlots can contain very high concentrations of organic nutrients and nitrogen, and design should be based on these two pollutants. Pretreatment with a lagoon or settling basin is necessary. Parallel treatment cells are desirable to give maintenance flexibility, and the system should be designed for gravity flow to eliminate pumping costs. One successful design for wastewaters flowing from an Alabama hog farm combines lagoon pretreatment with a marsh/pond/meadow system. A thorough discussion of design parameters for first order control systems is found in Hammer, "Designing Constructed Wetlands Systems to Treat Agricultural Nonpoint Pollution."[2]

Another difference is that site availability for agricultural applications of wetlands is usually not a problem. Land is readily available at relatively low cost.

Second order control requires wetlands which are primarily used for collection and treatment of run-offs from row crops containing high levels of both nitrogen and phosphorous. Careful placement is important so as to most judiciously trap sediments and capture pollutants from many areas of the farm.

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[2]Ibid, p. 11.

## 5.4. Market Size and Demand

The size of the market for constructed wetlands in the treatment of agricultural run-offs is the most compelling factor indicating opportunity. Most farms in the United States currently use BMP for land and water resource management. Wetlands are an extension of the more widely used BMP's and are easily integrated into existing erosion control systems.

For this market to expand incentives must be given to individual farmers to use constructed wetlands. Beyond the incentive for a farmer to practice sound natural resource management of his own land to prevent erosion, there is little incentive for a farmer to ensure that waters draining his land are not contaminated by pollutants such as nitrogen and phosphorous if enforcement is lax or if laws are not strict. Incentives came come from regulation and enforcement of discharges into the watershed.

The recent regulation of agricultural drainage into the Florida Everglades is an example of the scale regulatory requirements can produce. The state government's commitment to a $400 million cleanup of water pollution in the Everglades includes two artificial marshes totalling 17,700 acres. One marsh near Loxahatchee National Wildlife Refuge is estimated to cost $16 million.[3]

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[3]"U.S. and Florida Sign New Everglades Pact," Engineering News-Record, 11 March 1991, p. 11.

Another regulation pertaining to waterfowl habitat has resulted in farmers restoring 118,000 acres of wetlands over the past 18 months.[4]

**5.5. Regulation**

Governmental policy has shifted from the goal of achieving maximum productivity through wetland conversion to one of wetland protection and restoration. Interestingly, the U.S. Soil Conservation Service and the U.S. Department of Agriculture (USDA) now assist in protecting and restoring the same wetlands which they previously aided in destroying. Wetlands are being encouraged for use in all the types of applications described above; from wetlands that resemble natural marshes and perform a wide variety of functions to wetlands which treat specific wastewater discharges. This policy will continue as society as a whole becomes more aware of the ecological value that wetlands possess.

The 1985 Farm Bill and its "swampbuster" provision is an example of the impact that regulation can have on agricultural practices. The stipulation governing wetland destruction and the mandated soil conservation plan, which are prerequisites for USDA benefits, are forcing farmers to protect and restore wetlands and put in place conservation plans which include constructed, restored, and created wetlands. The desire to

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[4]William K. Stevens, "Restoring Lost Wetlands: It's Possible But Not Easy," New York Times, 29 Oct. 1991, p. C9.

retain or restore subsidies has had predictable consequences. Draining and filling of wetlands on agricultural lands have been reduced and restoration efforts are becoming commonplace. For example, farmers in the South are reconverting their soybean fields into wetlands.[5]

Government regulation can help to establish incentive for constructed wetlands by enforcing acceptable discharge concentrations of pollutants into streams and rivers. If lawmakers and regulators enact and enforce legislation which punishes the farmer for discharge violations, as is becoming more common in many states, the choice of using a low-cost wetland is more attractive. The Florida Everglades clean-up is an example where the polluter is being forced to pay. Farmers discharging phosphorous in farm run-offs are being taxed to raise funds for the $400 million clean-up effort.[6] This mechanism should provide farmers incentive to take preventative pollution control measures which are low-cost and effective. Various uses of constructed wetlands meet these two criteria.

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[5]Peter C. Myers, "Remarks: Increasing Our Wetland Resources," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington, D.C.: National Wildlife Federation, 1988), p. 240.

[6]"Everglades Law Signed, but Feds Decry Cleanup," Engineering News-Record, 27 May 1991, p. 13.

Limits of acceptable concentrations are generally agreed upon. More important, is the monitoring and enforcement of discharges and the expense incurred in so doing.

## 5.6. Risk

The risks involved in constructing wetlands for agricultural uses such as treatment of animal wastes and treatment of row crop run-offs will be discussed here. Risks involved in farmland reconversion by wetland restoration or creation will be discussed in section 7.5.

As has been shown, regulation plays an important role as a market driving force. Firms interested in the agricultural wetlands market need to be aware of regulatory changes which provide disincentive to farmers to use wetlands. A possible disincentives would be the unlinking of price supports with wetland protection and restoration measures. Another is federal or state subsidized construction of highly technological treatment systems that provide the finely tuned control capabilities found in many municipal wastewater treatment plants. The trend away from small family-owned farms and toward larger cooperative farming arrangements may make consolidated wastewater treatment systems feasible and economical. The land used for wetland treatment would be freed-up for more profit-generating row crops.

Technological risks associated with reduction of pollutants from animal wastewaters and from nitrogen and phosphorous fertilizers are similar to those for municipal wastewater treatment systems. The wastewater composition is well-known, and treatment methods well understood.

The presence of pesticides and chemicals in row crop run-offs present unique technological challenges concerning removal mechanisms and fate of these pollutants. Much research and testing remains to be done on specific removal mechanisms. These contaminants create wetland technology risks as well as liability risks that must be considered by firms entering the agricultural constructed wetlands market.

## 6. Stormwater Run-off Control and Treatment

Real estate developers and communities are increasingly turning to the use of constructed wetlands in their stormwater run-off control and treatment systems. Wetlands provide advantages to both the developer and the community.

### 6.1. Advantages

Constructed wetlands have the ability to provide effective treatment of stormwater with a system that is cost effective given availability of low-cost land resources. Wetlands provide attenuation of stormwater surge, erosion control, and sediment entrapment. Wetlands also provide aesthetic value to development projects.

### 6.2. Disadvantages

There are disadvantages to choosing wetlands for stormwater management. If the climate has sporadic storms or elongated wet and dry cycles it is difficult to maintain a reliable water supply to maintain the wetland vegetation. Extremely high flows create a flushing action in the wetland and previously trapped sediments and contaminants can be released. High flows must be detained and released into the wetland at a measured rate. There is the potential for creating vector or nuisance odor problems.[1]

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[1]Disadvantages are taken from Hantzsche, p. 17.

## 6.3. **Constructability**

Land availability is the most critical issue in choosing to use a wetland to manage and treat stormwater run-off. If land is available at reasonable cost this option can be cost effective.

A stormwater management system that employs a constructed wetland usually combines several different facilities. A storm sewer for collection will usually include screens or catchment basins for entrapment of debris such as litter, leaves, etc. The storm sewer outflow can empty directly into the wetland or into detention ponds designed to accommodate peak flows. Wetlands receiving high peak run-offs during storm events and relatively low flows at other times are susceptible to flooding and flushing and will require temporary water storage in ponds or lakes with adequate capacity for protection. The wetland size may be limited by land availability and the dry season flow quantity which can sustain wetland vegetation. During a large storm event the wetland will be unable to handle the quantity of flow. With flooding of the wetland, retention time will be reduced and the intended level of treatment will not be obtained. A temporary water storage facility is needed to hold the water until it can be released by a control structure into the wetland.

## 6.4. Technology

The technology required to construct a wetland for stormwater management is relatively simple and is not sophisticated. The most important aspects are handling the flow variance and specific treatment of the pollutants.

Stormwater run-offs contain solid debris, sediments, oils and grease from pavements, organic nutrients, nitrates, trace metals, deicing salts, and suspended solids. The first inch of rainfall produces the most polluted water containing oil and grease from roads and pavements.

Removal mechanisms operating in a wetland are much the same as explained for municipal wastewater and acid mine drainage. The key to treating storm run-offs is controlling the flow rate and retention time in the wetland. This can be done with storage basins, detention ponds, and oxidation ponds to hold the water until it can be released to the wetland. Control gates or weirs are needed to regulate flow.

Stormwater treatment wetlands also should be segmented allowing for temporary shut down and maintenance.

## 6.5. Market Size and Demand

Potential market size for constructed wetlands for stormwater control and treatment is large. These types of systems can be used for large and small real estate development projects such as new office parks, industrial parks, residential subdivisions, shopping malls, and hotels.

Also wetlands can and are being integrated into highway run-off control systems where they have utility in providing erosion control and water treatment. The fact that constructed wetlands provide acceptable treatment levels of nonpoint source pollution in combination with low construction costs makes this option attractive to developers.

Additionally, developers are being seen by society as "destructors" of the natural environment in search of profits. Environmental interest groups, governments, and the public are putting more and more pressure on developers to build without environmental degradation. The integration of wetlands as stormwater control or wastewater treatment systems into the development project gives developers an opportunity to be seen as environmentally conscious.

### 6.6. Regulations

Regulations controlling urban run-off are becoming more restrictive for developers. Most state, city, and municipal regulations and permitting agencies require control of run-offs for new development. Run-off control plans are now mandatory in most places.

### 6.7. Risk

Vectors and pests pose a real risk and a perceived risk. Public health risks concerning wetlands have been overstated in the past. Ingrained thinking about wetlands holds that they harbor disease and are a nuisance to public health. Research has shown that this is not as large a problem as previously thought.

Another problem is mosquito or other insect control. Various techniques exist to deal effectively with mosquitos. Natural predators such as mosquito fish have been successful. Keeping BOD loading levels low, minimizing stagnant areas, and uniform distribution of wastewater help in mosquito control.[2]

Another risk is uncertainty concerning regulations and treatment levels. If regulations become more restrictive by demanding higher treatment levels, modifications must be made to the wetland. Either wetland size must be increased or loading must be decreased. Where additional land is a problem the constructed wetland alternative loses its feasibility to serve the intended urban run-off area.

Public opposition due to siting considerations and the "not-in-my-back-yard" syndrome are risks that must be carefully considered. Opposition to a constructed wetland may be more intense than for a conventional treatment facility due to the larger size of the wetland. Perceived public concerns about unpleasant odors, harmful health effects, and decreased land values must be overcome by community ecucation programs which emphasize the positive aspects of wetlands. Another

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[2]Rich Stowell et al, "Mosquito Considerations in the Design of Wetland Systems for the Treatment of Wastewater," in Ecological Considerations in Wetland Treatment of Municipal Wastewaters, ed. Paul J. Godfrey et al. (New York: Van Nostrand Reinhold, 1985), p. 41.

source of public opposition is the long-held misunderstanding about wetland value to the ecosystem. Wetlands, marshes and swamps have historically been considered as useless land having little economic or social benefit.

## 7. Creation and Restoration

Creation and restoration of wetlands is becoming more and more popular. Natural wetland losses due to real estate development, infrastructure development, and agricultural reconversion combined with efforts of environmental groups and their desire to re-establish natural resources for wildlife and ecological purposes all impact to create opportunities for wetland creation and restoration. To reduce losses of wetlands the trend of federal, state and local legislators is to increase regulation of wetlands destruction. This trend has led to wetland mitigation laws which require reduction of proposed losses, restoration of degraded wetlands, and creation of compensatory wetlands.

### 7.1. Constructability

There are varying opinions as to the ease with which wetlands can be established. Restorations from previously degraded or drained wetlands have been shown to have a much greater chance of success than wetlands created from lands that never possessed wetland characteristics. Restorations can be as simple as opening a dike and allowing normal hydrologic cycles to resume, or they can be very complex, involving extensive site investigations to determine previous vegetation, wildlife, and their interactions.

There are no definite design parameters for creating natural wetlands as are being developed for the treatment of wastewaters. Restored and created wetlands are designed to look natural and to simulate the natural hydrologic regime. Geomorphologic and climatologic data of the area is necessary in re-establishment of hydrologic regimes. Other information that may be needed is land use history, macrotopography, microtopoghraphy, general surficial geology, stream-flow, lake hydraulics, groundwater levels and quality, bed-rock geology, surficial geology, stream-flow velocity, soil pore water data (storage, level, flow), water quality, water balance, groundwater storage and flow rate, and precipitation. Coastal projects need information on sediment concentration and transport, tidal dynamics, coastal energy, sea level changes, water residence time, and the chemical and physical properties of the water column.[1]

Wetlands of small scale have been moved from one site to another. This method is applicable to highway construction. At DuPage County, Illinois a 120-acre project was restored and three acres were relocated. The total cost of the project was $8.3 million. It is difficult to move soil and create a functional soil profile.[2] In this project excavation of the top ten inches of soil and relocation were done during a three-week period in winter when plants were dormant. The

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[1]Joseph S. Larson, "Wetland Creation and Restoration: An Outline of the Scientific Perspective," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington D.C.: National Wildlife Federation, 1988), p. 74.

[2]Ibid, p. 75.

soil mass contains seeds, rhizomes, roots, nutrient organic matter and invertebrates that are essential to wetland development.[3] Plant coverage equalled 90 percent after three growing seasons. Management of the wetland involved periodic burns to simulate natural fires which control unwanted plants or monoculture species that take over. Other successful sites include the Westford Corporate Center in Massachusetts and the North-South Tollway in Illinois.[4]

## 7.2. Technology

The natural wetland is being found to be a very complex ecosystem with many functions still not known or well understood. The effects of natural hydrologic fluctuations on wetland plants and interdependencies between the large diversity of plant and animal life are not known. The functioning of the enormous amount of micro-organisms, invertebrates and larger animals and their relationship with plants are not well understood.

For all that is not known there is much information that can be gathered to evaluate the practicality of creating or restoring a wetland. Known wetland functions that need to be replicated are groundwater recharge and discharge, flood storage, shoreline anchoring and dissipation of erosive forces, sediment trapping, nutrient retention and removal,

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[3]Salveson, p. 111.

[4]Ibid.

food chain support, habitat for fisheries, and habitat for wildlife.[5] For establishment of freshwater wetlands the following minimum information needs to be obtained: soil profile descriptions, general soil survey data, physical parameters (porosity, hydraulic conductivity, bulk density), and chemical parameters (pH, conductivity, cation exchange capacity, redox potential, total phosphorous, total and nitrate nitrogen, organic carbon). For more extensive projects the following are needed: site specific data on fiber content, phosphorous retention, pore water analysis, alkalinity, and exchangeable acidity, seedbank composition, and soil organisms, clay mineralogy, microbial assessment, heavy metal content, presence of pesticides, gas/toxin analyses, peat features, and soil temperature regime. Coastal wetlands require much the same data, plus available sediment, sand budgets, fine and course sediment fractions, and wetland age.[6]

Creation and restoration efforts have met with varying degrees of success. One wetland restoration specialist has taken credit for over 350 successful restorations along tidal areas of the East Coast with only seven or eight failures.[7] In a study of 32 created wetlands in Virginia less than 50

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[5]Larson, p. 73.

[6]Ibid.

[7]Stevens, p. C1.

percent complied with permit conditions.[8] A study in Florida showed most wetland projects that developers were required to construct as mitigation were improperly designed hydrologically.[9]

There is disagreement among scientists on criteria to judge success and on the length of time over which success must be evaluated. No standard has been set for developers, regulatory agencies, or legislators to follow in determining which wetland functions make a wetland.[10] There is no clear definition with which permitting agencies can base permitting requirements. A restored wetland can resemble a natural wetland in outward appearance, but not function as a natural wetland with the same diversity of plant and animal life and the same cycling of minerals, nutrients, and organisms. There have been numerous projects like the ones in the Florida study that have appeared successful for the first few years only to become monocultures or fail to support plant life later because of failures in hydrology.

The major obstacles to achieving successful wetland creation with a functioning food chain, fish habitat, and nutrient transformations depend upon the proper hydrological

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[8]Salveson, p. 96.

[9]Stevens, p. C9.

[10]Ibid.

regime and a soil system with aerobic, anaerobic, organic, and inorganic components in appropriate relationships.[11]

### 7.3. Market Size and Demand

There are many examples of restored wetlands which have the outward appearance of a natural wetland with plant life, wildlife, and hydrologic cycle. One prominent example is the restoration of the Hackensack meadowlands in New Jersey where over $5 million ($75,000 per acre) was spent to restore and preserve 151 acres. Another example is at Ballona, California where 216 acres where restored as a wildlife sanctuary at a cost of $8 million.[12] With both salt and freshwater marshes, the Ballona wetland required a complex mathematical hydrodynamic model of the estuary to simulate water flows throughout the system. The project uses an automated tide-gate control system to establish and maintain desired tidal water exchange rates. Total time required from conceptualization to completion of the functional system exceeded five years at a location with a commercial value of at least $1 million per acre.[13]

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[11]Larson, p. 73.

[12]Both examples are from Salveson, p. 97.

[13]Eric D. Metz, "Guidelines for Planning and Designing a Major Wetland Restoration Project: Ballona Wetland Case Study," in Proceedings of a Conference: Increasing Our Wetland Resources, ed. J. Zelazny and J. Scott Feierabend (Washington D.C.: National Wildlife Federation, 1988), pp. 80-87.

These large projects get the publicity; but, the largest demand is in the sum of the small projects that are done for developers, transportation departments, conservation groups, recreation departments, farmers, and other private owners.

## 7.4. Regulations

Multiple regulatory agencies are involved with wetland restoration/creation. The Fish and Wildlife Service, Army Corps of Engineers (ACOE), the Environmental Protection Agency (EPA), the Soil Conservation Service (SCS), the Department of Agriculture (USDA), and state and local governments all have different regulations that must be considered. The ACOE is the government agency which administers permitting to develop on wetlands and the mitigation measures that are required. The EPA has veto power over this authority. Usually the veto is not exercised; however, when the EPA and ACOE do disagree, extensive delays result while developers and contractors are caught in the middle.[14] The SCS and the USDA regulate wetlands with respect to agriculture operations as discussed earlier.

Regulations are the major market force in creation and restoration of wetlands. Regulations create the rules which define wetlands, which determine what mitigation measures are required for wetland losses, and which provide financial motivation for restoration and reconversion. Recent political

[14]Salveson, p. 34.

and scientific debate over the definition of a wetland has shown the importance of regulation in determining the extent of wetland restoration/creation markets. Proposed looser federal regulations governing development will obviate the need for many of the mitigation measures currently used. Developers may no longer be required to replace lands that would have been considered a wetland under previous law.

Federal, state and local governments have varying laws concerning what mitigation for lost wetlands will be required of developers, highway departments, private owners, etc. Usually the developer is required to first find an alternate site which does not impact on wetlands. If this is not possible the developer must minimize impacts in every way possible. Thirdly, the developer may be required to rectify impacts by repairing, rehabilitating or restoring damaged wetlands, and as a last recourse may be required to provide substitute wetland resources at a ratio of up to five acres for each one that is destroyed.[15] These mitigation steps are usually followed in sequence; however, the ACOE has at times varied from this policy.

Future regulatory changes are difficult to predict, except that generally, over the long term it can be expected that wetland protection will become stricter, given the increasing public sentiment for environmentalism in a democratic society.

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[15]Mitigation steps are from Salveson, p. 32.

### 7.5. Risk

Risks associated with the market for restored or created wetlands are of three types: political, scientific, and construction related.

Political ideology can cause changes in regulations and permitting requirements and create risks that can be difficult to predict. This risk is large given that restoration or creation of a wetland and its establishment can take many years. During the time needed for site investigations, construction, planting, and overall wetland functions' establishment the political climate and ensuing regulations can change. For example, regulations covering wetland definition may change during the site investigation process, suddenly leaving the wetland creation firm with projects that are no longer needed.

The technology required to create or restore a wetland to near-natural standards is complex and not well understood. Continued scientific investigation and the resulting increase in knowledge about wetlands and their functions can change the methods in which wetlands are created and restored. Guidelines of accepted practice can become more stringent making projects much more expensive which, in turn, will reduce demand.

Construction risk is high because often the vegetation and the hydrologic regime does not get established because of weather, take-over by monocultures, or other reasons. The complexity of wetland ecosystems is difficult to replicate, and depending on the owner's objectives the cost to create a near natural wetland ecosystem can be quite high. Much pre-construction scientific investigation and post-construction monitoring must be done to measure success or failure. Initial estimates about expenses involved in creating a wetland can vary significantly from the actual expenses due to lack of knowledge about wetland functions and the specific site characteristics. The successful restoration/creation of wetlands is often a trial and error process that is difficult to estimate with accuracy and can require years to get results.

Restoring or creating wetlands incurs some risk due to the need for replanting if the first planting dies. Problems such as abnormal weather, overcrowding of monocultures, improper soil composition, or indigenous plant unavailability may lead to larger than expected die off of the first planting. Otherwise, maintenance requirements and expenses are relatively low compared to constructed wetlands for wastewater treatment.

The risk that the market will go away or be severely restricted is high. If wetlands are protected and less and less are allowed to be developed the resulting need for mitigation by replacement will drop in turn. This market reduction that comes from growing pressure to protect wetlands, may be offset by a greater public urgency in wetland restoration of those wetlands that have been destroyed in the past. On the other hand if the wetland definition is broad and sound, scientific evidence shows wetland creation can adequately replicate natural wetlands, restrictions on development may relax, generating a large need for wetlands as mitigation projects.

Liability risks are lower for wetlands that are being created or restored than for wastewater treatment systems because no contaminants such as heavy metals or pathogens are being introduced into the natural environment. The public health or safety is not seriously affected by the success or failure of wetlands in meeting the functional equivalent of natural wetlands.

## 8. Evaluation of Risk

Table 3 summarizes the risks evaluated in the preceding sections. These risks are evaluated from the perspective of a firm considering entry into constructed wetland markets.

TABLE 3

| Risks Due to: | Muni. Waste Water | Acid Mine Drainage | Indus. | Non-Point Run-off | Urban Dev. | Agriculture Reconversion |
|---|---|---|---|---|---|---|
| Siting | medium | low | low | medium | medium | low |
| Technology | low | high | ???? | medium | high | high |
| Construction | low | medium | medium | medium | high | high |
| Regulation | low | medium | medium | medium | high | medium |
| Liability | low | high | high | medium | low | low |
| Market Demand | low | low | medium | medium | high | high |

### 8.1. Municipal Wastewater Treatment

Constructed wetlands for municipal wastewater treatment at present have the fewest associated risks. This is due to the extent of knowledge about the wastewater composition and contaminant removal processes, the observed operating record which is longer and provides a basis for empirical design and operating criteria, and the forces driving the market which are creating a predictable trend favoring the low-cost advantage gained by wetland treatment technology. The risk that is of the most concern is due to siting problems as a result of required wetland size and possible public opposition.

### 8.2. **Mining and Other Industries**

The main risk in treating acid mine drainage with constructed wetlands is the uncertainty of design which will be required to treat unique chemical characteristics of each site's flow. Because of the variance in chemical composition of mine drainage the contractor faces the possibility of performing an extensive site investigation to design a wetland treatment system which will function at a unique site. Specialization in one particular type of mine drainage, such as at coal mines, can limit this risk; however, specialization also limits the potential market.

Other significant risks include the question concerning sustainability of long-term metal removal and the ultimate fate of some metals and their concentration in the food chain.

Other industrial applications are subject to much of the same risks as the mining industry with a wide variety of wastewater chemical compositions requiring testing of prototypical systems before large-scale treatment systems can be fully implemented. However, for some industries the technological risk may be low based on wastewater that contains pollutants that are readily assimilated by the wetland. Liability risk may also be high depending upon the particular discharge to be treated. These liability risks may be a significant barrier to market entry for small-sized firms.

### 8.3. Nonpoint source run-off pollution

Nonpoint source run-off pollution applications of constructed wetlands involve risks due to regulatory changes which may effect future market demand and due to technological uncertainty regarding pesticide control. The large agricultural sector responds mainly to economic pressure brought on by laws like the Farm Bill. The long-term trend toward stricter regulatory requirements governing run-off favors constructed wetland use. The powerful pro-agriculture lobby; however, pushes for less restrictions on run-offs for productivity and economic reasons, and the laws may change resulting in a declining demand for run-off treatment. Stormwater run-off regulations face similar circumstances with the strong political force coming from developers and business.

### 8.4. Created or restored wetlands

Created or restored wetlands used to replace wetlands lost in urban development or to reconvert agriculture lands involve high risks due to regulatory variability, current technological and scientific understanding of wetland functions and processes, and the risk that market demand may be cyclical based on political ideology. Demand is driven by regulatory forces. Political agendas favoring real estate development without mitigation of wetland losses or strictly limiting development on wetlands altogether may cause demand to diminish. Construction risks are present due to the length of time required for wetland establishment.

### 8.5. Market Entry

In general, the principal barrier to entry to all types of constructed wetlands is the extensive scientific knowledge required concerning wetland ecology, hydrology, operating functions, and contaminant removal processes. Also extensive knowledge concerning applicable regulations and the enforcing agencies is required due to the power held by these agencies in establishing acceptable definitions, limits, practices and operating procedures. The contractor needs to be fairly sophisticated and able to understand and apply this knowledge to perform environmental studies of various types, to respond to unforeseen complications that arise due to climatic events, to understand the complex ecological processes occurring in wetlands, and to respond to changing regulations.

Firms with experience in environmental-related work can move into the constructed wetlands market quite easily. The work requires experience in working with environmental regulatory agencies, public health departments, agriculture and industrial clients, local community planning commissions, the scientific community, and little need for experience with the building trades.

Entry into the constructed wetlands market is relatively easy in terms of required capital investment. Equipment used in limited earthmoving operations and in construction of inlet distribution systems and flow control structures is all that is usually required.

The creation/restoration market which is demanded by developers, highway departments, communities, and private or non-profit organizations is particularly difficult to enter because of the extensive scientific investigations and specialized skills required to replicate natural wetland functions. The contractor must be staffed with the personnel to conduct pre-construction research required in gathering the necessary data to create a lasting, self-regulating wetland that functions naturally. Also, post-construction follow-up and monitoring is necessary to ensure the wetland becomes established according to permit requirements.

There is a long learning curve for new entrants into the market because it usually takes several years for the product, in this case a functioning wetland system, to fully develop. Many constructed wetlands start with empirically derived designs that later require modification or fine tuning to get them to the point of meeting original objectives. A commitment of several years is required for each project because of monitoring and performance verification during the first few growing seasons to ensure plant establishment or to modify the wetland as needed. With projects that require years to reach peak efficiency which is common for acid mine drainage and municipal wastewater treatment systems, or as a result of uncertain wetland technology, the learning process is slow.

The ability to effectively market and publicize wetland advantages and benefits to the client is important in generating business. For municipal wastewater treatment systems the product must be sold to a public which may have ingrained opposition against dumping sewage into an environment which is not highly controlled as is a conventional sewage treatment plant. Highlighting the record of successful operating systems and their cost advantages are the key attributes that must be conveyed to the client.

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