EPA United States Environmental Protection Agency
Office of Water

Constructed Wetlands for Wastewater Treatment and Wildlife Habitat

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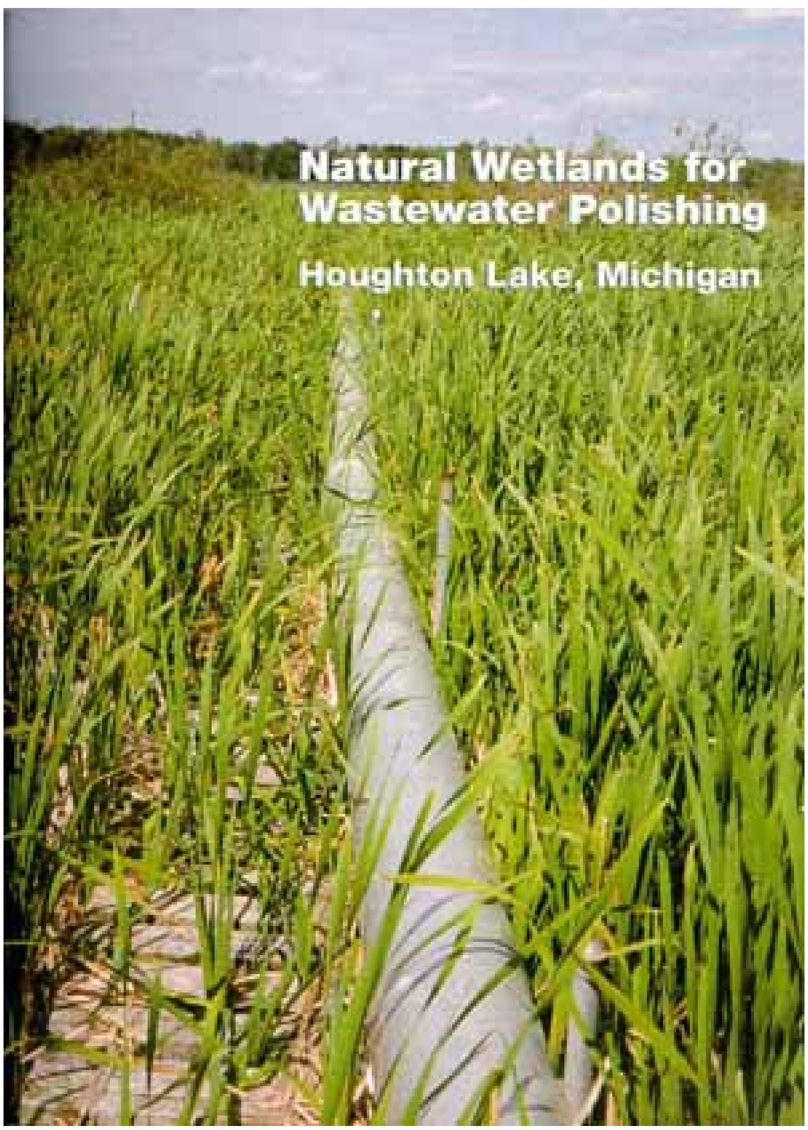
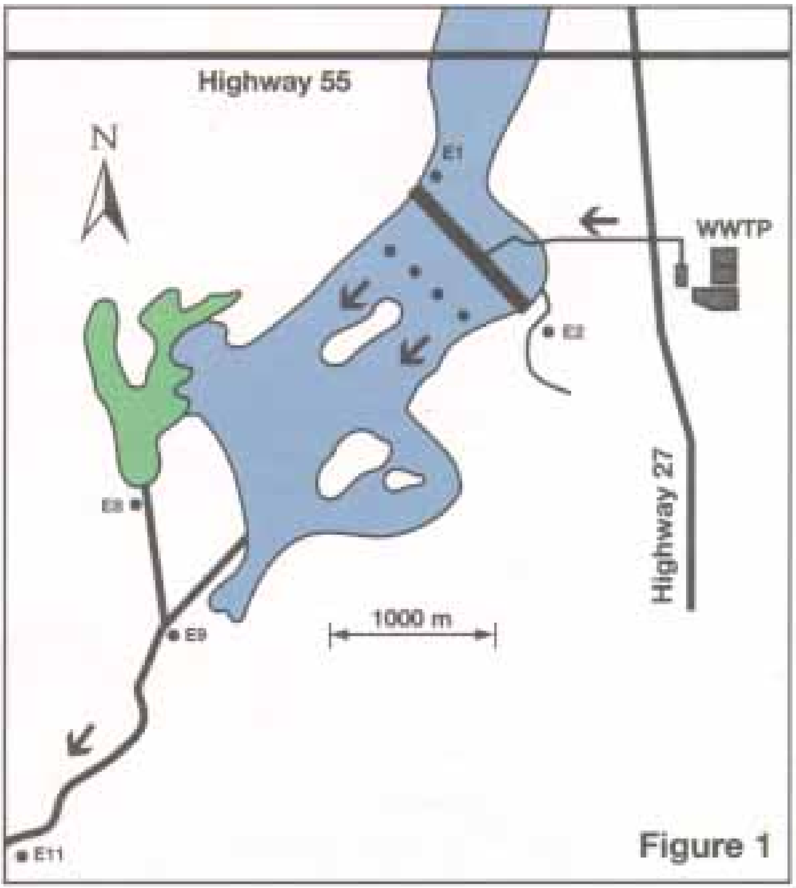
Natural Wetlands for Wastewater Polishing, Houghton Lake, Michigan



System Description



The wetland treatment site is located southwest of the lake. The land belongs to the State of Michigan and is dedicated to public and research uses. Dots indicate water monitoring stations.

The community of Houghton Lake, located in the central lower peninsula of Michigan, has a seasonally variable population, averaging approximately 5,000. A sewage treatment plant was built in the early 1970’s to protect the large shallow recreational lake. This treatment facility is operated by the Houghton Lake Sewer Authority (HLSA). Wastewater from this residential community is collected and transported to two 5-acre aerated lagoons, which provide six weeks detention. Sludge accumulates on the bottom of these lagoons, below the aeration pipes. Effluent is then stored in a 29-acre pond for summer disposal, resulting in depth variation from 1.5 feet (fall) to 10.0 feet (spring). Discharge can be to 85 acres of seepage beds, or to 85 acres of flood irrigation area, or to a 1500 acre peatland. The seepage beds were used until 1978, at which time the wetland system was started up. The wetland has been used since that time, with only occasional discharges to seepage or flood fields. The average annual discharge is approximately 120 million gallons. Secondary wastewater is intermittently discharged to the peatland during May through September, at the instantaneous rate of 2.6 mgd.

Provisions for chlorination are available, but have not been used, because of low levels of fecal coliform indicator organisms. Water from the holding pond is passed by gravity or pumped to a 3-acre pond which would provide chlorine removal in the event of the necessity of its use. Wastewater from this pond is pumped through a 12-inch diameter underground force line to the edge of the Porter Ranch peatland. There the transfer line surfaces and runs along a raised platform for a distance of 2,500 feet to the discharge area in the wetland. The wastewater may be split between two halves of the discharge pipe which runs 1,600 feet in each direction. The water is distributed across the width of the peatland through small gated openings in the discharge pipe. Each of the 100 gates discharge approximately 16 gallons per minute, under typical conditions, and the water spreads slowly over the peatland. The branches are not used equally in all years.

The peatland irrigation site originally supported two distinct vegetation types. One called the sedge-willow community included predominantly sedges (Carex spp.) and Willows (Salix spp.). The second community was leatherleaf-bog birch, consisting of mostly Chamaedaphne calyculata (L.) Moench and Betula pumila L., respectively. The leatherleaf-bog birch community also had sedge and willow vegetation, but only in small proportions. The edge of the peatland contained alder (Alnus spp.) and willow. Standing water was usually present in spring and fall, but the wetland had no surface water during dry summers. The leatherleaf-bog birch cover type generally had less standing water than the sedge-willow cover type. Soil in the sedge-willow community was 3-5 feet of highly decomposed sedge peat; while in the leatherleaf-bog there is 6-15 feet of medium decomposition sphagnum peat. The entire wetland rests on a clay “pan” several feet thick.

The wetland provides additional treatment to the wastewater as it progresses eventually to the Muskegon River eight miles away. Small, natural water inflows occur intermittently on the north and east margins of the wetland. These flows are partially controlled by beaver. Interior flow in the wetland occurs by overland flow, proceeding from northeast down a 0.02% gradient to a stream outlet (Deadhorse Dam) and beaver dam seepage outflow (Beaver Creek), both located 2-3 miles from the discharge (Figure 1.) Wastewater adds to the surface sheet flow. Hydrogeological studies have shown that there is neither recharge or discharge of the shallow ground water under the wetland.

The original leatherleaf-bog community also had sedge and willow vegetation in small proportions, and very low abundance of cattail.

The treated wastewater arriving at the peatland is a good effluent which contains virtually no heavy metals or refractory chemicals. This is due to the absence of agriculture and industry in the community. Phosphorus and nitrogen are present at 3-10 ppm, mostly as orthophosphate and ammonium. BOD is about 15 ppm, and solids are about 20 ppm. Typical levels of chloride are 100 ppm, pH 8, and conductivity 700 mmho/cm. The character of the water is dramatically altered in its passage through the wetland. After passage through ten percent of the wetland, water quality parameters are at background wetland levels. The system has operated successfully in the treatment of 1900 million gallons of secondary wastewater over the first sixteen years.

History

The Porter Ranch peatland has been under study from 1970 to the present. Studies of the background status of the wetland were conducted during the period 1970-74, under the sponsorship of the Rockefeller Foundation and the National Science Foundation (NSF). The natural peatland, and 6m x 6m plots irrigated with simulated effluent, were studied by an interdisciplinary team from The University of Michigan. This work gave strong indications that water quality improvements would result from wetland processes.

Subsequently, pilot scale (100,000 gal/day) wastewater irrigation was conducted for the three years 1975-77. This system was designed, built and operated by the Wetland Ecosystem Research Group at The University of Michigan. NSF sponsored this effort, including construction costs and research costs. The pilot study results provided the basis for agency approval of the fullscale wetland discharge system.

The full scale system was designed jointly by Williams and Works, Inc. and the Wetland Ecosystem Research Group at The University of Michigan. Construction occurred during winter and spring, 1978, and the first water discharge was made in July, 1978. Compliance monitoring has been supplemented by full scale ecosystem studies, spanning 1978 to present, which have focussed on all aspects of water quality improvement and wetland response. Those studies have been sponsored by NSF, and in major part by the Houghton Lake Sewer Authority.

This wetland treatment system has functioned extremely well for nutrient removal over its sixteen year history.

Table 1. Economics

Capita (1978 Dollars)

Holding Pond Modification	$38,600
Decholorination Pond	153,200
Pond-Wetland Water Transfer	83,600
Irrigation System	112,800
Monitoring Equipment	9,700
Total	$397,900

Annual Operating Costs (1991 Dollars)

Pumping	$2,000
Monitoring	800
Maintenance	500
Research	12,000
Total	$15,300

Hydrology

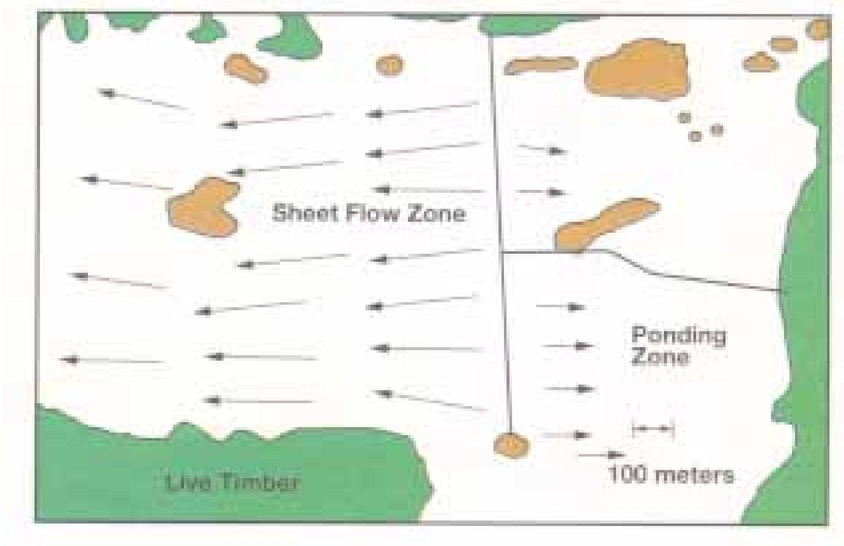


Figure 2

Water moves at about 30-100 m/d with a depth of about 20 cm.

On average, most of the water added to the wetland finds its way to the stream outflows. But in drought years, most of the water evaporates; and in wet years, rainfall creates additions to flow. During most of the drought summers of 1987 and 1988, all the pumped water evaporated in the wetland.

Water flow is strongly depth dependent, because litter and vegetation resistance is the hydrologic control. Doubling the depth causes a ten-fold increase in volume flow. Therefore, when the pump is turned on, water depths rise only an inch or two. For similar reasons, a large rainstorm does not flood the peatland to great depths.

There are no man-made outlet control structures, but both man and beaver have relocated the points of outflow, via culvert and dam placements. Inflows at E1 and E2 have ceased (see Figure 1). The point of principal stream outflow has changed from E8 to E9; and E9 has been relocated three times, twice by beaver and once by man.

The soil elevations in the discharge area were originally extremely flat, with a gentle slope (one foot per mile) toward the outlet. There has developed a significant accumulation of sediment and litter in the irrigation area, which has the effect of an increased soil elevation. This acts as a four-inch-high dam. As a consequence, the addition of wastewater along the gated irrigation pipe gives rise to a mound of water with the high zone near and upstream of the discharge pipe; in other words, there is a backgradient "pond". Depth at the discharge is not greater, but depths are greater at adjacent up and downstream locations. There is a water flow back into the backgradient pond, which compensates for evaporative losses there. But most water moves downgradient, in a gradually thinning sheet flow. (see Figure 2)

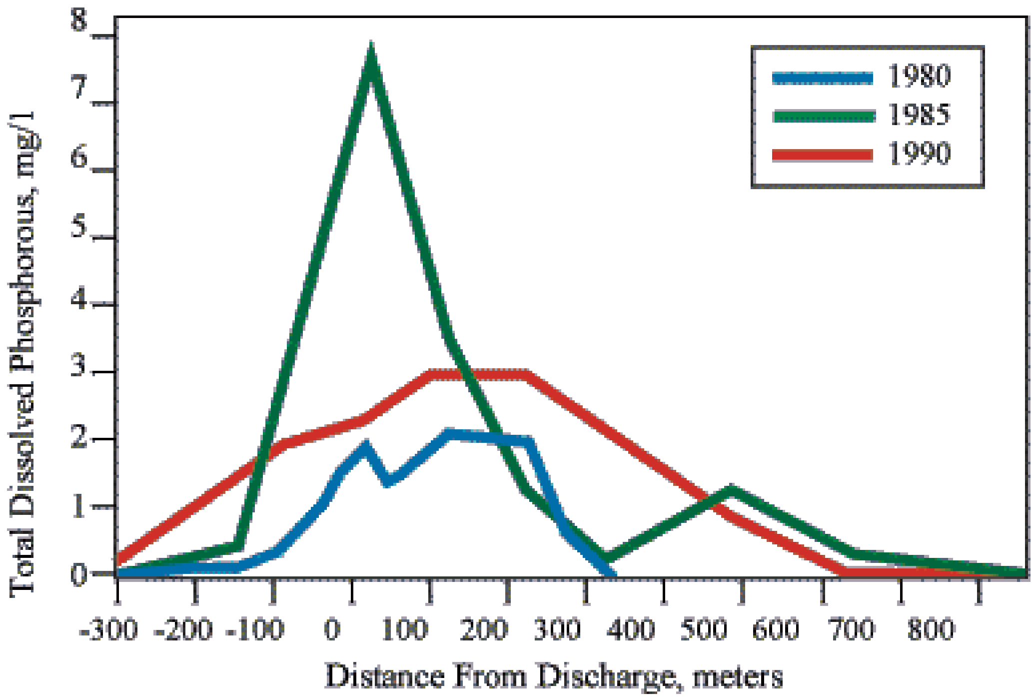
The hydroperiod of the natural wetland has been altered in the zone of discharge: dryout no longer occurs there, even under drought conditions.

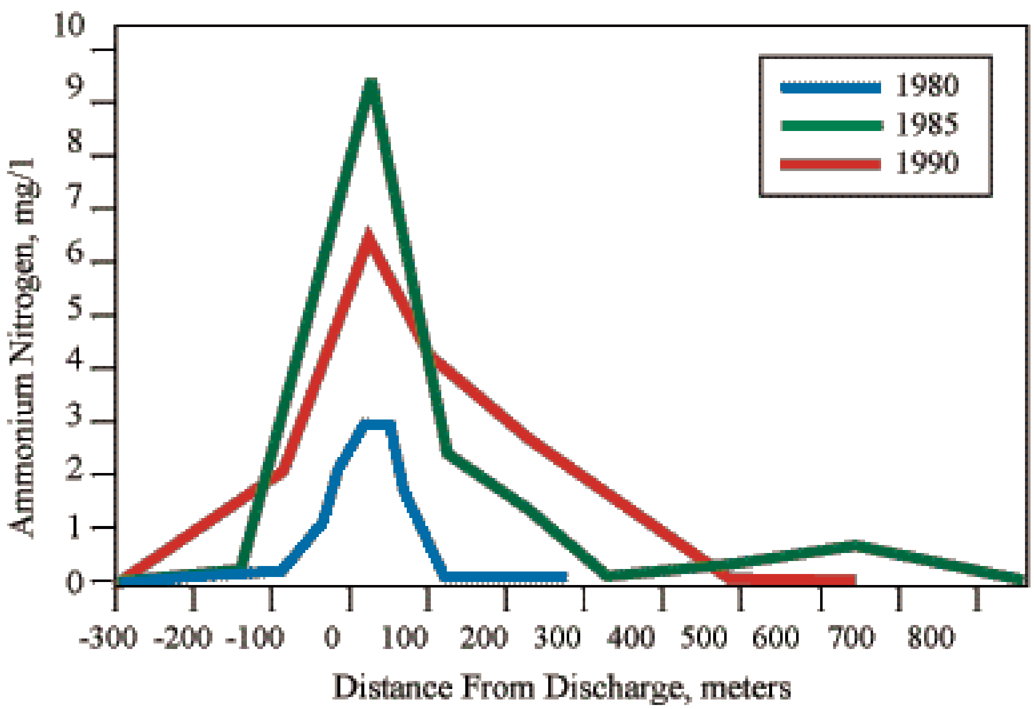
Table 2. Summary of Water Budgets.

Thousands of m3, 1.0 km2 zone. Inventory change not shown
The interval is the pumping season, typically May1-September 14.

Year	Precipitation minus Evapotranspiration	Wastewater Addition	Watershed Runoff	Outflow	Outflow Percent
1978	80	240	0	135	56
1979	-4	384	18	333	87
1980	-137	407	0	304	75
1981	99	455	30	558	123
1982	-38	404	20	386	96
1983	-110	485	132	487	100
1984	-24	546	73	602	110
1985	44	379	0	347	92
1986	-11	465	0	412	89
1987	-273	347	0	74	21
1988	-311	425	0	114	27
1989	-153	672	0	522	78
1990	-43	622	0	628	101
1991	-100	724	0	624	86
1992	-250 (est)	719	0	469	65
Averages	-82	485	18	400	80

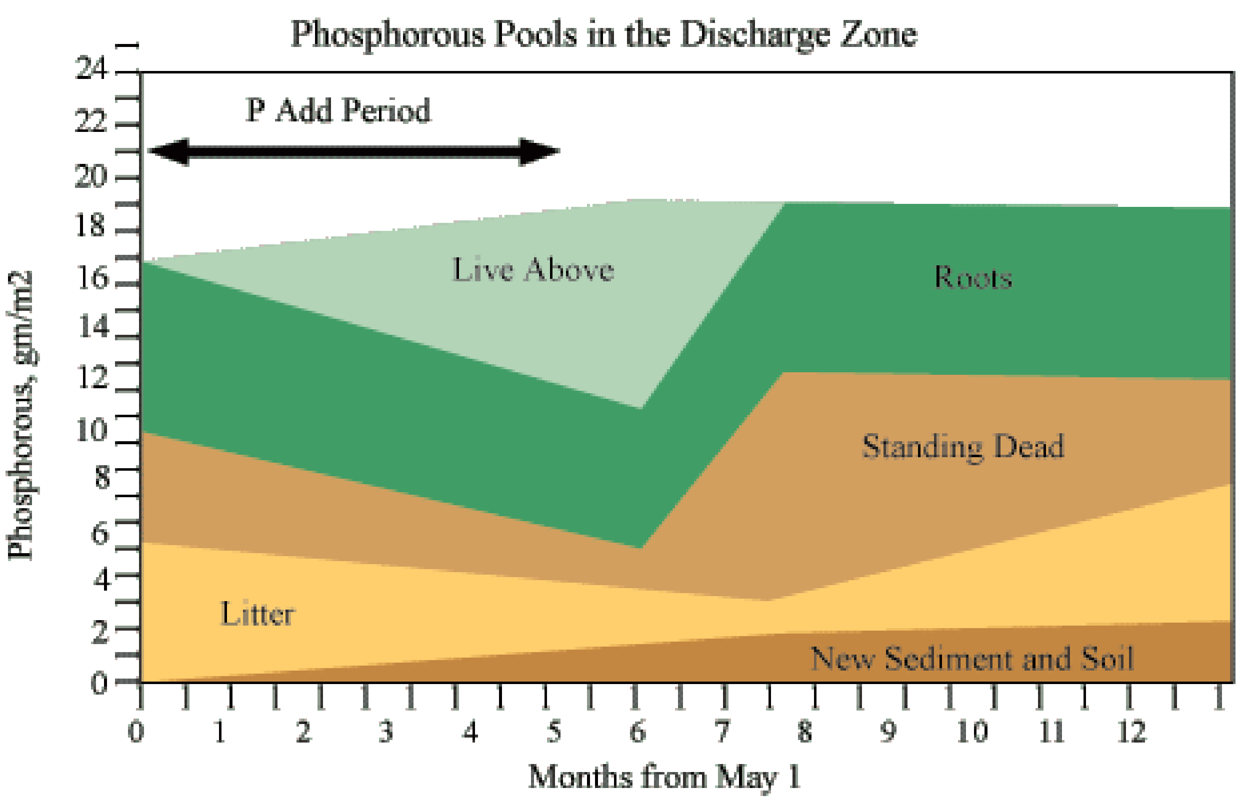
Water Quality





The phenomena interior to the irrigation zone lead to gradients in the concentrations of dissolved constituents in the direction of water flow. As the water passes through the ecosystem, both biotic and abiotic interactions occur which reduce the concentration for many species, including nitrogen, phosphorus and sulfur. Surface water samples from the wastewater irrigation area are collected and analyzed throughout the year. The changes in water chemistry as a function of distance from the discharge point are monitored by sampling along lines perpendicular to the discharge pipe, extending to distances up to 1000 meters. Such transects are made in the former sedge-willow area, along the central axis of the wetland.

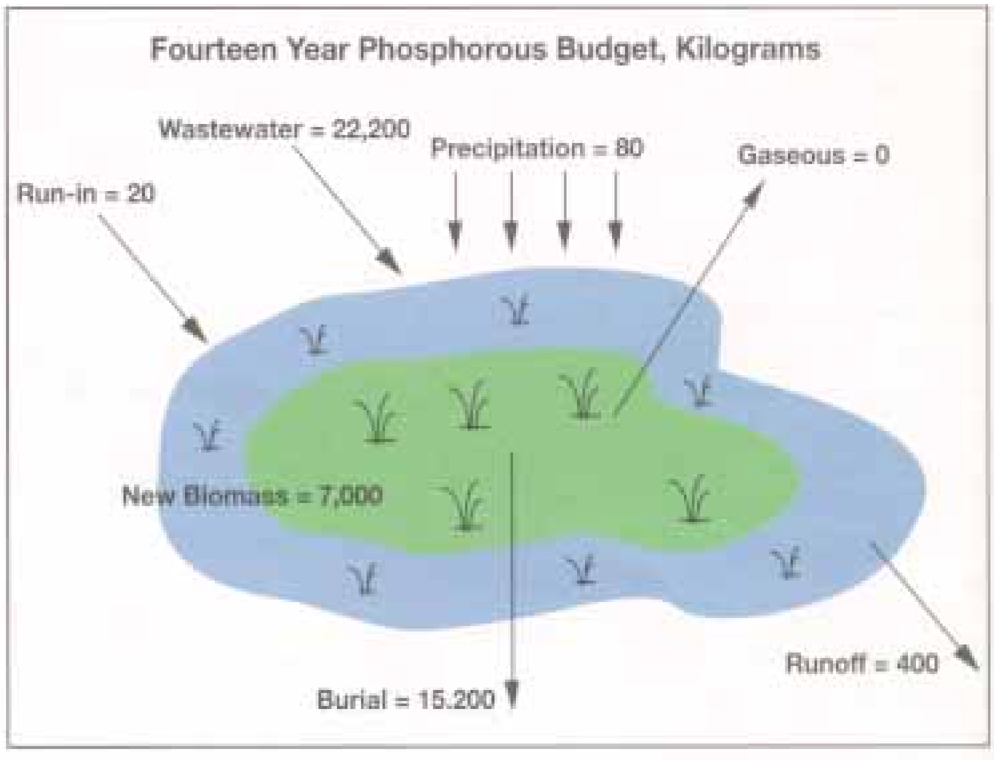
The transect concentration profiles are all similar. Water flow carries materials a greater distance in the downgradient (positive) direction than in the upgradient direction. Through the early years of operation, the zone of concentration reduction increased in size; background concentrations are now reached at distances of about 500 meters downstream of the discharge. The advance of nutrient concentration fronts during the application of wastewater is illustrated by tracking the location of phosphorus drop-off. Concentrations in excess of 1.0 mg/liter were confined to within 440 meters of the discharge point in 1990. It appears that nutrient removal processes are stabilizing.



Nitrogen species include organic, ammonium and nitrate/nitrite nitrogen. The wetland micro-organisms convert nitrate to nitrogen gas. Other bacteria convert atmospheric nitrogen to ammonium, which is in short supply; both for the natural wetland and for the fertilized zone. Large amounts are incorporated in new soils and in extra biomass.

Because the irrigation zone is imbedded in a natural wetland of larger extent, care must be taken in the definition of the size of the treatment portion of this larger wetland. A zone extending 300 meters upstream and 700 meters downstream, spanning the entire 1000 meter width of the wetland, encompasses the treatment zone with room to spare. Nutrient removal is essentially complete within this zone; some background concentrations will always be present in outflows.

The reductions in dissolved nutrient concentrations are not due to dilution, as may be seen from the water budgets. There are summers in which rainfall exceeds evapotranspiration, but on average there are evaporative losses, which would lead to concentration increases in the absence of wetland interactions.



It is possible to elucidate the mechanisms by which water-borne substances are removed in this freshwater wetland ecosystem. There are three major categories of removal processes: biomass increases, burial, and gasification. The production of increased biomass due to nutrient stimulation is a long-term temporary sink for assimilable substances. Accretion of new organic soils represents a more permanent sink for structural and sorbed components. A few species, notably nitrogen, carbon and sulfur compounds, may be released to the atmosphere, and thus are lost from the water and the wetland. Mass balance models have been constructed that adequately characterize these processes on both short and long term bases.

Some substances in the wastewater do not interact as strongly with the wetland as do nutrients. Chloride, calcium, magnesium, sodium and potassium all display elevated values in the discharge affected zone. Chloride, especially, moves freely through the wetland to the outlet streams.

Oxygen levels in the pumped water are good, approximately a 6 mg/l average. In the irrigation zone, levels are typically 1-2 mg/l in surface waters. The surrounding, unaffected wetland usually has high DO, representing conditions near saturation. The zone of depressed oxygen increased in size as the affected area increased, as indicated by the advance of an oxygen front both upgradient and downgradient. In addition, the diurnal cycle appeared to be suppressed in the irrigation zone.

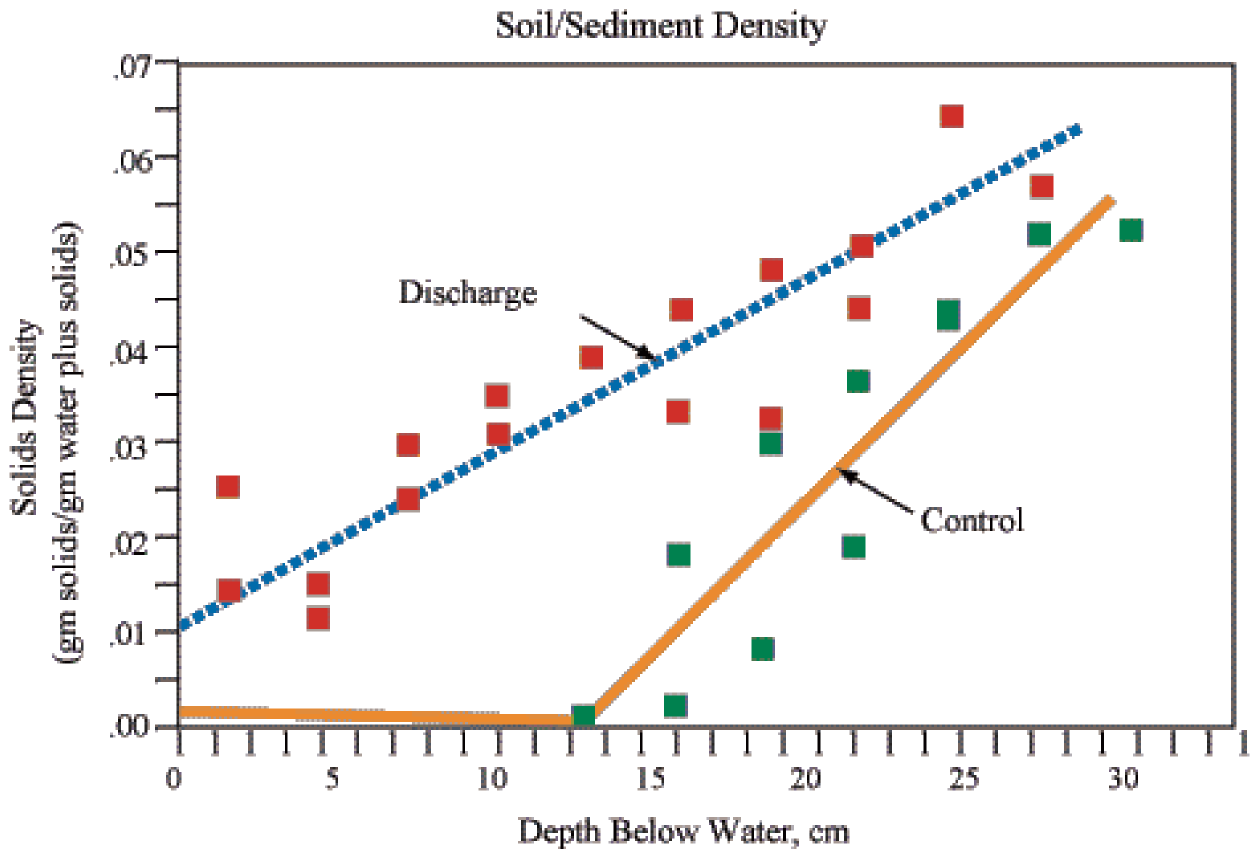
Redox potentials indicate that the sediments are anaerobic in the irrigation area, even at quite shallow depths. Steep gradients occur, leading to sulfate and nitrate reduction zones, and even to a methanogenesis zone, only a few centimeters deep into the sediments and litter.

Treatment Area and Nutrient reductions

DIN = Dissolved Inorganic Nitrogen = Nitrate plus Ammonium Nitrogen TP = Total Phosphorus.

Area, ha		**DIN,** mg/l			**TP,** mg/l		
Year		In	Out	Reduction %	In	Out	Reduction %
78	10	0.56	0.10	82	2.85	0.063	97
79	13	3.68	0.10	97	2.87	0.047	98
80	17	3.22	0.10	97	4.41	0.068	97
81	24	2.83	0.094	97	2.83	0.088	96
82	30	5.85	0.093	98	3.27	0.064	98
83	55	3.76	0.148	96	2.74	0.066	97
84	50	10.04	0.078	99	4.52	0.079	97
85	48	7.64	0.194	98	4.11	0.099	97
86	46	9.63	0.176	98	5.26	0.063	99
87	46	4.26	0.244	94	2.90	0.074	97
88	61	6.26	0.080	99	2.66	0.086	97
89	54	8.13	0.156	98	1.66	0.047	97
90	67	8.14	0.119	99	2.93	0.112	96
91	76	7.80	0.122	99	2.59	0.147	94
AVERAGES:		**5.69**	**0.129**	**96**	**3.31**	**0.074**	**97**

Soils and Sediments

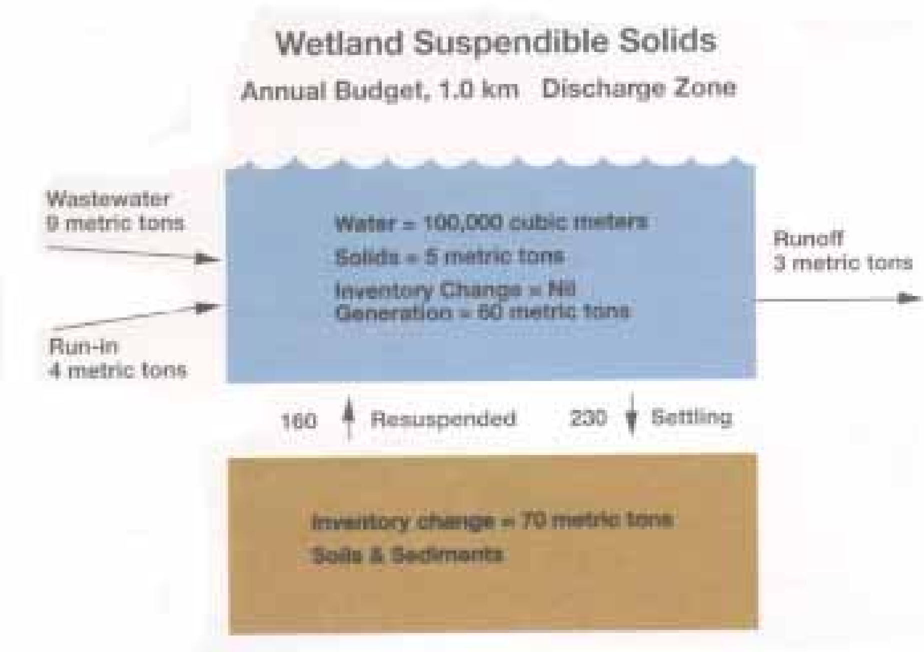


Wastewater solids are relatively small in amount and deposit near the discharge. Incoming suspended solids average about 25 mg/l, and the wetland functions at levels of about 5-10 mg/l. But internal processes in both natural and fertilized wetlands produce large amounts of detrital material, thus complicating the concept of "suspended solids removal".

Some fraction of each year's plant litter does not decompose, but becomes new organic soil. It is joined by detritus from algal and microbial populations. Such organic sediments contain significant amounts of structural components, but in addition are good sorbents for a number of dissolved constituents. The accretion of soils and sediments thus contributes to the effectiveness of the wetland for water purification. The natural wetland accreted organic soils at the rate of a two to three millimeters per year, as determined from carbon-14 and cesium-137 radiotracer techniques. The wastewater has stimulated this process to produce a net of ten millimeters per year of new organics in the discharge area. The maximum accumulation rate is located a short distance downflow from the discharge.

After more than a decade, sediment and litter accumulation total about 15

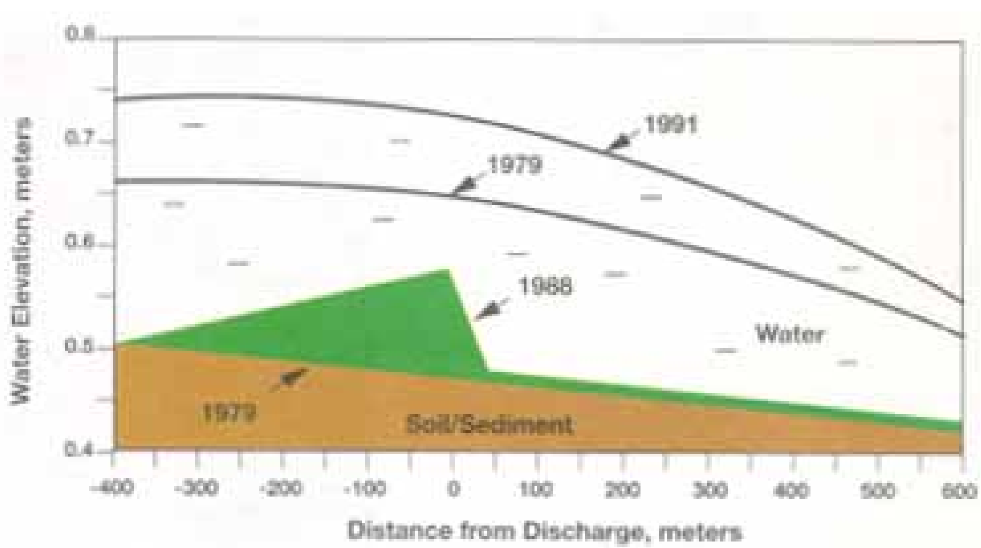
Sediment fall in the discharge area totals several millimeters per cm.



year, and this combines with wetland leaf litterfall to produce a large amount of large and small detritus. The majority of this detritus decomposes each year, but there is an undecomposable fraction. The result of continued generation and deposition of sediments, combined with the accumulation of the mineralized fraction of leaf and stem litter, is the accretion of new organic soil.

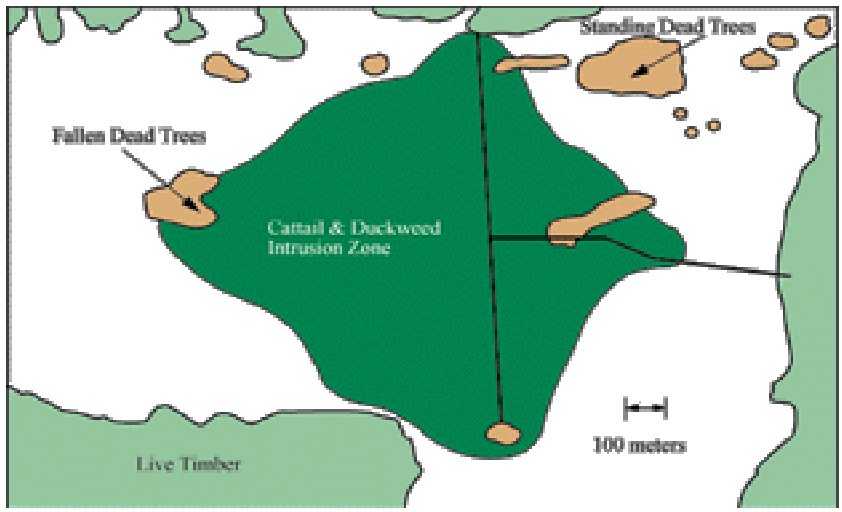
Part of the sediments are suspendible, and are transported by the flowing water. The rate of travel caused by sequential suspension and sedimentation is much slower than the rate of water flow; solids move only some tens of meters per year.

Estimated mass balances for particulate, transportable solids indicate the large internal cycle superimposed on net removal for the wetland.



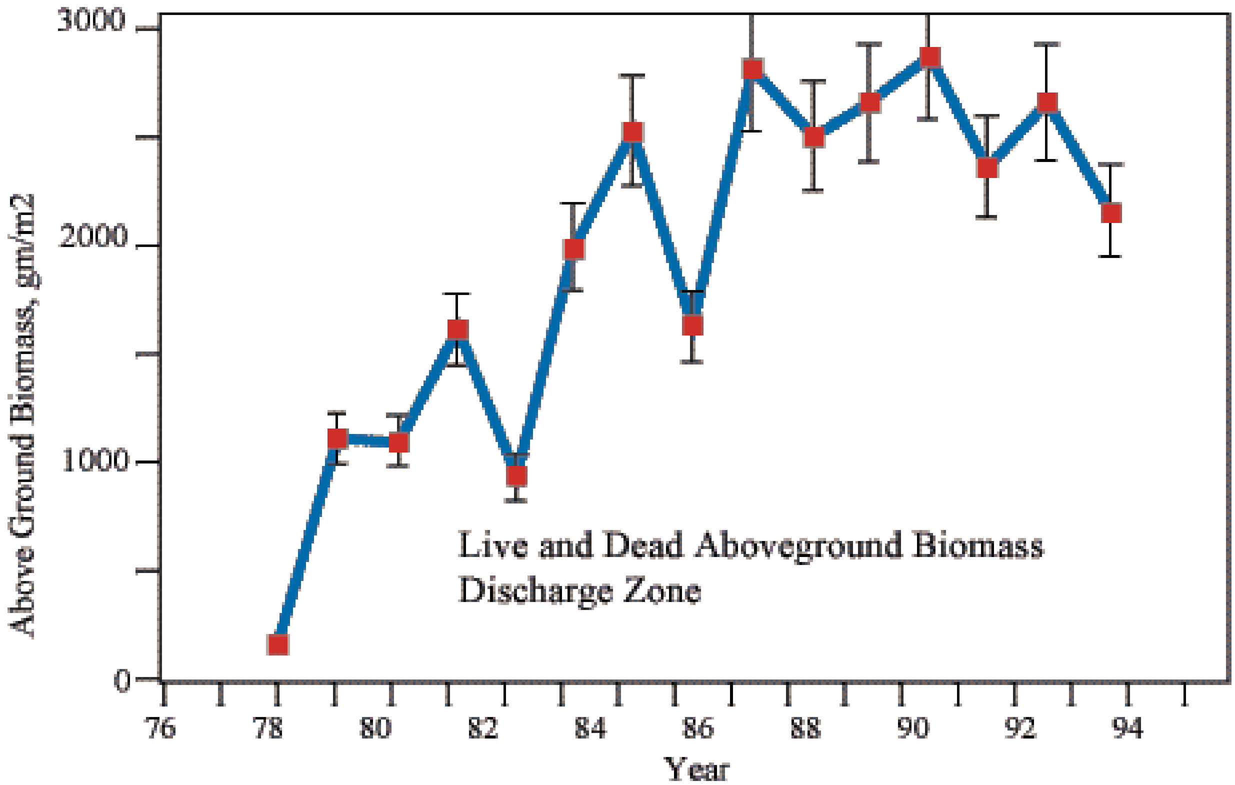
Vegetation

Many changes have occurred in the composition, abundance and standing crops of the wetland plants in the zone of nutrient removal. There are two observable manifestations of the wastewater addition: elevated nutrient concentrations in the surface waters, and alterations of the size, type and relative abundance of the aboveground vegetation. Vegetative changes occur in response to changes in hydraulic regime (depth and duration of inundation) and to changes in water nutrient status. The treatment area is taken to be the greater of these two measurable areas for each year.



When a wetland becomes the recipient of waters with higher nutrient content than those it has been experiencing, there is a response of the vegetation, both in species composition and in total biomass. The increased availability of nutrients produces more vegetation during the growing season, which in turn means more litter during the non-growing season. This litter requires several years to decay, and hence the total pool of living and dead material grows slowly over several years to a new and higher value. A significant quantity of nitrogen and phosphorus and other chemical constituents are thus retained, as part of the living and dead tissues, in the wetland. This response at the point of discharge in the Houghton Lake wetland has been slow and large. Below ground biomass responded differently from above ground biomass, however. Original vegetation required greatly reduced root biomass in the presence of added nutrients; 1500 gm/m2 versus 4000. However, the sedges initially present were replaced by cattail, which has a root biomass of 4000 gm/m2.

Approximately 65 hectares of the wetland have been affected in terms of visual vegetative change. Some plant species - leatherleaf and sedge—have been nearly all lost in the discharge area, presumably due to shading by other species and the altered water regime. Sedges in the discharge zone went through a large increase followed by a crash to extinction. Species composition within the discharge area is no longer determined by earlier vegetative patterns; cattail and duckweed have totally taken over. Cattail has extended its range out to about 600 meters along the central water track.



The cattail cover type did not exist in enough abundance (1.76% of the peatland area) to warrant study in pre-irrigation years, but was present in many locations (17% of all test plots). The early years of wastewater addition produced a variable but increasing annual peak standing crop of cattail. This change has been completed in the irrigation area, and there is no space for more plants, nor can they grow any larger.

The willows and bog birch are decreasing in numbers in the irrigation area. The fraction standing dead is low because the dead shrubs are pulled down by the falling cattail. Nonetheless, a high fraction of the standing stems are now dead. Further, the number of surviving clumps of stems is decreasing.

The aspen community near the pipeline completely succumbed in 1983. A second aspen island, located 500 meters downgradient, had also totally succumbed by 1984. The aspen on the edges of the peatland have died in backgradient and side locations where the shore slopes gradually. The alteration of the water regime has caused tree death along much of the wetland perimeter, in a band up to 50 meters wide at a few locations. Long-dead timber at these locations indicates that similar events may have occurred naturally in the past.

Public Use

The project was not designed for purposes of public use, but a set of regular users has evolved. The site serves several organizations as a field classroom. Each year, the sixth grade science classes from the Houghton Lake School pay visits—and ask the best questions. Ducks Unlimited and the Michigan United Conservation Clubs also schedule trips to the wetland. The Michigan Department of Natural Resources includes field trips to the system as part of their annual training course. And, Central Michigan University conducts a portion of its wetlands course at the site.

Many visitors, some from as far as New Zealand, come to inspect the treatment facility to learn of its performance.

The authorized operating period is set to allow deer hunting: the discharge is stopped in September to permit the wetland to "relax" from the influence of pumping. The bow-and-arrow season in October, and the rifle season in November, both find numerous hunters on and near the wetlands. Those hunters receive a questionnaire, which has demonstrated nearly unanimous acceptance of the project. The only complaint is that the boardwalk allows too easy access to the wetlands.

Duck hunting and muskrat trapping have occurred on an intermittent basis. These activities are new to this wetland, which was formerly too dry to support waterfowl and muskrats.

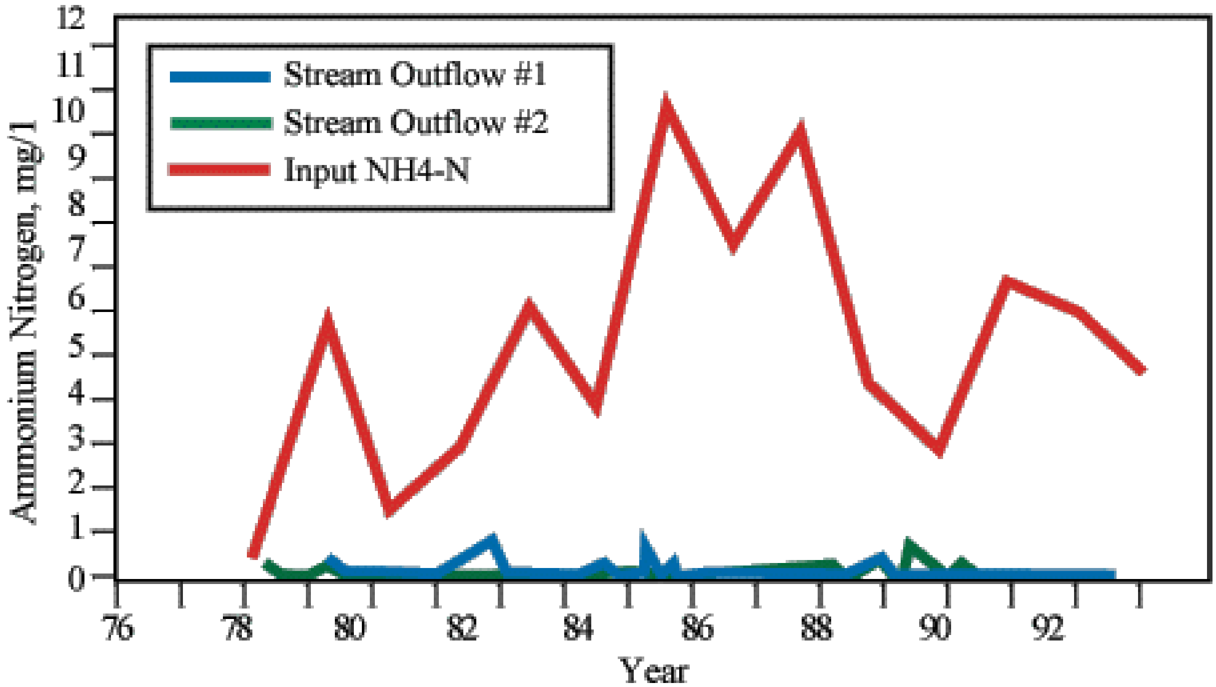
Animals

In addition to game species, coyotes, bobcats and raccoons frequent the wetland. Small mammals include a variety of mice, voles and shrews. The relative numbers have shifted with time in the discharge area; generally there are now fewer and different small mammals. The number of muskrats has increased greatly in the irrigation zone.

Bird populations have also changed. The undisturbed wetland (1973) contained 17 species, dominated by swamp sparrows, marsh wrens and yellowthroats. In 1991, the irrigation zone had 19 species, dominated by tree swallows, red wing blackbirds and swamp sparrows.

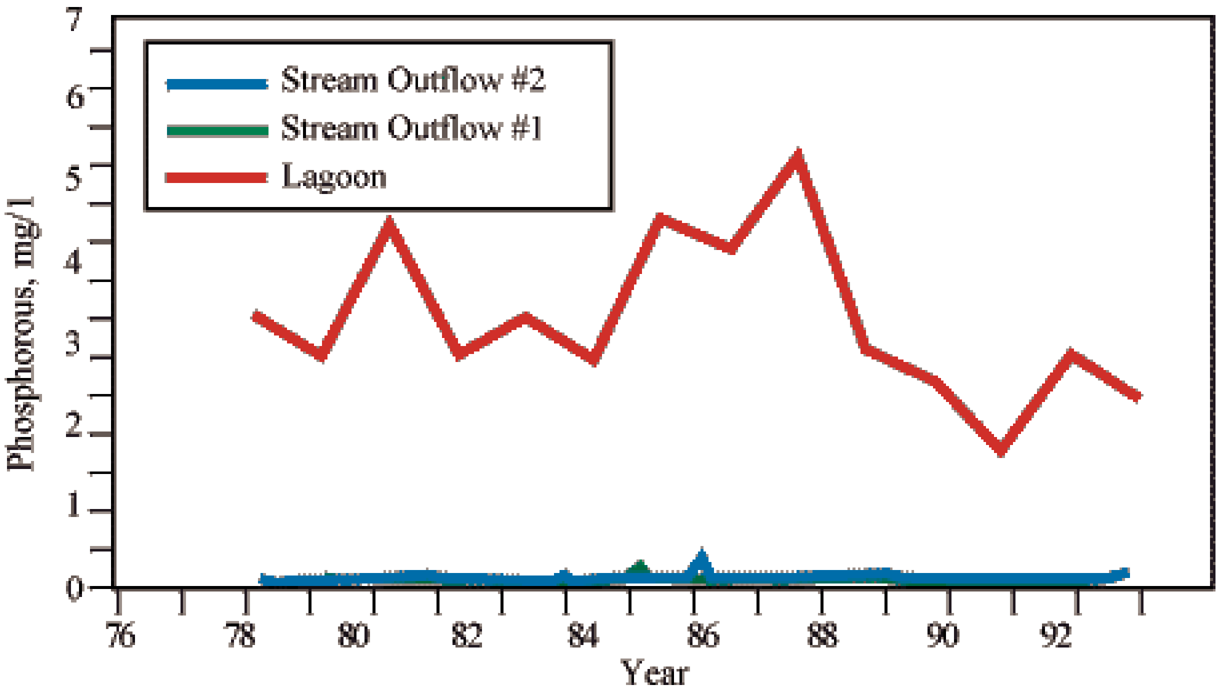
Insect species and numbers fluctuate from year to year, with no discernible pattern. In some years there are fewer mosquitoes near the discharge; in other years they are more numerous there. There are typically more midges in the discharge zone, and fewer mayflies, caddisflies and dragonflies.

Permits



The project operates under two permits: an NPDES permit for the surface water discharge, and a special use permit for the wetlands.

The Michigan Water Resources Commission issues the NPDES permit in compliance with the Federal Water Pollution Control Act. Both the irrigation fields and the wetlands are permitted. The wetlands part of the permit establishes three classes of sampling locations: the effluent from the storage or dechlorination ponds, a row of sampling stations approximately 800 meters downgradient from the discharge pipeline in the wetland (Figure 1), and steamflows exiting the wetland. Lagoon discharges are monitored weekly; interior points and stream outflows are measured monthly. Each location has its own parameter list (Table 3). The interior wetland stations are the early warning line. Background water quality was established in pre-project research. Target values are set which are the basis for assessing the water quality impacts at the interior stations.



The special use permit is issued by the Wildlife Division of the Michigan Department of Natural Resources. Under this permit, the Roscommon County Department of Public Works is granted permission to maintain a water transporting pipe across State-owned lands, maintain a wooden walkway on the peatlands to support a water distribution pipe, and to distribute secondarily treated effluent onto the peatlands. Under the terms of this permit, if circumstances arise that are detrimental to plant and animal life, the project comes under immediate review. Detrimental circumstances include detection of toxic materials, excessive levels of pathogenic organisms and excessive water depths. There has not been such an occurrence. This permit also requires monitoring of plant and animal populations, hydrology and water quality.

Water samples were collected for analysis at the points of input and output from the wetland for purposes of compliance monitoring. Water chemistry data for these inflows and outflows shows no significant increases in the nitrogen or phosphorus in the wetland waters at these exit locations.

Table3. Permit Monitoring Points and Target Values

L = Lagoon Discharge **I** = Wetland Interior **O** = Stream Outflow

Parameter	*Location*	*Background Value*	*Target Value*
Chloride	L, I, O	28 mg/l	
pH	I, O	7.0SU	8.0 SU
Ammonium Nitrogen	L, I, O	0.7 mg/l	3 mg/l
Nitrate Nitrogen	L, I, O	0.04 mg/l	0.12 mg/l
Nitrite Nitrogen	L, I, O	0.008 mg/l	0.1 mg/l
Total Phosphorus	L, O		
Total Dissolved Phospohorus	L, I, O	0.05 mg/l	0.5 mg/l
BOD5	L, O		
Suspended Solids	L		
Fecal Coliforms	L		

Operator Opinions

Mr. Brett Yardley, operator of the facility, believes "It is a great system. It has low maintenance, and is good for the community." Importantly, he feels that the regulators (Michigan DNR) are "on my side." The comments he receives are all positive.

Awards

Clean Waters Award 1974, 1985

Michigan Outdoor Writers Association

Award of Merit 1977

Michigan Consulting Engineers Council

Award for Engineering Excellence 1977

American Consulting Engineers Council

State of Michigan Sesquicentennial Award 1987

Michigan Society of Professional Engineers

People

The treatment facility is operated by:

Mr. Brett Yardley
Houghton Lake Sewer Authority
P. O. Box 8
1250 S. Harrison Road
Houghton Lake, MI 48629

Wildlife and land use considerations are coordinated by:

Mr. Rich Earle
Research/Surveys Section Head
Houghton Lake Wildlife Research Station
Box 158
Houghton Lake Heights, MI 48630

Research is conducted and archived by: Dr. Robert H. Kadlec

Wetland Ecosystem Research Group
Department of Chemical Engineering
Dow Building
The University of Michigan
Ann Arbor, MI 48109-2136

Literature

Several thousand pages of documentation exist for this project. The principal categories of documents are:

* **Annual reports.** Each operating year: compliance monitoring results; research results for vegetation, hydrology, internal water chemistry; and research results for all types of animals, insects, and invertebrates.

* **Research reports.** Background studies and pilot system performance are contained in several reports and monographs.

* **Technical papers.** Forty published papers appear in a wide variety of literature sources, and involve many authors.

* **Dissertations.** Fourteen MS and PhD theses have originated from the project.