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LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS, TOWN OF FENTON SANITARY LANDFILL, BROOME COUNTY, NEW YORK

Final Report

Prepared for

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ABSTRACT AND KEY WORDS

Municipal sanitary landfills generate leachate that New York State regulations require to be collected and treated to avoid contaminating surface water and groundwater. One option for treating leachate is to haul it to a municipal wastewater treatment facility. This option may be expensive, may require excessive energy for transportation, and may require pretreatment to protect the receiving facility's processes. An alternative is on-site treatment and discharge. Personnel from the Town of Fenton, New York; Hawk Engineering, P.C.; Cornell University; and Ithaca College designed, built, and operated a pilot constructed wetland for treating leachate at the Town of Fenton's municipal landfill. The system, consisting of two overland flow beds and two subsurface flow beds, has been effective for 18 months in reducing levels of ammonia (averaging 85% removal by volatilization and denitrification) and total iron (averaging 95% removal by precipitation and sedimentation), two key constituents of the Fenton landfill's leachate. The system effects these reductions with zero chemical and energy inputs and minimal maintenance. A third key constituent of the leachate, manganese, apparently passes through the beds with minimal removal.

This report documents and discusses the Fenton system's design and performance. Also covered are two companion laboratory experiments using Fenton landfill leachate: 1) a microcosm experiment which examined the effects of leachate pretreatment on plant growth and the effects of plants and leachate on maintenance of soil permeability and removal of chemicals from the leachate; and 2) a floating plant experiment which examined the toxicity of leachate sampled at different stages of the constructed wetland treatment process.

Key words: constructed wetland, landfill leachate, leachate treatment, *Typha glauca, Lemnaceae,* microcosms

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SUMMARY

Municipal sanitary landfills generate leachate that New York State regulations require to be collected and treated to avoid contaminating surface water and groundwater. One option for treating leachate is to haul it to a municipal wastewater treatment facility. This option may be expensive, may require excessive energy for transportation, and may require pretreatment to protect the receiving facility's processes. An alternative is on-site treatment and discharge. Personnel from the Town of Fenton, New York; Hawk Engineering, P.C.; Cornell University; and Ithaca College designed, built, and operated a pilot constructed wetland for treating leachate at the Town of Fenton's municipal landfill. The system, consisting of two overland flow beds and two subsurface flow beds, has been effective for 18 months in reducing levels of ammonia (averaging 85% removal by volatilization and denitrification) and total iron (averaging 95% removal by precipitation and sedimentation), two key constituents of the Fenton landfill's leachate. The system effects these reductions with zero chemical and energy inputs and minimal maintenance. A third key constituent of the leachate, manganese, apparently passes through the beds with minimal removal.

The New York State Energy Research and Development Authority (the Energy Authority) contracted with the Town of Fenton, who subcontracted with Hawk Engineering, P.C., Cornell University, and Ithaca College to investigate the potential of constructed wetlands to provide landfill leachate treatment or pretreatment in an energy-efficient and environmentally sound manner. The investigation consisted of the design, construction, and evaluation of a constructed wetland for treatment of landfill leachate at the Town of Fenton Sanitary Landfill in the Town of Fenton, Broome County. Additional laboratory studies were completed with the objective of developing effective ways to remove any specific leachate contaminants that were resisting removal in the landfill system.

The specific objectives of the project were:

- To develop an energy-efficient alternative to conventional landfill leachate treatment, capable of being utilized by landfills in New York State and elsewhere;

- To design and construct a leachate treatment system using constructed wetlands; and

- Through intensive monitoring, to assess the effectiveness of the effluent treatment system components in removing and degrading leachate contaminants at the Town of Fenton Landfill.

Use of constructed wetlands for treatment of landfill leachate is a relatively new idea, and very few other research sites exist. Worldwide research has been conducted, however, on use of constructed wetlands for treatment of a variety of wastewaters, ranging from domestic to industrial. The effectiveness of treatment has been shown to depend primarily on the ratio between the size of the plot and the quantity of flow. Hydraulic clogging is the most oft-cited problem, resulting in unintentional surface flow, reduced retention time, and inadequate treatment.

The leachate treatment system design at the Town of Fenton Sanitary Landfill included two methods to evaluate the effectiveness of wetland plants to treat municipal landfill leachate. The two methods used were the overland flow method and the root-zone method.

The overland flow method is a pretreatment system where the objective is to reduce high levels of dissolved iron and manganese, organic matter, ammonia-nitrogen, and benzene by oxidation, precipitation, and volatilization, and to reduce the risk of clogging in subsequent root-zone beds.

The root-zone method of wetland wastewater treatment is based on the percolation of wastewater through the soil rather than flow over the surface. Leachate contaminants are removed by aerobic decomposition, filtration, and oxidation in the area of the plant root-zones. The root structure theoretically maintains or increases soil hydraulic conductivity and supplies oxygen to soil microorganisms involved in the contaminant oxidation process.

The constructed wetland system for the Town of Fenton Sanitary Landfill was designed in 1989 and constructed in 1989 and 1990. The system became operational in October 1989. Additional planting of the cells continued in 1990 and 1991.

In general, the constructed wetland system consists of two overland flow cells with a total area of 290 m^2 and two root zone cells with a total area of 250 m^2. The beds were operated in series, with the two overland flow cells followed by the two root-zone cells. The substrate used in the two overland flow cells (beds 1 and 2) was a clayey topsoil which prevented subsurface flow and promoted surface flow. The substrate used in the root-zone cells (beds 2 and 3) was coarse No. 2 gravel (1.3 cm or 0.5 inch maximum size) to allow subsurface flow. Reed canary grass (*Phalaris arundinacea*) was planted in the overland flow beds. Cattails (*Typha glauca*) were planted in the root-zone beds. Some experimental studies were done in the laboratory using floating plants as research organisms. A 3,000-gallon double-wall steel underground storage tank was installed at the end of the system for liquid storage. The system began operation on January 1990 with leachate flowing into manhole 1, bed 1, bed 2, bed 3, and bed 4.

The water in the overland flow beds was on the order of 25 cm (10 inches) deep and it was maintained without plants for the last 1.5 years.

The major contaminants in the leachate from the Fenton landfill were inorganic nitrogen (almost entirely in the ammoniacal form), iron (probably mostly in the ferrous or reduced form), and manganese. Loading rates averaged 135 g of inorganic nitrogen per day in 0.78 m^3/day of leachate.

The objective of this project was to devise a treatment system for leachate from the Fenton landfill under the following conditions:

- There would be no pretreatment or addition of chemicals.
- There would be no pumps or mechanical devices that would require energy; the flow through the system was to be by gravity and there would be no devices for mechanical aeration.
- The beds would be planted with local plants and hence the plants would be adapted to the site; the plants would not be watered or irrigated.
- There would be no annual harvesting or replanting of vegetation.
- The beds would be relatively easy to construct, and maintenance requirements would be minimal; there would be no complicated distribution systems or flow regulators.
- No devices or constructed pools that would attract vandals, recreational users, and/or nuisance wildlife would be installed.
- The system would not generate odors or be unattractive visually.

The findings are summarized as follows:

- Experiments on the effect of leachate on floating plants (Duckweed family) showed that raw untreated leachate in concentrations of 100% or 50% either killed plants within a few days or caused a great reduction in the reproduction rate. This was also true for leachate that had been aerated over a 1-month period. Plants growing in leachate taken from beds 2, 3, and 4 reproduced at a low rate but were not killed. Morphologically, plants from bed 2 tended to be larger but thinner than normal and possessed longer than normal roots. Conversely, plants in leachate taken from bed 4 were smaller than average, had only short stumps for roots, and did not separate from each other. Experiments growing plants in various concentrations of iron and manganese indicated that these elements were not responsible for the lower growth rates seen in plants growing in leachate. With further study, these plants could prove beneficial as pollutant indicators in leachate treatment systems.

- The treatment system reduced the inorganic nitrogen concentration by 60 to 100%; the best removal was during the summer of 1991 and the poorest removal was during the period January to March 1991. The reduction in inorganic nitrogen concentration was the result of loss of inorganic nitrogen, primarily in the overland flow beds, and dilution when precipitation exceeded evaporation and transpiration losses. The most likely mechanism of loss of inorganic nitrogen was by volatilization of NH_3. The net of annual precipitation minus evaporation and transpiration was about double the input of leachate.

- The concentration of iron was reduced by the treatment system; the average concentration of iron before and after treatment was 34 and 0.63 g/m^3, respectively, in unfiltered and uncentrifuged samples. Since the solutions were above pH 7 in all beds and the oxygen concentration was more than 2 ppm in all beds, the iron in the samples from the end of the treatment system was almost certainly oxidized, and the iron that was in the samples was either part of precipitated iron compounds or was sequestered by complexes and microorganisms.

- The manganese concentration in the treatment system was not reduced except by dilution.

- There was very little if any reduction in permeability of the root-zone beds over 18 months, and there was no overland flow in any part of the root-zone beds. In a greenhouse study in boxes filled with sand and treated with leachate for 18 months, there were modest reductions in permeability but no clogging.

- The research done here cannot be extrapolated to situations in which organic contaminants (such as pesticides) are in high concentrations or where readily decomposable organics (or potential for biological oxygen consumption) are appreciably higher than in the Fenton leachate. Nothing that was done here sheds any light on removal of high concentrations of metals such as lead, cadmium, nickel, etc.

- The economic benefit associated with the leachate treatment system using constructed wetlands at the Town of Fenton Sanitary Landfill includes a cost savings of approximately $1,200 per year when capitalized construction costs and annual operation costs of the on-site system are compared to off-site hauling and treatment costs. The energy benefit of on-site treatment by constructed wetlands at the Fenton site includes the fuel savings associated with not having to transport the leachate to a treatment plant and not having to treat the leachate at a treatment plant. The environmental benefits of on-site treatment include a reduction of contaminant concentrations in the leachate and avoidance of consumption and combustion of fossil fuels that would otherwise be necessary for transporting and treating leachate at an off-site treatment plant.

- Based on the information gathered at the Fenton Sanitary Landfill and additional published data and site-specific studies, leachate treatment systems using constructed wetlands can be designed for a variety of landfill sites in various climates.

Section 1
INTRODUCTION

BACKGROUND

Municipal sanitary landfills generate leachate that New York State regulations require to be collected and treated to avoid contaminating surface water and groundwater. One option for treating leachate is to haul it to a municipal wastewater treatment facility. This option may be expensive, may require excessive energy for transportation, and may require pretreatment to protect the receiving facility's processes. An alternative is on-site treatment and discharge.

The Town of Fenton Sanitary Landfill located in the Town of Fenton, Broome County, New York, generates leachate which requires on-site treatment prior to discharge into the adjacent intermittent stream or off-site treatment at a sewage treatment facility. The leachate is generated as a result of precipitation percolating through the municipal solid waste. New York State regulations (6 NYCRR Part 360) state that leachate from a solid waste management facility must not be allowed to drain or discharge into surface water except pursuant to a State Pollutant Discharge Elimination System (SPDES) permit. A SPDES permit imposes effluent discharge standards.

Since its leachate did not meet effluent quality standards for a SPDES permit, the Town of Fenton considered three options for leachate disposal.

1. Have the leachate transported to and treated at a municipal wastewater treatment facility 23 miles from the site.

2. Build a complete on-site sewage treatment plant which would require power, continual maintenance, sludge disposal, and monitoring by a qualified operator.

3. Construct a gravity-fed, gravity-discharge wetland treatment system.

Option 3, the use of constructed wetlands for on-site treatment of the Town of Fenton Sanitary Landfill leachate was chosen. The intention was to reduce the contaminants in the leachate to a level whereby a SPDES discharge permit could be issued by New York State.

On-site treatment of leachate would avoid the energy costs associated with transportation and treatment costs of a sewage treatment plant. A gravity-fed, gravity-discharge system would result in low energy usage and low maintenance costs. In the event SPDES permit discharge limits were still exceeded, the constructed wetland system would provide leachate pretreatment required for disposal at a municipal wastewater treatment facility.

The Town of Fenton in association with Hawk Engineering, P.C., Cornell University, and Ithaca College designed, constructed, operated, and monitored the constructed wetlands for treatment of leachate at the Town of Fenton Sanitary Landfill. The project was developed in response to a New York State Energy Research and Development Authority (Energy Authority) program for Innovative Technologies for Landfill Leachate Management. The objectives of the Energy Authority program were to "facilitate the development of innovative landfill leachate treatment, pretreatment, recycling, and related technologies in an energy efficient and environmentally sound manner; to accelerate the decomposition of landfill municipal waste by the use of various recycle techniques; to increase gas production rates by accelerating refuse decomposition; to reduce contaminant concentrations in solids, soils, leachate, groundwater and gases; and to encourage the use of this technology by landfills in New York State" (Energy Authority 1986). In addition, the purpose of the program was to "facilitate the development of technologies which will remediate landfill environments which have already been impacted by addressing energy efficient, economically feasible, and environmentally sound treatment of contaminant presences in all phases" (Energy Authority 1986).

Funding for the research project was provided in part by the Energy Authority, Town of Fenton, Cornell University, and Ithaca College. The project was designed by Hawk Engineering, P.C., and constructed by the Town of Fenton. Research into water chemistry and system operation and management was provided by Cornell University. Plant growth and adaptation to chemicals were studied by Ithaca College. All project team members participated in each project phase. Hawk Engineering, P.C. provided overall project management to coordinate contractors, schedules, technical matters, and information dissemination.

The constructed wetland system was designed in 1989 and constructed in 1989 and 1990. The system became operational in October 1989. Additional planting of the cells continued in 1990 and 1991.

The leachate treatment system design included two methods to evaluate the effectiveness of wetland plants to treat municipal landfill leachate. The two methods used were the overland flow method and the root-zone method.

The overland flow method is a pretreatment system in which the objective is to reduce high levels of dissolved iron and manganese, organic matter, ammonia, and benzene by oxidation, precipitation, and volatilization.

The root-zone method of wetland wastewater treatment is based on the percolation of wastewater through the soil rather than flow over the surface. Leachate contaminants are removed by aerobic decomposition, filtration, and oxidation in the area of the plant root zones. The root structure purportedly maintains or increases soil hydraulic conductivity and supplies oxygen to soil microorganisms involved in the contaminant oxidation process.

In general, the constructed wetland system consists of two overland flow cells 30.5 meters (m) (100 feet) long by 9.1 m (30 feet) wide and two root-zone cells 30.5 m (100 feet) long and 9.1 m (30 feet) wide. The cells were operated in series, with the two overland flow cells followed by the two root-zone cells.

PROJECT OBJECTIVES

The overall project objective was to design, develop, and evaluate an energy-efficient and environmentally sound landfill leachate treatment system using constructed wetlands.

Specific objectives were to:

- Develop an energy-efficient alternative to conventional landfill leachate treatment, capable of being utilized by landfills in New York State and elsewhere.

- Design and construct a leachate treatment system using constructed wetlands.

- Assess the effectiveness of the effluent treatment system components in removing and degrading leachate contaminants at the Town of Fenton Landfill site through intensive monitoring.

- Manage loading rates and modes of operation so that recommendations about design criteria (bed size, plant materials, planting techniques, loading rates, and operation parameters) could be developed for other landfills.

- Determine permeability, permeability changes, flow rates, and flow patterns in the root-zone beds.

- Conduct research with small laboratory experimental units to develop effective ways of removing any specific constituents which resisted removal in the land system.

- Conduct a review of state-of-the-art European root-zone treatment methods as they apply to New York State conditions.

- Collaborate and coordinate with other groups in the United States, such as the Tennessee Valley Authority, which are also studying the root-zone technique in similar applications.

- Develop a public information program that would provide press releases, a 1/2 hour broadcast-quality video, a slide set, presentations to interested groups, articles for professional journals, tours of the site, and preparation of a handbook on application of the root-zone treatment to other sites.

CONTRACTOR AND SUBCONTRACTOR RELATIONSHIPS

The project was administered and executed under the following contractor and subcontractor relationships and responsibilities:

Town of Fenton - Primary Contractor

- Project sponsor responsible for contract administration.

- Highway Department responsible for the construction of the Town of Fenton Landfill Leachate Management System.

- Highway Department responsible for the day-to-day maintenance, operation, and security of the leachate management system.

Hawk Engineering, P.C. - Subcontractor to the Town of Fenton

- Project engineer, responsible for overall project management; communications with the Energy Authority; preparation of construction plans, specifications, and engineering report; preparation of submittals to New York State Department of Environmental Conservation (NYSDEC); construction coordination; preparation of record drawings; coordination of water quality analysis according to NYSDEC's requirements; and assisting in preparation of progress reports and payment requests.

- Responsible for management of field operations in conjunction with the Town of Fenton.

- Responsible for evaluating the applicability of the Town of Fenton Landfill Leachate Treatment System to other future landfills.

Cornell University - Subcontractor to the Town of Fenton

- Investigators responsible for assisting the Town in site monitoring, managing loading rates and operation methods, determining the hydraulics of the root-zone beds, conducting research on contaminant removal, collecting samples, preparing the research report, evaluating the applicability of the technology to other landfills in New York State.

- Review of the work of the European Consortium established to work on the root-zone method, and coordination with other groups in the United States, such as the Tennessee Valley Authority, and public information programs.

Ithaca College - Subcontractor to Cornell University

- Investigators responsible for collecting wetland plants, planting them in the root-zone beds, determining the most effective plants, researching plant growth and optimum loading rates, collecting samples, and preparing research findings.

PURPOSE AND SCOPE OF REPORT

The purpose of this report is to detail the activities conducted, data gathered, and conclusions drawn in fulfilling the objectives of the project. Section 2, Site Description and Landfill History, contains a history and description of the project site. Section 3, Project Description, describes the activities associated with project design criteria, design, construction, operation, and vegetation planting of the leachate treatment system. In addition, Section 3 describes the public information program developed to report project-related information (press releases, site tours, technical papers, slide shows, and videotapes, etc.) to the public. Section 4, Research Methods and Results, details the research associated with leachate treatment system operation, monitoring, management and evaluation, and other studies. Economic, energy, and environmental benefits are outlined in Section 5, Benefits of the Constructed Wetland System. Typical leachate characteristics and design, construction, and operation and monitoring recommendations for constructed wetland leachate treatment systems are included in Section 6, Applicability of Design to Other Landfills. Section 7, Glossary contains definitions of important technical terms used in the report.

APPLICABILITY OF INFORMATION FROM OTHER EUROPEAN AND UNITED STATES PROJECTS

Use of constructed wetlands for treatment of landfill leachate is a relatively new idea, and very few other research sites exist. At the First International Conference on Constructed Wetlands for Wastewater Treatment in 1988, the only papers addressing treatment of landfill leachate were those discussing the Fenton Landfill and the Landstrom Landfill, Tompkins County, New York (Trautmann et al. 1989, Staubitz et al. 1989).

At the Tompkins County landfill, four parallel root-zone beds were built for comparison of various substrates and for analysis of the role of vegetation in leachate treatment (Surface et al. 1991). Three of the beds were planted with *Phragmites australis*, and the fourth was left unplanted as a control. One bed was filled with coarse gravel (6 centimeter[cm] diameter), one with pea gravel (1 cm diameter), and the remaining two with a mixture of sand and gravel. Leachate residence time was approximately 15 days. The most effective treatment occurred during the summer in the sand/gravel beds. While phosphorus and metal removal remained consistent year-round, colder temperatures caused treatment efficiencies to drop for biochemical oxygen demand (BOD), NH_4^+, and potassium (K). Hydraulic conductivities of all substrates except the coarse gravel decreased over the study period and were not affected by the presence of the 2-year-old *Phragmites* plants.

At the International Conference on the Use of Constructed Wetlands in Water Pollution Control held in Cambridge, UK, in September 1990, one paper out of the 70 presented covered use of wetlands for treatment of landfill leachate (Birbeck et al. 1990). The paper was on work conducted in British Columbia, where six 3- x 15-m test plots were constructed using sand, crushed gravel, or 20-millimeter (mm) stone, covered with topsoil, and planted with *Typha latifora* or *Juncus effusus*. With a retention time of two days, the test plots removed an average of 6 g NH_4-N/m^2/day. Precipitation of iron hydroxide blocked flow through some of the test plots.

From all the presentations, poster sessions, and papers given at this conference, the following general conclusions were apparent:

- Wetland systems can be designed to treat almost any wastewater, with the effectiveness of the treatment dependent on the ratio between the size of the plot and the quantity of flow. In some cases, the area required makes wetland systems infeasible.

- Many systems are effective in reducing BOD to about 20 milligrams per liter (mg/l), which seems to be the generally accepted standard for wastewater discharges in European countries.

- Nitrogen (N) reduction has been variable and apparently changes with age, harvest removal, and other unknown factors. Plants do not provide as much oxygen to the root zone as some supporters of the root zone method have contended, and N removal rates consequently have been lower than expected. Nitrification and denitrification occur primarily at the air-water interfaces rather than within the root zone.

- Phosphorus (P) removal is a function of substrate composition, with removal increasing with decreasing particle size and increasing iron (Fe) content of the substrate.

- Hydraulic conductivity is the major problem in many systems. Clogging results in surface flow, reduced retention time, and inadequate treatment.

- The role of plants in constructed wetlands is debatable. Justification for plants is based on: a) filtering action of fallen vegetation, which is effective in removing particulates from surface flow, b) aesthetic reasons -- plants are attractive and perhaps help to control odors, c) vegetation helps to insulate the soil surface in winter, d) any oxygen that plants add to the root zone contributes to nitrification, and e) plant roots may help to prevent clogging and maintain hydraulic conductivity of the substrate.

At the International Symposium on Constructed Wetlands for Water Quality Improvement held in Pensacola, Florida in October 1991, several papers discussed wetland treatment of landfill leachate. The proceedings of this conference have not yet been published, but the abstracts include discussion of sites in West Virginia and Florida where constructed wetlands are being used for leachate treatment (Sanders et al. 1991; Elawad 1991; Martin and Miller 1991; Dohms 1991; Miller and Moshiri 1991).

At the Perdido Landfill in Escambia County, Florida, leachate is collected and used in composting of solid wastes. The leachate from this composting operation is channeled through a series of 14 surface-flow wetland beds. Discharge from the wetland system is returned to the composting operation or to the initial leachate collection pond rather than released to the environment. Species used in the wetland beds include *Typha*, *Phragmites*, *Scirpus*, *Juncus*, and *Eichornia*.

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Section 2

SITE DESCRIPTION AND LANDFILL HISTORY

SITE LOCATION

The Town of Fenton Sanitary Landfill is located at the east end of Spencer Road, which is accessible from Ballyhack Road, in the Town of Fenton, Broome County, as shown in figures 2-1 and 2-2. The landfill is situated on a 49.32-acre parcel of land owned by the Town of Fenton.

REGULATORY JURISDICTION

The landfill is under the jurisdiction of the NYSDEC, Region 7, Binghamton Sub-office. The landfill is subject to regulation under 6 NYCRR Part 360, Solid Waste Management Facilities; 6 NYCRR Parts 700-705, Water Quality Regulations for Surface Waters and Groundwaters; and New York State Pollutant Discharge Elimination System (SPDES) Article 17, Titles 7 and 8.

LANDFILL CONSTRUCTION, OPERATION, AND CLOSURE

The landfill site was operated for approximately 20 years as an open dump. Engineering plans and an operation manual were prepared in 1979 (Hawk Engineering, P.C., 1979) to bring the site into compliance with New York State regulations governing solid waste management facilities (6 NYCRR Part 360). An Operation Permit was issued in 1978 and expired in 1982. From 1978 to October 31, 1989, the site operated as an active sanitary landfill. On October 31, 1989, the site ceased receiving solid waste.

Wastes accepted included household waste generated within the Town of Fenton. Wastes not accepted included institutional waste, industrial process waste, volatile and flammable wastes, water and wastewater treatment plant sludges, septic tank wastes, incinerator fly ash and residues, pesticide containers, radioactive wastes, explosives, or other hazardous wastes.

The total waste area of the landfill is approximately 3.72 hectares (9.2 acres). An area of 0.85 hectares (2.1 acres) was provided with a final cover in the 1970s. An area of 2.87 hectares (7.1 acres) is covered with approximately 61 cm (24 inches) of soil cover, topsoil, and vegetation.

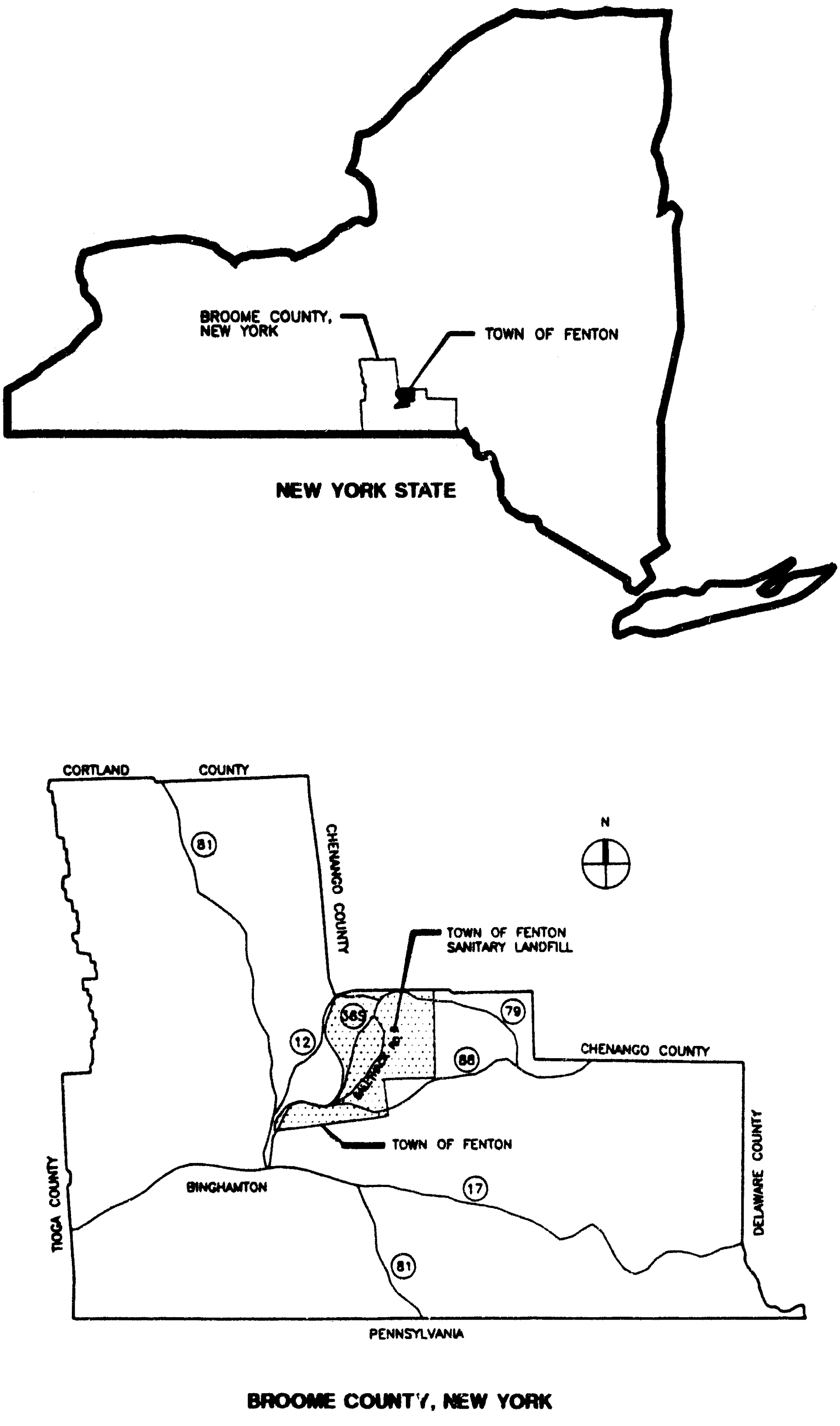
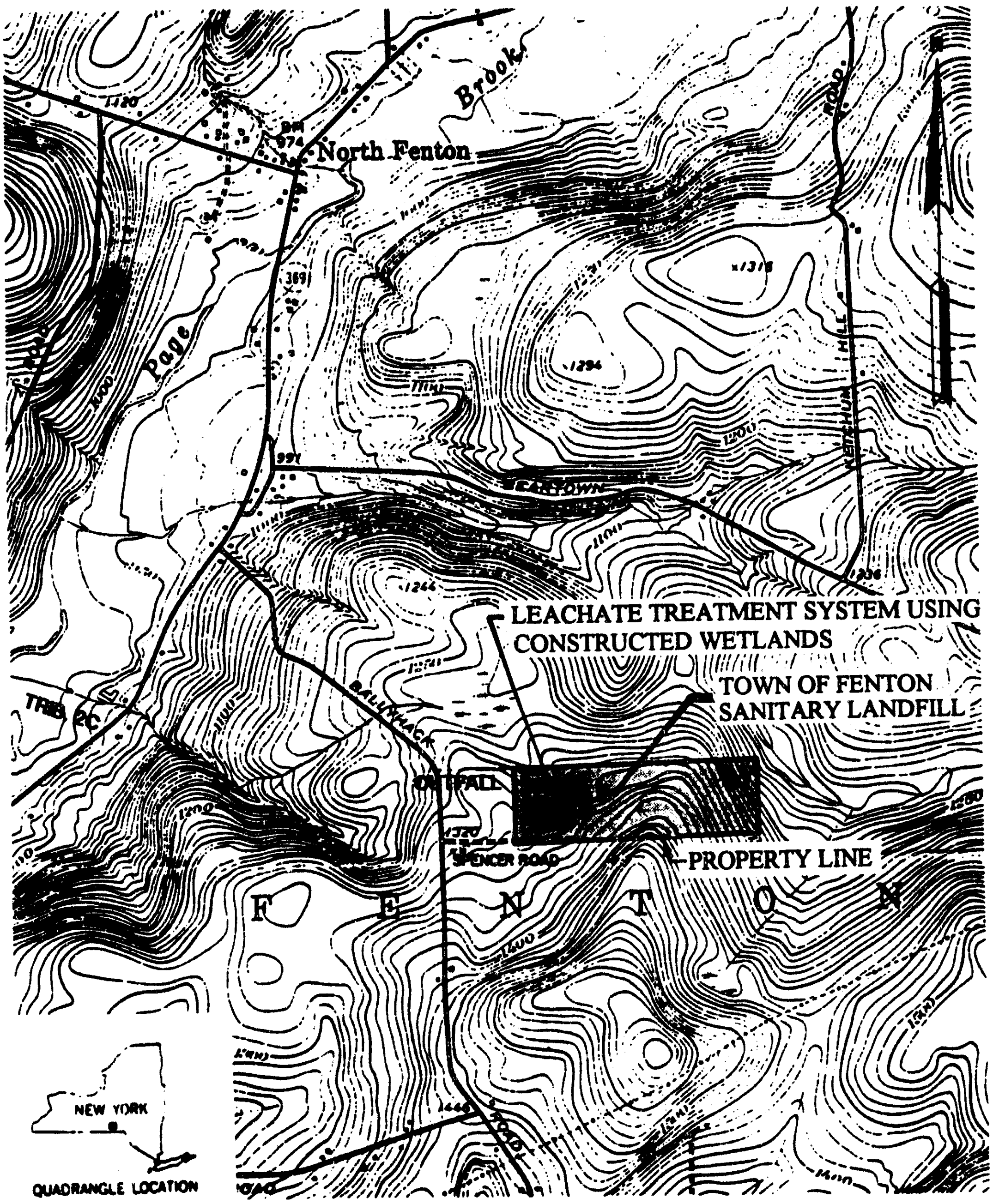


Figure 2-1. Town of Fenton Sanitary Landfill location maps.



Scale 1" = 2,000'

Source: United States Geological Survey, 1960, Chenango Forks Quadrangle, 7.5 Minute Series (Topograhphic) Scale 1"= 2,000 feet, Washington, D.C.: USGS.

Figure 2-2. Site topography.

In 1978, the Town of Fenton constructed five leachate filter ponds to control the discharge of leachate. Between each pond was a stone-filled berm covered by a geotextile which allowed leachate to flow from one pond to another but removed particulates. The geotextile filters were cleaned periodically to prevent clogging. In addition, ponds 2 through 5 were planted with cattails. The ponds were tested monthly for pH, chlorides, specific conductivity, ammonia, nitrites, nitrates, and total iron. A reduction in contaminants was achieved between pond 1 and pond 4 as indicated in Table 2-1.

Table 2-1. 1988 water quality in leachate ponds.
(mean annual values in mg/l except pH, in standard units [SU])

Parameter	Pond 1	Pond 4	Effluent Standards
Chlorides	264	232	250
Specific Conductivity	2063	1820	-
Ammonia (NH_3)	55.8	32.90	-
Nitrites (NO_2)	0.044	0.039	-
Nitrates (NO_3)	2.06	1.65	-
pH	7.07	7.35	6.5-8.5
Total Iron (Fe)	8.66	7.75	0.03

The landfill continues to generate leachate as a result of precipitation percolating through the cover and solid waste. The operation of the ponds has been discontinued. The leachate is now directed into a set of four wetland treatment cells for contaminant removal, and then discharged into an intermittent stream, an unnamed tributary of Tributary 2C of Page Brook, which discharges into the Chenango River. Pretreatment water quality is monitored quarterly. Post-treatment water quality is monitored monthly.

SITE TOPOGRAPHY AND SOILS

Before placement of any solid waste in the landfill, the site sloped downhill from the southeast to the northwest. The site now contains a mound of solid waste approximately 9 m (30 feet) high. The northwest area of the site, outside the limits of solid waste, is relatively flat and includes a wet area where cattails and other wetland plants grow.

In general, the soils on the site are classified in the Volusia Mardin Association, which are deep, somewhat poorly drained to well drained, gently sloping to very steep soils that have an impervious subsoil on uplands. Specifically, the soil is classified as Volusia Channery Silt loam, 3 to 8% slopes

(VoB), as shown in Figure 2-3. The Volusia series consists of deep, strongly acid, somewhat poorly drained loamy soils that formed in very firm, dense glacial till. The till is acidic or very low in lime. The soils are characterized by seasonal wetness and shallowness to the dense, slowly permeable fragipan (USDASCS 1971).

On-site soils were used for daily cover materials in the operation of the landfill.

SITE CLIMATE, TEMPERATURE, PRECIPITATION, AND STORMWATER DRAINAGE

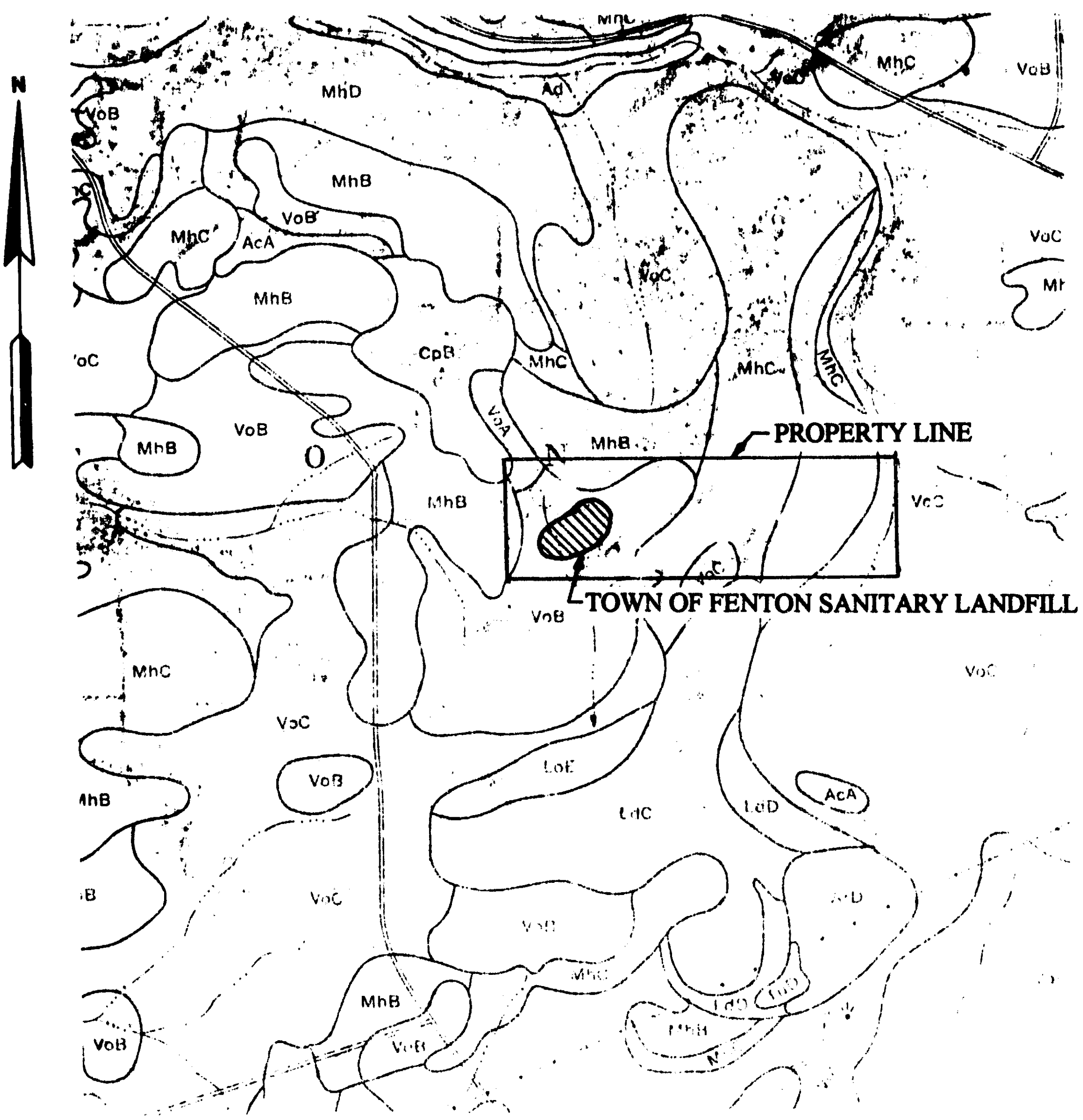
Broome County has a humid climate characteristic of continental northeast United States. Summers are pleasantly warm while winters are cold with periods of stormy weather.

Temperatures in the summer generally range from the 10°C to 31°C (50°F to 88°F). Temperatures over 32°C (90°F) occur an average of two to four days per year. Humidity varies between 60 and 90%. Winter temperatures normally range from -10°C to 5°C (13°F to 42°F). Temperatures below -17°C (0°F) can be expected approximately six to ten days per year.

The annual precipitation in Broome County ranges from 71 cm (28 inches) to 114 cm (45 inches). Monthly precipitation gradually increases from an average of nearly 6.4 cm (2.5 inches) during the winter to 9.4 cm (3.7 inches) during the summer. Winter brings approximately 178 cm (70 inches) of snow, which results in 17.8 cm (7 inches) of water on the average.

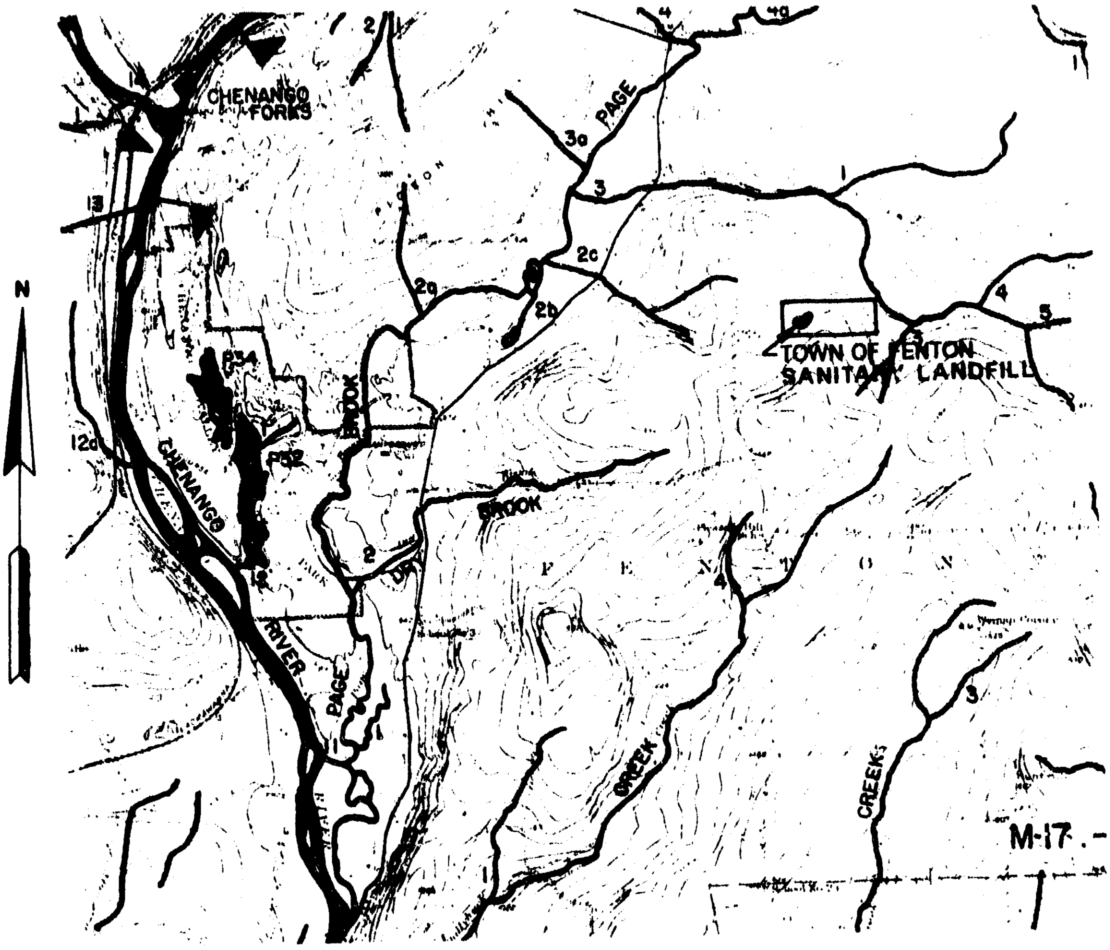
At the landfill, stormwater drainage is directed around areas of solid waste by drainage swales and is ultimately discharged into an unnamed tributary of Tributary 2C of Page Brook (6 NYCRR Part 931, 1983) as shown in Figure 2-4. In 1991, New York State revised the classifications of waterways in the Susquehanna Basin (6 NYCRR Part 931, 1991). The description of tributary 2C of Page Brook was changed as follows:

Description	1983	1991
Waters Index Number:	SR-44-11-2C	SR-44-11-2C
Character of District:	Woodland, open fields	Woodland, open fields
Condition of Waters:	Natural	Natural
Present Use:	Drainage	Drainage
Best Usage:	Drainage	Fishing
Class:	D (Drainage)	C



Source: United States Department of Agriculture Soil Conservation Service, 1971, Soil survey of Broome County, New York, Washington, D.C.: Superintendent of Documents.

Figure 2 - 3. Soils map.



SCALE 1"=1 MILE

Source: 6 NYCRR Part 931, Susquehanna River drainage basin, Albany, New York.

Figure 2-4. Drainage map.

SITE HYDROGEOLOGY

Empire Soils Investigations, Inc. completed a Hydrogeologic Investigation of the site in October 1989. This report (Empire Soils Investigations, 1989) states:

- The geology at the site consists of a thin layer (up to 11.85 feet) of undisturbed and reworked glacial till overlying weathered, laminated, medium-hard shale of the Devonian age, Sonyean Formation.

- Groundwater is found in the unconsolidated deposits and bedrock at the site. The groundwater units in the unconsolidated deposits and bedrock are hydraulically connected and appear to form a water table aquifer. The direction of groundwater flow is to the northwest, with a hydraulic gradient across the site from well W-1 to well W-4D of 0.03 ft/ft.

- The unconsolidated deposits and bedrock at the site are not classified as an aquifer. The area in which the landfill is located provides recharge to aquifers in the valleys of Page Brook and the Chenango and Susquehanna rivers.

- The hydraulic conductivity of the unconsolidated deposits is between 2×10^{-4} and 4×10^{-4} cm/sec. The hydraulic conductivity of the bedrock is between 1×10^{-5} and 3×10^{-2} cm/sec. Assuming the upper bedrock strata behaves as an aquifer of homogeneous porous media, the average linear velocity of groundwater flow is between 0.008 and 25 ft/day.

- Based on water quality analyses on samples collected from the monitoring wells, it appears that landfill leachate has affected groundwater quality. Concentrations of water quality parameters and dissolved metals were generally elevated in downgradient monitoring wells in comparison to background levels in the upgradient well. Vinyl chloride and/or dichlorofluoromethane were identified in the samples from one well.

- Surface water at the landfill has also been affected by leachate from the landfill. Based on surface water samples collected by Hawk Engineering, P.C., downstream samples exhibited elevated concentrations of water quality parameters in comparison to the upstream sample.

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Section 3
PROJECT DESCRIPTION

DESIGN CRITERIA

Wetlands as defined by the U.S. Environmental Protection Agency (USEPA) and Army Corps of Engineers are: "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (40 CFR 230.3 and 33 CFR 328.3).

Constructed wetlands can range from the "creation of a marsh in a natural setting where one did not permanently exist before to intensive construction involving earth moving, grading, impermeable barriers or erection of containers such as tanks or trenches. The vegetation that is introduced or emerges from these constructed systems will generally be similar to that found in the natural wetlands" (USEPA 1988).

Various factors were considered in formulating a design to meet the objective of providing an energy-efficient and environmentally sound constructed wetland treatment system for landfill leachate. These factors include site selection, process design, and physical design features.

Site selection factors which affect design include:

- Site selection procedures,
- Site hydrogeology, and
- Leachate quantities and flow rates.

Process design factors which are used as a basis to determine the physical design features include:

- Leachate characteristics,
- Leachate loading rates,

- Pretreatment requirements,
- Vegetation,
- Substrate, and
- Effluent standards.

Physical design features include:

- System configuration,
- Liner system,
- Inlet/outlet structures, and
- Distribution system.

LEACHATE TREATMENT SYSTEM DESIGN

The leachate treatment system design included two methods to evaluate the effectiveness of wetland plants to treat municipal landfill leachate. The two methods are the overland flow method and the root-zone method.

The overland flow method is a pretreatment system where the objective is to reduce high levels of dissolved iron and manganese, organic matter, ammonia-nitrogen, and benzene by oxidation, precipitation, and volatilization.

The root-zone method of wetland wastewater treatment is based on the percolation of wastewater through the soil rather than flow over the surface. Leachate contaminants are removed by aerobic decomposition, filtration, and oxidation in the area of the plant root zones. The root structure has been purported to maintain or increase soil hydraulic conductivity and supply oxygen to soil microorganisms involved in the contaminant oxidation process.

The leachate treatment system at the Town of Fenton Sanitary Landfill is located on the low area of the site adjacent to existing leachate filter ponds which are no longer used. Leachate from a perimeter leachate collection system is channeled into a set of four beds each approximately 30.5 m (100 feet) long by 9.1 m (30 feet) wide. Beds 1 and 2 are each lined with two 0.9-mm (36-mil) chlorosulfanated polyethyene (CSPE) geosynthetic membranes and a clay substrate, as shown in Appendix A, Construction Plans, to prevent leachate migration into groundwater. Beds 3 and 4 are each lined with three 0.9-mm (36 mil) CSPE membranes.

The beds are interconnected with a series of pipes to allow variability in directing leachate to specific beds. Beds 3 and 4 outlet into manholes which are connected to an 11.356-m^3 (3,000-gallon) holding tank. The holding tank outlets into Pond 5. In the event discharge into Pond 5 is prohibited by parameters exceeding the limits specified in the SPDES permit, the holding tank would be pumped and the treated effluent recirculated into the system or hauled to a wastewater treatment facility.

Beds 1 and 2 employ the overland flow method for pretreatment of the leachate. Reed canary grass (*Phalaris arundinacea*) is planted in a substrate of topsoil and clay in beds 1 and 2.

Effluent from beds 1 and 2 is directed into bed 3 and then bed 4. Beds 3 and 4 employ the root-zone method of treatment and are planted with cattails (*Typha glauca*) in a substrate of coarse gravel.

<u>Site Selection</u>

Siting considerations for a constructed wetland are largely dependent on the source of leachate to be treated. The site should generally be located close to the source of leachate, that is, at the landfill, to minimize transportation or pumping costs. Although a given site may not be optimum for wetland construction, engineering design, construction, and operational controls can make a poor site suitable.

Site characteristics that affect design, construction, and operation include ease of access, land area available, soils, topography, geology, hydrology, and leachate quantities.

The site chosen for the constructed wetlands leachate treatment system research project was at the Town of Fenton Sanitary Landfill located in the Town of Fenton, Broome County. To eliminate transportation costs or pumping costs, the constructed wetland system was located downgradient of the leachate outflow. Access to the site was provided by an existing landfill perimeter road. After clearing and grading, sufficient land area was available (approximately one acre) to construct and operate the wetland treatment system. Since the area was generally at an elevation lower than the rest of the landfill site, a minimum of earthwork was required to establish site grades for a gravity flow system.

A hydrologic investigation completed for the landfill site in October 1989 indicated site geology consisting of a thin layer (up to 350 cm [11.5 feet]) of undisturbed and reworked glacial till overlying weathered, laminated, medium hard shale. Groundwater was found in the unconsolidated deposits and bedrock. The groundwater units in the unconsolidated deposits and bedrock are hydraulically connected and form a water table with groundwater flowing northwest, towards the site selected for the constructed wetland treatment system. The area is not classified as an aquifer. Based on analyses of groundwater samples from six monitoring wells, it appeared that landfill leachate affected groundwater quality. Concentrations of water quality parameters were generally higher in downgradient monitoring wells than in upgradient wells. Surface water had also been affected by leachate, based on elevated concentrations of certain substances in downstream samples compared to upstream samples (Empire Soils Investigations, Inc., 1989).

Since the landfill was not constructed with a liner system, the total amount of leachate contributing to groundwater contamination cannot be collected for treatment. However, a leachate cutoff trench located around a part of the landfill perimeter collects a portion of the leachate, which can then be treated before discharge to Tributary 2C of Page Brook.

The estimated amount of leachate flowing from the perimeter collection trenches was approximately 3,785 l (1,000 gallons) per day. Flows are generally higher in fall and spring and lower in the summer. During extended dry periods, the flow stops altogether.

Process Design Factors

Process design factors which were used as a basis to determine project physical design features include leachate characteristics, effluent standards, leachate loading rates, pretreatment requirements, vegetation, substrate, and operating water depths.

Leachate Characteristics. The character of the existing leachate has been monitored monthly since 1983 for a limited number of parameters which included chlorides (Cl), specific conductivity, ammonia nitrogen (NH_3), nitrites (NO_2), nitrates (NO_3), pH, and Fe. Additional testing of leachate parameters was completed in 1986, 1989, and 1990 as shown in Appendix B, Leachate Quality Analyses. Additional leachate characteristics are tabulated in Appendix C, Field Sampling Results, along with analyses of water within the operating treatment system.

Effluent Standards. The level of leachate treatment required prior to discharge was to be identified in a SPDES permit. Since the SPDES permit was not available prior to design of the system, guidance values published by the NYSDEC (1987) were used to set treatment goals and concentration limits. A draft SPDES permit was issued by the NYSDEC in January 1992. The effluent limitations and monitoring requirements in the draft permit are summarized in Table 3-1.

Leachate Loading Rate. The leachate loading rate is the volume of leachate applied per day divided by the surface area of the wetland treatment system, expressed in liters per square meter day (l/m^2-d). The total hydraulic loading rate also includes precipitation and evapotranspiration factors in addition to the leachate loading rate. The hydraulic loading rate was not estimated in the preliminary design.

Since the perimeter cutoff trench collects only a portion of the leachate, the leachate outflow rate was used in determining the wetland treatment system leachate loading rate. Using a preliminary design flow of 3,785 l (1,000 gallons) of leachate per day and a total area of 290 m^2 for the two overland flow beds gives a leachate loading rate of 13 l/m^2-d. At 3,785 l per day, the loading rate in the two root-zone beds with a total surface area of 250 m^2 is 15 l/m^2. At a leachate flow of 1000 l/day (250 gal/day), the loading rate is 3.4 l/m^2-d and 4 l/m^2-d, respectively, for the overland flow beds and the root-zone beds.

Pretreatment and Treatment Requirements. Initially, leachate from the distribution box was directed into a small holding pond where it was allowed to aerate and settle before entering the wetland treatment system. In order to bypass the holding ponds, a pipe was installed from the distribution box to mh 1 to allow leachate to flow directly to the wetland treatment system.

Vegetation. Reed canary grass (*Phalaris arundinacea*) was proposed for the overland flow beds since it will thrive in water depths less than 10 cm (4 inches). Cattails (*Typha sp.*) were proposed for the root-zone beds because of their extensive root systems and ability to survive and thrive in water depths ranging from 15 to 25 cm (6 to 10 inches). The root-zone method of leachate treatment is based on the percolation of leachate through the substrate and around the plant root systems.

Table 3-1. Fenton Landfill Draft SPDES Permit Effluent Limitations and Monitoring Requirements

Effluent Parameter	Discharge Limitations: Daily Average	Discharge Limitations: Daily Maximum	Discharge Limitations: Units	Minimum Monitoring Requirements: Measurement Frequency	Minimum Monitoring Requirements: Sample Type
Flow	Monitor	Monitor	gpd	Monthly	Instantaneous
pH (Range)	6 -9		SU	Monthly	Grab
Oil & Grease	Na	15	mg/l	Monthly	Grab
CBOD5	Na	Monitor	mg/l	Monthly	24-hr comp.
Nitrogen, TKN (asN)	Na	Monitor	mg/l	Monthly	24-hr comp.
Nitrogen, Ammonia (as N)	Na	Monitor	mg/l	Monthly	24-hr comp.
UOD	Na	15	mg/l	Monthly	24-hr comp.
Solids, Dissolved	Na	Monitor	mg/l	Monthly	24-hr comp.
Solids, Suspended	Na	10	mg/l	Monthly	24-hr comp.
Barium	Na	1.0	mg/l	Monthly	24-hr comp.
Iron	Na	0.3	mg/l	Monthly	24-hr comp.
Manganese	Na	2.0	mg/l	Monthly	24-hr comp.
Silver	Na	0.004	mg/l	Monthly	24-hr comp.
Phenols, Total	Na	0.005	mg/l	Monthly	24-hr comp.
Benzene	Na	0.006	mg/l	Monthly	Grab
Bis (2 Ethylhexyl) Phthalate	Na	3.0	mg/l	Monthly	24-hr comp.

Note: UOD = 1.5 x CBOD5 + 4.5 x TKN

Action Level Parameters:					
Aluminum		0.25	mg/l	Quarterly	Grab
Boron		2.0	mg/l	Quarterly	Grab
Nickel		0.13	mg/l	Quarterly	Grab

Reference: New York State Department of Environmental Conservation. 1992. Draft State Pollutant Discharge Elimination System (SPDES) Discharge Permit, Town of Fenton Sanitary Landfill. NYSDEC. Syracuse, New York.

Substrate. A fairly impervious clay was chosen to be the substrate for the overland flow beds since it would allow the leachate to flow over its surface and minimize subsurface flow. A coarse gravel (No. 2 gravel, 3.8-cm [0.5 inch] size) was chosen for the root-zone beds to allow leachate to flow freely around the root systems and minimize clogging.

Physical Design Features

Physical features addressed during the design phase of the project included system configuration, liner system, inlet/outlet structures, and distribution system.

System Configuration. A system consisting of a series of long-narrow beds in a generally serpentine layout was chosen as the configuration most suitable to meet the objectives of the project as shown later in Figure 4-1 and Appendix A, Construction Plans.

Liner System. The liner system design consisted of two geomembrane layers separated by a sand leak detection layer. An additional geomembrane layer was added to the liner system for beds 3 and 4 to assure hydraulic separation from beds 1 and 2.

Inlet/Outlet Structures and Distribution System. The inlet structure consisted of a 6-inch PVC pipe embedded in a coarse stone (#2) drain area to facilitate distribution into bed 1. Piping between beds consisted of 6-inch PVC pipe perforated within the drain area for each bed. A concrete sump box is located at each end of each bed (except at the inlet structure to bed 1) for monitoring and sampling purposes.

LEACHATE TREATMENT SYSTEM CONSTRUCTION

The Town of Fenton began rough-grading the site in November 1988. Fine-grading was completed in April 1989, and construction proceeded in accordance with construction plans and specifications prepared by Hawk Engineering, P.C. (Hawk Engineering 1989a and 1989b).

The sand subbase layer, underdrain, perimeter berms, and leachate piping were installed in May 1989. The 15-cm (6-inch) gate valves designed to control leachate flow were eliminated from the project due to potential harm from freezing in winter. Caps at the ends of the leachate piping systems were installed to control flow.

The Town contracted with Palco Linings, Inc. (Palco) to furnish materials and supervise installation of a 36-mil. CSPE liner. Three liner systems were furnished by Palco and installed by the Town under the supervision of a Palco technical representative. The liners were inspected for uniformity, damage, and imperfections. All CSPE liner field seams were inspected visually and non-destructively tested by means of an air lance test. Potential leaks were patched with CSPE liner material and retested with the air lance.

The Town constructed exterior and interior berms for the beds at a height to provide 61 cm (2 feet) of freeboard between high water level and top of berm. A third CSPE liner was installed in bed 3 and bed 4 for additional protection under the root-zone system. PVC drain pipes were installed between the third liner and the primary liner. The liner systems were completed in August 1989.

A clay/topsoil substrate was installed in bed 1 and bed 2. Ithaca College began planting bed 1 and bed 2 with reed canary grass in June 1989 and began planting bed 3 and bed 4 with cattails in September 1989.

In October 1989, the Town installed the 3,000-gallon double-wall steel underground storage tank and completed the manholes and leachate piping system. The system began operation on October 4, 1989, with leachate flowing into manhole 1 (mh1), bed 1, bed 2, bed 3, and bed 4 to provide moisture for the plant root systems. The purpose of mh1 was to provide a chamber for regulating and monitoring incoming flow. The outflow pipe from bed 4 was plugged until the holding tank installation at the end of the system was completed.

On January 24, 1990, leachate was routed to the 11.356-m^3 (3,000-gallon) holding tank. In November 1990, bed 1 and bed 2 were widened to provide additional overland flow treatment area. The Town completed access road grading and placed topsoil and seed on the project area to provide a vegetative cover. Cornell University placed wooden baffles in bed 1 and bed 2 to provide additional retention time for the overland flow treatment area. Construction was substantially complete in December 1990. A Construction Documentation Report was completed by Hawk Engineering, P.C. (Hawk Engineering 1991).

PLANTING OF THE ROOT-ZONE BEDS

Overland Flow Beds

1989. The overland flow beds were completed in early summer 1989 and planting was begun in late June. Reed canary grass was planted in both beds at a density of approximately 25 shoots/m^2. The planting unit was made up of a small cluster of shoots (1-5) with attached roots and rhizomes. All shoots were trimmed to a length of approximately 1 m before planting to reduce transpiration and water stress.

The majority of the area of both beds was planted completely by July 20 and the bed levelled to reduce small mounds and depressions caused by the planting activities. This helped to prevent channeling of leachate flow through the beds. A few additional plantings were made during August because some plants had not grown. Additional leveling of the beds was performed.

The canary grass grew very well and by September 15 both overland flow beds were well vegetated. Below-ground root growth and rhizome growth was excellent, insuring the health and continued growth of the plants the following summer.

The canary grass plants stayed green and healthy until mid-November, two to three weeks longer than plants in natural marshes, and they began growth two to three weeks earlier in spring. This was probably owing to the warm temperatures of the leachate, which averages about 5°C - 8°C even in January.

1990. The plants grew very well in the spring of 1990, and in fact, grew so dense the project team decided to harvest bed 1 to compare chemical transformations in non-vegetated and vegetated beds. Harvesting was done in early July and in such a way that the tips of new shoots emerging were still above the water surface. The new shoots began growth after the harvest but within a month almost all had died; only a few scattered shoots were still alive and growing. The reason for the mortality of the shoots is unknown, but may have occurred because rainfall caused the water level to rise too high, killing the plants.

Canary grass in bed 2 grew well throughout the 1990 season. In autumn 1990, both beds 1 and 2 were flooded with leachate to a depth greater than before. This helped with retention time in the system but caused heavy mortality of canary grass over the winter.

1991. By spring 1991, only a few clumps of canary grass were left in beds 1 and 2. A few other plants, mostly cattails, had entered the beds, but most of the surface area of both beds was unvegetated.

By midsummer, these other plants had begun growth, so that by autumn a mix of open water and clumps of aquatic plants characterized the two beds. Plants invading the beds included cattails, burr reed, and sedge. In addition, some reed canary grass had survived. Thus, by autumn 1991, the overland flow beds were characterized by large areas of open water, alternating with areas of plants of different species. It appeared that the cattails were most vigorous and they may be the species to take over these first two beds.

Root-Zone Beds

1989. Construction of the root-zone beds was finished after that of the overland flow beds; thus, planting was delayed and did not begin until September. Plants were dug at the Cornell University ponds research site and shoots with attached roots and rhizomes were planted in both beds 1 and 2 during September and October.

1990. There was considerable mortality of cattails over winter, and so additional plantings were made during May and several other times throughout the rest of the year. Bed 3 became well-vegetated by the end of the year, but bed 4 still showed few plants due to heavy mortality. This bed was somewhat higher than the others, causing the water table to be somewhat low for cattail growth.

1991. Additional plantings were again made during summer 1991, so that by autumn the beds were quite well-vegetated. Bed 3 was the best established, and density of the shoots and growth of the root and rhizome systems approached that found in mature cattail stands. This bed had a mature cattail stand in 1992. In the summer, four large clumps approximately 1 x 3 m in size were planted in bed 4 and they did well. About 200 additional small clumps were also planted at that time.

Summary

In late autumn 1992, the overland flow beds had a mixture of open water areas alternating with a mixture of plants including reed canary grass, cattails, burr reed, and sedge. Some or all of these plants would continue to grow in the future, reducing the amount of open water. The cattails, burr reed, and sedge grow less densely than canary grass, however, and so much of the water surface would still be exposed to air for oxygenation.

The root-zone beds were vegetated with cattails. Bed 3 was well-developed and close to a mature system, while bed 4 would probably not be a mature system for a few years.

SYSTEM OPERATION AND MANAGEMENT

By design, a minimum operation and maintenance regime was imposed on the system. Some ambient conditions more extreme than would be encountered during normal periods were also simulated.

- There was no pretreatment of leachate or addition of chemicals.

- There were no pumps or mechanical devices that required power; the flow through the system was by gravity and there were no devices for artificial aeration.

- The influent flow volume was varied in order to determine how various loading rates and a fluctuating regime influenced the degree of treatment.

- During periods of low flow, the plants were not watered, even during the very dry summer of 1991.

- Beds 3 and 4 were planted with cattails from the adjacent wetlands; there was no attempt to grow exotic species in the gravel beds.

A few modifications were made during the course of the project.

During the winter of 1990-91, straw was used to insulate distribution boxes and other critical components. Neither the beds nor the landfill outflow froze during this mild winter. Although the beds were not operational during the winter of 1989-90, they did not freeze until the landfill froze.

The reed canary grass in the overland flow beds was harvested once in the early summer of 1990. It did not regrow and the overland flow beds were not replanted. A few emergent species had invaded by the fall of 1991.

No serious operational problems were encountered. There were minor problems with flow regulation, which was accomplished using a 16-m (52-ft) section of garden hose connected to a short section of laboratory tubing fitted with screw-type pinch clamp. Sometimes the garden hose clogged (but not at the pinch clamp).

PUBLIC INFORMATION

A public information program was implemented to report the objectives, feasibility, and progress made in establishing a constructed wetland system for treatment of landfill leachate and provide guidance in designing, constructing, and operating other systems.

Dissemination of information about the potential of constructed wetlands for treatment of landfill leachate has been facilitated by a public information video and a 35-mm slide set. The video addresses the concept of leachate treatment using constructed wetlands and includes the research at Landstrom Landfill, Tompkins County, as well as at the Fenton site. The slide set is annotated and includes photographs of the site construction and operation and visual displays research results.

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Hawk Engineering, P.C., 1989a, Construction Plans, Leachate Treatment System Using Constructed Wetlands, Town of Fenton Sanitary Landfill, Town of Fenton, New York State.

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New York State Department of Environmental Conservation, 1987, Division of Water Technical and Operational Guidance Series (1.1.1), Ambient Water Quality Standards and Guidance Values.

United States Environmental Protection Agency, 1988, Design Manual, Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment, Center for Environmental Research Information, Office of Research and Development (EPA/625/1-88/022), Cincinnati, Ohio.

Section 4
RESEARCH METHODS AND RESULTS

This section describes work by Cornell University and Ithaca College personnel in operating, monitoring, and evaluating the constructed wetland system to treat the Town of Fenton's sanitary landfill leachate. The section also summarizes two parallel laboratory experiments that used leachate from the same landfill: a soil microcosm experiment and a floating plant culture experiment. Each of these subprojects is described separately and the results are integrated in a summary section.

The project tasks at the landfill site were to:

- Establish the management policies and physically manage the day-to-day operation of the system at the landfill.
- Examine the characteristics of the wetland plants planted in the system and invading from adjacent areas.
- Monitor the composition of the landfill leachate as it moved through the system.
- Assess the effectiveness of the various components of the treatment system.
- Monitor peripheral streams.

Section 4.1 highlights key findings from the field and related laboratory work, drawing from more-detailed coverage in the rest of Section 4. Section 4.2 examines how the wetland plants developed. Section 4.3 describes how the operational results were monitored and infers the chemical, biological, and physical processes that account for the system's performance. Section 4.4 describes the soil microcosm experiment. The purpose of this subproject was similar to that of the field work: to assess the influence of aquatic macrophytes and landfill leachate on artificial wetland system permeability maintenance and inorganic pollutant removal. Section 4.5 describes the plant culture experiment. This experiment's purpose was to determine the effect of landfill leachate on certain floating aquatic plants. Section 4.6 applies the field and laboratory experiences suggests ways the treatment of the leachate from the Fenton landfill might be improved, and discusses how the data collected here can be useful in designing treatment systems for other landfills.

Figure 4-1 is a plan view of the leachate treatment system. It locates the four leachate treatment beds, indicates the path of water flow through and between the beds, and identifies the project's sampling points. Since this system is completely open to the atmosphere, precipitation adds water to the leachate as it flows through the wetland, diluting the leachate, and evaporation removes water from the system, concentrating the leachate. Thus, the constructed wetland system is "treating" a changing mixture of precipitation and landfill leachate. The following terms are used in Section 4:

- **(landfill) leachate** -- water that passes through the landfill, is collected by the landfill's leachate collection system, and is delivered to mh 1; the term also refers to that portion of the water within the treatment system which originated from mh 1, as opposed to precipitation.

- **(treatment system) influent** -- water that enters the constructed wetland system's bed 1; influent consists of essentially 100% landfill leachate; it is measured at mh 1.

- **(treatment system) effluent** -- water that flows out of the wetland system's bed 4, subsequently passing through mh 4 and finally to the holding tank.

Since most discussion in this section covers the water resident within (usually also flowing through) the four wetland beds, when there is no specific reference to leachate, influent, or effluent, the reader should assume that the resident water is being discussed. Starting out as 100% leachate at the upgradient end of bed 1, this resident water consists of a fluctuating mixture of water coming from the landfill and from precipitation.

KEY BIOLOGICAL, CHEMICAL, AND PHYSICAL FINDINGS FROM THE FIELD

Plant Development

The first two of the four beds were planted with *Phalaris arundinacea* (reed canary grass). Plants grew very well and the beds were well-vegetated by summer 1990. Bed 1 was harvested completely in July 1990; it failed to regenerate probably owing to high water conditions. Bed 2 was subsequently affected negatively by high water. The first two beds at project's end were a mixture of open water, some reed canary grass, cattails, sedge and burr reed (see Section 3.5).

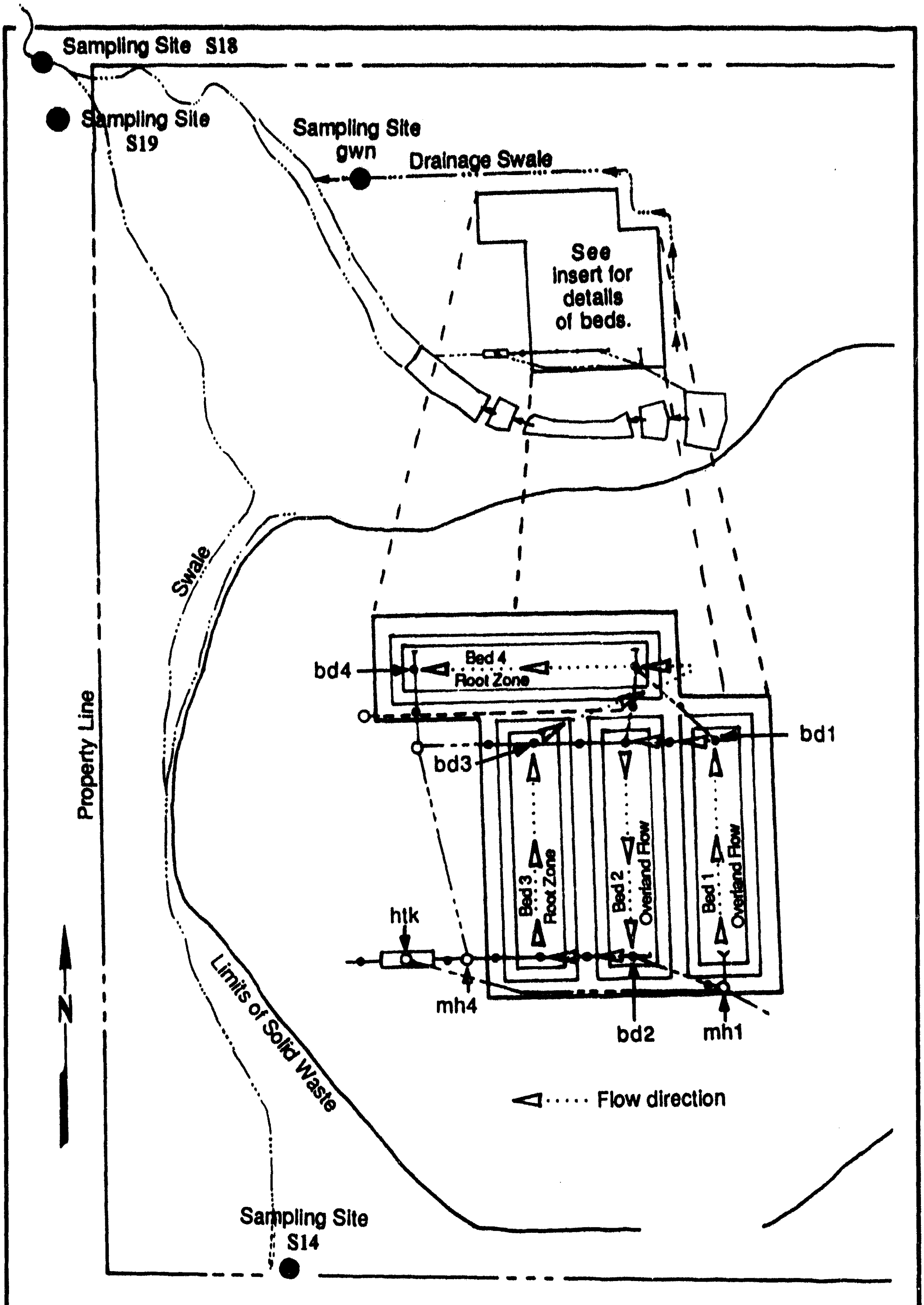

Figure 4 - 1. Physical configuration, flow patterns, and sampling locations.

Beds 3 and 4 were planted continuously from 1989-1991. Beds 3 and 4 became well-vegetated, mature cattail marsh communities in 1993.

Reed canary grass has low percentages of air space in leaf and rhizome and none in the roots, while cattails have 87% aerenchyma in leaves and 57% in roots. It appears that most of the wetland plants studied had extensive aerenchyma tissue. Further, plants that grow in deeper water have more aerenchyma than the same species growing in shallow water (see Section 4.2).

Phragmites communis reproduces extensively by underground rhizomes but it may also produce aboveground stolons. These may grow to a length of 10 m and produce new shoots along their length. Stolon formation and growth are seen as a second means of reproduction in this species.

Reed canary grass grows exceptionally well in landfill leachate, owing probably to the warm leachate temperatures and to high nutrient levels. It can be an excellent plant in constructed beds, especially those which can be harvested periodically. It probably grows too dense in beds that need oxygen supplied to the water surface.

In beds 3 and 4, the plant density, length of shoots and biomass have approached levels found in natural marshes. Their chemical contents do not differ greatly from natural wetlands; the chemical standing crop is less than that of natural sites. For example, nitrogen values are approximately 29 grams per m^2 (g/m^2) in Fenton. Other sites may have twice that amount in the biomass.

Both raw leachate and leachate filtered through all four beds had an adverse effect on floating plants in a laboratory experiment. Plants were killed by raw leachate; they survived in filtered leachate, but were smaller than average and did not separate at maturity (see Section 4.5).

Chemistry

This section summarizes some of the most important observations about the landfill leachate and changes in composition as it moves through the treatment system. See Section 4.3 for details.

Table 4-1 shows average concentrations of selected constituents in the landfill leachate where it entered the treatment system at mh 1. The results indicate that the most important of these substances that must be reduced in concentration are inorganic nitrogen and iron.

Table 4-1. Seasonally averaged composition of landfill leachate, 1989 and June 1990-November 1991. (All values in mg/l except as noted.)

	Period							
Parameter	7/89-10/89	5/90-9/90	10/90-12/90	1/91-3/91	4/91-6/91	7/91-10/91	11/91	90-91 mean
Samples*	11	17	12	13	12	18	4	
Ca	245	205	165	148	235	189	125	**184**
Mg	122	117	95	57	94	101	46	**97**
K	457	237	150	128	192	216	98	**188**
Na	458	606	392	237	360	424	198	**429**
Fe	28.2	28.9	29.8	34.0	65.3	13.1	42.1	**31.2**
Mn	4.4	2.0	1.8	1.8	2.7	1.6	1.6	**1.9**
Zn	0.17	0.23	0.20	0.27	0.30	0.09	0.30	**0.21**
Al	0.49	0.43	0.30	-	-	-	-	**0.37**
Cd	<0.01	<0.01	<0.01	-	-	-	-	**<0.01**
Cu	0.17	0.01	0.01	<0.01	<0.01	<0.01	0.01	**<0.01**
Ni	0.07	0.03	0.03	<0.01	0.07	0.05	0.03	**0.03**
Cr	<0.01	<0.01	<0.01	-	-	-	-	**<0.01**
Co	<0.01	<0.01	<0.01	-	-	-	-	**<0.01**
Pb	0.07	0.01	0.03	<0.01	<0.01	0.07	0.01	**0.02**
As	0.29	<0.02	-	-	-	-	-	**<0.02**
pH	-	7.24	7.17	7.23	7.09	7.26	7.23	**7.20**
O_2	-	1.9	2.1	3.7	2.0	2.9	5.3	**2.6**
Temp (°C)	-	20.2	10.5	3.2	17.2	18.9	6.7	**13.9**
O_2 Consum. (mg/l/day)	11.5	11.9	6.0	8.1	4.9	8.5	**8.5**	
NH_4-N	-	219	181	127	163	157	120	**169**
NO_3-N		1.8	0.7	1.2	0.9	3.8	1.3	**1.8**
Kjeldahl N	206	247	192	124	166	183	-	**195**

* Maximum number of analyses done.

All samples acidified with HCl.

Values preceded by "<" were less than the detection limit of laboratory method. The value given is the detection limit.

"-" indicates no sampling or analysis done for this parameter during the period.

Figure 4-2 shows the concentrations of inorganic nitrogen at several positions in the treatment system averaged within the same six 1990-91 intervals used in Table 4-1. From left to right, the clusters follow the flow of water through the system. The important conclusion from Figure 4-2 is that the concentration of inorganic nitrogen is reduced by about 70 to 100%, depending on season. During August and September of 1991, the reduction in inorganic nitrogen was almost 100% because there was very little inflow during this period. The highest effluent concentrations occurred during January to March 1991.

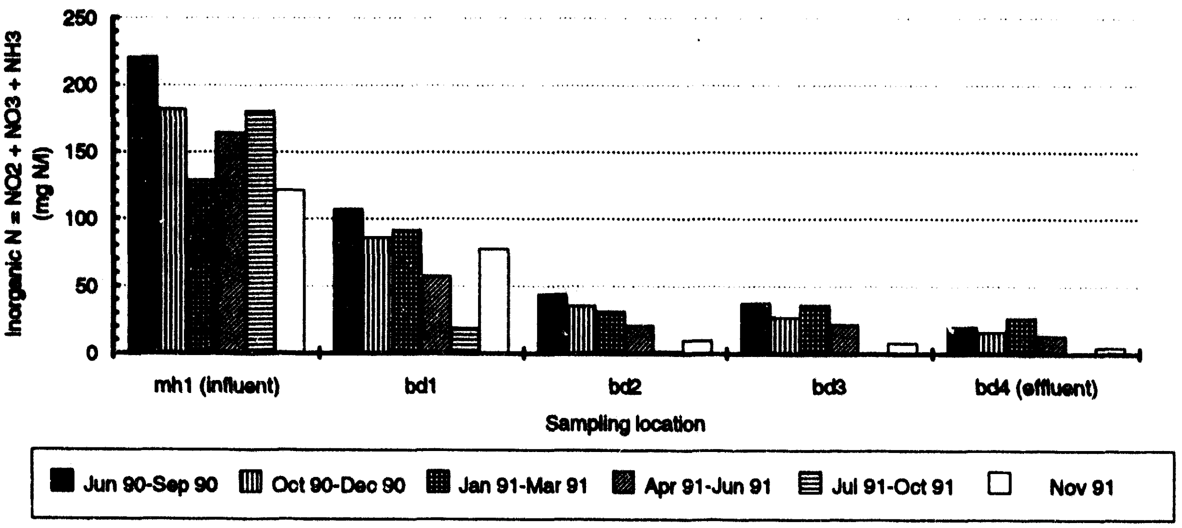

Figure 4-2. Seasonal nitrogen patterns. Note that concentrations in bd2, bd3, and bd4 are close to zero during Jul-Oct 91 due to very low flow.

Part of the reduction in concentration results from loss from the system and part is due to dilution by net precipitation. Figure 4-3 illustrates the ratio of inorganic nitrogen, iron, and calcium to potassium at the various sampling positions within the treatment system, all ratios expressed relative to their concentrations in full-strength leachate at mh 1. The potassium should be conserved in its passage through the system since it does not participate in any chemical reactions in an important way and since the loading of potassium is considerably in excess of plant uptake. Thus any change in the ratio is an indication of reaction within the treatment system. Both inorganic nitrogen and iron concentrations are reduced in each successive bed while the calcium decreases and then increases.

With regard to nitrogen, the system performed differently during different parts of the project period. Combining the approaches of Figures 4-2 and Figure 4-3, Figure 4-4 re-expresses seasonal nitrogen data similar to those in Figure 4-2 using potassium ratios, and influent-relative scaling as in Figure 4-3. Removing the effects of dilution reveals a seasonal pattern of greater inorganic N losses during warmer parts of the year, an effect consistent with the chemical and biological processes that appear to account for most of this loss, namely ammonia volatilization plus nitrification-denitrification. Dilution operates in the opposite seasonal pattern, reducing influent concentrations more during cooler periods, since there is a greater surplus of precipitation over evaporation at such times than in the warmer summer.

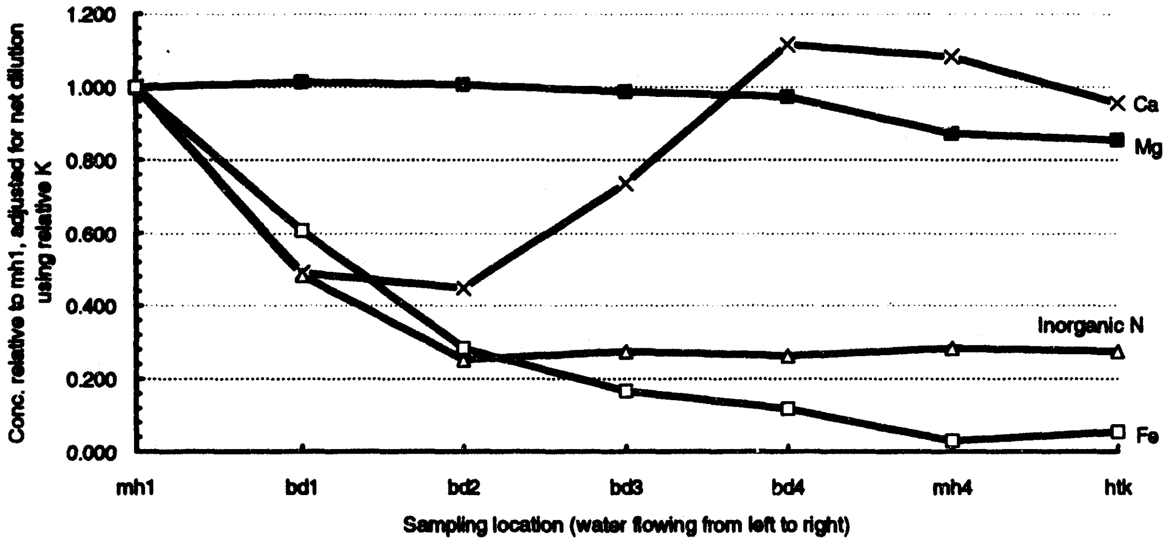

Figure 4-3. May 1990 - November 1991 average patterns of element distribution through the treatment system.

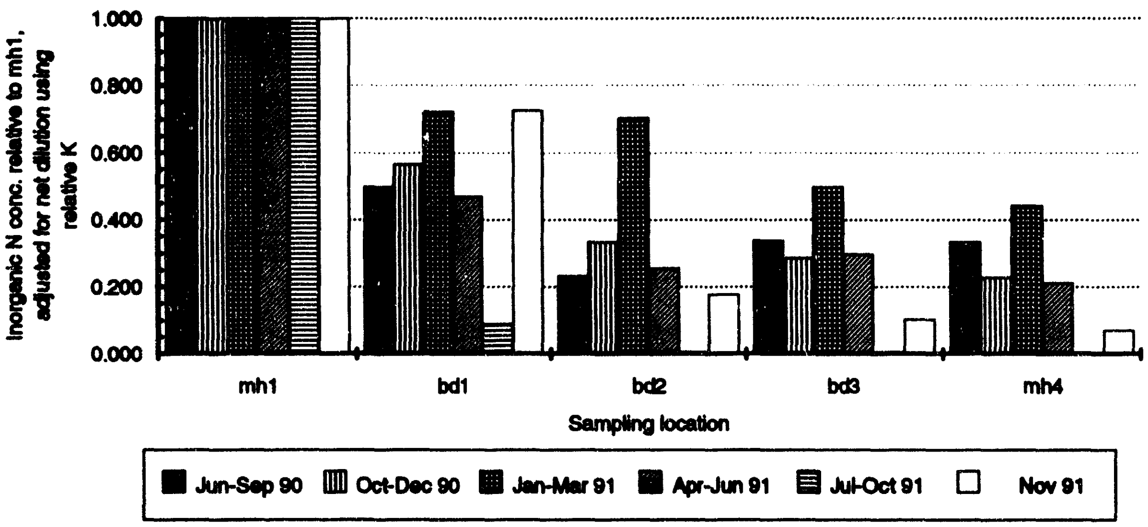

Figure 4-4. Seasonal nitrogen patterns, adjusted for net dilution using K, relative to influent. (Note zero values during Jul-Oct 91 due to near-zero flow.)

Average leachate flows were relatively stable over the project period, except that there were very low flows experienced during summer 1991, when there was essentially no effluent from the system. Precipitation and dilution were highest during October 1990 through March 1991 (Figure 4-5).

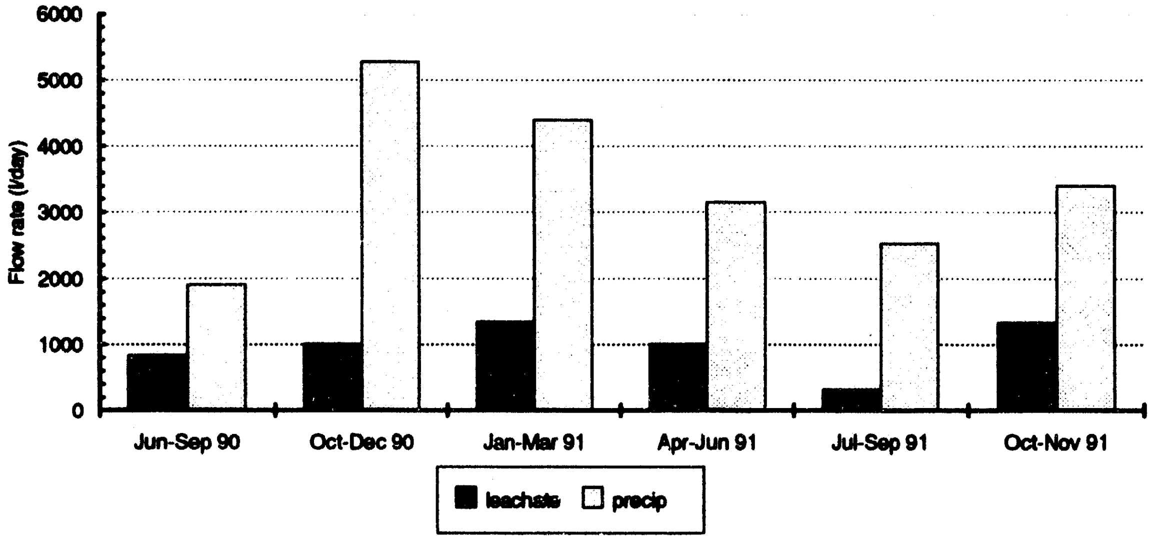

Figure 4-5. Seasonality of leachate and precipitation inflow. 1200 m. sq. (13000 ft. sq.) drainage area. Some regulation of leachate flow.

Weekly temperature, pH, dissolved oxygen, and oxygen consumption data complemented the primary chemical measurements. Figure 4-6 summarizes these by season. In this figure, a bar cluster shows the average longitudinal profile of a parameter through the system during a season.

The leachate entering bed 1 (at mh 1) was neutral to slightly acidic. By the time the water flowed through bed 1 it became slightly to moderately basic. This effect was probably due to the equilibration of carbon dioxide between the leachate and the atmosphere and the related precipitation of calcite. Water temperature patterns were most strongly influenced by air temperature. Dissolved oxygen concentrations were relatively low in the entering leachate at mh 1, but recovered rapidly in overland flow bed 1 and remained high in bed 2, as intended. Oxygen levels fell off during travel through the latter beds during all seasons. Beds 1 and 2 showed a strong seasonality in oxygen levels, the higher levels appearing during the colder periods when oxygen is more soluble and chemical and biological oxygen consumption slow.

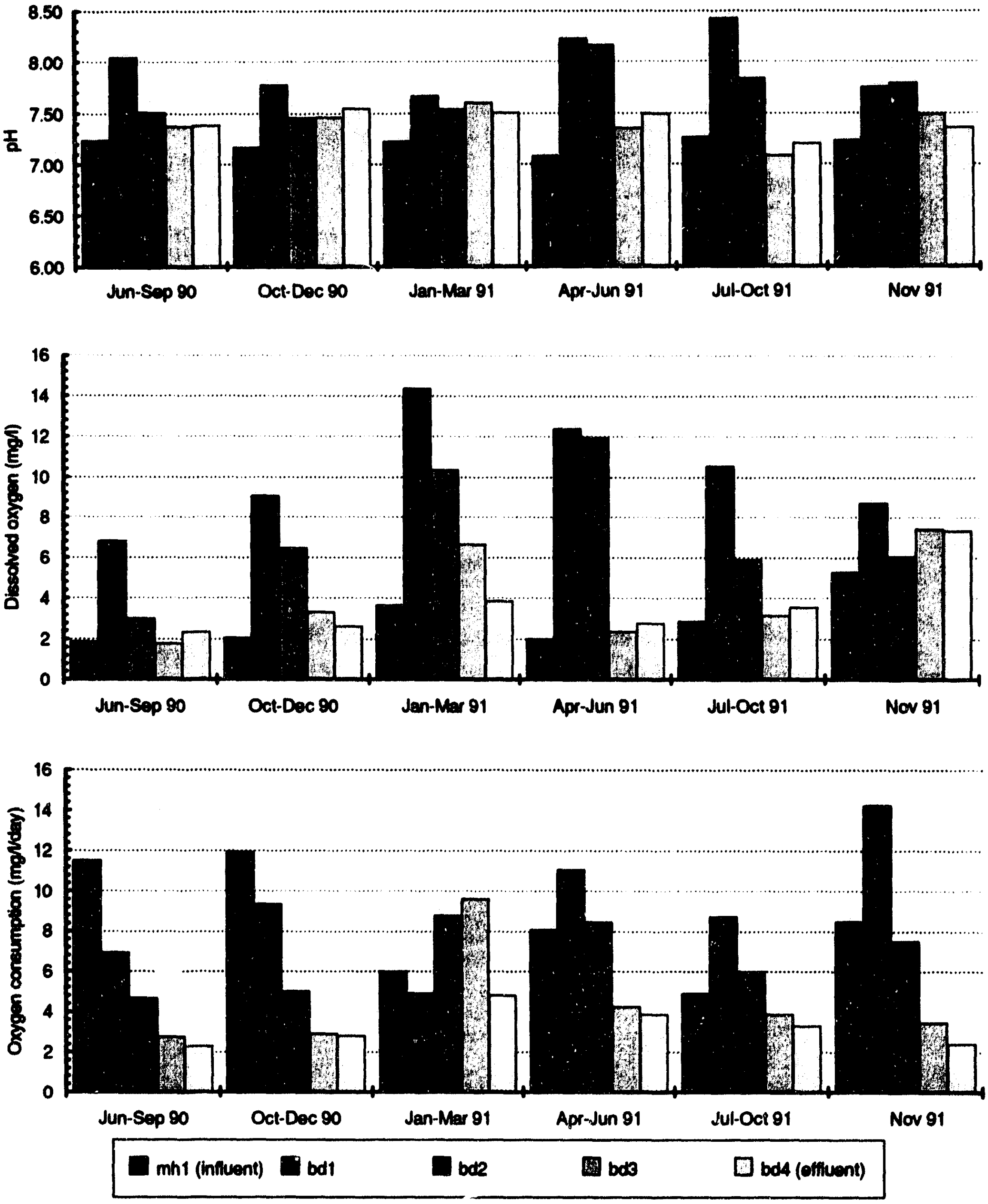

Figure 4-6. Seasonal onsite conditions.

PLANT GROWTH AND ADAPTATION TO CHEMICALS

This section reviews four facets of wetland plants in the Fenton leachate treatment system and other wetlands:

- Aerenchyma presence in several species,
- Stolon development in *Phragmites*,
- Growth, biomass accumulation, and chemical content of reed canary grass, and
- Growth, biomass accumulation, and chemical content of cattails.

Aerenchyma In Plant Tissues

Plants need oxygen for metabolism, and without it aerobic respiration cannot take place. Due to the low solubility of oxygen in water, wetland and aquatic plants have adapted a means of transporting oxygen to submerged roots, which cannot obtain a sufficient amount of oxygen from their surroundings. Monocotyledons in particular have evolved enlarged spaces in their tissues for the transport and storage of gases (Arber 1920). Oxygen diffuses from the aerial shoot to the root, supplying it with a short-term supply that may have other uses as well. For example, in addition to oxygen for metabolism, some oxygen may diffuse outside the root, oxidize the toxic reduced ions such as ferrous iron, manganous ions, and sulfide present there, and cause them to accumulate and form a plaque on the surface of the roots (Crowder and Macfie 1986; Taylor et al. 1984). These deposits may prevent the plant from taking up too many elements which could become toxic. Lastly, increased root diameter due to the formation of aerenchyma tissue may increase the root surface area, leading to greater absorption capacity (Crawford 1983).

One of the purposes of this study was to examine the anatomy of four species of wetland plants, *Phalaris arundinacea* (reed canary grass), *Typha angustifolia* (cattail), *Sparganium eurycarpum* (burr reed) and *Carex lacustris* (sedge) to determine the presence of aerenchyma tissues in shoots, roots, and rhizomes. It was hypothesized that, as water depth increased, the percent volume of aerenchyma would increase.

Methods. The plants were harvested from Michigan Hollow and South Hill sites, both near Ithaca, New York. The plants harvested were average, healthy representatives of the site. Freehand cross sections of the shoot, leaf, root, and rhizome were made. They were treated with a solution of 1%

phloroglucinol and 25% hydrochloric acid to stain the tissues. Scale drawings were made of each of the sections under 10x magnification. The drawings were transferred to 2-mm ruled graph paper and the percent area attributed to aerenchyma calculated. Areas of spongy or very fine, netlike cells were treated as areas of open space.

Results. Table 4-2 gives percentages of aerenchyma in five species of wetland plants. The species are arranged in general order from *Phalaris*, the species characteristic of the driest sites, to *Carex* in intermediate sites, then to *Phragmites*, *Sparganium*, and *Typha*, all characteristic of deeper water sites.

Table 4-2. Percentage of aerenchyma tissue in different organs of five wetland macrophytes.

Species	Stem	Leaf	Root	Rhizome
Phalaris arundinacea	57	21	0	16
Phragmites communis	49	26	62	45
Carex lacustris	43	34	41	
Sparganium eurycarpum	90	50	Sp.*	
Typha angustifolia	87	52	Sp.	

* Sp. indicates the tissue was spongy rather than having discrete air spaces.

The two grasses, *Phalaris* and *Phragmites*, were similar in their distribution of aerenchyma but did differ in degree of air space present. *Phalaris*, in common with grasses, exhibits a hollow stem but otherwise does not have extensive aerenchyma tissue. Rhizomes and leaves have about 20% aerenchyma, and roots lack it entirely. The other grass, *Phragmites*, also had a hollow stem but had considerable amounts of aerenchyma in other tissues, ranging from approximately 30% in leaves to 60% in the roots.

Figure 4-7 illustrates the type and distribution of aerenchyma in *Phalaris*. Note that the stem, though hollow, has cells at the nodes. These are very spongy in appearance and probably do not inhibit the movement of air to a large extent. *Phragmites* (Figure 4-8) is very similar to *Phalaris* in stem, leaf, and rhizome appearance. The major difference is the amount of aerenchyma in the roots, *Phragmites* having a well-developed system.

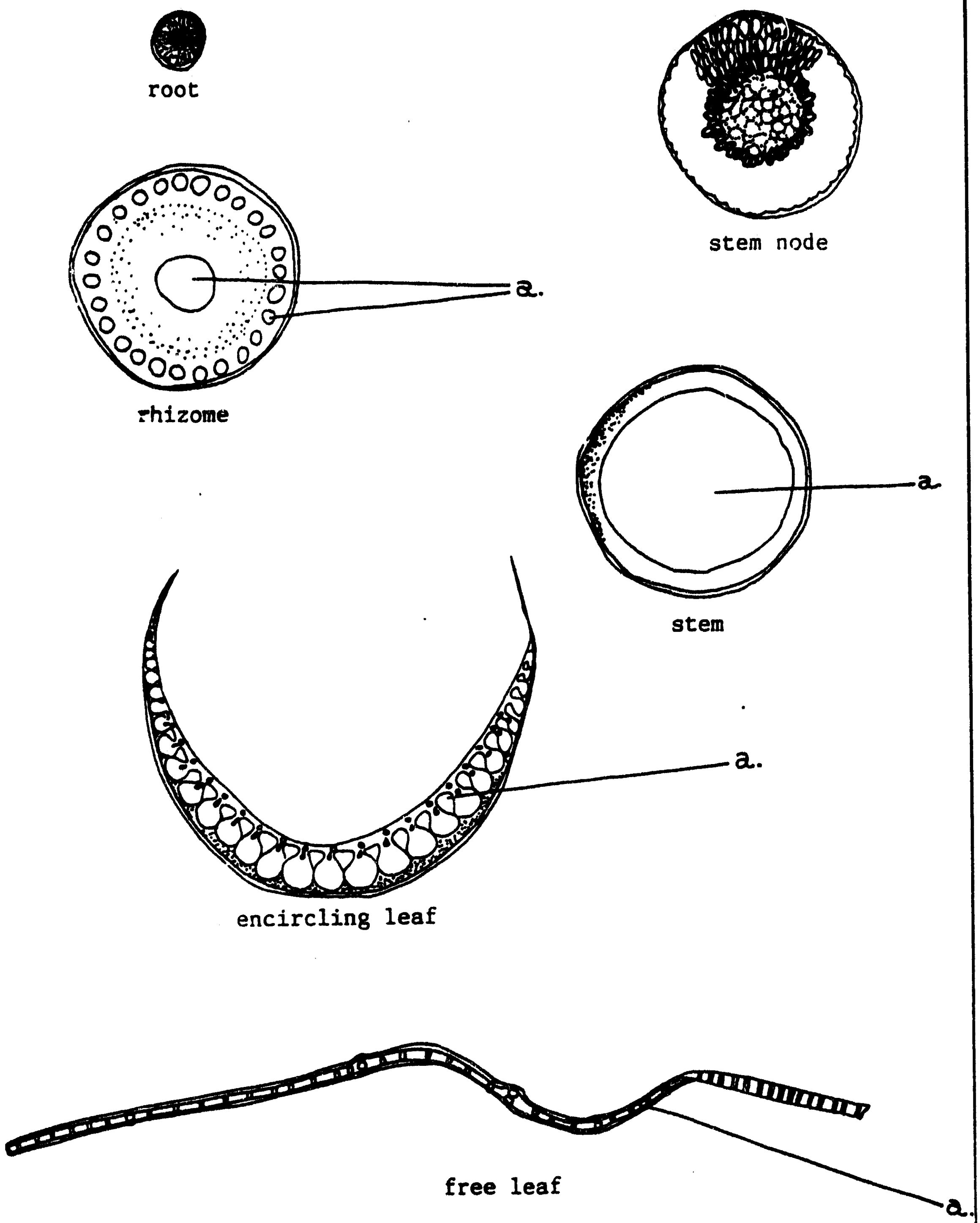

Figure 4 - 7. Cross sections of tissues of *Phalaris arundinacea*. The "a" refers to air spaces.

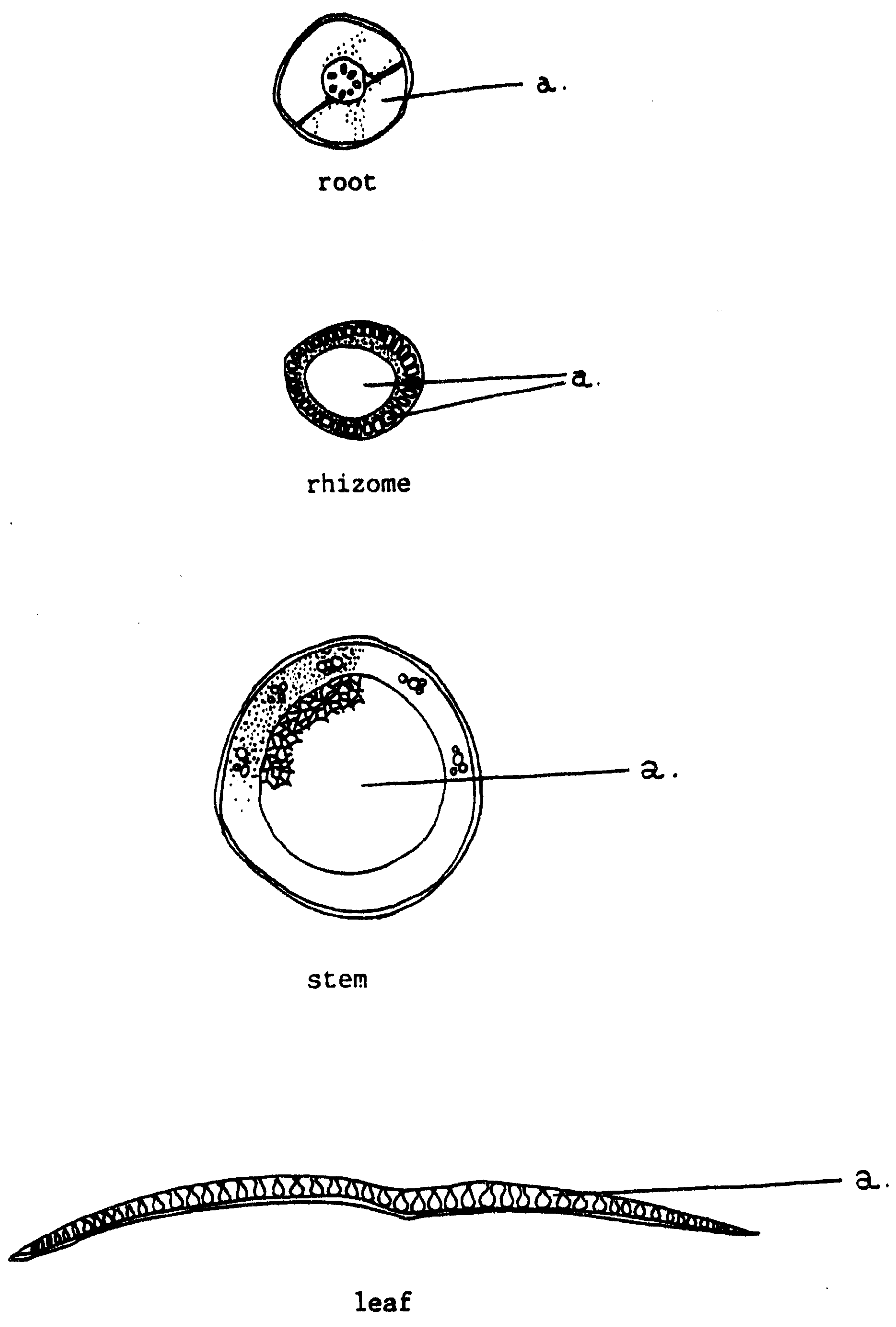

Figure 4 - 8. Cross sections of tissues of *Phragmites communis*. The "a" refers to air spaces.

Carex lacustris is intermediate between the drier-site *Phalaris* plants and the other wet-site species (Table 4-2). The different parts of the plant do not vary widely, all averaging about 35-45% aerenchyma. The illustration (Figure 4-9) shows this distribution clearly; note especially the large amount of aerenchyma in the rhizome, located just inside the epidermis.

Sparganium and *Typha* both have extensive aerenchyma tissue, almost all parts having over 50% (Table 4-2). The rhizomes are the exception because they have no discrete air channels. Rather, the cortex is very spongy in appearance. Such tissue may not slow diffusion of gases to any extent. Anatomically, the two species are similar to each other (Figures 4-10, 4-11). Both have large, somewhat spongy leaves with large aerenchyma spaces with spongy areas at the nodes. Roots are also similar to each other, as are the rhizomes. The spongy tissue of the rhizomes looks similar in both species.

Table 4-3 presents both above- and below-ground information on aerenchyma tissues in *Phalaris* and *Typha* when roots and rhizomes were grown in experimental anoxic conditions. All parts of *Phalaris* had about 40% aerenchyma, except the stem bases, which had 60%. In *Typha*, values varied from a low of 56% in roots and leaf bases to 75% in the leaf tips. Rhizomes were spongy and it was not possible to determine a value for open air spaces.

Table 4-3. Percentage of aerenchyma tissue in *Phalaris arundinacea* and *Typha angustifolia* grown under experimental anoxic conditions.

Tissue	*Phalaris*	*Phragmites*
Root	41	56
Rhizome	42	Sp.*
Leaves	39	65
Stem Base	60	Sp.

* Sp. refers to spongy tissue rather than true aerenchyma tissue.

Discussion. *Phalaris* shows the least amount of aerenchyma of any of the plants sampled. This species typically grows at the edges of wetlands and in wet meadows where the soils may dry during summer; extensive aerenchyma is probably not necessary for oxygen to diffuse to the roots. It is probably very significant that the *Phalaris* grown in anoxic nutrient solution in the laboratory (Table 4-3) developed extensive air spaces. This suggests (as Armstrong 1967 indicate) the possibility of considerable variation in species depending on soil water conditions.

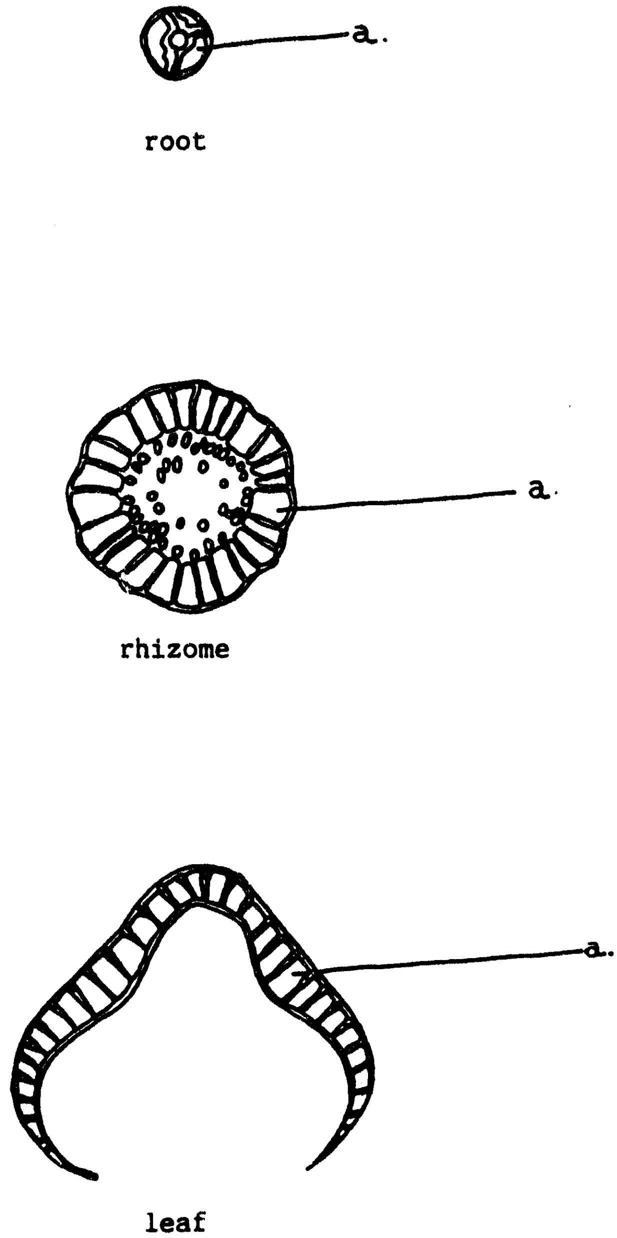

Figure 4 - 9. Cross section of tissues of *Carex lacustris*. The "a" refers to air spaces.

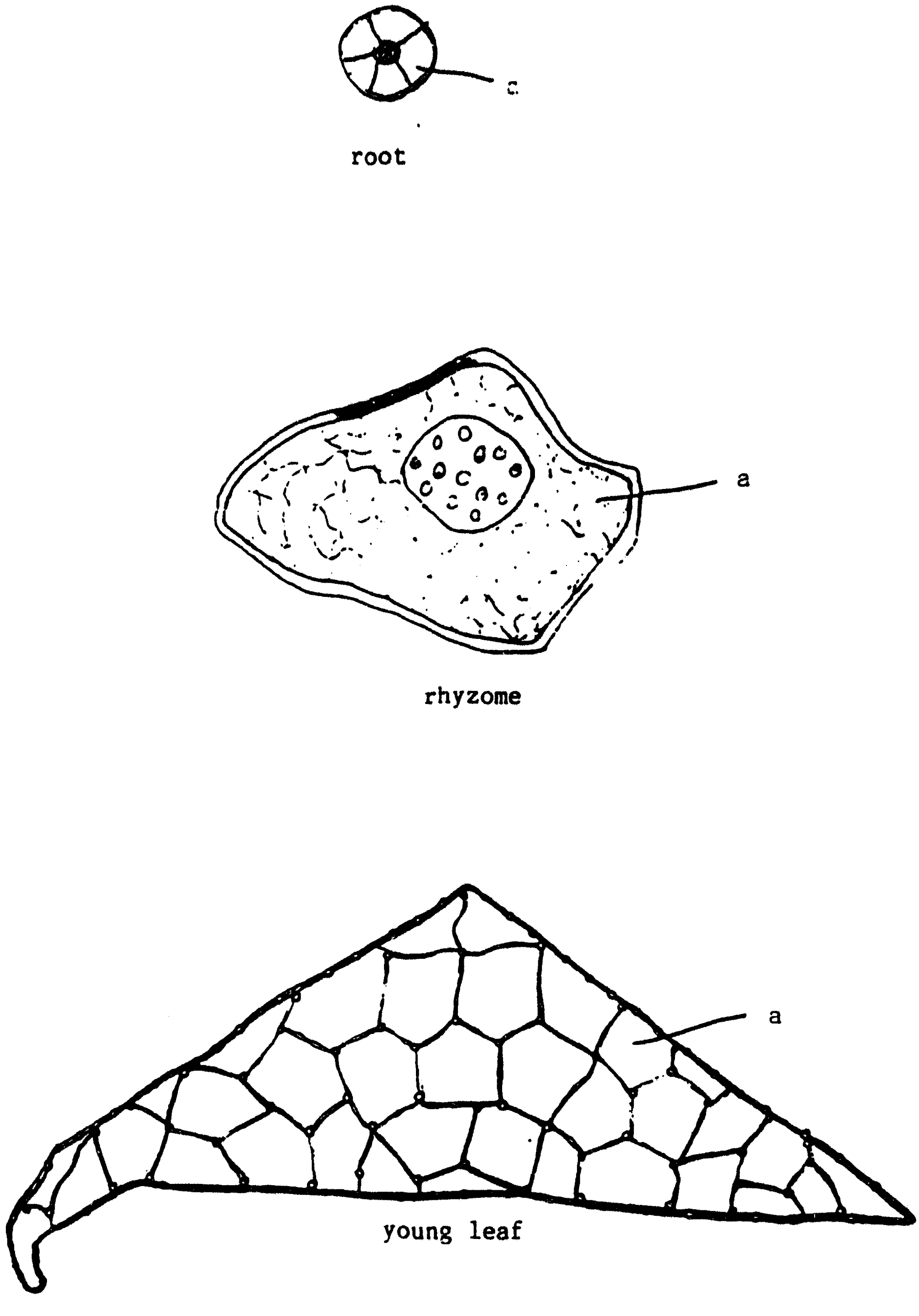

Figure 4 - 10. Cross sections of tissues of *Sparganium eurycarpum*. The "a" refers to air spaces.

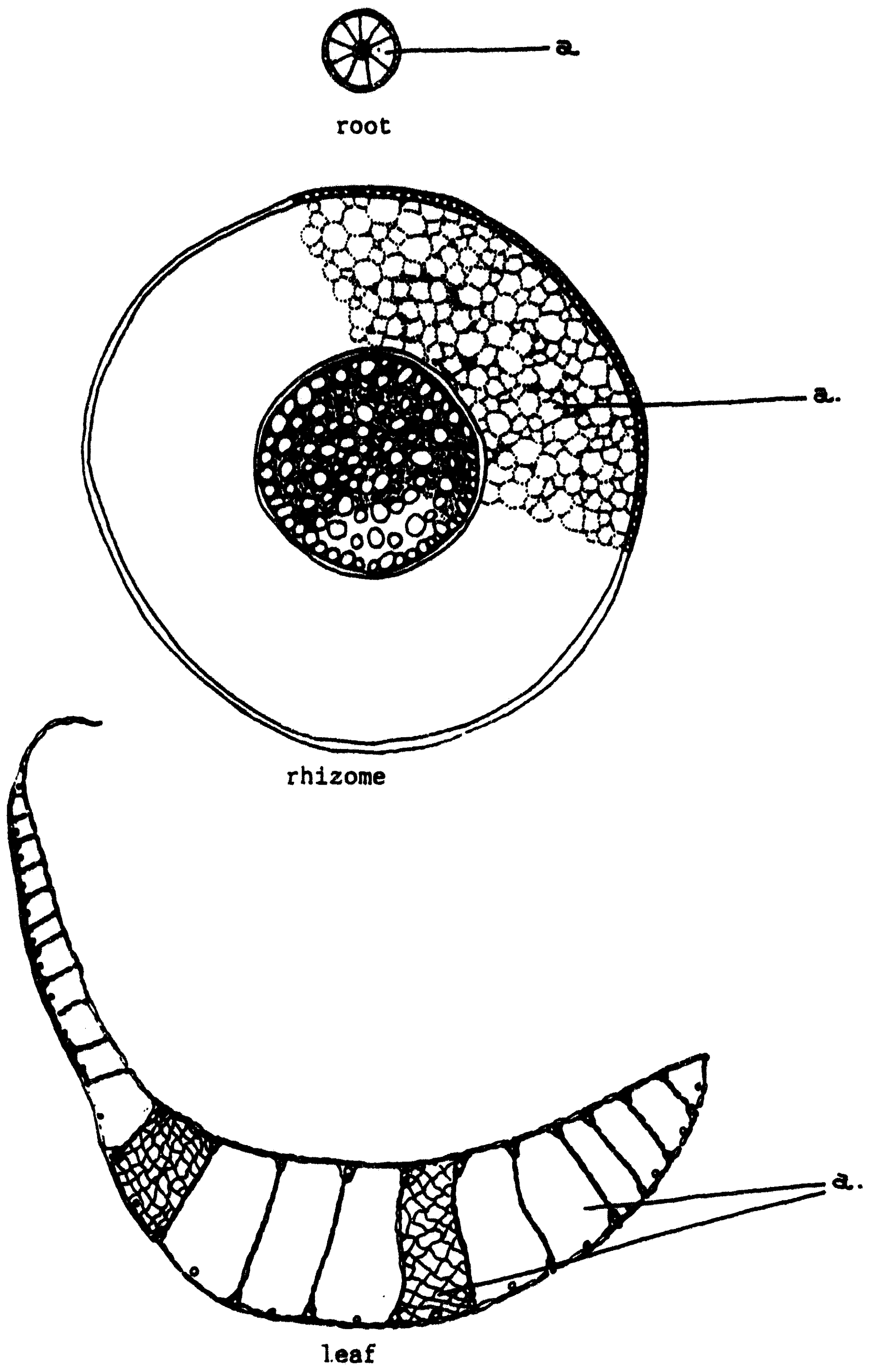

Figure 4 - 11. Cross sections of tissues of *Typha angustifolia*. The "a" refers to air spaces.

Both *Phalaris* and *Phragmites* had low percentages of air spaces in leaves. Large amounts of air spaces are probably not needed there because of the hollow stem typical of grasses. Although there was a spongy cellular layer present at the nodes, this was probably not a significant factor in slowing down diffusion throughout the stem and to the below-ground structures.

Sparganium and *Typha* are closely related, have a similar growth habit, and are usually found in deep-water sites. They both have large air spaces in leaves and roots and a very spongy cortex in the rhizomes. Airflow in both of these species should be fast enough for all metabolic needs of the below-ground organs.

Carex lacustris is intermediate in water depth distribution of the species studied here, and the air space amount and distribution indicates this, averaging only about 33% in each tissue studied.

The plants grown in solution culture grew very well; both types developed extensive air space systems. *Phalaris* developed much more aerenchyma than plants grown in the field. Cattails had somewhat less air space in experimental plants in the leaves. This might have been due to the young age of the leaves in the experiments compared to plants grown in the wild. In the experiments, neither plant species showed any evidence of plaque, which is found on wild plants, on the roots and rhizomes (Bartlett 1961; Crowder and Macfie 1986; Taylor et al. 1984). It may be that the plants were still growing vigorously and were using all internal oxygen for respiration. A second factor may be that the roots were young, had not been exposed to the harsh conditions of soil and thus had no wounds or breaks in the epidermis. Both factors would probably prevent quantities of oxygen from diffusing from the root systems.

The data presented here indicate that wetland plants have extensive aerenchyma tissue, as Armstrong (1967, 1972), Conway (1937), Ogden (1974), and Sand-Jensen et al. (1982) indicated. Further, plants that grow in shallow water or moist sites have less than plants that grow in deep water. Comparison between field-grown and experimental anoxic grown plants indicate that plants are able to change percentages depending on their environment. This could be a fruitful avenue of further research.

Stolon Formation In *Phragmites Communis*.

Phragmites communis is a large macrophyte that frequently dominates large areas of wetlands. Because of its dominance it is one of the most studied of all wetland plants and has been used in a number of projects concerning constructed wetlands, particularly in Europe. It is being used in the Landstrom

Landfill project, having been planted in three of the four beds; there is one small clump that has grown in bed 4 at Fenton.

Phragmites usually forms pure stands due to the development of a large and extensive below-ground rhizome system. Not so well known is that this species may also produce very long aboveground stolons. In her reviews, Haslam (1972, 1973) termed these stolons legerhalme and noted they sometimes reached lengths of 10 m. Bjork (1967) included a photograph of a stolon approximately 750 cm long from a stand in Sweden, but other than these reports, there are few references in the literature. Both the Fenton and Landstrom populations grew stolons. Stolons also grow in populations along the New York State Thruway near Syracuse and in Irondequoit Bay near Rochester. One of the purposes of this study was to observe and measure some stolon characteristics.

Methods. At Fenton, measurements were made during summer 1991 of the length of the primary stolon and the length of shoots developing along it. At Landstrom, some plants were harvested, brought back to the laboratory and air-dried. Measurements of lengths and the weights of various parts of the system were then determined to arrive at a biomass allocation pattern.

Results. Stolons often develop from a small, immature clump of shoots, but they grow rapidly, averaging at Fenton approximately 10 cm growth per day. Nodes are produced at approximately 20-cm intervals (probably less when water is present on the surface), but what is produced is highly variable. To illustrate this, Table 4-4 gives data on five stolons collected in late August. The five ranged from 600 to 940 cm in length and varied in percentage of biomass allocated to different parts of the system.

Table 4-4. Length, weight, and percent biomass allocation patterns in five *Phragmites communis* systems collected at Landstrom Landfill constructed beds on August 29, 1991.

Length	Weight	Percent of Total Weight				
(cm)	(g)	I Stolon	Shoots	II Stolon	Rhizomes	Roots
490	112	24.8	38.4	19.8	10.8	6.0
686	92	40.9	43.9	2.3	4.6	8.1
940	97	51.1	26.8	20.8	0.0	1.2
600	76	59.7	19.2	4.7	10.8	5.4
620	85	42.3	38.6	16.4	0.0	2.5

A comparison of two of the stolon systems illustrates the differences in allocation patterns. The first system was 490 cm long and weighed 112 g, the most of any system for both parameters. It had 25% of its total weight in the primary stolon, the least of any system, but 17% below-ground. In contrast, the longest stolon was 940 cm and had 51% of its biomass in the primary stolon. It had no rhizomes developed and only 1.2% of the system was made up of roots, the least of any system.

Discussion. Stolon development in *Phragmites* is not well known but apparently is common to most stands. The stolons have probably often been mistaken for typical upright shoots that have lodged. They are found usually at the edges of the stand, growing out over an essentially unvegetated area.

Phragmites is a clonal plant that usually produces both long and short rhizomes below-ground, a growth form typical of many large wetland plants (Bernard 1990). Stolon formation, in contrast, appears to be a life history strategy enabling the plant to grow into a new area and forage for sites in which to grow. Thus, every 20 cm, a new plant system may develop if conditions are suitable. If conditions are not suitable, then the shoot and the entire system not rooted will die in autumn. Observations in this project indicate that few of the shoot systems that develop along the primary stolon are successful in any one year.

More data are needed on this aspect of *Phragmites* growth. Needed in particular is an understanding of what environmental conditions promote shoot, root, and rhizome growth. When this is known, it may make planting constructed wetland beds much easier, since stolons will allow an area to be vegetated much more easily than by traditional planting.

Growth, Biomass and Chemical Content of Reed Canary Grass (*Phalaris Arundinacea*)

Phalaris arundinacea is a large macrophyte common in wetland situations in the central New York area. It grows particularly well in heavy, saturated soils along the edges of ponds and streams and in wet pastures. This species was planted in beds 1 and 2 at Fenton since the soils were high in silt and clay and it was not originally intended that the water would be very deep. The purposes of this part of the project were to determine: 1) life history and seasonal changes in development of *Phalaris*, 2) biomass patterns, 3) chemical patterns in plant tissues, and 4) the effect of heat on growth.

Methods. A variety of methods was used in this portion of the project. First, control sites were established at the Cornell Ponds research facility and a few smaller sites were located on the Ithaca College campus. For life history analysis, individual shoots in permanent plots were tagged with a number and measured at two-week intervals. Plants outside the permanent plots were harvested, brought back to the laboratory, washed carefully, dried and weighed. Both above- and below-ground tissues were sampled and weighed to determine biomass values.

Some of the plant material was washed more carefully in a mixture of D. W. and 0.5 N Hcl, dried in an oven at 70°C, then ground in a Wiley Mill using a 40 mesh screen. These ground samples were taken to Cornell and analyzed for chemicals in the Department of Soils, Crops and Atmospheric Sciences testing laboratory.

To determine the effect of heat on growth, plants were grown in pots that were placed in a large water bath which had heaters and water circulators; one set at 25°C, the other at 37°C. The control was a water bath exposed to normal greenhouse temperatures.

Results. Results of the *Phalaris* study are considered in terms of life history, biomass, plant chemistry, and heat effects.

Life History. Reed canary grass is a perennial and illustrates a life history common to many wetland plants. Briefly, the seasonal developments proceed as follows: During winter, most of the living biomass is present in root and rhizome tissues below-ground (Table 4-5). The new shoots that will develop in spring are already formed as buds along the rhizome system and some have grown aboveground and are green. In three sites sampled, green biomass ranged between 43 and 81 g/m^2.

Table 4-5. Winter biomass of reed canary grass at the Cornell Ponds Research Facility, the Ithaca College Pond site, and bed 1 at the Fenton constructed wetland. (All values are g/m^2. Date of collection is indicated.)

	Cornell Ponds 3/27/90	Ithaca College 11/30/90	Fenton 3/19/90
Green Shoots	62.4	42.6	80.9
Roots	97.6	149.4	126.4
Rhizomes	264.0	326.1	205.1
Total	424.0	518.1	412.4

In spring, all formed shoots begin rapid growth. Shoots grew approximately 2 cm/day during May and at a somewhat lower rate in June. By July 1, most shoots have reached maximum length and have flowered. During summer, wind or rain may cause the plants to fall over (lodge). When they do, axillary buds along the prostrate stems become active and new upright shoots form. Some of these shoots grow roots and may become sites of new shoot systems (Table 4-6), especially in sites with low shoot density.

Table 4-6. Length and weight of shoots, number of axillary shoots, and presence or absence of roots on axillary shoots of *Phalaris arundinacea* (reed canary grass) during midsummer 1990. Plants were collected during July 1990.

	High-Density Site		Low-Density Site
	Upright	Lodged	Lodged
Shoot Length (cm)	127	123	114
No. Axillary Shoots/Shoot (avg of 30 plants)	15	93	153
Weight Shoot (g)	0.4	1.5	
Roots Present	No	No	Yes

Plants also vary in form depending on water depth. In sites where the water table is just above or below the soil surface, axillary roots do not develop, but when the water is deep, adventitious roots form. They may become quite large and probably aid in uptake of chemicals from the water.

Biomass. Table 4-5 presents data on living biomass in winter at three sites, the Cornell ponds, Ithaca College, and Fenton bed No. 1. Fenton had the lowest total biomass at 412 g/m^2, but the largest green shoot biomass at 81 g/m^2, about twice the Ithaca College value. Fenton also had the lowest below-ground total, 331 g/m^2, which was 30 g less than at Cornell and approximately 140 g less than at Ithaca College.

Tables 4-7 and 4-8 compare density, weight per shoot, and biomass at Cornell Ponds and at Fenton during 1990. At Cornell (Table 4-7), shoot numbers ranged from $247/m^2$ in spring to a maximum of 287 on September 1, 1990. By October 15, most shoots had died, leaving 210 $shoots/m^2$. Green shoot weight increased from 0.25 g each to a maximum of 4.7 g on August 1, 1991, then declined to 1.6 g each by October 15. The winter above-ground green biomass of 62 g/m^2 increased to a high of 1,408 g/m^2 by July 1, then declined to 337 g on October 15.

Table 4-7. Density, weight per shoot and above-ground and below-ground biomass for *Phalaris arundinacea* at the Cornell Ponds site. (All weights are dry weights; plants were collected in 1990.)

Date	Density (shoots/m²)	Dry wt. /Shoot (g)	Aboveground Green (dry) (g/m²)	Roots (g/m²)	Rhizomes (g/m²)	Total (g/m²)
Winter	247	0.25	62.4	97.6	264.0	424.0
June 1	346	2.60	899.0	111.2	286.4	1296.6
July 1	320	4.40	1408.0	81.6	398.4	1888.0
August 1	285	4.70	1339.0	95.7	189.3	1624.0
Sept. 1	287	2.90	832.0	87.6	239.2	1158.8
Oct. 15	210	1.60	337.0	102.3	296.3	735.6

Below-ground, root weights did not vary greatly, ranging from a low of 82 g/m^2 on July 1 (the same date of the high rhizome biomass of 398 g/m^2) to a high of 111 g/m^2 on June 1. The lowest rhizome biomass was reached on August 1. The peak biomass at Cornell was 1,888 g/m^2, on July 1.

At Fenton (Table 4-8), the number of shoots did not vary greatly from the situation at Cornell except in autumn and winter, when the Fenton numbers were higher; by October 15, Fenton had over 100 more shoots per m^2 than Cornell. Fenton shoots also tended to be larger than Cornell shoots, reaching a maximum weight of 5.4 g each by July 1. The larger density and shoot weight at Fenton contributed to larger biomass aboveground, the maximum of 1,713 g/m^2 being approximately 300 g/m^2 more than at Cornell. Root weights varied by approximately

Table 4-8. Density, weight per shoot and above- and below-ground biomass of *Phalaris arundinacea* in the Fenton constructed wetlands. (Values of winter and June 1 - July 1 are averages from beds 1 and 2; on July 17 a complete harvest of bed 1 occurred; the rest of the values are from bed 2 only. All weights are dry weights; plants were collected in 1990.)

Date	Density (shoots/m2)	Wt/shoot (g)	Aboveground Green (dry) (g/m^2)	Roots (g/m^2)	Rhizomes (g/m^2)	Total (g/m^2)
Winter	270	0.30	80.9	126.4	205.1	412.4
June 1	304	3.60	1094.0	152.0	204.1	1450.0
July 1	297	5.38	1315.0	205.0	197.0	1717.0
July 17			808.0			
August 1	336	5.1	1713.0	186.0	215.0	2114.0
Sept. 1	308	4.21	1293.0	203.0	246.0	1742.0
Oct. 15	317	2.3	729.0	178.0	253.0	1160.0

75 g/m^2 during the season, whereas rhizome weights varied by only about 50 g/m^2. In total, Fenton biomass tended to be higher during the year, reaching a maximum of 2,114 g/m^2 by August 1.

The July 17, 1990, biomass value at Fenton (Table 4-8) represents a complete harvest. It is lower than other estimates because the plants were cut approximately 30 cm above the soil surface, leaving older shoots to bud new shoots from their bases.

Plant Chemistry. Chemical data for above-ground tissues are presented in Table 4-9. They illustrate three important points. First, some elements, namely nitrogen, aluminum, nickel, and boron, were all in lower concentrations in plants in bed 2 than in bed 1, while concentrations of potassium, iron, and manganese increased. The others, calcium, magnesium, copper, and zinc remained about the same. Second, six of the elements were higher in plants in bed 2 than in the control Cornell plants. These were nitrogen, potassium, iron, manganese, aluminum, and boron. Lastly, the values reported for bed 2 are within the range of most values reported in the literature. For the main macronutrients listed in related studies and in literature references in general, it appears that *Phalaris* in Fenton beds contain nutrient elements consistent with values of plants in natural wetland systems.

Table 4-9. Chemical contents of shoots and flowers of reed canary grass (*Phalaris arundinacea*) growing in Fenton beds 1 and 2 and in Cornell Ponds. (Values in mg/kg dry matter, except as noted; plants collected in July 1990.)

	Fenton Bed 1		Fenton Bed 2		Cornell
Element	Shoots	Flowers	Shoots	Flowers	Shoots
N (%)	2.4	1.7	1.7	2.2	1.1
K (%)	1.9	0.6	2.8	0.7	2.0
Ca (%)	0.05	0.04	0.06	0.04	0.19
Mg (%)	0.06	0.03	0.09	0.12	0.13
Fe	6.7	28.5	19.1	24.5	nd
Cu	2.0	0.9	1.9	0.9	2.7
Zn	8.6	7.1	8.7	27.7	10.5
Mn	65.9	36.1	117.7	113.0	nd
Al	106.0	36.0	18.4	nd	nd
Ni	1.0	0.4	0.2	0.4	0.3
B	172.0	59.7	117.7	9.1	30.9

Note: "nd" indicates the level was below the analytical detection limit.

Table 4-10 presents data for roots and rhizomes for *Phalaris* in bed 1 at Fenton and at Cornell. The data indicate that there is no large concentration of nitrogen, potassium, calcium, or magnesium in below-ground tissues. Further, all the other constituents, with the exception of boron, had greater concentrations in below-ground tissues than aboveground. This is due first to the difficulty of cleaning these tissues of all debris, thus inflating the values. This is particularly true of iron concentrations. Second, it is due to the conservative nature of some of these elements such as copper and zinc. They do not tend to move internally in the plants to any large extent, thus the below-ground tissues typically have greater concentrations than aboveground tissues.

Table 4-10. Chemical contents of roots and rhizomes of reed canary grass (*Phalaris arundinacea*) growing in Fenton bed 1 and in Cornell Ponds. (Values in mg/kg except as noted; plants collected in 1990.)

	Fenton Bed 1		Cornell Ponds	
Element	**Roots**	**Rhizomes**	**Roots**	**Rhizomes**
N (%)	1.2	1.6	1.0	1.1
K (%)	0.3	0.7	0.6	0.5
Ca (%)	0.2	0.1	0.4	0.1
Mg (%)	0.2	0.1	0.2	0.1
Fe	31,182.0	9,940.0	3,302.0	967.0
Cu	4.8	2.7	11.0	7.0
Zn	35.1	20.0	27.8	27.5
Mn	694.7	287.0	31.0	0.4
Al	9,072.0	6,029.0	4,446.0	1,081.0
Ni	6.7	5.6	10.9	2.7
B	67.4	36.9	10.5	4.7

Heat Effect. Plants growing in both normal greenhouse temperatures and at 25°C showed no vegetative growth response after a 2-week period. The plants growing in 37°C water, however, died after about 10 days of treatment. No green aboveground tissues survived the latter treatment, but roots and rhizomes were still alive and new shoots grew aboveground approximately one week after the experiments were terminated.

Discussion. *Phalaris* has a relatively plastic life history; some aspects of the timing of seasonal events and growth form differ under different environmental conditions. Perhaps of most importance, *Phalaris* responds to the warm leachate by beginning growth approximately two weeks earlier in spring and lives approximately two weeks longer in autumn. Thus, if actively growing plants are helpful in treating leachate, the season can be extended considerably, and if a plant was located in a more southerly area it might continue growth all year.

Water depth is key to the success of *Phalaris*. The plants grew extremely well when leachate flowed through the beds freely; once the water level was raised, most of the plants died. The same effect can be seen in natural wetlands; deep water areas have very low plant density and most of them lodge during midsummer.

It appears that the combination of warm water and high nutrient levels in the leachate lead to higher biomass than is usually found for this species. The large aboveground biomass of over 1,700 g/m^2 compares to the high of 1,408 g/m^2 at Cornell and values in other studies of 1,500 g/m^2 (Kline and Broersma 1983), 1,451 g/m^2 (Mason and Miltmore 1970), 1,151 g/m^2 (Ho 1979) and 1,497 g/m^2 (Linden et al. 1981), all in unpolluted wetlands. Kline and Broersma (1983) stated that *Phalaris* achieved a maximum of 3,000 g/m^2 when fertilized with nitrogen. It is probable that biomass could increase at Fenton since the beds were only one year old and some areas would have increased in density as the beds matured.

The 808 g/m^2 harvested in bed 1 in July 1990 probably represents an amount that could be harvested yearly without harm to the population (high water levels immediately after harvesting apparently killed the Fenton plants) under normal water conditions. Such a harvest, if done yearly, would remove chemicals from the beds. Approximately 20 g N/m^2 would be removed at each harvest, about half of the yearly uptake of 40 g N/m^2 for the beds as a whole. This latter value was determined by the following: maximum biomass 2,114 less minimum biomass 412 = 1702 x 2.4% N = 40.8 g N/m^2. This figure compares to the total N budget of 38.9 g/m^2 found by Linden et al. (1981).

The tissue nutrient levels in Fenton beds are not greatly different from those found at the Cornell ponds or those reported by Kline and Broersma (1983) or the other authors cited above. Some of these would be released when plants die-back in autumn, but it does not appear that large quantities would be flushed from the system at one time.

Few studies have been made of the effect of heat stress on plants. They include those of Adriano et al. (1984), who found large changes in plant growth under different conditions in a warm water pond; the growth changes were associated with changes in plant nutrient levels. Barbara Bedford (personal communication, 1990) has studied both *Carex lacustris* and *Typha latifolia* in a marsh system subjected to warm water inflow. She found *Typha* to be relatively unaffected, whereas most *Carex* plants died within a year.

Reed canary grass could not tolerate 37°C water temperatures over a 10-day period. In systems where the leachate is very warm this plant might not survive when exposed to high air temperatures also. That is a subject for further investigation.

Biomass and Chemistry of Cattail (*Typha Glauca*) in Wetland Beds

Cattails (*Typha glauca*) were planted in beds 3 and 4 at Fenton. The soil was composed of small stone. Planting of these beds, especially bed 4, continued throughout the whole period of the project. Bed 3 was well-vegetated the last summer of the project; bed 4 required additional time to become mature.

Botanists disagree on the exact taxonomic status of *Typha glauca* which is common in the central New York area. Some believe it to be a hybrid between the narrow-leaf and broad-leaf cattails; others believe it to be a distinct species. In any event, it is readily distinguished in the field: it grows far taller than the other species and may attain a height of 350 cm.

Methods. Most of the biomass data collection occurred in 1991 when bed 3 was well-vegetated. It was the principal bed sampled during the project and it was apparent that plants near the input end of the bed were larger and darker green in color than plants at the output end.

Samples 50 x 50 cm in size were taken from areas at both ends of the bed and all above- and below-ground materials were harvested. These were brought back to the laboratory, washed, dried, and weighed. Some of the material and other cattail material from each of the four beds and from cattails on the Ithaca College campus and from Irondequoit Bay near Rochester were used for chemical analysis. These plants were washed carefully in water containing 0.5 N Hcl, dried in an oven, then ground in a Wiley Mill using a 40-mesh screen. These samples were analyzed in the laboratory of the Department of Soils, Crops and Atmospheric Sciences at Cornell University.

Results. Table 4-11 summarizes data on the number of shoots, shoot height, and biomass in both the input and output ends of bed 3. Density and height of shoots at the input end were both much higher than at the output end. This translated into an aboveground biomass almost three times higher at the input end: 1,446 versus 492 g/m^2. The same situation prevailed below-ground, roots having three times greater biomass and rhizomes having two times greater biomass at the input end of the bed. Total biomass was thus over two times greater at the input end: 2,444 versus 950 g/m^2.

Table 4-11. Number of shoots, average shoot height and weight of above- and below-ground materials in *Typha glauca* from the input and output beds of Bed 3 at Fenton on August 24, 1991.

		Aboveground		Belowground		Total
	Shoots/m^2 (no.)	Height (cm)	Weight (g/m^2)	Roots (g/m^2)	Rhizomes (g/m^2)	Weight (g/m^2)
Input	30	234	1446	156	841	2444
Output	19	154	492	51	407	950

Table 4-12 presents chemical data for shoots of cattails growing in each of the four beds and from the Ithaca College site. These data are from plants collected in 1990. There is very little reduction seen across the four beds in nitrogen, but a greater reduction in potassium, iron, manganese, nickel, and molybdenum. Iron and manganese in particular are much reduced. This is important since these two elements are in high concentrations in the leachate. Other elements such as calcium, magnesium, copper, zinc, aluminum, and boron are more conservative and tend to stay about the same across the four beds, or in some cases increase from bed 1 to bed 4. Only five elements, nitrogen, calcium, aluminum, nickel, and boron are higher in bed 4 than in the control plants.

Table 4-13 presents data for above- and below-ground chemistry of cattails in both input and output ends of bed 3 and for similar tissues in plants collected in Irondequoit Bay. Most of the metals such as copper, zinc, aluminum and iron are in higher quantities below-ground than aboveground. In contrast, the important more mobile metabolic elements nitrogen and phosphorus are higher aboveground than below-ground. Some of the metals are in higher concentration below-ground in the output end of the bed than the input end. This is true for copper, zinc, aluminum, and lead.

Most elements are at approximately the same level in cattails in Fenton and Irondequoit Bay. The exceptions that are higher at Fenton are aluminum, iron, boron, and magnesium aboveground and copper (output end) and manganese below-ground. Fenton plants are very high in sodium but Irondequoit Bay plants are even higher, owing probably to excessive use of road salt in the watershed.

Table 4-12. Chemical contents of shoots of cattails (*Typha glauca*) growing in Fenton beds and plants growing on the Ithaca College campus. (Values in mg/kg except as noted. Plants collected in August 1991.)

	Fenton				IC
Element	Bed 1	Bed 2	Bed 3	Bed 4	Campus
Nitrogen (%)	2.8	2.6	2.8	2.6	2.2
Potassium (%)	2.7	3.1	1.7	1.5	3.2
Ca (%)	0.5	0.6	0.8	0.7	0.2
Mg (%)	0.2	0.3	0.2	0.2	0.2
Fe	44.5	19.6	nd	nd	nd
Cu	2.7	2.5	4.3	4.2	8.9
Zn	15.5	13.7	18.0	16.3	18.5
Mn	1505.0	1638.0	1100.0	417.0	643.0
Al	nd	5.2	2.6	4.9	3.7
Ni	2.3	2.1	0.2	1.1	0.5
B	49.9	46.8	43.0	85.9	67.6
Mo	7.9	5.7	1.5	0.8	15.7

Note: "nd" indicates level below analytical detection limit.

The differences between the input and output ends of bed 3 in biomass (Table 4-11) and chemical content (Table 4-12) also result in a much different chemical crop. For example, at the input end of bed 3, there are approximately 27 g N/m^2 aboveground and 6.6 g below-ground, a total of 33.6 g N/m^2. In contrast, there are only 5.4 g N/m aboveground and 4.5 g below-ground, a total of just 9.9 g N/m at the output end. In total, both input and output ends had lower N values than found at Irondequoit Bay where the total was 67 g N/m^2 in the mature site (Bernard and Seischab 1991).

__Discussion__. Plants in bed 3 at Fenton are well-established. Density in the input end approached normal levels of approximately 33-40 shoots/m^2 (Bernard and Fitz 1979; Bernard and Seischab 1991). Shoot height was also below average for this species. The output end plants are smaller than the input end plants.

Table 4-13. Average chemical amounts in above- and below-ground tissues of *Typha glauca* from input and output ends of Bed #3 at Fenton on August 24, 1991. (Also given are comparable values from plants sampled in Irondequoit Bay wetlands. Values are in mg/kg except where indicated. Irondequoit Bay data from Bernard and Seischab [1991].)

	Bed 3 - Input		Bed 3 - Output		Irondequoit Bay	
Parameter	**Above**	**Below**	**Above**	**Below**	**Above**	**Below**
Cu	4.1	20.6	2.9	44.6	5.3	15.6
Ni	1.8	11.5	1.3	10.5	1.6	9.6
Cr	2.9	3.7	1.7	5.8	1.4	6.0
Co	nd	nd	nd	nd	nd	0.6
Mo	2.2	nd	2.0	nd	0.4	0.6
Zn	13.3	27.0	9.1	57.3	17.5	59.8
Ca (%)	0.62	0.76	0.7	0.7	1.0	1.3
Al	60.8	1299.7	55.5	2330.0	17.3	1875.0
Fe	368.4	19439.0	292.0	10745.0	67.4	18006.0
Pb	1.6	8.6	1.0	14.6	0.6	18.9
B	27.7	37.8	14.0	26.0	12.7	132.0
Mn	1417.8	715.5	818.2	921.0	597.6	457.0
K (%)	1.3	1.53	1.3	1.8	1.4	0.4
Mg (%)	0.3	0.51	0.3	0.53	0.2	0.5
Na	1728.5	7367.6	2488.7	8531.0	3601.0	10013.0
P (%)	0.11	0.06	0.05	0.04	0.25	0.2
N (%)	1.85	0.67	1.1	0.99	2.7	0.8

Note: "nd" indicates level below analytical detection limit.

The input aboveground biomass of 1,446 g/m^2 was somewhat higher than Bernard and Fitz (1979) found, but lower than the 2,360 g/m^2 of Bernard and Seischab (1991) in Irondequoit Bay or 2,320 g/m^2 in Minnesota (Andrews and Pratt 1978).

Below-ground values for this species are scarce, but Andrews and Pratt (1978) reported a range of below-ground values from 2,400 to 3,100 g/m^2 in Minnesota, while Bray (1960), reported an average value of approximately 2,960 g/m^2, also in Minnesota.

Chemical contents of plants across all four beds showed differences. Those aboveground that declined were potassium, iron, manganese, nickel, and molybdenum; those that increased were copper, aluminum, and boron. The others showed little change. Copper and molybdenum were higher in the Ithaca College control plants than at Fenton. This could be due to the location of the Ithaca control plants near a roadway.

Table 4-13 shows, in general, that Fenton plants did not differ greatly in chemical levels compared to Irondequoit Bay plants. In addition, almost all were reduced in amount from the input to the output end of the beds aboveground, although this was not the case below-ground, where some of the metals were higher in the output end. Nitrogen, phosphorus and potassium levels were all lower in Fenton than levels reported by Bernard and Fitz (1979) in their site near Ithaca.

Finally, nitrogen aboveground at 29 g/m^2 was lower than found in other studies quoted above, another strong indication that, while bed 3 looked well established in 1992, it was not yet mature.

SYSTEM MONITORING AND ASSESSMENT

This section summarizes and evaluates the chemistry of the influent, effluent, and resident water from the constructed wetland system. Particular emphasis is placed on the transformations and fates of inorganic nitrogen, iron, and manganese. The interrelationships among pH, calcium, and carbon dioxide are also reviewed.

Monitoring

Preliminary Studies. Preliminary laboratory studies were carried out with the objectives of:

- Determining the chemical and physical characteristics of the landfill leachate,

- Developing appropriate laboratory procedures for analysis of the leachate and water within the treatment system, and

- Developing protocols for management of the samples between the time they were removed from the site and completion of the analysis.

Before completion of the treatment system, samples of landfill leachate were collected and analyzed for inorganic constituents and total N. The inorganic parameters included pH, inorganic nitrogen (NO_3 + NO_2 + ammoniacal N), O_2, Ca, Mg, Fe, Mn, Zn, Cu, Cd, and selected other substances. After the samples were brought to the laboratory, the biological oxygen consumption was measured. (More details on the analytical procedures are given later.)
The initial studies of the leachate indicated that there was considerable ferrous iron and that the samples were charged with CO_2 in excess of equilibrium with the atmosphere. These observations led to the expectation that upon exposure to air the iron would be oxidized from Fe^{+2} to Fe^{+3} quickly by atmospheric oxygen and precipitated as an insoluble iron oxide-hydroxide, and that CO_2 would be lost to the atmosphere with concurrent precipitation of $CaCO_3$ (probably as calcite).

These observations raised the following questions:

- How rapidly would these reactions occur?

- How much iron and calcium would be removed from solution?

- What other elements would be co-precipitated?

- How rapidly would the precipitates settle out of the treatment stream?

- How should the samples of leachate and the intermediates be treated after they were collected in the field and prior to analysis?

Initially, the first two questions were addressed by attempting to separate solid from solution at various stages of treatment. The laboratory studies were aimed at accomplishing this without incurring major changes in composition during the processing in the laboratory.

First, filtration was tried as a means of separating solution from solid, using fresh leachate from the landfill. Many different filtering media and techniques were tried but in all cases the filters clogged after passing only a few ml of solution. Centrifugation was tried next as a separation technique. However, the turbulence created by centrifuging oxidized substantial amounts of iron. To limit this effect, Oak Ridge-type tubes were employed. These were filled completely and then closed with screw-type tops during centrifuging. The following comparisons were made. Fresh landfill leachate was used to completely fill an Oak Ridge-type tube and the cap was screwed on so that there were no air bubbles in the tube. The sample was then centrifuged at about 2,400 times gravity for 30 minutes. The supernatant was poured off and acidified with concentrated Hcl. An aliquot of the original, uncentrifuged sample was also acidified with concentrated HCl and the two samples were analyzed for Ca, Mg, K, Na, Fe, Mn, Zn, Cu, and selected other metals.

The composition of the original, acidified samples collected during the summer of 1989 is listed in Table 4-14. Figure 4-12 illustrates that the centrifuging did not result in major changes in composition of the fresh leachate with respect to Ca, Mg, K, Na, Mn, Total Kjeldahl N, Cd, Cu, or Ni, but that there was considerable loss of Fe, Zn, and P with centrifuging. The original state (that is, while it was still in the landfill) of these last three substances is uncertain because the observed changes may be a consequence of oxidation of iron during the necessary laboratory manipulations. The loss of Zn and P may be through sorption/coprecipitation with the Fe.

The experiences cited in the last two paragraphs led to the conclusion that procedures for separating particulate from solution without major changes in the composition would be difficult and not worth the effort. The final sample-handling protocol involved acidifying the samples as soon as they were removed from the beds, then freezing them until analysis. The samples were acidified by adding approximately 1 ml of concentrated HCl per 100 ml. This resulted in a pH near 1. This had the dual result of dissolving precipitated metals and preventing the metals from sorbing to the sample bottle. This approach kept all metals in solution but eliminated the possibility of distinguishing Fe^{+2} from Fe^{+3}.

Another preliminary experiment tracked changes in leachate samples held and aerated for several weeks. During summer 1989, approximately 19-l (5-gal) samples of the leachate were collected weekly and brought to the laboratory where they were continuously aerated with a small stream of air such that the samples were kept aerobic but were not agitated sufficiently to create major turbulence. Several "vintages" of samples were maintained in parallel. The objective was to simulate the overland flow beds, keeping the solution aerated but allowing the particulate matter to settle. Subsamples were extracted

Table 4-14. Concentrations of selected components in landfill leachate, July-October 1989 (mg/l)

	Mean	Std. Dev.	07/13	07/17	08/04	08/07	08/17	08/21	08/31	09/05	09/28	10/02	10/12
			Date sample was collected										
Ca	245.4	41.7	214.5	291.1	289.7	208.1	273.5	286.7	268.3	275.9	197.5	204.1	190.3
Mg	122.1	19.5	112.9	132.6	133.	72.94	124.6	137.1	129.6	141.7	107.9	115.8	134.8
K	457.4	95.4	370	456	494	259	460	529	500	584	383	424	572
Na	457.6	77.3	423	468	483	268	440	496	484	546	414	456	556
Fe	28.2	15.3	40.22	38.08	33.34	60.29	25.64	21.01	20.2	7.31	32.08	25.41	6.5
Mn	4.4	1.4	5.35	5.87	4.79	6.48	5.09	4.44	4.02	2.93	4.39	3.69	1.26
Zn	0.17	0.07	0.26	0.25	0.21	0.11	0.15	0.17	0.13	0.11	0.26	0.07	0.1
Al	0.49	0.07	0.5	0.52	0.46	0.59	0.50	0.41	0.51	0.43	0.56	0.37	0.57
Cd	<0.01	0.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	0.17	0.04	0.16	0.16	0.15	0.15	0.16	0.17	0.16	0.16	0.26	0.16	0.23
Ni	0.07	0.01	0.04	0.07	0.07	0.06	0.09	0.06	0.07	0.08	0.05	0.06	0.07
Cr	<0.01	0.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Co	<0.01	0.00	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb	0.07	0.04	0.09	0.02	<0.01	0.04	0.09	0.08	0.14	0.03	0.08	0.07	0.11
As	0.29	0.27	0.81	0.07	0.03	0.76	0.10	0.02	0.27	0.27	0.23	0.33	0.26
P	0.81	0.16	0.85	1.02	0.60	0.90	0.92		0.74	0.61	0.62	1.01	0.77
TKN	206.2	33.1	190.8	210.1	219.4	121.1	200.		216.2	239.8	193.9	208.8	247.2

All samples acidified with HCl.

Values preceded by < were less than the detection limit of laboratory method. The value given is the detection limit.

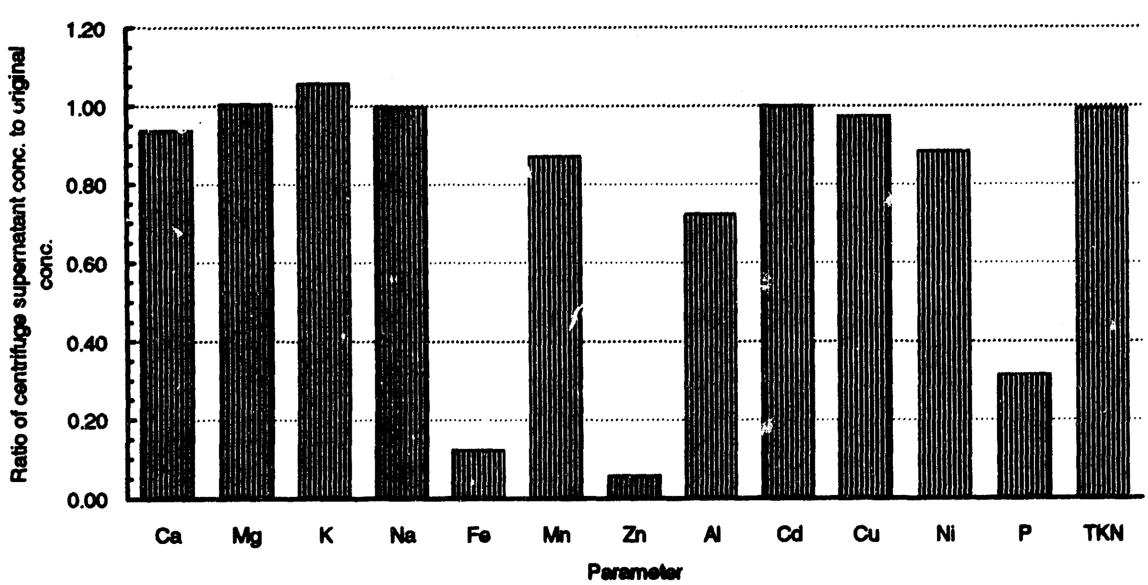

Figure 4-12. Effect of sample centrifuging.

periodically, centrifuged and separated, acidified, and analyzed for selected inorganic constituents. Table 4-15 and Figure 4-13 summarize the results. These data represent the ratio of a sample's constituent concentration at the specified age to the day-zero concentration in the same vintage. The most remarkable aspect of the data is the rapid loss of Ca, Fe, and Mn from solution and the relatively constant composition of the solutions after about 10 days. The total N content decreased gradually over the 92-day sampling period, probably as a result of NH_3 volatilization, since denitrification is unlikely in these aerobic solutions.

The Mg and K contents were relatively constant; the small increase at the longest time periods probably resulted from evaporation. The conservation of K is used in later data interpretation in the following way. K does not undergo any important losses by precipitation. Immobilization by microorganisms and plants is likely to be small, since the amount of K in solution is relatively high. For these reasons, the concentration of K will change primarily in relation to evaporation and dilution by precipitation. Thus, the best measures of loss of inorganic N, Mn, and Fe are changes in the ratios of these ions to K, since they will undergo the same changes in dilution and concentration as K.

Sampling Locations, Procedures, and Analysis. From June 1, 1990 through November 25, 1991 weekly samples were taken from the constructed wetland system in order to appraise the behavior of the individual components of the system with respect to removal of several chemical constituents. In addition to the constituents listed below, the temperature of the water, the inflow of leachate, the cumulative effluent volume from the treatment system, and precipitation were measured.

Figure 4-1 earlier in this section showed the locations of the twelve primary sampling points within and around the constructed wetland system. Samples were taken at the following points in series within the treatment system:

- mh 1, where the leachate was transferred from the landfill to the treatment system;
- the downgradient ends of beds 1, 2, 3, and 4 (bd1, bd2, bd3, and bd4);
- mh 4, between bed 4 and the holding tank); and
- the final holding tank (htk).

Table 4-15. Effect of prolonged aeration on composition of 11 samples of landfill leachate. (Samples were centrifuged, then the supernatant was acidified with HCl prior to analysis. Values shown are ratios to day-zero concentrations.)

	Days since start of experiment										
	0	11	15	30	43	53	57	67	70	88	92
Ca	1.00	0.19	0.12	0.08	0.09	0.11	0.09	0.12	0.24	0.10	0.05
Mg	1.00	1.00	0.96	0.96	0.99	1.00	0.98	1.02	1.05	1.18	1.69
K	1.00	0.92	0.84	0.86	0.90	0.91	0.92	0.98	0.85	1.10	1.88
Na	1.00	0.98	0.97	0.70	0.69	0.76	1.02	1.12	1.11	1.27	2.00
Fe	1.00	1.10	0.05	0.30	0.18	0.24	0.14	0.06	0.24	0.22	0.23
Mn	1.00	0.02	nd	0.07	0.02	nd	0.03	nd	nd	0.05	0.01
Zn	1.00	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Al	1.00	0.53	0.66	0.73	0.38	0.62	0.60	0.52	0.79	0.61	0.82
Cd	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cu	1.00	1.00	1.00	1.07	0.74	1.00	1.20	1.00	1.07	1.13	1.18
Ni	1.00	1.75	1.20	1.33	1.17	1.17	0.83	1.60	0.75	1.13	2.60
As	1.00	3.09	6.57	3.54	0.73	0.91	2.92	0.12	0.14	0.34	0.45
P	1.00	1.14	0.64	0.75	1.04	1.10	1.17	1.33	2.31	2.05	2.27
TKN	1.00	0.96	0.94	0.22	0.15	0.16	0.15	0.14	0.16	0.15	0.21

"nd" represents result less than detection limit of analytical method.

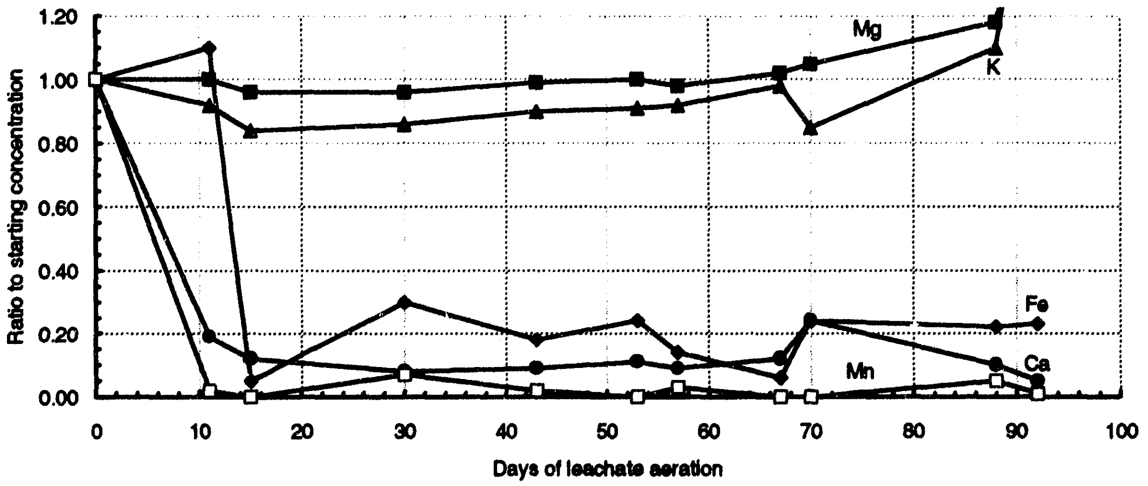

Figure 4-13. Results of leachate aeration laboratory experiment.

Mh 1 represents the quality of untreated landfill leachate, and also the treatment system influent. Bd4 represents treatment system effluent. Mh 4 and htk also represent system effluent, the former being little different from bd4 effluents, and the latter reflecting compositing over time.

Peripheral sampling sites included:

- S14, located at a point where drainage swale enters the Town property and at a higher elevation than the landfill;
- S19, a tributary above s18, most of s19's drainage area is land adjacent to the Town property;
- Gwn, the outflow from the landfill's subsurface drainage system; and
- S18, downstream from s14, s19, and gwn, at the point where this stream leaves the Town property after receiving drainage from the Town property.

S18 represents the possible future receiving water for the constructed wetland effluent.

See Appendix C for individual sampling data from these peripheral sites.

Besides field measurements described later, three samples at each time and location were collected for laboratory determinations. First, a 250-ml sample was collected in a plastic bottle containing 2 ml of concentrated HCl. The acid lowered the pH to about 1, dissolved any precipitated metals, and prevented sorption of metals to the bottle walls. This sample was analyzed for selected metals, Kjeldahl nitrogen, and total phosphorus. It was frozen until analysis. The second sample consisted of 2-l of medium in a plastic bottle, with no preliminary chemical treatment. This sample was analyzed for oxygen consumption and inorganic nitrogen within 2 days after collection. The third sample, also untreated, consisted of 150-250 ml in a plastic bottle. This sample was stored frozen for possible future use.

At the landfill site, pH, water temperature, and O_2 content were determined with portable meters. The temperature and pH measurements were made with a Beckman model 11 portable pH meter with temperature probe and automatic temperature compensation for the combination pH electrode. The O_2 measurements were made with a Yellow Springs Model 54A O_2 meter fitted with a YSI 5700 Series electrode.

Inorganic N and O_2 consumption were determined in the laboratory. The O_2 consumption measurement began on the same day the samples were taken, and inorganic N was determined the following day.

The "oxygen consumption" test measured the short-term biological component of oxygen demand in the undiluted samples. A standard 5-day BOD test dilutes a sample so there is sufficient oxygen present for five days of aerobic biological activity; the test then measures the change in oxygen content over the next 120 hours. This project's method approximated field conditions during which the leachate is first exposed to the atmosphere in overland flow beds 1 and 2, where oxygen would rarely be limiting even in full-strength leachate. Because the pH was usually 7.5 or above, the oxidation of ferrous iron was expected to be rapid in the presence of molecular O_2 (Stumm and Lee 1961). To simulate the well-oxygenated overland flow conditions, untreated samples were vigorously aerated for about 30 minutes in the laboratory, following which the O_2 content was determined. Then, a bottle fitted for a glass stopper was filled completely with the solution and the stopper inserted, taking care to exclude air bubbles. After 8 to 16 hours the solutions in the bottles were analyzed for O_2 using the O_2 meter. The difference in concentration was used to calculate O_2 consumption per 24 hours. The initial aeration was sufficient to oxidize any ferrous iron, since the pH was 7 to 9 and hence the oxygen consumption was a measure of biological rather than chemical O_2 consumption. Studies illustrated that O_2 consumption was linear with time for the range of O_2 concentrations maintained in the solutions.

$NO_3 + NO_2$ and NH_3 in the samples were measured within 24 hours using steam distillation (Keeney and Nelson 1982). In this procedure, the NH_3 is determined by adding an excess of MgO and distilling with steam for four minutes. The distillate is collected in a borate buffer and the NH_3 titrated with HCl. The NO_3 (+ NO_2) is determined by adding Devarda's alloy to the residue from the NH_3 determination (thus reducing the nitrate and nitrite to ammonia), then repeating the distillation and titration process. Several spot checks were made for NO_2; concentrations were usually less than 1 mg/l.

Table 4-16 summarizes the sampling and analysis procedures for each parameter in the field program.

Table 4-16. Summary of sampling and analytical methods used in field program.

Parameter	Analysis location	Sample handling	Analysis methods
O_2	field	Measure with meter and probe *in-situ*	Yellow Springs model 54A meter, YSI 5700 series electrode
Water temperature	field	(As for O_2)	Beckman model 11 meter
pH	field	(As for O_2)	Beckman model 11 meter
Oxygen consumption	lab	Collect 2 l sample in plastic bottle (no chemical additives)	Custom method: Begin same day as sampled; aerate vigorously for 30 min to oxidize ferric iron; measure initial oxygen content; seal, excluding air bubbles; unseal and measure oxygen content 8-16 hr later
$NH_4^+ + NH_3$	lab	(Part of sample for oxygen consumption; refrigerate until analysis)	Agronomic standard method: Begin within two days after sample collection. Steam-distill with excess MgO, collect distillate into borate buffer, titrate using HCl (Keeney and Nelson 1982).
$NO_3^- + NO_2^-$	lab	(Part of sample for oxygen consumption; refrigerate until analysis)	Agronomic standard method: Add Dvarda's alloy to solution used to titrate NH_3, reducing any NO_3 and NO_2 to NH_3. Then redistill and retitrate as above (Keeney and Nelson 1982).
Total Kjeldahl N (TKN) (organic nitrogen plus ammonia and ammonium)	lab	Add 2 ml conc. HCl to 250 ml plastic sample bottle; then fill bottle with sample (resulting pH approx. 1). Freeze until analysis.	APHA-AWWA-WPCF Standard Method 4500-N_{org}
Total Ca, Mg, K, Mn, Fe, Zn, Na, Al, Ni, Cu, Cd, Co, Cr	lab	(Part of sample for TKN analysis)	APHA-AWWA-WPCF Standard Method 3120: Inductively Coupled Plasma (ICP) Spectrometer

Assessment

Appendix C contains the detailed sampling results from the field program. Using these data and results from several additional laboratory experiments, this section examines several chemical, physical, and microbiological processes that appear to control the leachate-treatment performance of the constructed wetland system. The key processes examined include:

- Separating dilution and mass loss using potassium
- Interrelated dynamics of pH, calcium, and carbon dioxide;
- The rate of conversion of ammonia to nitrate by the nitrification process;
- pH and potential ammonia volatilization;
- Relationship between influent nitrogen loading and nitrogen loss;
- Iron and manganese behavior; and
- Maintenance of permeability in subsurface flow beds 3 and 4.

Use of Potassium to Distinguish Net Substance Loss from Dilution. In this area's climate, on annual average, the concentrations of many chemical elements in the influent leachate will drop since there is an excess of precipitation over evaporation: on the order of 20 inches in a normal year. To distinguish dilution from chemical, physical, and biological processes which also reduce concentrations, this project used potassium as a tracer element whose concentration is relatively unaffected by processes other than dilution. A necessary condition for this to be true is that the storage of K in the plants in the system is not a large fraction of the loading of K. Recall that for the most part there was no removal of plant biomass from the system, so that storage in the plants was the only avenue of loss (potassium is not lost by volatilization and all potassium compounds are soluble).

In the following, equations describing the nitrogen/potassium ratio are developed with the objective of illustrating how plant storage may influence the ratio. The same principles apply to other substances for which this report uses potassium as a dilution indicator.

First, the nitrogen and potassium balance equations are written as follows:

$$N_b = 0 = F_i n_i - N_p - N_l - F_o n_o \quad [1]$$

$$K_b = 0 = F_i k_i - K_p - F_o k_o \quad [2]$$

Where

N_b, K_b = N and K balance, respectively;

n_i, k_i = concentration of N and K in landfill leachate, respectfully;

F_i, F_o = inflow and outflow volume, respectfully;

N_p, K_p = net mass immobilized of N and K by plant, respectively;

N_l = mass nitrogen loss from system;

n_o, k_o = N and K concentration in outflow, respectively;

These apply over any consistent time interval.

Solving [1] and [2] for n_o and k_o

$$n_o = (F_i n_i - N_p - N_l)/F_o \quad [3]$$

$$k_o = (F_i k_i - K_p)/F_o \quad [4]$$

Dividing [3] by [4]:

$$n_o/k_o = F_i n_i - N_p - N_l)/(F_i k_i - K_p) \quad [5]$$

If $N_p << F_i n_i$ and $K_p << F_i k_i$, [5] becomes:

$$n_o/k_o = (F_i n_i - N_l/(F_i k_i) \quad [6]$$

Dividing [6] by n_i/k_i and simplifying:

$$(n_o/k_o)/(n_i/k_i) = 1 - N_l/(F_i n_i) \quad [7]$$

Note that the right expression is N lost as a fraction of N input and that the ratio $(n_o/k_o)/(n_i/k_i)$ decreases and N_l increases as expected.

In case N_p and K_p are not $<< F_i n_i$ and $<< F_i k_i$, respectively, the approximation is made that

$$N_p = (m)(F_i n_i) \text{ and } K_p = (m)(F_i k_i) \qquad [8]$$

The basis for this approximation is that the N and K contents of the plants are not very different and that the initial concentrations of N and K in the landfill leachate are not very different.

Substituting these approximations into equation [5] and simplifying as in [7]:

$$(n_o/k_o)/(n_i/k_i) = 1 - N_l/([l-m][F_i n_i]) \qquad [9]$$

According to equation [9], plant uptake tends to overestimate net loss; that is, the ratio $(n_o/k_o)/(n_i/k_i)$ decreases as m increases. Again recall that the condition we are approximating is no removal of plant biomass.

The net result of the above is to show that the ratio $(n_o/k_o)/(n_i k_i)$ is a biased estimate of loss when plant uptake is not small relative to loading and ratio $(n_o/k_o)/(n_i k_i)$ is reduced as plant uptake increases.

For ion X and the case where precipitation and uptake are operating,

$$X_b = 0 = F_i x_i - X_p - F_o x_o \qquad [10]$$

where X_b = balance for ion X

F_i, F_o = inflow and outflow as above,

X_p = mass amount of X taken up by plants or precipitated,

x_i, x_o = concentrations in landfill leachate and effluent, respectively.

Now suppose $X_p = (n)(F_i x_i)$ and following the operations in the preceding paragraphs:

$$(x_o/k_o)/(x_i/k_i) = (l-n)/(l-m) \qquad [11]$$

The substance of this equation is that the ratio is increased as m increases and hence plant uptake of K increases the ratio.

Now turning attention to the implications of the above developments to the ratios used in several places: In the overland flow beds when there was no emergent vegetation, the storage in the creatures living in the water was expected to be small or at least be in a quasi-steady state, since the biomass turns over in a matter of a very few weeks. In the root-zone beds, there was uptake of K during the growing season by the cattails, but probably a corresponding release of K during the fall and winter when the plant material decomposed. In the former case, the uptake would overestimate loss of N, while in the latter case "m" would be negative and hence would underestimate the actual loss of N. Overall, these two effects were expected to balance each other during a year of operation. Thus, while crude, the ratios were reasonable approximations to the losses corrected for dilution.

pH and Carbon Dioxide. Perhaps the most important factor influencing the treatment system was the pH of the water. The pH is a key variable in chemical processes that remove inorganic N, Fe, and Mn from the water. In the next several paragraphs, some of the variables influencing pH will be discussed and the relevance of pH to chemical changes in the leachate will be evident in subsequent discussion. The subject is treated in more detail by Stumm and Morgan (1982).

The amount of CO_2 dissolved in the water and the solubility of $CaCO_3$ dominate pH and considerable other chemistry of the leachate as it moves through the treatment system. The mineral calcite is the usual form of $CaCO_3$ and the following discussion will assume that the solubility of the $CaCO_3$ is characterized by the calcite solubility product. The following discussion summarizes some of the data.

First, consider the chemistry of solutions in equilibrium with pure calcite. In a solution of calcite in otherwise pure water at a specified temperature, either the total amount of CO_2 in solution or the pH of the solution determines the concentration of Ca in solution. That is, a measurement of either total inorganic carbon in solution or of pH is enough to calculate the concentration of all ions (including Ca) in solution from the well-known ionization constants of carbonic acid and the solubility product of calcite (Hutchinson 1957).

In solutions such as the landfill leachate, the situation is not so simple, but reasonable approximations are possible based on the amounts of cations whose charge is balanced by the carbonate ions. For example, ignoring the effects of ionic activity, the addition of moderate amounts of salts such as NaCl, KCl, and/or $Mg(NO_3)_2$ will have no major effect on the calculated concentration of Ca, H^+, and carbonate species. However, adding such components as NaOH, KOH, or HNO_3 makes calculated concentrations based on calcite and water unrealistic. In this case, when the pH is in the range of 7 to 8.5, some fraction of the cationic charge is balanced by carbonate ions. (In this pH range and at the concentrations in the leachate, the OH ion concentration is not very important.) The effect of such "excess" of cations over anions of strong acids (e.g., Cl, SO_4, and NO_3) is to increase the concentration of the carbonate ions and hence reduce the solubility of Ca by the common ion effect.

By invoking the electrical neutrality condition and calcite solubility, the Ca concentration becomes a function of two variables; one variable is either pH or concentration of total inorganic carbon in solution, and the second variable is the concentration of cations in excess of anions of strong acids. By inference, the electrical neutrality of the solutions is maintained by the carbonate ions in the pH range of 7.5 to 9. This assumes that the solution is dominated by the cations Ca, Mg, K, and Na and the anions Cl, SO_4, NO_3, HCO_3, and CO_3. The equation below defines excess cationic charge, (A), to be

$$A = (2[(Ca^{+2}) + (Mg^{+2})] + [K^{+}] + [Na^{+}] - 2[SO_4^{-2}] - [Cl^{-}] - [NO_3^{-}])1{,}000$$

in which the brackets indicate molarities (units of moles/liter), and the 1,000 converts from molarity to moles/m^3.

According to this approximation, there is enough HCO_3 and CO_3 in solution to establish the electrical neutrality of the solution.

The foregoing discussion describes conditions in which the solution and the calcite are in equilibrium. However, the kinetics of dissolution and precipitation are not instantaneous, so that several hours may elapse between the time composition of the solution is changed and equilibrium with calcite is reached (Hutchinson 1957). Usually after several hours the solutions will be nearly enough in equilibrium with calcite for the purpose of establishing broad generalizations about conditions which control pH and Ca concentration in solution.

The total inorganic carbon (and hence HCO_3 and CO_3) in solution is ephemeral because the solutions are not often in equilibrium with atmospheric CO_2. While in the landfill, the solutions are isolated from the atmosphere, allowing CO_2 produced by microbial activity to accumulate in the solution. The concentration of inorganic carbon in the solutions increases to levels far beyond those expected if the solutions were in equilibrium with the CO_2 in the normal atmosphere. Upon exposure to the atmosphere, the solutions lose this CO_2 rapidly.

In traveling through the treatment system, the total inorganic carbon in solution is not often in equilibrium with atmospheric CO_2 because algal photosynthesis/respiration and microbial respiration use/produce inorganic carbon faster than the solutions can equilibrate with atmospheric CO_2. This is a major factor in determining the pH of the solutions, as will be documented later.

Usually the inorganic carbon in solution is expressed in terms of the concentration expected in equilibrium with CO_2 in a gas phase. Dissolved CO_2 thus may be described in terms of partial pressure in a gaseous phase in equilibrium with the solution. For example, the normal atmosphere is about 0.035% CO_2. During the day, in water bodies where algal photosynthesis is active, the inorganic carbon in the water would act as if it were in equilibrium with a gas phase containing less than 0.035% CO_2 because the algal photosynthesis uses CO_2 faster than it can be sorbed from the atmosphere. On the other hand, in flooded soils the inorganic carbon in solution may act as if it were in equilibrium with a gas phase containing 10 to 1,000 times more than atmospheric CO_2. This high concentration is the result of CO_2 generation by microbial respiration at a rate faster than it can escape to the atmosphere.

The following discussion illustrates how the foregoing theoretical considerations are useful in explaining some of the changes in the chemistry of the leachate as it moves through the treatment system. This chemistry can aid in making reasonable predictions about how modifications to the treatment system would likely influence the treatment and how the results may be extrapolated to other locations.

Figure 4-14 illustrates the relationships among pH, Ca in solution, partial pressure of CO_2, and excess of cations over anions of strong acids (A). Recall that A is the amount of cation charge that must be balanced by HCO_3^- and CO_3^{-2}. Figure 4-13 shows that the concentration of Ca in the landfill leachate fell by a factor of seven after a few days of aeration, representing a drop from 200 mg/l to 30 mg/l. This is consistent with a change in partial pressure of CO_2 from about 0.1 atm to nearly that expected in the normal atmosphere containing 0.035% CO_2. Second, note that an excess of cations over anions of strong acids tends to decrease the concentration of Ca in solution. However, this variable does not lead to a large change in pH if the concentration of CO_2 in the equilibrium gas phase is kept constant.

pH measured *in situ* differs considerably from that measured in the same water returned to the laboratory and aerated with atmospheric CO_2 for 24 hours. The measurements are shown in Table 4-17 and compared with calculations based on calcite equilibrium in Figure 4-15. First, the data in Table 4-17 show that the pH increases upon equilibration with atmospheric CO_2. Probably the increase in pH is a consequence of decreasing inorganic carbon. These observations are further illustrated in Figure 4-15, where the pH and Ca are plotted against A for atmospheric CO_2. The results are reasonably consistent with the expectations so long as A is allowed to vary somewhat.

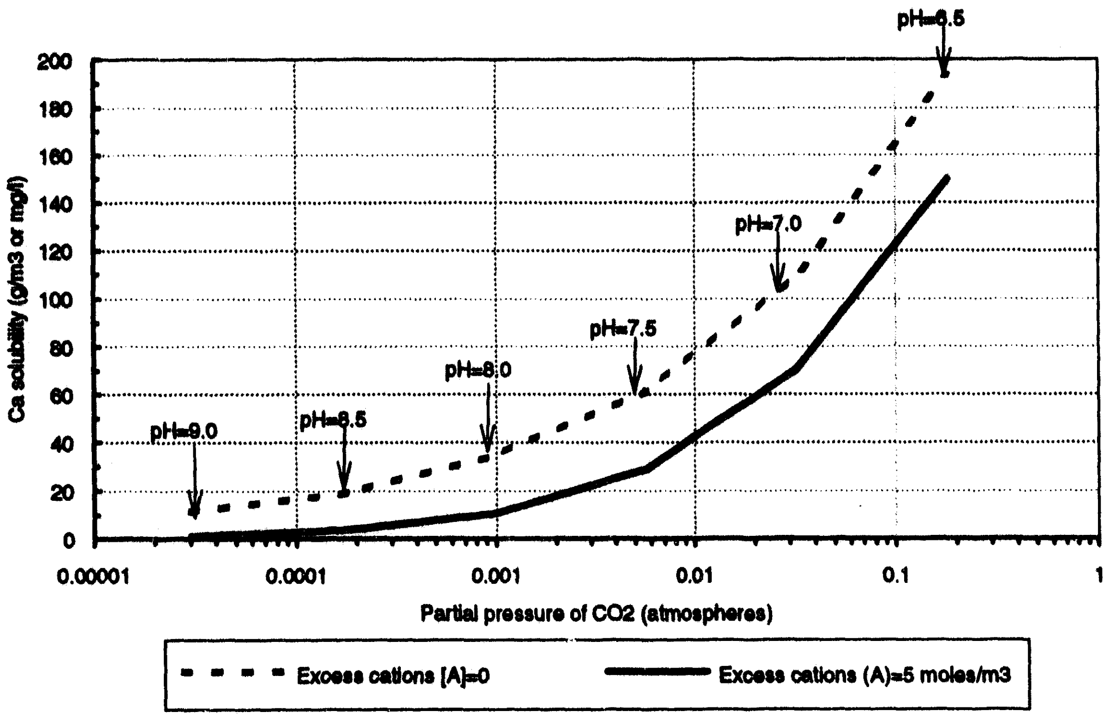

Figure 4-14. Calcium solubility as a function of partial pressure of CO2, for different excess cation levels.

Table 4-17. pH at several sampling positions, in the field and after 19-hr aeration in the laboratory.

Position	Field pH	Laboratory pH
mh1	7.64	8.74
bd1	8.15	8.45
bd2	7.88	8.70
bd3	7.09	8.62
bd4	7.00	8.42
mh4	8.11	8.60
htk	8.10	8.48
s18	7.64	8.48

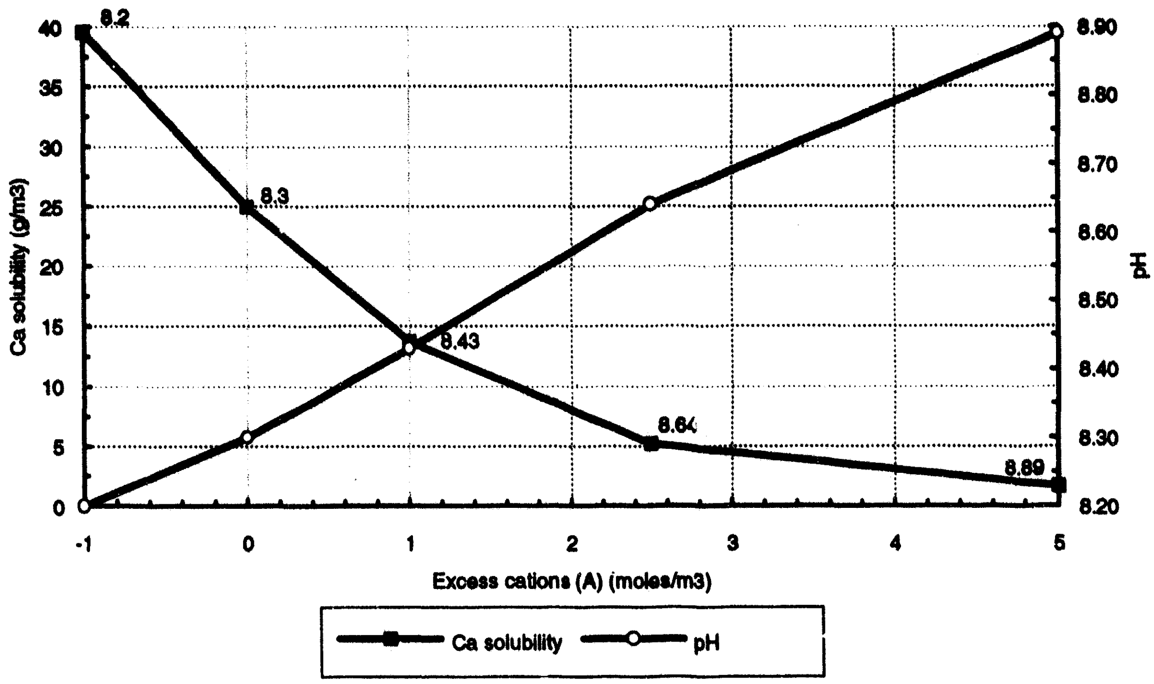

Figure 4-15. Relationship of equilibrium calcite solubility and pH to excess cations.

Figure 4-16 illustrates the diurnal variation in pH in the beds. The pH in the overland flow beds undergoes a large change. During the day the pH increases because the CO_2 is being used by photosynthesis faster than it can be replenished by transfer across the air-water interface. During the night, respiration by the algae and microorganisms produces CO_2 faster than it can escape to the atmosphere. In the two gravel beds, there is no photosynthesis and the microbial activity causes the CO_2 to increase above atmospheric levels because of restricted interchange with the atmosphere.

Several chemical reactions may influence A, the excess of cations over anions of strong acids. The following are some examples:

a) NH_3 volatilization and/or ionization of NH_4OH:

$$NH_4^+ + HOH \text{ --> } NH_4OH + H^+ \qquad [13]$$

$$NH_4OH \text{ --> } NH_3 + HOH \qquad [14]$$

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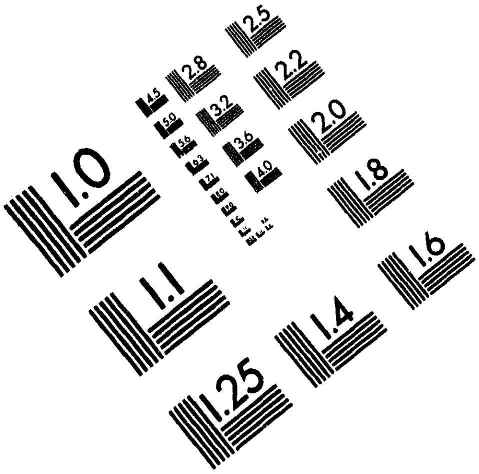
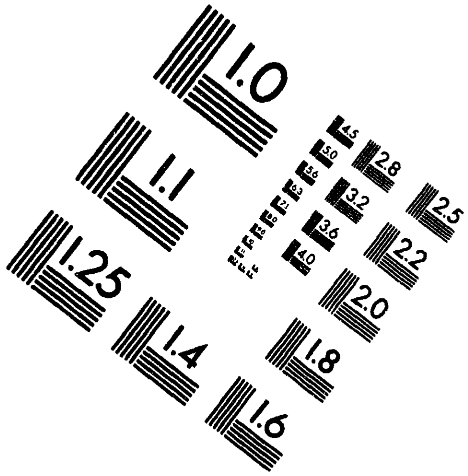

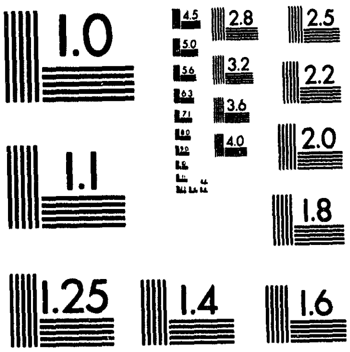

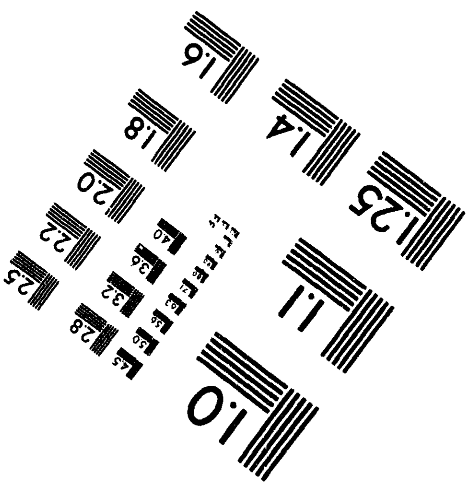
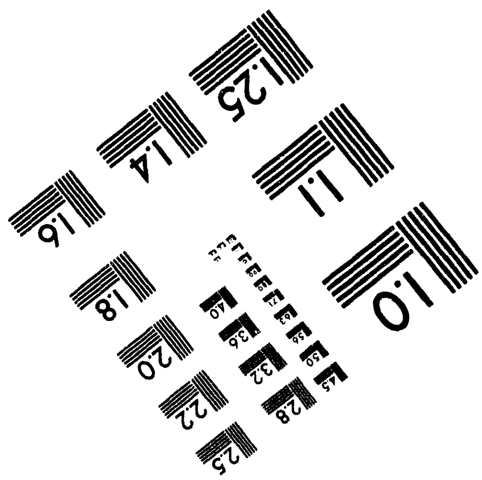

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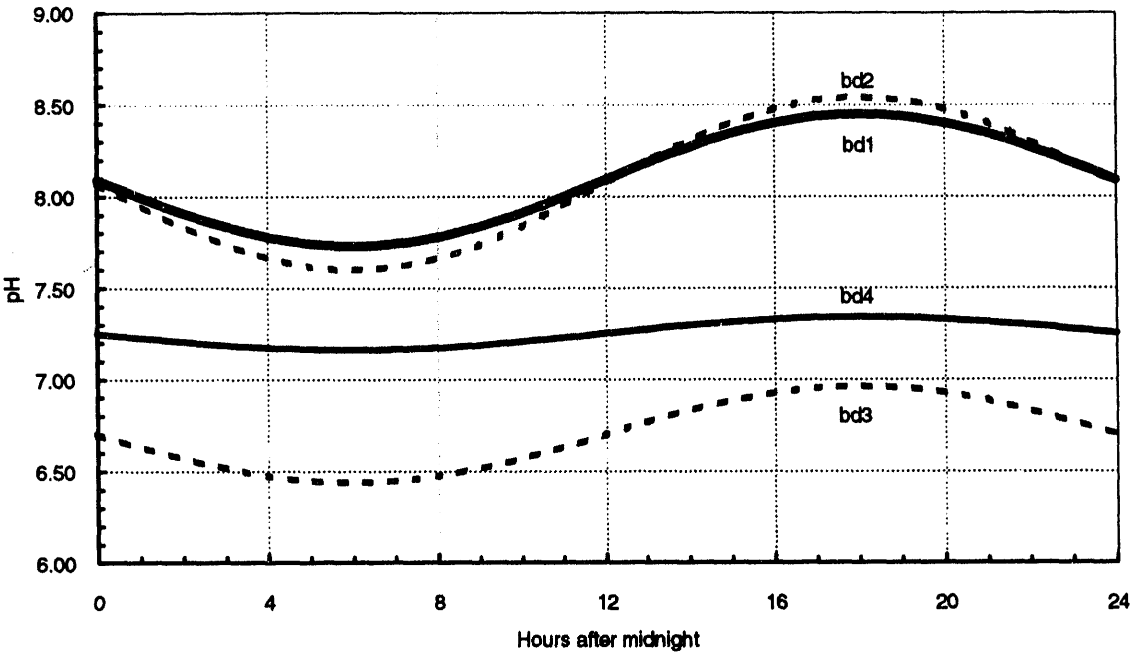


Figure 4-16. Calculated diurnal pH variation in different parts of treatment system.

As the NH_3 is lost to the atmosphere with nearly constant pH in the pH range 8 to 9, NH_4^+ ions are lost and H^+ ions are produced. Sooner or later this will reduce the pH but the net effect is to decrease A.

b) Oxidation of Fe^{+2} and precipitation of $Fe(OH)_3$:

$$4\,Fe^{+2} + O_2 + 10\,HOH \rightarrow 4\,Fe^{+3}(OH)_3 + 8\,H^+ \qquad [15]$$

c) Nitrification of NH_4:

$$NH_4^+ + 3/2\,O_2 \rightarrow NO_3^- + 2\,H^+ \qquad [16]$$

The net effect of b) and c) is to reduce A.

Several other chemical reactions may materially influence A, but the above illustrate why A may change during the travel of the leachate through the system.

The effect of calcite on buffering a solution is illustrated in Figure 4-17. In this figure the pH is calculated for solutions in equilibrium with atmospheric CO_2. pH is plotted against values of A. In one case, the solutions are also in equilibrium with calcite and in the other case no calcite is present. In this latter case the pH is determined by A. The important point to note is that if A is larger than about 1 mole/m^3, the presence or absence of calcite is unimportant, but when A is less than this the effect of absence of calcite is very important.

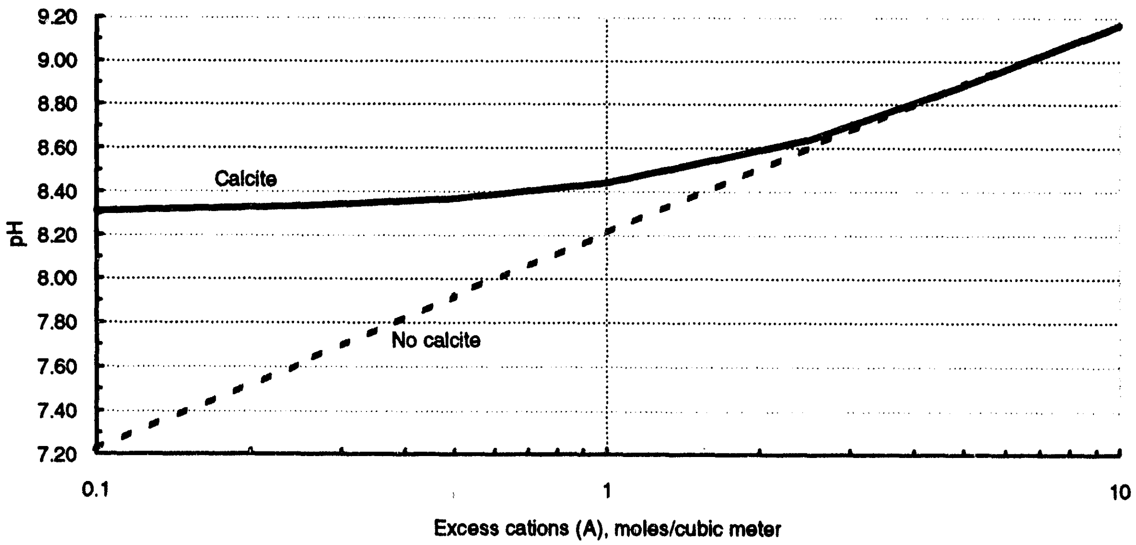


Figure 4-17. Calcite buffering of pH change due to excess cations. (Solution assumed in equilibrium with atmospheric CO2.)

Inorganic Nitrogen. Several aspects of the behavior of the inorganic and organic N in the leachate were studied in the laboratory. The experiments were designed to quantify microbiological processes that convert nitrogen among different forms. The leachate might contain carbon-rich substrates which aerobic microorganisms could use as energy sources; these might be deficient in N and hence the organisms would use inorganic N from the solution -- a process of immobilization. On the other hand it might contain nitrogen-rich compounds that would be rapidly decomposed to yield inorganic N -- a process of mineralization. Finally, the ammoniacal N in solution will be oxidized to nitrate by the microorganisms to some extent -- a process of nitrification. Nitrification is a necessary precursor to denitrification -- the conversion of NO_3 to N_2 or other gaseous nitrogen compounds under conditions where oxygen is absent. Denitrification can have considerable importance in removing N from the leachate.

The experimental procedure was a bit more complex than first glance might indicate. Since the object was to follow inorganic N transformations exclusive of NH_3 volatilization, it was necessary to manage the solutions so that they were well supplied with O_2, yet air flow was restricted enough that NH_3 volatilization was minimal.

Briefly, the experimental procedure was as follows. 200 ml of the test solution was placed in 2,000-ml Erlenmeyer flasks fitted with rubber stoppers. The flasks were placed on a shaker at a low setting so they were gently agitated. At weekly intervals, the stoppers were removed and the air replenished in the flask. Periodically, samples were removed and analyzed for NH_4 and NO_3 using steam-distillation procedures.

Since there is some question about whether or not the nitrifying organisms would be abundant in the leachate and whether or not the effluent might be toxic to nitrifiers, an inoculation was performed on fresh leachate; the source of the inoculant was a sample of leachate that had undergone nitrification in the laboratory as evidenced by accumulation of NO_3. In addition, selected samples received additions of NH_4 and/or NO_3. Table 4-18 lists the treatments. The leachate labeled "new" refers to a sample of leachate collected on September 18, 1989. It was stored overnight under anaerobic conditions and aerated vigorously for 1 hour before being placed in the different treatments. The sample referred to as "old" was collected about six weeks earlier. It had been incubated in the laboratory since then with constant aeration; as evidenced by the NO_3 content it had undergone nitrification and NH_4 had either been lost by volatilization or nitrification, but in any event the inorganic N content was considerably reduced. Table 4-19 lists the composition of the original samples. The following paragraphs summarize the results.

Table 4-20 summarizes the results of linear regressions of total inorganic N on days of incubation. Although several of the regression coefficients were significantly different from zero at the 5% probability level, the net of mineralization minus immobilization was of little importance since there were relatively small changes in total inorganic N when expressed as % change per week as shown in Table 4-20. The regression coefficients in Table 4-20 suggest that there was net immobilization with the "new" leachate, while there may have been a small amount of mineralization with the "old" leachate.

Table 4-18. Description of nitrification experiment treatments.

Treatment ID	New (ml)	Old (ml)	NH_4 added?	NO_3 added?
New	200	0	no	no
New + Old	200	25	no	no
New + NO_3	200	0	no	yes
Old	0	200	no	no
Old + NH_4	0	200	yes	no
Old + NH_4 + NO_3	0	200	yes	yes

Table 4-19. Initial composition of landfill leachate samples used in nitrification experiment.

Parameter	New (mg/l)	Old (mg/l)
Ca	275.90	289.70
Mg	141.70	133.00
K	584.00	494.00
Na	546.00	483.00
Fe	7.31	33.34
Mn	2.93	4.79
Zn	0.11	0.21
Al	0.43	0.46
Cd	nd	nd
Cu	0.16	0.15
Ni	0.08	0.07
Cr	nd	nd
Co	nd	nd
Pb	0.03	nd
As	0.27	0.03
P	0.61	0.60
Total N	239.80	219.40

Samples untreated prior to experiment.

"nd" indicates value less than detection limit of analytical method.

Table 4-20. Linear regressions of inorganic N against days of incubation.

Treatment	Regression equation	Slope significant?	Change (%/week)
New	N = 192 - 0.96*t	yes[*]	-4
New + Old	N = 193 - 0.56*t	yes	-2
New + NO_3	N = 262 - 0.82*t	yes	-2
Old	N = 127 + 0.47*t	yes	+3
Old + NH_4	N = 205 - 0.30*t	no	-1
Old + NH_4 + NO_3	N = 264 - 0.06*t	no	-1

[*] "Yes" indicates that the slope is significantly different from zero at 5% probability level.

The nitrification was estimated by measuring loss of NH_4. The concentration of NH_4 is plotted against time in Figures 4-18 and 4-19. An examination of Figure 4-18 suggests that loss of NH_4 is approximately proportional to the concentration of NH_4; in Figure 4-19, the same data are plotted except that the vertical scale is normalized by dividing by the initial ammonium concentration. The results indicate that the reduction in NH_4 concentration occurs at roughly the same rate in all treatments. This analysis leads to the conclusions that apparently there is no lag period for nitrification and that inoculation with leachate that had already undergone nitrification did not affect the rate of nitrification.

A regression of total Kjeldahl N against total inorganic N yielded the equation:

$$Y = -29 + 1.14X, \qquad R^2 = 0.87, \qquad n = 13 \text{ d.f.}$$

in which Y = mg/l total N and X = mg/l inorganic N

This result is consistent with the foregoing observations that there was very little mineralization or immobilization of N during the long-term incubation studies. Furthermore, this indicates that the inorganic N in the leachate is the major source of N, and hence reduction of inorganic N in the treatment system is an excellent indicator of total N removal and treatment efficiency.

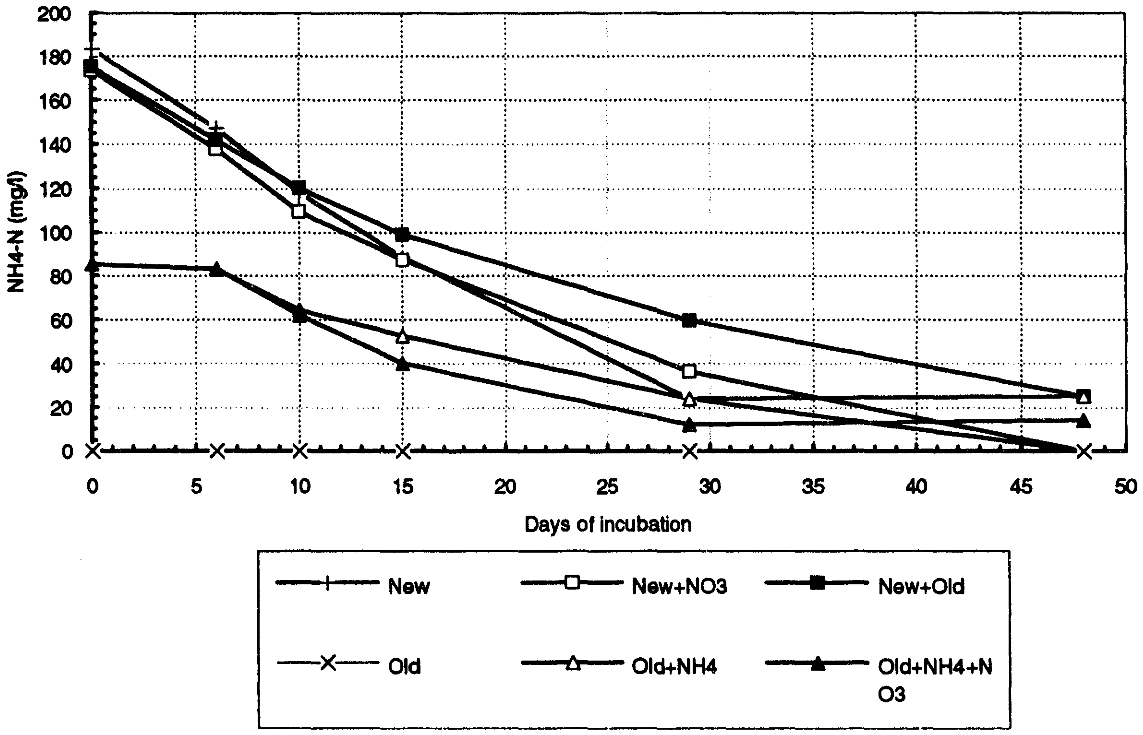


Figure 4-18. Decrease of NH4-N content during incubation in laboratory. (Decrease in NH4-N is accompanied by corresponding increase in NO3-N.)

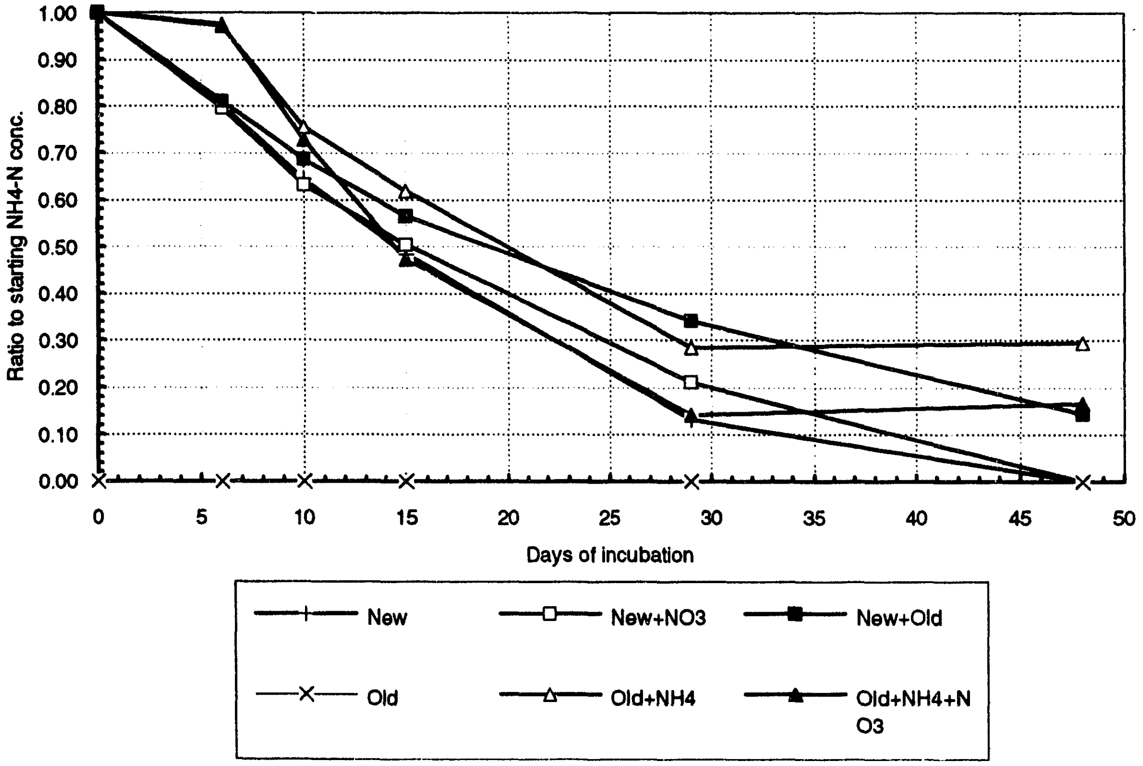


Figure 4-19. Decrease in NH4-N, scaled for different starting concentrations.

In conclusion, these studies support the following statements:

- About 85% of the total N was inorganic N, and essentially all of the inorganic N in the landfill leachate was ammoniacal N.

- Nitrification of the ammoniacal N is relatively slow even when solutions that have undergone nitrification were used as inoculants. This means that nitrification-denitrification is not likely to be a major avenue of loss of N.

__Ammonia Volatilization.__ The laboratory studies of inorganic N behavior indicate that nitrification is a very slow process. The NO_3 content of the solutions in the overland flow beds was usually low, with the exception of September 1990, when NO_3 concentrations were relatively high (Appendix C, Table C-2). The weekly data do not reveal another such episode. Low nitrate is consistent with the expectations based on the laboratory studies. Research on fertilizer N loss from rice paddies indicates that sometimes NH_3 volatilization is the major loss mechanisms, while other studies show that both NH_3 volatilization and nitrification-denitrification are important (Fillery et al. 1986; Fillery et al. 1986b; Simpson et al. 1988). NH_3 volatilization was likely an important avenue of loss of inorganic N in the Fenton treatment system.

Volatilization of NH_3 from flooded rice paddies has been the subject of extensive research in rice growing areas. It is also an important phenomenon in ponds in New York (Bouldin et al. 1974). This information was a major reason for inclusion of the overland flow beds in the original design.

The following equations describe the general nature of the reactions. First, the rate of loss is proportional to the escaping tendency of the NH_3, which is proportional to the difference in partial pressure of NH_3 in solution and the atmosphere remote from the water (Hales and Drewes 1982):

$$F_{NH3} = K_v(P_w - P_a) \qquad [17]$$

where F_{NH3} is the loss rate of NH_3 (g N/m^2/hour)
K_v = constant
P_w = partial pressure of NH_3 in equilibrium with solution (g/m^3)
P_a = partial pressure of NH_3 in atmosphere remote from the air-water interface g N/m^3.

$$P_w = NH_3 10^{(1.6937 - 1477.7/T)} \qquad [18]$$

where NH_3 is the concentration of NH_3 in solution (g N/m^3) and
T is absolute temperature (degrees K).

The well-understood ionization of ammoniacal N partitions the total between ammonium ion and ammonia, as expressed by Freney et al. (1988):

$$NH_3 = \frac{TAN}{1 + 10^{(0.09018 + 2729.92/T - pH)}} \qquad [7]$$

where TAN = total ammoniacal N (NH_4^+ and NH_3) in solution (g N/m^3)
T = absolute temperature (degrees K)
pH = pH of solution

Based on the foregoing equations, pH, ammoniacal N, and temperature are sufficient to calculate P_w. However K_v is a complex function of wind speed, temperature profiles in the boundary layer in the atmosphere immediately above the water, and turbulence in the water (Leuning and Denmead 1984; Freney et al. 1985).

Despite the uncertainty in K_v, some important conclusions may still be drawn about design factors that will enhance NH_3 volatilization. In the following paragraphs, equations [17] to [19] will be used to calculate P_w for some conditions that were observed in the treatment system.

Figure 4-20 illustrates the effect of pH on P_w for 25°C and 100 g TAN/m^3. This illustrates the very important role of pH in NH_3 loss.

Figure 4-16 illustrates the observed diurnal pattern in pH as a consequence of algal photosynthesis. That data combined with the data in Figure 4-20 yields Figure 4-21. Figure 4-21 shows the diurnal pattern of P_w for observed temperature and pH and fixed TAN, plotted separately for the two overland flow beds and one hypothetical tank planted with cattails. In the overland flow beds, the value of P_w undergoes a marked diurnal variation with a brief maximum at mid-afternoon; this is consistent with observations in rice paddies (Fillery and DeDatta 1986; Fillery et al. 1986a; Fillery et al. 1984; Leuning and Denmead 1984; Trevitt et al. 1988; Simpson et al. 1988; DeDatta et al. 1987a; DeDatta et al. 1987b).

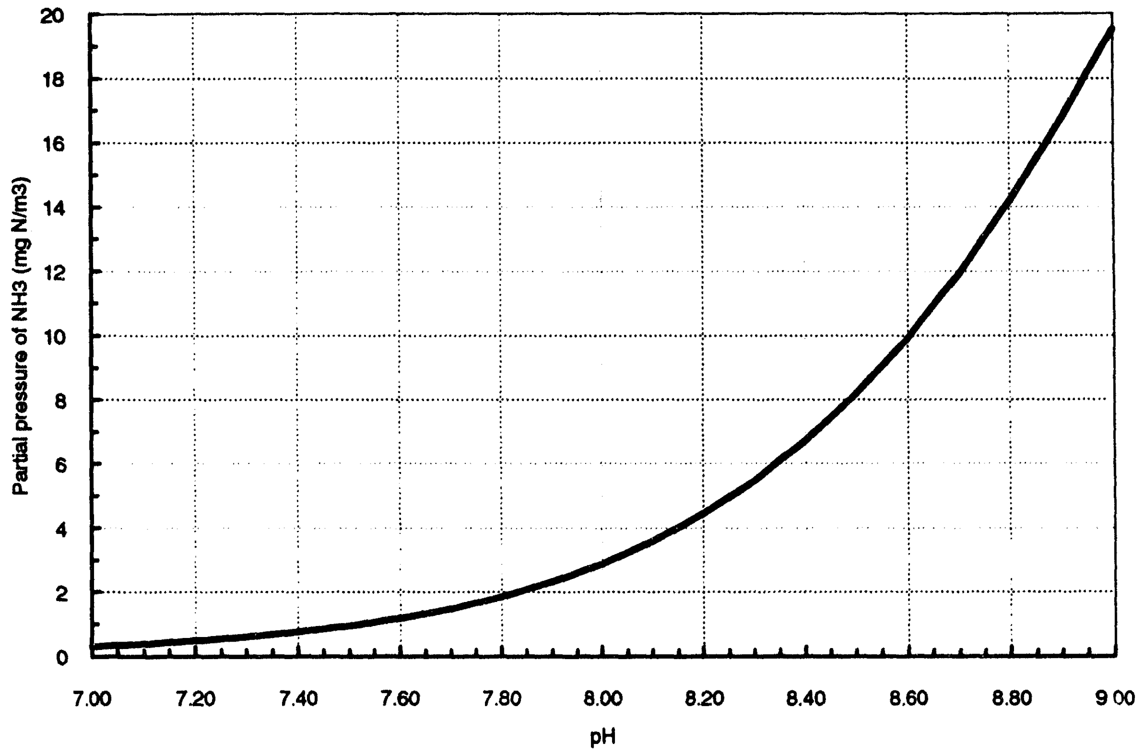


Figure 4-20. Partial pressure of ammonia in equilibrium with solution, as related to pH.

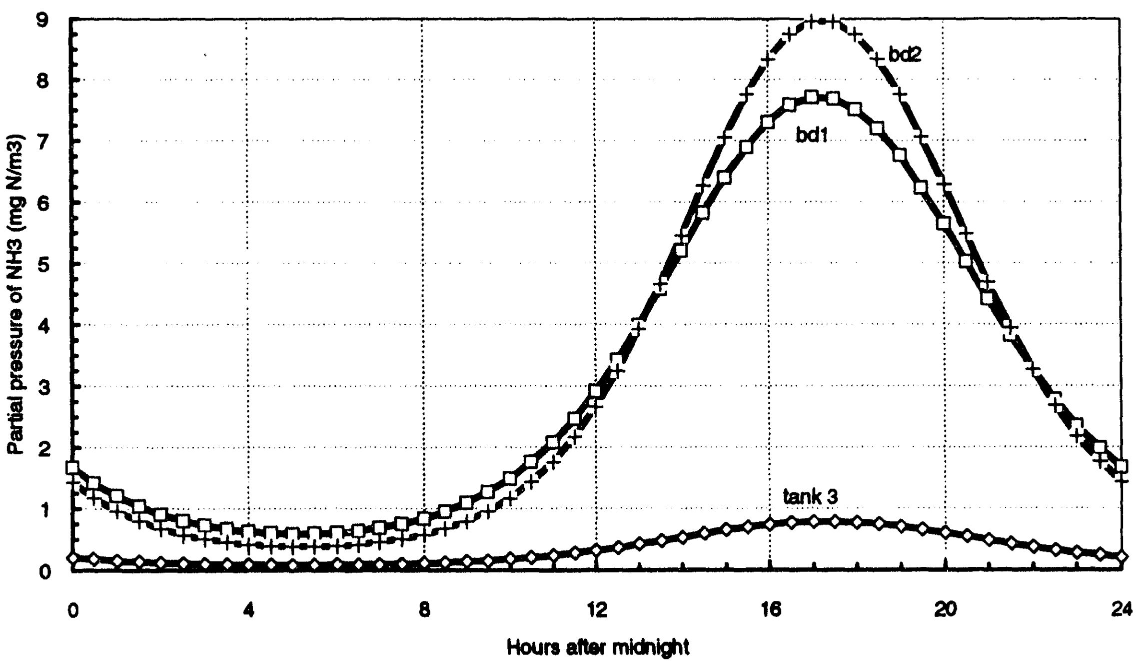


Figure 4-21. Diurnal pattern of equilibrium partial pressure of ammonia for constant total ammoniacal nitrogen, in different parts of treatment system. (Tank 3 holds 200 gallons water, 2 feet deep; planted with cattails.)

This figure implicates algal photosynthesis as a major factor in NH_3 loss. This is consistent with other research (Simpson et al. 1988; Fillery et al. 1986).

An important design factor is whether or not to have emergent plants in the overland flow beds. There are three ways in which emergent species will reduce NH_3 volatilization:

- They will reduce algal photosynthesis and hence reduce pH during the day;
- The vegetation will severely reduce turbulence at the air-water interface and hence reduce loss of NH_3 (Fillery et al. 1984; Humphreys et al. 1988); and
- Respiration by the increased biomass will increase CO_2 concentrations in solution and thereby reduce pH.

Figure 4-21 shows that the first of these factors will reduce the potential by a factor of 8; the others would reduce it even more. The conclusion is that emergent plants will inhibit NH_3 so severely that if the objective is to enhance NH_3 volatilization, emergent plants should be kept out of the overland flow beds. As illustrated in Figure 4-16, the pH in the root zone beds was always below 7.5, and hence the potential for NH_3 volatilization is much less than for the overland flow beds. If there were no plants in the root-zone beds, algal photosynthesis would likely by unimportant because of lack of light. NH_3 volatilization from the gravel beds is probably not important, so this is not a relevant argument for or against emergent species in the gravel beds.

Effect of Loading on Inorganic N Loss. The objective of the following discussion is to examine the relationships among inorganic N loading, inorganic N, concentration and temperature as the landfill leachate moved through the treatment system. Loading equals the influent mass of inorganic N per day, computed from flow X concentration at mh 1.

Linear regressions of concentrations of inorganic N at the ends of beds 1 through 4 on loading of inorganic N and/or temperature were calculated. The regressions employed smoothed data -- running averages over 4 weeks. Load and temperature were independent (R^2 = 0.02). Table 4-21 lists the results together with averages of the several independent variables and average concentration in the landfill leachate at mh 1.

Table 4-21. Linear regressions of inorganic N concentrations at the ends of beds 1 through 4 on loading of inorganic N and/or temperature (All data represent four-week running averages.)

Key: Y = inorganic N concentration (moles m^{-3})
L = loading (g N day^{-1})
T = temperature

Means (and standard deviations) of independent variables:
L = 132 (72)
T = 13 (8)
L*T = 1839 (1699)

Location	Mean (std)	Equations	R^2	Degr. freedom
Manhole 1	Y = 168 (41)			
Bed 1	Y = 69 (37)	Y = 26 + 0.32*L	0.40	70
		Y = 93 - 1.82*T	0.14	70
		Y = 52 + 0.37*L - 2.32*T	0.64	69
		Y = 80 + 0.14*L - 4.25*T + 0.015*L*T	0.68	68
Bed 2	Y = 24 (20)	Y = 7.2 + 0.13*L	0.21	70
		Y = 35 - 0.78*T	0.09	70
		Y = 18 + 0.15*L - 0.97*T	0.34	69
		Y = 31 - 0.04*L - 1.87*T + 0.007*L*T	0.38	68
Bed 3	Y = 22 (19)	Y = 9.5 + 0.096*L	0.14	70
		Y = 36 - 1.04*T	0.19	70
		Y = 23 + 0.12*L - 1.20*T	0.39	69
		Y = 37 + 0.0012*L - 2.18*T + 0.007*L*T	0.44	68
Bed 4	Y = 14 (12)	Y = 9.3 + 0.036*L	0.05	70
		Y = 26 - 0.87*T	0.32	70
		Y = 19.8 + 0.051*L -0.94*T	0.41	69
		Y = 27 -0.010*L -1.46*T + 0.004*L*T	0.44	68

First, note that the average inorganic N concentration was 168, 69, 24, 22, and 14 for mh 1 and beds 1 through 4, respectively. This illustrates that on the average the concentration was reduced by about a factor of 10 by the treatment system. Most of the reduction occurred in bed 1, which suggests the loss mechanisms are concentration-dependent.

In the regression analysis summarized in Table 4-21, the loading seems to become less important and temperature more important from beds 1 to 4. In no case did the interaction term load x temperature appear very important.

The importance of the temperature variable is likely the result of the following:

- Increased temperature enhances the volatilization of NH_3 because of the temperature effect on the chemistry of the solutions, as illustrated by the equations [6] and [7]; and

- Increased temperature probably enhances photosynthesis by algae and this increases the potential for NH_3 volatilization;

Figure 4-22 plots the concentration of inorganic N for beds 1 and 4 against the N load at mh 1. In Figure 4-23 the concentrations of inorganic N at the ends of beds 1 and 4 are plotted against temperature. These illustrate the wide variation in results even when 4-week running averages are used.

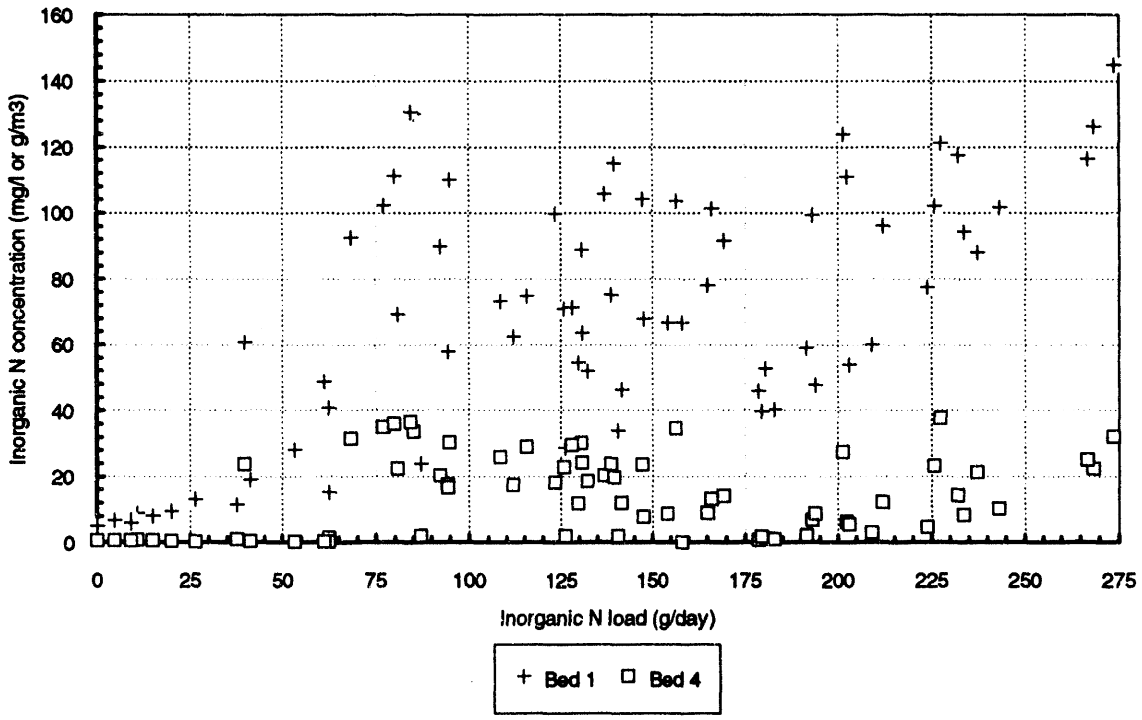


Figure 4-22. Relationship between concentration and loading of inorganic N, beds 1 and 4. Data are weekly, smoothed using 4-term moving averages.

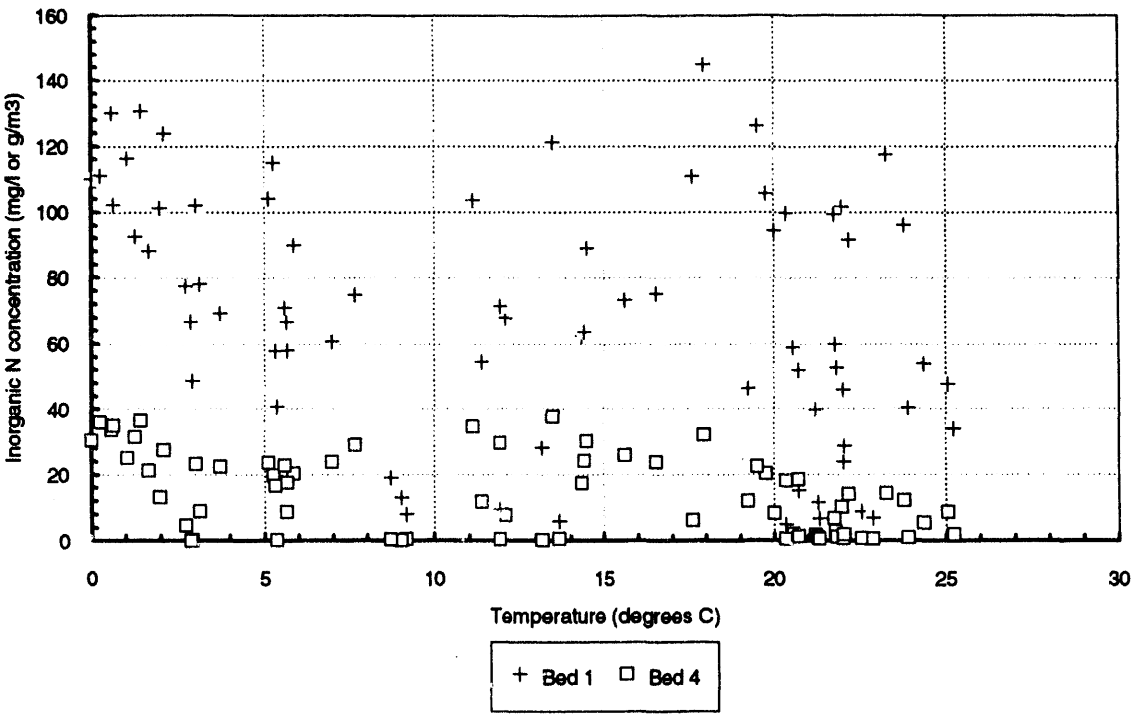


Figure 4-23. Relationship between inorganic N concentration and temperature, beds 1 and 4. Data are weekly, smoothed using 4-term moving averages.

The total area of the two overland flow beds was 290 m^2 and of the root-zone beds was 250 m^2 for a total combined area of 540 m^2. An important question is how useful are the regression equations in extrapolating to other situations and for estimating area required for some particular character of effluent. Perhaps the best answer is that this is one way to summarize the results. Surely the coefficients in the equations are uncertain. A second answer is that the results will always be variable and hence the uncertainty in the coefficients reflects the nature of such systems. The concentration of inorganic N in the treatment system effluent will always be variable because the loading, the rate of loss, precipitation inputs, and evaporation all vary with weather both by season and within seasons. The only way to counteract this variability is to increase the residence time in the treatment system so that the final product reflects the effects of the weather averaged over a longer period of time. This also has the advantage of "polishing" the outflow and thus improving the quality of the effluent. Thus the answer is to increase the holding time to the extent it is economically feasible to do so. Perhaps one way to do this is to build a large holding reservoir at the end of the treatment system with a capacity to hold about a 6-month supply of precipitation, minus evaporation, plus flow from the landfill.

Iron and Manganese. Reduced forms of iron and manganese are the most soluble forms; the oxidized forms are so insoluble at neutral and basic pH values as to be unimportant in this system. The landfill leachate contains iron and manganese far in excess of the amounts expected for oxidized forms, and hence the major amounts of iron and manganese in the landfill leachate are probably in reduced form. This issue is discussed earlier in this section in relation to the 1989 preliminary studies.

The reduced iron would be expected to oxidize quickly at the pH and oxygen concentrations found in the overland flow beds. Relatively insoluble precipitates would be formed. These precipitates may be very finely divided and hence remain in suspension for considerable periods of time. The oxidation of the manganese will be slower and perhaps less complete. The samples were not centrifuged or filtered but were acidified after removal from the beds, and hence there was no differentiation between particulate and dissolved forms of either iron or manganese.

Figures 4-24 and 4-25, illustrate the behavior of iron and manganese, respectfully, in the treatment system. The treatment system largely removed the iron. However, for all practical purposes the treatment system did not remove the manganese. The Fe/K and Mn/K ratios illustrate the variable effects of the different seasons on the performance of the overland flow and root zone beds. Perhaps the root-zone beds are partially anaerobic, and hence the increases in manganese result from reductions in these anaerobic zones. The iron would also undergo reduction but it would be reoxidized once the oxygen concentration was restored.

Ways to increase the effectiveness of the system for manganese removal are not very evident. A first guess would be to convert the root-zone beds to overland flow beds. It is very likely that the root-zone beds will become more anaerobic as time goes on and the root residues increase. Presently the oxygen concentrations are very low and there are likely to be anaerobic pockets; the anaerobiosis is likely to increase, particularly during the summer when the temperature is high and microbial activity in the root-zone beds is most active.

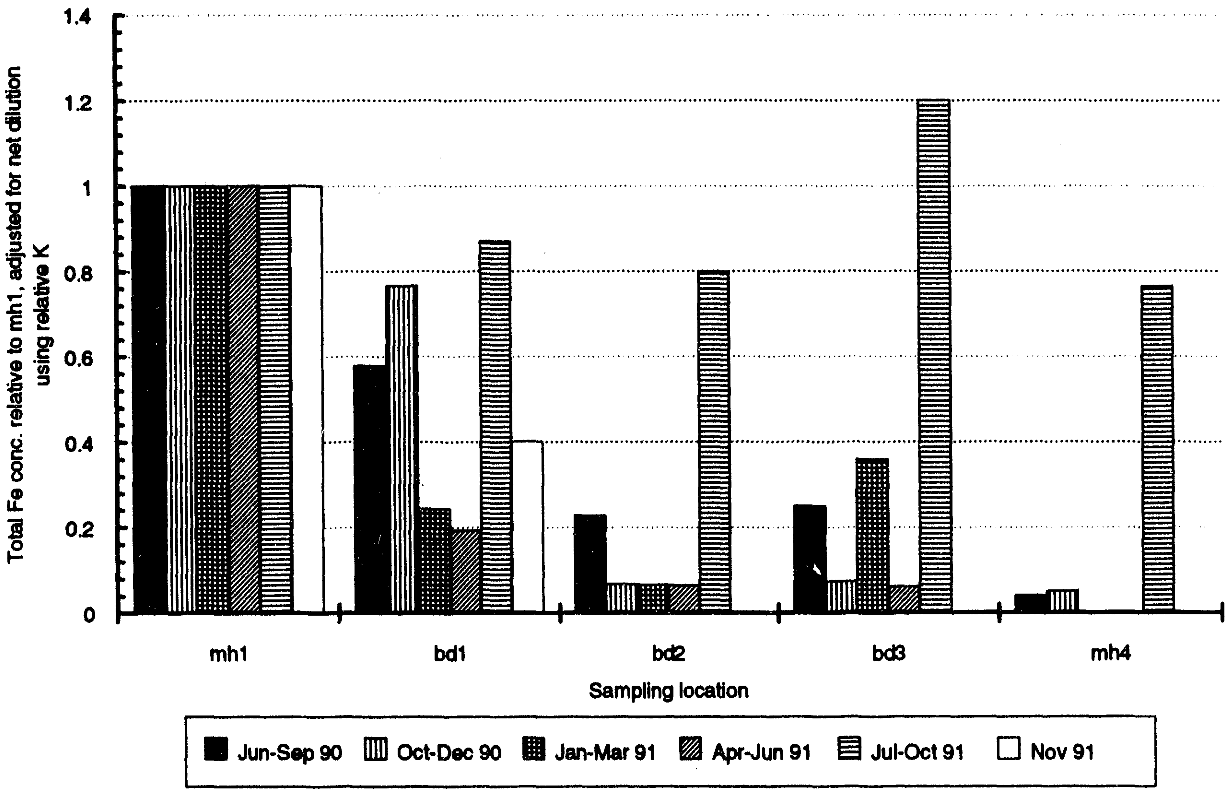


Figure 4-24. Seasonal iron patterns, adjusted for net dilution using K, relative to influent. (Results for Nov 91 in bd2, bd3, mh4 essentially zero.)

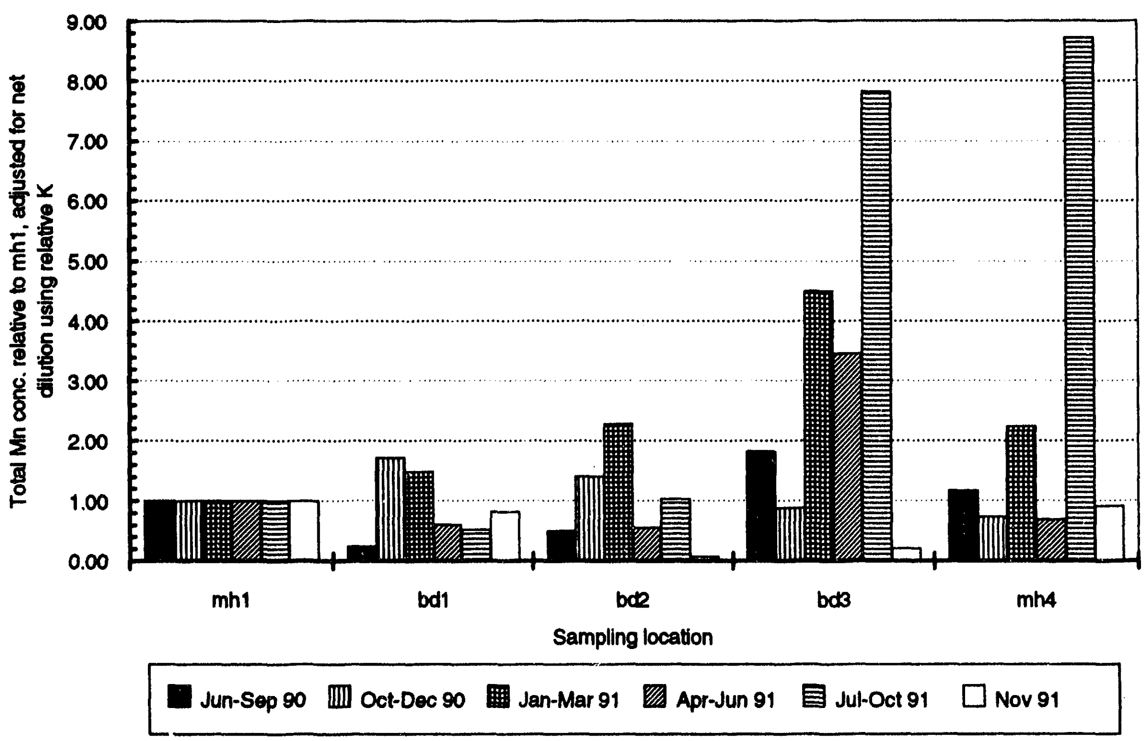


Figure 4-25. Seasonal manganese patterns, adjusted for net dilution using K, relative to influent.

Permeability. Maintenance of permeability is an important indicator of the potential active life of the beds. The results from two different experimental treatment systems have revealed very limited lowering of permeability. In the landfill treatment system, the gravel beds (3 and 4) did not clog to an extent causing overland flow, and there were relatively small changes in permeability during one year of measurement. The sand beds in the greenhouse experiment did not suffer a large reduction in permeability over almost 18 months (see section 4.4).

Yet previous experimental gravel beds at the Fenton landfill site clogged rapidly. The rapid clogging of filters described in the preliminary studies indicates that the leachate from the landfill contained viscous materials that were capable of clogging. The clogging of hoses described in section 3.4 further illustrates the potential.

The following are hypotheses about why this project did not suffer from serious reductions of permeability as a result of clogging. Clogging seems to occur when the leachate is fed in a steady stream into the beds; at the point of entry there is rapid degassing of CO_2 from the leachate, with precipitation of $CaCO_3$ and concurrent oxidation and precipitation of iron oxides and hydroxides. In addition, there are viscous materials in the leachate and there may be production of microbial products that contribute to the clogging. This latter effect has been reported to be enhanced when effluents contain large amounts of inorganic N relative to carbon, which is the situation with the leachate. In the treatment system these reactions were completed in the overland flow beds. The treated solutions entering the gravel beds were nearly at equilibrium with the atmospheric O_2 and CO_2, and hence there was not much precipitation at the point of entry. The viscous materials in the leachate had been degraded by this time and the condition for further production of such materials was not present.

In the greenhouse experiments the leachate was added in one large batch to the drained (and perhaps partially oxidized) sand; for the next two weeks the sand was periodically watered so that the solutions probably remained in the reduced condition. The net result was that there was no clogging because the products of oxidation and degassing were reduced in volume and dispersed throughout the whole volume of sand. Perhaps the periodic draining also reduced the potential for clogging.

The following are suggestions that might alleviate clogging in other systems:

- The overland flow beds may effectively eliminate the clogging problem.

- Pretreatment with forced air for sufficient time would precipitate the calcite and iron oxides. If this is followed by settling in a holding tank, the clogging effect would probably be eliminated, or at least the permeability of any subsequent treatment beds would be only slowly reduced.

- Third (but perhaps less certain) would be to collect and hold the leachate in tanks and then flood the beds very rapidly. Following a specified period, the beds would be drained and kept under aerobic conditions for several days before reflooding. In this manner, the clogging agents would be dispersed by the rapid loading, and during the aerobic period the clogging agents of microbial origin would be partially or completely degraded.

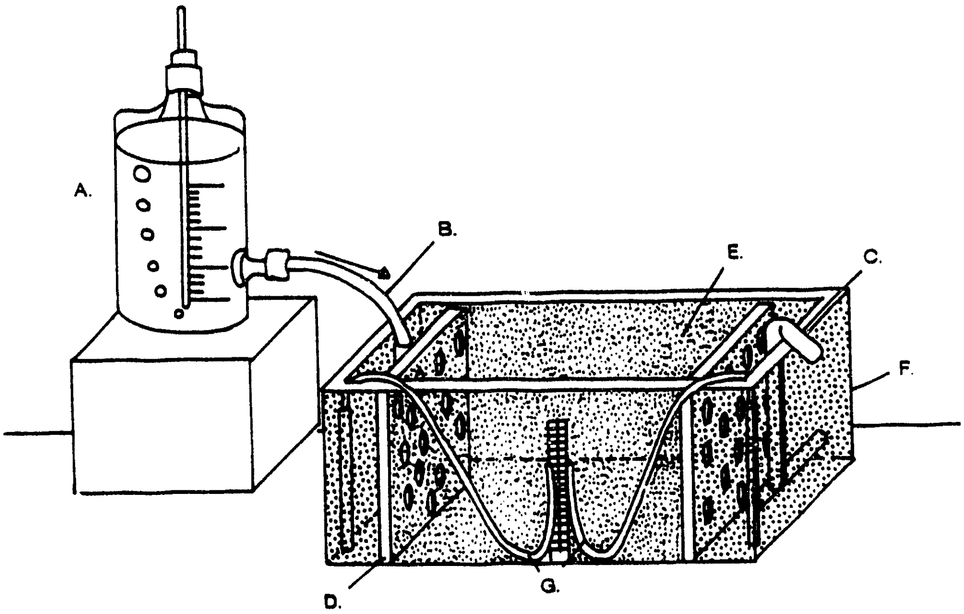
MICROCOSM STUDIES OF ARTIFICIAL WETLAND SYSTEMS

As part of the Fenton Landfill project, a microcosm study was established in greenhouses at Cornell University. Microcosms are meant to simulate, on a small scale, many of the important components of systems that will be implemented on a larger, field scale. The purpose of a microcosm study is to test important assumptions concerning the functioning of the larger system being simulated. There are several aspects of microcosms that make them well-suited for such studies. Microcosms can be kept under greater control, subjected to more treatments, and designed to facilitate performance measurements in ways that are often not practical or too expensive to implement in larger systems.

In this project, microcosms were developed to simulate artificial wetland systems for treating landfill leachate. Several studies have indicated that when waste water moves through porous media in which aquatic macrophytes are rooted, permeability of the media can be maintained and inorganic pollutants in the waste water can be reduced. However, the mechanisms through which the permeability of the wetland beds is maintained and inorganic pollutants are removed from water are not well understood. Such an understanding is necessary to develop appropriate and effective design criteria for the wide range of environments in which these systems may be expected to operate. Also, treatment systems may be expected to operate over many years. Predicting the performance of these systems over time is difficult without a basic understanding of their functioning.

Experimental Design and Procedures

In the design of this experiment, the experimental unit was a microcosm box (Figure 4-26). Eighteen boxes were filled with sand and placed on greenhouse benches and randomly assigned to one of five treatments.



Schematic representation of experimental system constructed to simulate artificial wetland wastewater treatment bed. A.-Mariotte bottle, B-Influent pipe, C-Effluent pipe, D-Perforated styrofoam, E-Sand, G-Water level indicators.
Source: McIntrye and Riha, 1991.

Figure 4 - 26. Microcosm structure.

The treatments were:

1) unplanted, liquid fertilizer applied;
2) planted, liquid fertilizer applied;
3) unplanted, fresh landfill effluent applied;
4) planted, fresn landfill effluent applied; and
5) planted, aerated effluent applied.

Three microcosm boxes were assigned to treatments 1, 3, 4, and 5, while six microcosm boxes were assigned to treatment 2. Table 4-22 summarizes the overall experimental design. The table also introduces brief names for each factor combination tested, such as "+l +p" for "leachate and plants." These will be used in later figures.

Table 4-22. Treatments and identifiers in microcosm experiment.

Dosage	Plants	No Plants
Fertilizer solution	"-l +p" boxes 7, 9, 12, 13, 14, 15	"-l -p" boxes 1,2,11
Fresh leachate	"+l +p" boxes 5, 10, 18	"+l -p" boxes 4, 6, 16
Aerated leachate	"+la +p" boxes 3, 8, 17	--

The boxes were planted with rhizomes of *Typha glauca* on May 1, 1989. Landfill leachate or liquid fertilizer treatment was initiated on June 6. These additions remained in the microcosms generally about two weeks. At this time, the microcosms were drained, the microcosm effluent sampled for analysis, the microcosms rewetted, and the permeability measurements made. Then the microcosms were drained and a liquid fertilizer or fresh or aerated landfill leachate was added. These treatments continued until May 30, 1990. The microcosms were maintained in the greenhouse under 14 hours of light provided by metal halide 1000 W clear lamps. Systems were watered as needed to maintain ponding at the surface.

At the end of the experiment, plant shoots and roots were harvested. Sand was rinsed from the roots as much as possible. The plants were dried to constant weight, ground, and sampled for analysis. The sand was also sampled for analysis.

Multi-ion analyses were run on all plant samples, soil samples, and the microcosm effluent. Nitrogen analyses (NH_4 and NO_2+NO_3) were performed on all microcosm influent and effluent using steam distillation methods. Analytical methods were generally the same as in the Fenton landfill tests.

Permeability measurements were made using a constant-head device connected to an influent pipe in each microcosm. The head was calculated as the difference in the water level between the influent and effluent ends of the boxes. The discharge rate was measured by collecting the microcosm effluent in a graduated cylinder every 10 seconds. For each microcosm, three readings were made and averaged.

Table 4-23 summarizes all sampling procedures used in the greenhouse microcosm experiment.

Permeability

A decrease in permeability of all microcosms occurred as the experiment progressed. This decrease was observed in a similar previous study (McIntyre and Riha 1991). It could not be attributed to the procedure used to measure permeability, since repeated permeability measurements were made on the unplanted boxes for several months before treatments were imposed, and no decline in permeability was observed. Also during this earlier phase, half of the microcosms were flooded continuously and half were left drained between measurements. No differences in permeability between these pre-treatments were found, indicating that the subsequent decline in permeability was not due to alternating aerobic and anaerobic conditions. In the first six months after treatments were imposed, permeability declined exponentially in all microcosms (Figure 4-27). Permeability of the microcosms was still quite high (0.9 to 1.6 cm/s) when the experiment was concluded. The cause of this decline is still unclear.

In contrast to common expectations about the effects of plants in constructed wetlands (e. g. Brix, 1987), there was no evidence that the presence of *Typha glauca* in the microcosms enhanced their permeability. In fact, the permeability of planted microcosms declined slightly more than in the unplanted microcosms (Figure 4-28). The permeability of the microcosms that received landfill leachate did not decline more

Table 4-23. Sample handling methods for microcosm experiment.

Parameters	Sample Type	Sample Handling Method
$NH_4^+ + NH_3$	water	Collect sample in plastic bottles, freeze until analyzed.
$NO_3^- + NO_2^-$	water	Collect sample in plastic bottles, freeze until analyzed.
Total Ca, Mg, K Mn, Fe, Zn, Na, Al Ni, Cu, Cd, Co, Cr	water	In microcosm influent and effluent samples, collect immediately before and after treatment. Add 2 ml conc. HCl to 250 ml plastic sample bottle; then fill bottle with sample (resulting pH approx. 1). Freeze until analysis.
Total Ca, Mg, K Mn, Fe, Zn, Na, Al Ni, Cu, Cd, Co, Cr	roots and some sand	Weigh, dry, grind in hammer mill, reweigh. Ash 20g samples at 400°C, dissolve in 2 ml conc. HCl, re-ash, and take up in 1+9 HCl. Use weight loss to correct for sand.
Total Ca, Mg, K Mn, Fe, Zn, Na, Al Ni, Cu, Cd, Co, Cr	sand	Dry 20g sample, ash at 400°C, reweigh. Add 10 ml conc. HNO_3, then re-ash. Take samples up in 1+9 HCl.
Total Ca, Mg, K Mn, Fe, Zn, Na, Al Ni, Cu, Cd, Co, Cr	shoots	Weigh, dry, reweigh, grind. Follow same procedures as for roots, with no correction for sand. 1+9 HCl.

For sample analysis methods, see Table 4-16.

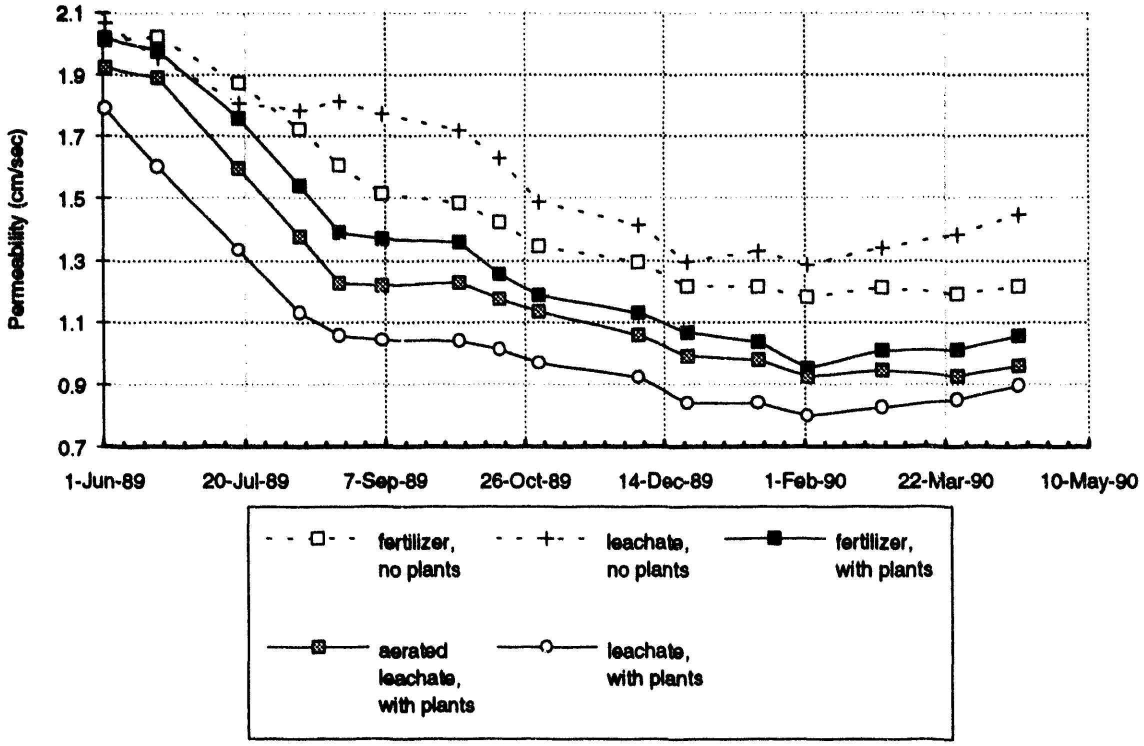


Figure 4-27. Permeability changes over course of microcosm experiment. (Data represent treatment means smoothed using 3-term moving averages.)

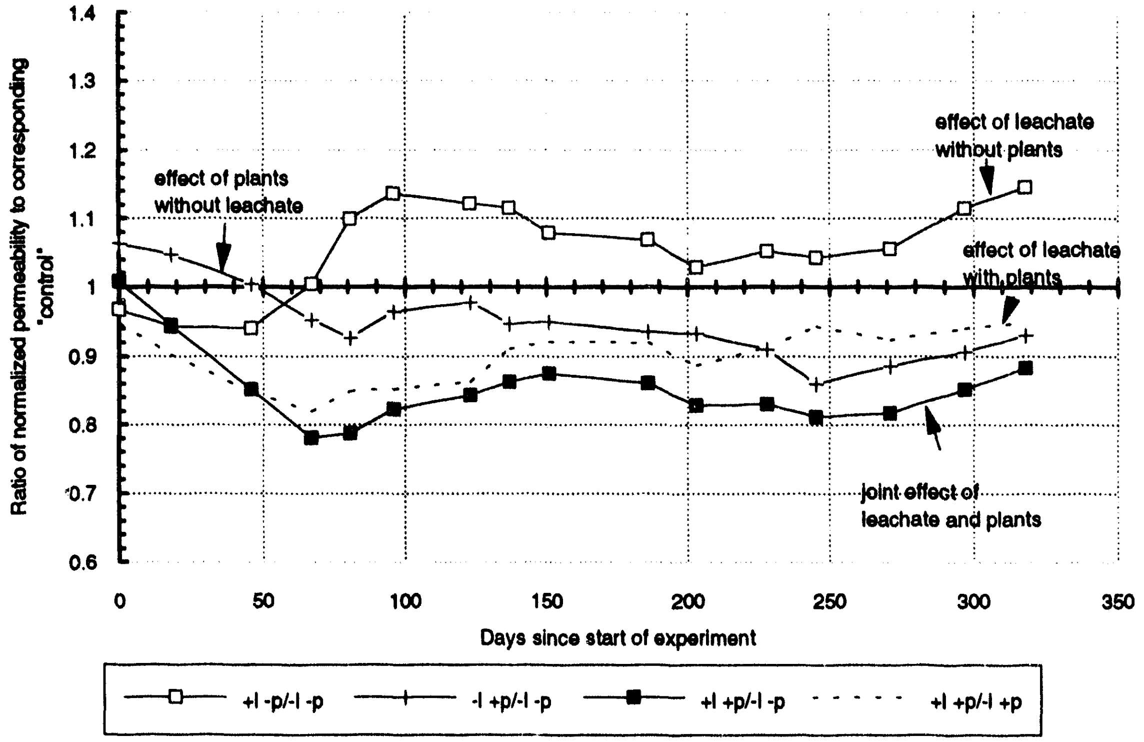


Figure 4-28. Effects of plants and leachate on microcosm permeability. (Data represent treatment means smoothed with 3-term moving averages, expressed relative to starting conditions.)

than those that received liquid fertilizer treatment. Aeration of the landfill leachate for several days before applying it to the microcosms did not affect permeability compared to microcosms treated with unprocessed leachate (Figure 4-29).

__Nitrogen Removal__

Landfill leachate was applied to three sets of microcosms generally every few weeks. At the same time, a fertilizer solution was applied to the remaining microcosms. In both cases, the solutions remained in the microcosms for two or more weeks before they were drained and another batch of fertilizer or leachate applied. The fertilizer solution applied contained 70 mg/l N (14 mg/l urea-N, 36 mg/l NH_4-N, 20 mg/l NO_3-N). The landfill leachate applied ranged in N concentration from 77 to 232 mg N/l, with essentially all N in the form of NH_4 (with one exception, when NO_3 levels were 70 mg N/l in the aerated landfill leachate).

On average, in all treatments at least 50% of the applied nitrogen did not appear in the microcosm effluent (Figure 4-30). The unplanted treatment that received fertilizer solution removed on average 70% of the applied nitrogen. However, this varied with season, removal being greater than 90% at the beginning and end of the experiment and only about 60% in the middle of the experiment (the winter months) (Figure 4-31). A similar pattern was observed in the planted microcosm that received fertilizer solution, but at all times removed nitrogen was as great as or greater than in the unplanted microcosms receiving fertilizer solution. It appeared that in the winter NO_3 was not removed from the solution in the unplanted, fertilizer-treated microcosms (Figure 4-32).

The lowest removal rate (50%) was for the unplanted microcosms that received leachate. The removal rate did not show a distinct seasonal pattern, but the amount of N in the leachate applied in winter was generally lower than that applied at other times (Figure 4-33). The planted microcosms that received leachate removed on average 75% of the applied nitrogen. Aerating the leachate did not substantially affect either the amount or pattern of leachate nitrogen removal. Essentially all nitrogen remaining in the landfill leachate at the end of each treatment period was in the form of NH_4. At all times, the planted microcosms receiving leachate removed more nitrogen than those receiving fertilizer solution, so the leachate did not appear to be inhibiting plant removal of nitrogen. The planted microcosms receiving leachate required more time after the experiment was initiated to reach a maximum removal rate (Figure 4-31) than did the planted microcosms receiving fertilizer solution. This is not surprising, considering the greater amounts of N applied in the leachate.

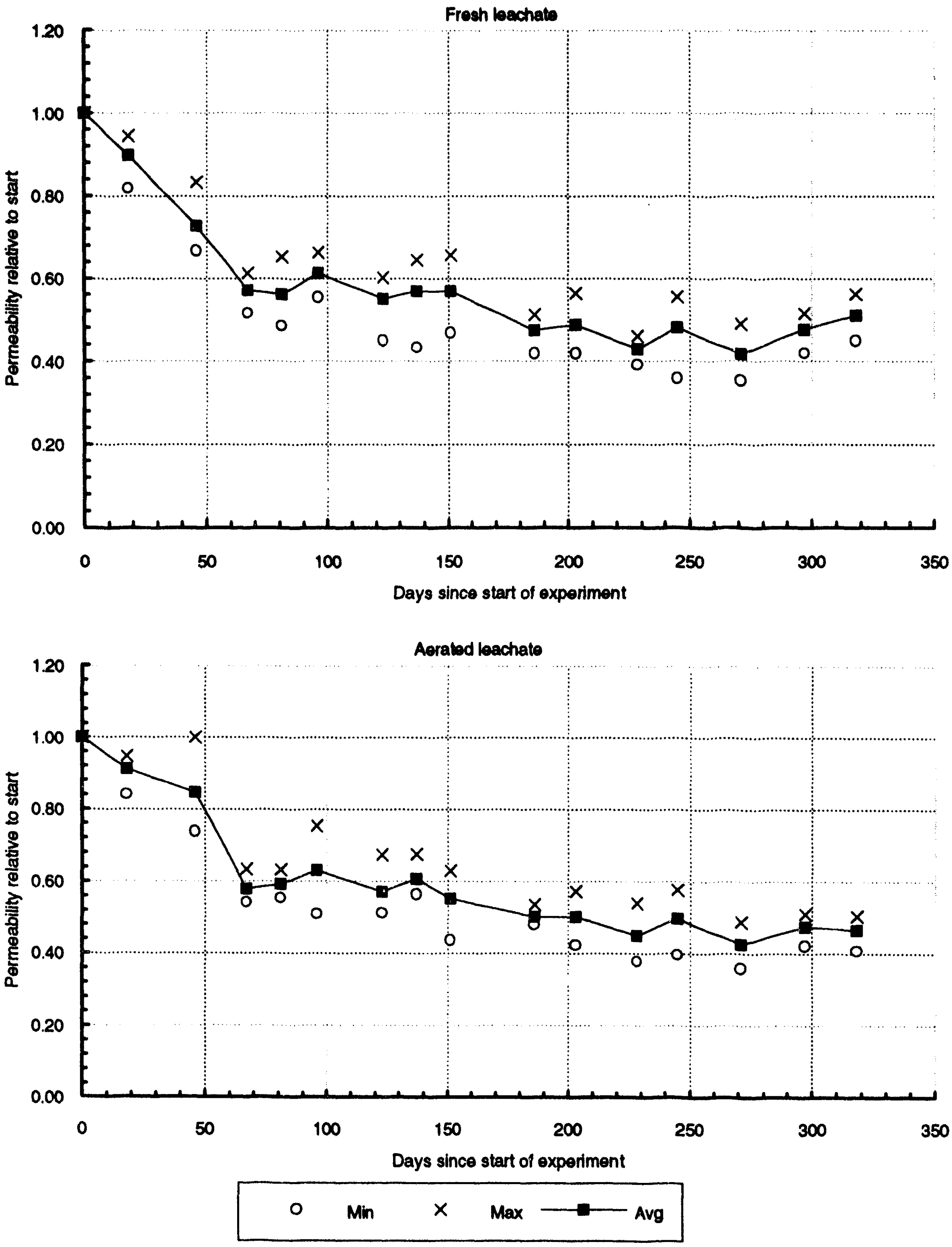


Figure 4-29. Effect of leachate aeration on microcosm permeability. (Solid lines represent treatment averages, x and o symbols represent range among replicates. Data expressed relative to starting conditions. Both cases include plants.)

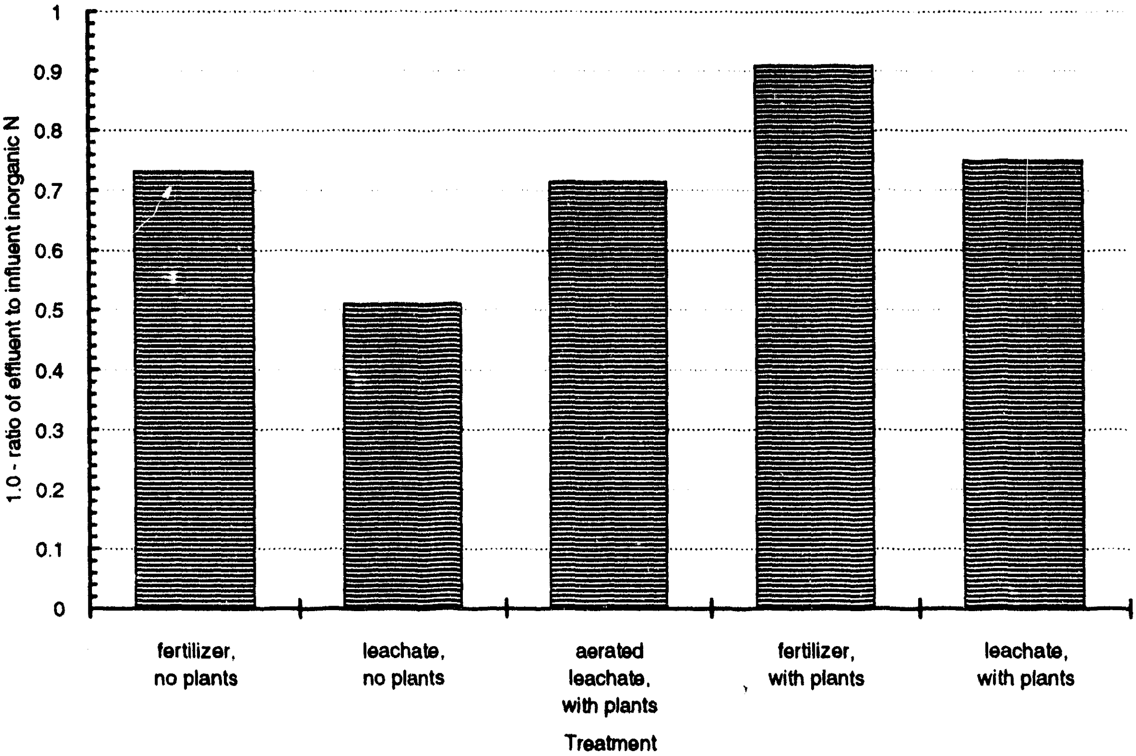


Figure 4-30. Average inorganic N removal in microcosms. (Data represent treatment means averaged over lifetime of experiment.)

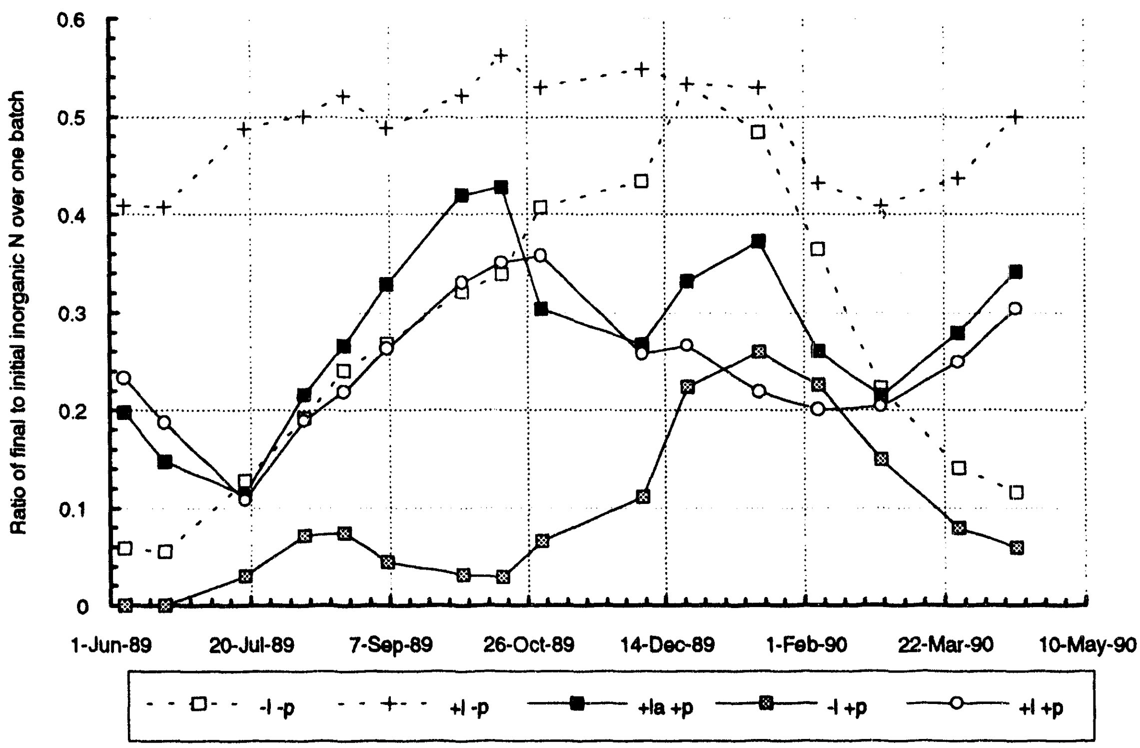


Figure 4-31. Inorganic nitrogen removals over course of microcosm experiment. (Data represent treatment means smoothed using 3-term moving averages.)

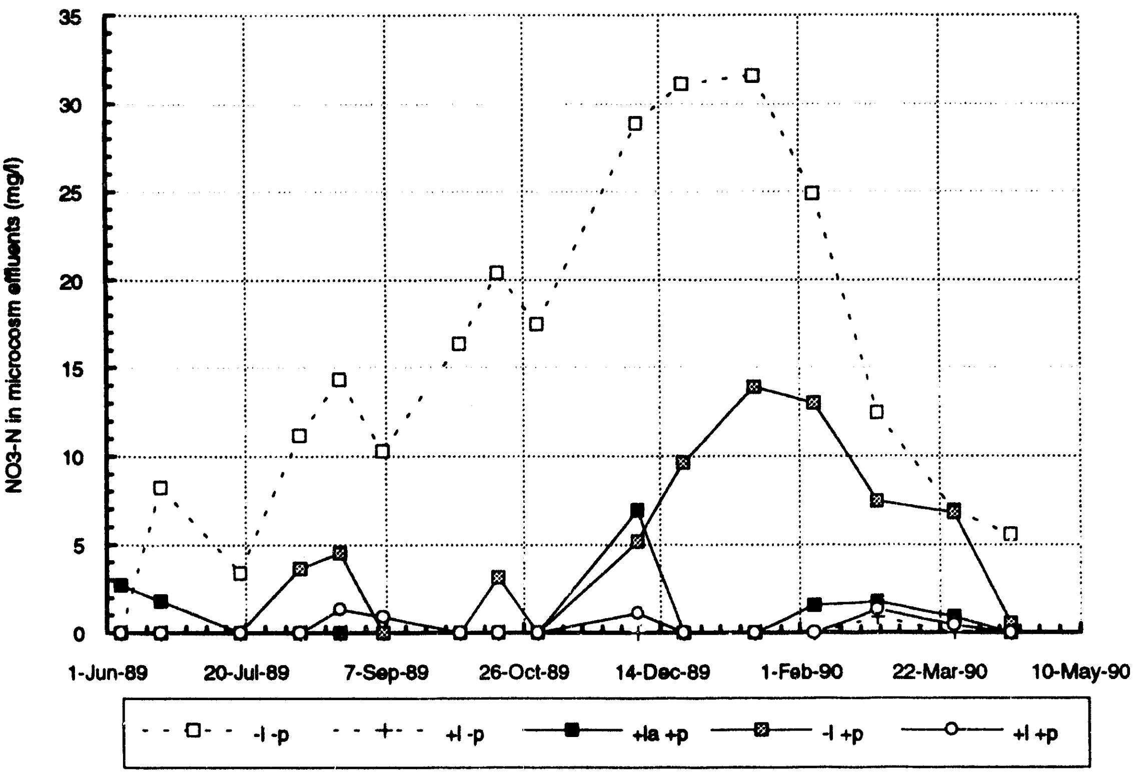


Figure 4-32. Nitrate in microcosm effluents over course of experiment. (Data represent treatment means.)

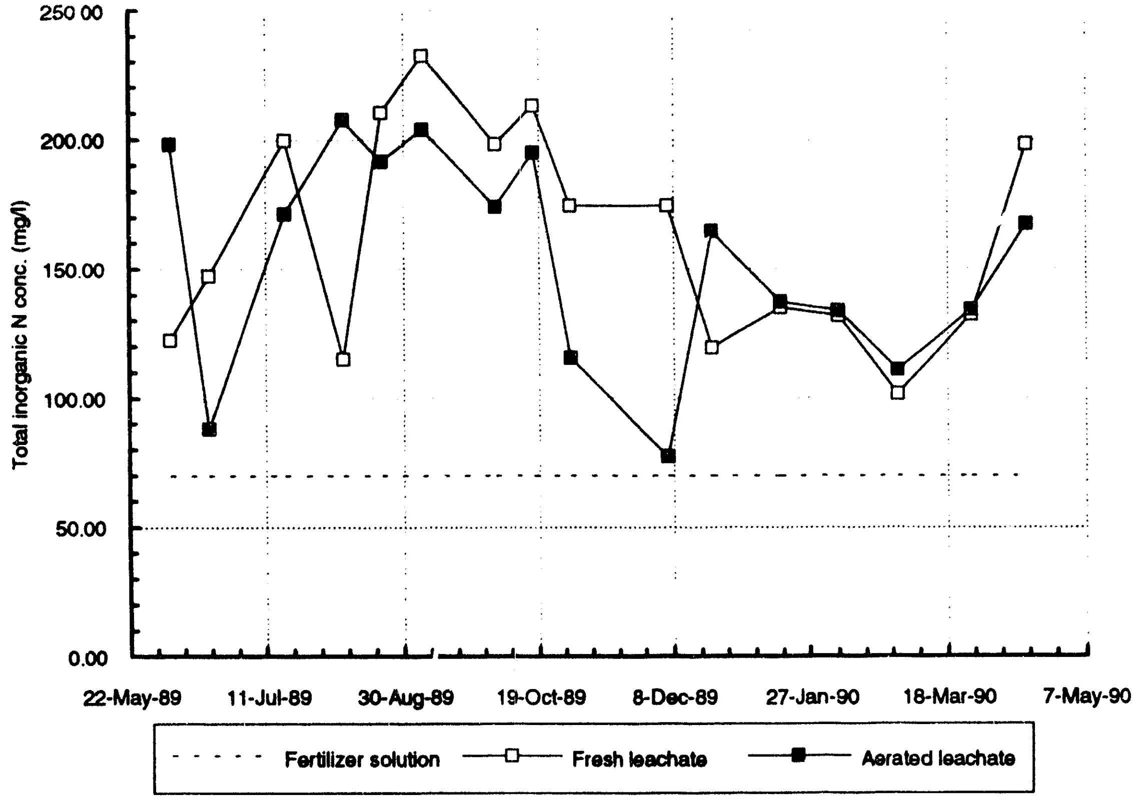


Figure 4-33. Inorganic N concentrations in microcosm influent.

Other Inorganic Ion Removal

The treatment means of several inorganic ion concentrations in the water after residing two or more weeks in the microcosms are presented in Table 4-24. These are the averages of all the batch applications of leachate or liquid fertilizer. The effluent from landfill leachate-treated microcosms had more Mn, Fe, Mg, K, and Na compared to the effluent from the liquid fertilizer treated microcosms. Plant uptake was clearly important in reducing K in water from both the leachate and liquid fertilizer treatments. The presence of plants appeared to inhibit Ca removal in both the fertilizer- and leachate-treated microcosms. The most noticeable treatment differences were between fresh and aerated leachate. Systems receiving aerated leachate had less Mn, Ca, and Fe remaining in the processed water compared to systems receiving fresh leachate.

The elemental content of the sand, roots, and shoots, which were sampled at the completion of the experiment, is presented in Table 4-25. Sand in the microcosms that received aerated leachate appeared to have less Mn than sand in the microcosms that received fresh leachate. Shoots of the plants grown in aerated leachate had lower Ca and Mn concentrations than their fresh leachate counterparts. The roots of plants grown in leachate-treated microcosms had higher concentrations of Fe and Mn than their liquid fertilizer-grown counterparts.

There was no difference in final root weights among the planted microcosms (Table 4-26). Final shoot weight of plants grown in the aerated leachate was lower that of plants grown with fresh leachate or liquid fertilizer.

Discussion

The discussion of permeability of the Fenton landfill wetland beds in section 4.3 suggested that clogging of wetland waste treatment systems may occur when leachate with elevated levels of CO_2 is exposed to the atmosphere. Degassing could occur with a subsequent precipitation of calcite and oxidation of iron and manganese. Such precipitates could decrease pore size. The sand in the unplanted microcosms that received landfill leachate did have significantly more Ca and Mn at the end of the experiment than in all other treatments. The similarity of the planted, leachate-treated sand to the treatments that received no leachate is likely the result of more reduced conditions and higher dissolved CO_2 levels in the microcosms with plants. Such conditions would favor the reduction of iron and manganese and therefore enhance their solubility. The higher CO_2 levels could enhance the dissolution of calcite. In any case, the increase in calcium and manganese found in the unplanted, leachate-treated microcosms

Table 4-24. Treatment methods related to microcosm effluent qualities. (Values represent averages over life of experiment [mg/l]).

Replicate means

Box #	Treatment*	Ca	Mg	K	Na	Fe	Mn	Zn
1	-l -p	55	13	35	17	0.00	0.02	0.20
2	-l -p	49	13	47	16	0.00	0.00	0.27
11	-l -p	55	12	37	17	0.00	0.09	0.19
7	-l +p	81	15	9	17	0.00	0.00	0.15
12	-l +p	83	15	17	17	0.00	0.00	0.22
14	-l +p	71	13	15	16	0.00	0.02	0.12
4	+l -p	124	61	130	254	4.64	1.34	0.24
6	+l -p	144	67	139	272	7.00	1.90	0.12
16	+l -p	136	63	136	261	3.99	1.51	0.11
5	+l +p	179	72	126	289	4.60	1.56	0.15
10	+l +p	166	65	112	264	4.01	1.25	0.14
18	+l +p	172	66	106	258	3.81	1.15	0.12
3	+la +p	75	56	112	252	1.00	0.26	0.28
8	+la +p	82	63	120	284	1.05	0.31	0.14
17	+la +p	85	56	112	243	1.13	0.29	0.15

Treatment means

Treatment	Ca**	Mg	K**	Na	Fe**	Mn**	Zn**
-l -p	53 d	12	40 c	16	0.00	0.04 b	0.22 a
-l +p	79 c	14	14 d	16	0.00	0.01 b	0.16 ab
+l -p	135 b	64	135 a	262	5.21 a	1.58 a	0.16 ab
+l +p	173 a	68	115 b	270	4.14 a	1.32 a	0.14 b
+la +p	81 c	59	115 b	259	1.06 b	0.29 b	0.19 ab

* "l" stands for leachate, "la" for aerated leachate, and "p" for plants.

** Letters following numbers indicate groups of means within a column that are not significantly different from one another at 5% level by Student's T test. For example, in the "Ca" column, the two values labelled "c" are not significantly different from each other.

"nd" indicates value less than detection limit of analytical method.

Table 4-25. Treatment methods related to final microcosm sand and plant chemical contents.

Sand analyses (mg/kg except OM)

Treatment	%OM	Ca	Mg	K	Na	Fe	Mn	Zn
-l -p	0.26	156 b	12	9.83	3.50	114	2.75 ab	1.16
-l +p	0.35	220 b	48	6.50	4.83	162	1.59 b	1.52
+l -p	0.43	326 a	46	10.00	4.50	148	6.06 a	1.65
+l +p	0.31	159 b	22	12.50	12.00	161	4.20 ab	1.47
+la +p	0.33	154 b	26	17.50	9.67	141	1.34 b	2.25

Root analyses

Treatment	Ca	Mg	K	Na	Fe	Mn	Zn
	%	%	%	%	%	%*100	%*100
-l +p	1.28a	0.30	1.21	0.26	0.07 a	0.47 a	0.31 a
+l +p	0.99a	0.29	1.30	0.29	0.13 b	1.46 b	0.45 a
+la +p	1.34a	0.44	1.15	0.41	0.19 b	1.12 b	0.54 a

Shoot analyses

Treatment	Ca	Mg	K	Na	Fe	Mn	Zn
	%	%	%	%	%	%*100	%*100
-l +p	1.51 a	0.20	1.41	0.24	0.014 a	1.13 a	0.201
+l +p	1.40 a	0.29	2.01	0.39	0.013 a	5.65 b	0.214
+la +p	0.92 b	0.34	1.65	0.28	0.012 a	2.29 c	0.317

Letters following numbers indicate groups of means within a column that are not significantly different from one another at 5% level by Student's T test. For example, in the "Ca" column, the two values labelled "a" are not significantly different from each other.

Table 4-26. Treatment means of final microcosm plant dry matter.

	Treatment mean biomass (g)		Ratio
Treatment	Shoots	Roots	root/shoot
-l +p	611 a	1294 a	2.12
+l +p	696 a	1629 a	2.42
+la +p	395 b	1250 a	3.20

Letters following numbers indicate groups of means within a column that are not significantly different from one another at 5% level by Student's T test. For example, in the "Shoots" column, the two values labelled "a" are not significantly different from each other.

was not associated with a decrease in permeability. Precipitates of these elements may not have been present in sufficient quantities to significantly reduce the number and size of pores. In addition, the landfill leachate was applied to the surface of the entire system, thus diluting the effect of precipitates relative to many inlet systems.

The development of bacterial mats at water inlets may plug pores. It is possible that clogging by microorganisms may have been responsible for the initial decline in permeability observed in all microcosms. Enhanced bacterial clogging of leachate treated systems was not expected because of low BOD content of the landfill leachate.

It is clear from these and other studies that substantial amounts of inorganic nitrogen can be removed from wastewater when it is ponded for an extended period. There was no evidence that NH_4 in the landfill leachate was being nitrified in either the planted or unplanted microcosms. In the absence of plant uptake, it must be assumed that NH_4 was volatilized and lost as NH_3. As discussed previously, higher temperatures and rates of photosynthesis by algae favor NH_3 production. Both such conditions were present in the greenhouse, although temperatures and solar radiation were lower during the winter than the summer months. This may explain the somewhat reduced rates of removal during the winter months, even though the landfill leachate generally contained less nitrogen during this period.

The increase in leachate nitrogen removal seen in the microcosms planted with cattails is almost certainly due to plant uptake. The increasing ability of the planted microcosms at the beginning of the experiment to remove nitrogen relative to the unplanted controls is consistent with the pattern of plant growth. However, this sink for nitrogen will not persist indefinitely unless plant material is harvested regularly. The degree to which the presence of plants may have reduced NH_3 volatilization is unclear. However, there is no reason to suppose that plants will enhance volatilization. Therefore, as previously mentioned, in the absence of plant harvesting, there is little reason to think that planted wetlands will enhance NH_4 removal relative to unplanted systems.

The pattern of NO_3 concentrations in the unplanted microcosms treated with liquid fertilizer suggests that denitrification occurred at much lower rates in the winter than the summer months. Perhaps this was due to reduced greenhouse temperatures and reduced carbon supply from algae during winter months when less solar radiation is received. Further study of the NO_3 dynamics in these simple systems is warranted.

The results suggest that aeration of the leachate did result in precipitation of Ca, Mn, and Fe and that this reduced the concentration of these ions in the landfill leachate water added to the boxes. This supposition is further supported by the fact that neither Ca, Mn, nor Fe was found in elevated levels in the sand or plants of the microcosms that received the aerated leachate when compared to the microcosms that received fresh leachate.

There was little evidence that the presence of plants, when considered over the entire experimental period, significantly reduced the concentration of any ion except K. The effect of leachate pre-aeration on reducing Ca, Mn, and Fe was much more noticeable. This supports the suggestion proposed earlier in the report that overland flow beds that promote aeration of the leachate are essential in Fe, Mn, and Ca removal. The presence of plants did not appear to promote a rhizosphere environment that enhanced removal of inorganic ions. Over the period of this study, there was little evidence that plant uptake significantly reduced the concentration of base cations and metals in the landfill leachate. As previously mentioned, the rationale for the inclusion of aquatic macrophytes in wetland treatment systems should be based on functions other than permeability maintenance and inorganic pollutant removal.

LABORATORY STUDIES ON GROWTH OF FLOATING PLANTS AS AFFECTED BY LEACHATE

The family *Lemnaceae* or duckweeds, are free-floating water plants with a world-wide distribution (Landolt 1980). Approximately 40 species make up the family, which is divided into five genera. All exhibit considerable vegetative growth through budding of new plants from the mature plant. Two genera (*Spirodela* and *Lemna*) have two budding pouches, the other two (*Wolffia* and *Wolffiela*) have just one pouch. New plants usually remain attached to the mother plant, forming small colonies for a day or so, and then separate (Bernard et al. 1990).

Duckweeds are the world's smallest flowering plants (Armstrong 1986), ranging in size from the species *Wolffia angusta*, which averages about 0.5 mm in length, to *Spirodela polyrhiza*, about 1.5 cm in length (Figure 4-34). The plant body is not differentiated into stem or leaf and is called a frond. The fronds vary in the four genera, those of *Wolffia* and *Wolffiela* are very simple and lack roots. Fronds of *Lemna* have one root and those of *Spirodela* have more than one.

A useful quality of these plants is that they are easy to grow in axenic culture. This makes it possible to eradicate all other organisms from the culture, ensuring controlled conditions. Their small size, wide distribution, ease of maintaining cultures, and rapid rate of reproduction make them a convenient experimental plant.

Ithaca College has a collection of duckweeds in axenic culture. Some of the species in this collection were used in experiments on the effects of Fenton landfill leachate on plant growth. No duckweeds occur naturally in the ponds or in the experimental beds at Fenton. Ithaca College students carried out a series of laboratory experiments over two years. Their purposes were to observe the growth of species of duckweed, specifically *Spirodela polyrhiza*, *Lemna minuscula*, *Wolffia borealis*, and *W australiana* in solutions of landfill leachate of various concentrations. *Lemma minor*, the local species, was not available, so *Lemma miniscula* was used for the experiments. The two species are similar in morphology.

Methods

All experimental work was done in a clean room using axenic culture and all transfer of plants was done in a laminar flow hood (Bowker et al. 1980). In each experiment plants were grown in small, sterile

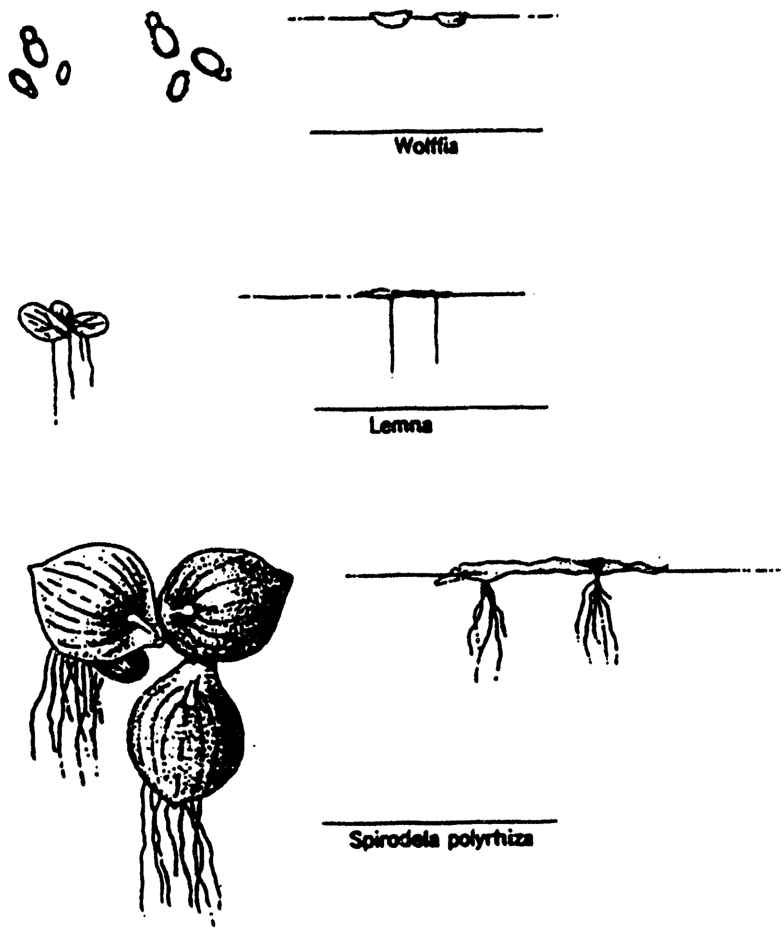


Figure 4 - 34. Illustrations of the three taxa of the family *Lemnaceae* used in laboratory experiments.

petri dishes in either a modified Allan and Arnon solution (Allen and Arnon 1955) or landfill leachate of various concentrations. All experiments were performed for 14 days, beginning with six healthy fronds being placed in each petri dish with the appropriate solution. All plants in each experiment were taken from a culture started with just one plant; thus, all plants in each separate experiment had the same genetic composition. Six replicates of each different nutrient or leachate level were prepared and placed in an incubator that provided continuous illumination at a temperature of 25°C. Plants were taken from the incubator at intervals and plants counted and their condition noted. New solution was prepared and given to the plants at the end of seven days.

At the end of the experiment, plants in each dish were counted and, in some experiments, the length of roots and the total weight of plants in the dishes was determined.

Results

Experiment 1: The effect of raw and aerated leachate on *Spirodela polyrhiza* and *Wolffia borealis*. In this experiment plants were grown either on raw leachate collected from mh 1 or in leachate that had been aerated for one month. In both cases, a 50% dilution of the leachate was also made. Table 4-27 presents data on the effect of the raw untreated and aerated leachate on the growth of the two plants. It is clear that all experimental solutions had a great effect on plant growth. *Spirodela* growing in the control solution grew to a total of 323 plants in 14 days, 5-10 times the growth in raw or aerated leachate, either full or half-strength. The *Wolffia* plants were similar, the control dishes growing to 5-8 times more plants than the experimental. It may be significant that plants in aerated leachate did not grow as much as plants in raw leachate.

Table 4-27. Growth of *Spirodela polyrhiza* and *Wolffia borealis* in raw (untreated) leachate from the Fenton landfill and leachate aerated one month. (Numbers are number of plants in culture at end of the experiment.)

	Control	Raw Leachate		Aerated Leachate	
Species	AAN	100%	50%	100%	50%
Spirodela poly.	323	51	70	30	60
Wolffia borealis	85	14	--	11	--

Experiment 2: The effect of leachate from the landfill and from experimental beds on growth of *Lemna minuscula* and *Wolffia australiana*. Table 4-28 compares growth of *Lemna* and *Wolffia* in control and solution from Fenton's mh 1 and from the downgradient ends of each of the four constructed treatment beds. Both plants grew approximately the same in the experimental dishes. All plants in raw leachate and from bed 1 died within four days of the beginning of the experiment, while all the others survived but only grew to an average of 39 plants per dish. The controls grew to 745 (*Lemna*) and 562 (*Wolffia*) plants per dish during the same time period.

Table 4-28. Growth of *Lemna minuscula* and *Wolffia australiana* in raw (untreated) leachate collected from mh1 at Fenton and leachate collected from the ends of four treatment beds. (Numbers are number of plants in culture at the end of the 14-day experiment.)

Species	Control	mh1	Bed 1	Bed 2	Bed 3	Bed 4
Lemna min.	745	Dead	Dead	35	39	42
Wolffia aust.	562	Dead	Dead	50	42	25

Experiment 3: The effect of iron and landfill leachate on growth of *Spirodela polyrhiza* and *Lemna minuscula*. Table 4-29 illustrates growth of plants at five different iron concentrations compared to growth in either control or landfill leachate. All experimental plants in solution culture grew somewhat less than control plants. but it wasn't until concentrations reached 20 mg/l that number of plants began to decline. At 40 mg/l, *Spirodela* grew only about half as well and *Lemna* grew less than half as well. Although high iron concentrations seem to have an effect on growth, the effect is not nearly as strong as the landfill leachate; only about 70 plants grew in culture, regardless or whether the leachate was raw or had filtered through the constructed beds.

The effects were seen not only in plant numbers but plant weight. Plants growing in 0.3 mg/l Fe to 20 mg/l concentrations all weighed about 0.33 g per dish. Those growing in 40 mg/l concentration weighed only 0.18 g per dish, and those in landfill leachate weighed only 0.07 g per dish.

Table 4-29. Growth rate of *Spirodela polyrhiza* and *Lemna minuscula* in control, five iron solutions, and raw leachate and treated leachate from Fenton landfill. (Numbers represent number of plants at end of 14-day experiment.)

		Iron solutions (mg/l)					Fenton Leachate	
Species	Control	0.3	1	5	20	40	mh1	Bed 4
Spirodela poly.	413	297	325	324	304	224	80	75
Lemna min.	807	707	698	793	617	320	60	64

Experiment 4: The effect of manganese and landfill leachate on growth of *Spirodela polyrhiza* and *Lemna minuscula*. Table 4-30 illustrates growth of plants at five different manganese concentrations compared to growth in either control or landfill leachate. None of the concentrations except the 0 manganese seemed to have any effect on growth of either species, although there is a slight indication that levels about 5 mg/l and above may begin to have an inhibiting effect.

Table 4-30. Growth rate of *Spirodela polyrhiza* and *Lemna minuscula* in control, five manganese concentrations, and raw leachate and treated leachate from Fenton landfill. (Numbers represent number of plants at end of 14-day experiment.)

		Manganese solutions (mg/l)					Fenton Leachate	
Species	Control	0	0.3	1	3	5	mh1	Bed 4
Spirodela poly.	413	235	412	406	417	339	80	75
Lemna min.	807	236	735	828	779	698	60	64

Effects of leachate on Plant Form. Landfill leachate, whether raw, aerated, or filtered through the constructed beds, had a great effect on the morphology and health of plants. The effect was different depending on the leachate concentration. Plants growing in raw leachate tended to become very dark green with purple spots and were somewhat larger in area than control plants. They also appeared very thin and almost transparent. The root systems of *Spirodela* and *Lemna* became very elongated in raw leachate, growing to a length of up to 10 cm. In contrast, plants in aerated leachate were much smaller in size than normal, tended to be a lighter green, and the new plants budded off from the mother plant did not separate, with the result that small compact colonies of up to 10-20 plants resulted. Roots on these plants did not grow and formed small stubs less than 1 cm long.

No adverse growth forms were noted in plants growing in the different iron concentrations, but those growing in high manganese tended to be smaller and more yellow in color, and developed a white line across the top of the plant.

Discussion

There is much still to learn about the effect of landfill leachate on plants. The duckweeds proved in these experiments to be fine experimental organisms, changing growth rates and form and health as conditions changed. Further experimentation needs to be done before it can be determined what component of the leachate caused the effects seen. It apparently is not iron nor manganese, because these caused neither the reduction in reproduction nor the morphological effects seen (Epstein 1972).

One surprising result is that both the raw leachate and the leachate either aerated or filtered through the constructed beds had an adverse effect on the plants. While the type of leachate did not have a great effect (in most cases) on numbers of plants at the end of the experiment, the type did have a major effect on the type of growth form exhibited. The aerated leachate caused plants to be smaller than average. Their root systems were reduced to small stubs, and they failed to separate as normal. This may be due to a nutrient deficiency rather than the presence of a toxic substance; since the leachate had already gone through all four beds, most of the chemicals in large supply had been considerably reduced (see chemical data elsewhere in this report).

Plant response varied in the different experiments. This was due no doubt to the variation in chemistry of landfill leachate. The chemistry depends on a number of factors which can vary at different periods.

SUMMARY OF EXPERIENCE WITH FENTON LEACHATE AND IMPLICATIONS FOR LANDFILL LEACHATE TREATMENT IN GENERAL

This section provides:

- A summary of observed changes in chemistry of the leachate at Fenton as it traveled through the treatment system;
- Suggestions for improvement in the Fenton system;
- An integrated discussion of selected topics, problems, and uncertainties in the light of associated research in the laboratory and greenhouse and other experience documented in the literature.

Summary of Observations at Fenton.

- The ultimate test of the treatment system is to produce an effluent which does not harm the receiving stream, as interpreted by DEC in the SPDES permitting process. In this regard, the major contaminants in the leachate from the Fenton landfill were inorganic N (almost entirely in the ammoniacal form), Fe (probably mostly in the ferrous or reduced form), and Mn.
- Nitrogen loading rates averaged 135 g of inorganic N per day in 0.78 m^3/day of effluent.
- The treatment system reduced the inorganic N concentration by 60 to 100%; the best removal was during the summer of 1991 and the least removal was during the period January to March 1991.
- The reduction in inorganic N concentration was the result of loss of inorganic N, primarily in the overland flow beds, and dilution by precipitation. The most likely mechanism of loss of inorganic N was volatilization of NH_3. The net of precipitation minus evaporation and transpiration was about double the input of leachate.

- The concentration of iron was reduced by the treatment system; the average concentration of iron before and after treatment was 34 and 0.63 mg/l, respectively, in unfiltered and uncentrifuged samples. Since the solutions were above pH 7 in all beds and the oxygen concentration was more than 2 ppm in all beds, the iron in the samples from the end of the treatment system is almost certainly oxidized, and the iron that is in the samples is either part of precipitated iron compounds or else it is sequestered by complexes and microorganisms.

- The manganese concentration in the treatment system was not reduced except by dilution. Manganese chemistry and behavior are discussed more fully in a later section.

- There was very little if any reduction in permeability of the root-zone beds over 18 months and no overland flow in any part of the root-zone beds.

<u>Possible Modifications of the Fenton System which might Improve Treatment.</u>

The treatment system at the Fenton landfill might be improved by the following modifications:

- If the area of overland flow beds was expanded and the residence time increased, the removal of nitrogen, iron, and manganese would be enhanced. Additional beds could be built or perhaps one of the root-zone beds could be converted to an overland flow bed.

- The root-zone beds could be fitted with baffles to reduce the possibility of channeling.

- The flow from the overland flow beds to the root-zone beds could be regulated so the residence time in the overland flow beds would be increased when the precipitation exceeded evapotranspiration; the water stored would serve as a buffer against prolonged periods when evapotranspiration exceeded precipitation.

- The area at the end of the beds could be graded to form a fairly long, sinuous, and low-gradient path between the outflow from the treatment system and the stream. This might be useful in enhancing the removal of nitrogen, iron, and manganese at least during the summer when stream flow is low and the impact of the effluent from the treatment system is maximum.

Integrated Discussion of Selected Topics.

Permeability. Maintenance of permeability is an important indicator of the potential active life of the root-zone beds. The results from two different experimental treatment system have revealed very limited lowering of permeability. IN the landfill treatment system, the gravel beds (3 and 4) did not clog to such an extent as to result in overland flow, and there were relatively small changes in permeability during one year of measurement. The sand beds in the greenhouse experiment did not suffer a large reduction in permeability over almost 18 months (see section 4).

Previous experimental gravel beds at the Fenton landfill site clogged rapidly, however. The rapid clogging of filters described in the preliminary studies indicates that the leachate from the landfill contained viscous materials capable of causing clogging. The clogging of hoses described in section 3 further illustrates this potential.

The following are hypotheses about why this project did not suffer from serious reductions of permeability as a result of clogging. Clogging seems to occur when the leachate is fed in a steady stream into the beds; at the point of entry there is rapid degassing of CO_2 from the leachate, with precipitation of $CaCO_3$ and concurrent oxidations and precipitation of iron oxides and hydroxides. In addition, there are viscous materials in the leachate and there may be production of microbial products that contribute to the clogging. This latter effect has been reported to be enhanced when effluents contain large amounts of inorganic N relative to carbon, which is the situation with the leachate (Vandevivere and Baveye 1992). In the Fenton treatment system these reactions were completed in the overland flow beds. The treated solutions entering the gravel beds were nearly at equilibrium with the atmospheric O_2 and CO_2, and hence there was not much precipitation at the point of entry. Presumably the viscous materials in the leachate had been degraded by this time and the conditions for further production of such materials were not present.

In the greenhouse experiments, the leachate was added in one large batch to the drained (and perhaps partially oxidized) sand; for the next two weeks, the sand was periodically watered, so that the solutions probably remained in the reduced condition. The net result was that there was no clogging, because the products of oxidation and degassing were reduced in volume and dispersed through the whole volume of sand. Perhaps the periodic draining also reduced the potential for clogging.

The following suggestions might alleviate clogging in other systems; their utility depends upon an economic and performance evaluation of the several alternatives:

- Overland flow beds may effectively eliminate the clogging problem.

- Pretreatment with forced air for sufficient time would precipitate the calcite and iron oxides. If this is followed by settling in a holding tank, the clogging effect would probably be eliminated or at least the permeability of any subsequent treatment beds would be only slowly reduced.

- Third (but probably less certain) would be to collect and hold the leachate in tanks and then flood the beds very rapidly. Following a specified period, the beds would be drained and kept under aerobic conditions for several days before reflooding. In this manner, the clogging agents would be dispersed by the rapid loading, and during the aerobic period the clogging agents of microbial origin would be partially or completely degraded.

Nitrogen Removal by Plants in Root-Zone Beds Compared to Nitrogen Removal by Overland Flow Beds without Emergent Plants. In beds 1 and 2 the concentration of inorganic N was reduced from 168 to 24 mg/l averaged over the whole period (Table 4-21); some part of this was due to dilution and some to loss. Based on N/K ratios, the results in Figure 4-4 indicate that on the order of 70% of the influent N was lost during passage through the overland flow beds (with considerable variation among seasons). These beds have an area of 290 m^2. The average yearly influent loading was 135 g N/day. Thus loss was on the order of 120 g N/m^2 during one year.

An alternative to the overland flow beds would be to grow and harvest emergent wetland plants such as cattails, reed canary grass, or *Phragmites*. Harvesting and removal are essential since if the plants remain their biomass would eventually decompose and re-release the inorganic N into the treatment system. Thus, the important questions is how much N can be expected in harvestable biomass. The harvestable biomass of reed canary grass was estimated to range from 20 to 40 g/m^2. N in harvestable biomass of cattails would probably be less. Hurry and Bellinger (1990) estimate that N removal by harvesting of reed canary grass could be as much as 49 g/m^2 in England.

Comparison of N removal in the overland flow beds with the foregoing estimates of removal by harvesting indicates that the overland flow beds are the better choice. The overland flow beds are also easier to manage because they do not have to be harvested. In addition, the biomass from plant harvest must be disposed of somehow; probably the safest disposal is back to a secure landfill.

The foregoing discussion ignores the possible loss of N by nitrification-denitrification in the rhizosphere of plants in root-zone beds. Several observations and speculations indicate this is uncertain. First, examination of performance in beds 3 and 4 (Table 4-21, figures 4-2, 403, and 404) indicates relatively small or no removal of N. The greenhouse microcosm results showed little difference in N loss between the planted and unplanted cases. Finally, Schierup et al. (1990) in a survey of 72 systems in Denmark found modest if any removal of N. Nitrification is a necessary precursor to denitrification; the laboratory studies on nitrification (Table 4-20) illustrate that it is a relatively slow process in the Fenton leachate. The study by Bedford et al. (1991) shows that the amount of O_2 remaining after respiration is so small that unless the O_2 consumption in the soil is uncommonly low there will be a very small volume of soil with molecular O_2 in the rhizosphere, a necessary condition for nitrification.

Iron. With respect to iron precipitation and removal, the following conditions are most important:

- Sufficient conditions for rapid oxidation of iron are high pH and molecular O_2. The Fenton leachate was saturated with respect to $CaCo_3$; this furnished the buffering necessary to maintain a high pH against the release of H+ by the oxidation of iron, volatilization of NH_3, and loss of CO_2. Molecular oxygen is provided by algal photosynthesis and exposure to atmospheric O_2 in the overland flow beds.

- The particulate forms of iron can best be separated from the solution by sedimentation. This occurs in both the overland flow beds and the root-zone beds. Perhaps the turbulence in the root-zone beds is less than in the overland flow beds, and hence they are more effective in separation of the particulate matter.

- The role of emergent plants is uncertain. Some evidence supports the idea that emergent plants promote O_2 transport into the root-zone. Other evidence supports the view that plants do not transport sufficient O_2 to be of much consequence. Although seldom discussed, the important factor is the transport relative to consumption in the soil; under high temperatures and/or high organic matter contents, the bulk of the soil will be anaerobic; under low temperatures and/or low organic matter, the bulk of the soil will be aerobic.

- The samples taken from beds 3 and 4 usually contained 4 to 6 g/m^3 of molecular O_2 (Figure 4-6) during the cooler months, but these dropped to about 2 g/m^3 during the warmer months. The iron tended to be lower during the episodes when O_2 was high and vice versa (Figure 4-24). Note in Figure 4-24 that the iron was below detection limits during the last period (November 1991).

- The above discussion suggest that the root-zone beds have been useful in removing iron. The question which remains is whether organic matter will accumulate to levels causing oxygen depletion sufficient to reduce the particulate iron; in case this happens, the iron delivered to mh 4 will likely rise significantly.

The role of the root-zone beds in removing heavy metals is discussed more fully in a later section.

Manganese. The behavior of manganese in the beds is puzzling; the behavior varied among beds and sampling periods (Figure 4-25). In the laboratory studies the following was found:

- In the leachate as it emerged from the landfill, the manganese was in a form which was not removed from solution by centrifuging (Table 4-14; Figure 4-12); presumably it was in reduced form in solution.

- In other laboratory studies where the solutions were aerated for periods up to 50 days, manganese converted to a form removed by centrifuging after as few as 11 days (Table 4-15, Figure 4-13); presumable it was oxidized or co-precipitated during this interval. Yet despite this rather clear behavior in the laboratory, the behavior varied among beds and sampling periods (Figure 4-25).

For the interested reader, the following are some relevant references to the chemistry of manganese (and iron, since they are usually discussed together) in the flooded soil and overlying water. First, the characteristics of the thermodynamically stable solid phases of various compounds are listed by Lindsay (1979), who also uses stability diagrams for pH and oxidation state. However, the kinetics of iron and manganese reduction and oxidation in soil and water systems is such that seldom are such systems in equilibrium because the conditions (e.g., pH and oxygen and carbon dioxide concentrations) change more rapidly than kinetics allow equilibrium to be re-established. The chemistry of flooded soils and the kinetics of reduction are described in several papers dealing with flooded rice (Patrick and Reddy 1979; Ponnampuruma 1979; and Yamane 1979). The kinetics of oxidation of formerly reduced systems is described by Stumm and Morgan (1981) for water, and McKenzie (1989) describes the kinetics pertinent to soil. Howeler and Bouldin (1971) describe some chemistry of the interface between water and soil.

The substance of the foregoing is that if the pH is above 8 and the water/soil is nearly in equilibrium with atmospheric oxygen, the kinetics of oxidation of both iron and manganese are rapid relative to residence time in beds 1 and 2, and that oxidized iron and manganese form relatively insoluble compounds. Based on this, the manganese is expected to be oxidized and precipitated in beds 1 and 2; there is some evidence that this occurred (see Figure 4-25). If the manganese was oxidized and precipitated, why was there still manganese at the end of bed 2? Perhaps the precipitates were so small that they did not settle to the bottom (there was considerable turbulence in the water in beds 1 and 2), and hence were carried along with the water; or perhaps the manganese was complexed and hence protected from oxidation/precipitation; or perhaps the pH was not high enough nor the residence time long enough.

At the end of bed 3 and in mh 4, the manganese concentrations varied widely among sampling intervals. First, perhaps some manganese was carried into the root-zone beds either as fine precipitates or as complexes, where it settled out in the more quiescent state of the root-zone beds. Second, perhaps the beds were a mosaic of reduced and oxidized zones; in the reduced zones the manganese would be reduced to soluble form, but the pH in the oxidized zones was low enough that the reoxidation would be slow (see figures 4-6 and 4-16 for the description of pH). The extent of reduction would depend on microbial activity (which in turn would be determined by temperature and supply of substrate) and oxygen replenishment from the atmosphere. Information on the rate of the interchange of gases between the atmosphere and solution in beds 3 and 4 may be inferred from Figure 4-3. This figure shows the calcium concentration decreases from mh 1 to bed 2 and then increases; presumably, this is a consequence of loss/accumulation of carbon dioxide from microbial respiration and concurrent decrease/increase in solubility of calcium carbonate (see Figure 4-14); but the interchange between solution and atmosphere was too slow to maintain equilibrium with the solution in the root-zone beds. Superimposed on the patterns of oxidation and reduction would be plant uptake, which could remove substantial amounts of manganese from solution (see Table 4-12 for information on manganese content of plants).

The foregoing discussion implies that the observed behavior in the beds is consistent with the literature, but it hardly leads to clear-cut guidelines for future designs, nor does it provide much information about how the system may behave as the root-zone beds mature and the inputs of plant biomass increase.

Increases in biomass could lead to even more reduction and hence a lessening of manganese removal. In the Fenton landfill leachate, the concentration of reduced manganese is low so that removal of large amounts of manganese is not necessary. Perhaps in other cases where manganese is high, the best treatment would be prolonged residence time.

The situation with iron is somewhat simpler because the oxidation of iron in the presence of oxygen is more rapid than for manganese. In the root-zone beds, any reduced iron is oxidized on the aerobic zones and during passage to mh 4.

Long-Term Behavior of Iron, Manganese, and Other Metals. An hypothesis is that the iron coatings on roots and in the oxidized rhizosphere accumulate several heavy metals, and hence the root-zone beds are a means of treating wastes which contain more than traces of heavy metals. The oxygen leaking from the root oxidizes iron, as evidenced by accumulation on the root surfaces. Presumably, this is a consequence of transport of oxygen through linked, gas-filled pore space in the plant (called aerenchyma) and subsequent leakage of oxygen out of the roots and into the rhizosphere. The roots and stems of plants used in studies described here were well-supplied with aerenchyma and hence had the necessary physical characteristics for transport and leakage of oxygen into the rhizosphere (Tables 4-2 and 4-3, figures 4-7, 4-8, 4-9, 4-10, and 4-11). The roots of plants were analyzed for several ions. The results are shown in tables 4-10 and 4-13 for beds and in Table 4-25 for the microcosm experiments.

There is no easy way to distinguish between ions which are part of the coatings on the roots and ions which are inside the root and part of the metabolic pool of the root. In Table 4-25, except for iron, the content of ions in the roots was comparable to that in the shoots, which suggests that most of the root content was metabolic. In Table 4-13, the contents of several ions in the roots were much higher than in the tops. The interpretation of this data is problematic. Perhaps the most useful statement that can be made is that this is a subject which needs careful study. The data reported here are inconclusive as to whether or not root-zone beds are effective in removing more than traces of heavy metals.

Another reason for caution is the following. The long-term effects of immobilization of iron, manganese, and other metals on the roots and in the oxidized rhizosphere will depend on continued maintenance of the oxidized state, since reduction of the soil/iron will cause the ions to revert to their original state in solution. Wetland soils are a mosaic of oxidized and reduced zones. The soil in the rhizosphere is oxidized. The thickness of the oxidized zone around the roots depends on the balance between transport by the plant and consumption by microbial activity in the soil. But most of the soil volume is in a reduced state. As the roots and rhizomes die and decompose, the coatings and the rhizosphere become reduced. Based on this reasoning, the immobilization of iron, manganese, and other metals is ephemeral when viewed from the perspective of several years. A quasi steady state develops in which new roots replace those undergoing decomposition and these new roots develop a reduced rhizosphere, which essentially replaces the old rhizosphere now undergoing reduction. Thus, as root-zone beds mature and the amount of plant residues build up, immobilization of metals in the rhizosphere as a consequence of oxidation becomes less important. Basically, the oxidized rhizosphere is ephemeral (on a yearly basis) so far as any given volume of soil is concerned, and hence any beneficiation by immobilization of metals as a consequence of oxidation of the rhizosphere is ephemeral.

The Fenton root-zone beds began with minimal plant material and minimal organic matter, evolving to contain significant quantities of both after years of operation. Correspondingly, oxygen demand (to decompose organic matter) and oxygen supply (via plant roots) both begin at low levels and increase with time. Thus, an important questions which arises is whether or not the rooted plants in the beds can supply enough oxygen to maintain the gravel in an oxidized state, or perhaps more precisely, what volume of the beds will remain oxidized foı the next several years. Associated research by Bedford et al. (1991) illustrate that the plants cannot supply enough oxygen to decompose the root material on a long-term basis. Thus, the fraction of the volume of the gravel beds that is reduced will likely increase as the beds mature, and as a consequence, their ability to immobilize heavy metals will decrease.

Other investigators have measured both iron and manganese accumulation in the rhizosphere; however, the ratio of manganese to iron in the rhizosphere is less than that in solution, indicating that the oxidation/precipitation of manganese is considerably less than that of iron (Bacha and Hossner 1977). At least one reason is that oxidation of manganese can only occur at a higher redox potential than iron. In addition, the kinetics of oxidation of manganese are slower than in the case of iron. Thus, there are both thermodynamic and kinetic reasons why manganese will be less prevalent than iron in the oxide coatings on roots (Mendelssohn and Postek 1982).

The essence of the foregoing is that the role of root-zone beds in removing heavy metals from waste water is uncertain. Only further experience will furnish the answers to this important questions.

Leachate which has High Organic Matter and/or Large BOD. If the landfill leachate contains large amounts of readily decomposable organic matter (in other words, high BOD), pretreatment in beds planted with reed canary grass, cattails, or *Phragmites* probably would be useful as a way to assure the acceptability of the effluent for treatment systems such as the one at Fenton. BOD removal from primary and secondary sewage effluents has been studied in several places. Various substrates (e.g., gravel or sand or soil), plant varieties, and even unplanted beds (DeBusk et al. 1990) have been effective in removal of BOD. Shierup et al. (1990), and Coombs (1990) summarize experience in Denmark, Germany, and England, respectively.

Toxic Organics. The research done here cannot be extrapolated to situations where toxic organic contaminants are in high concentrations.

Loss, Accumulation, and Dilution of Target Substances. The Fenton constructed wetland system processes different target substances in several ways to reduce their concentrations:

- Ideally, the system destroys a target substance by converting it chemically into something innocuous. An example of denitrification, the conversion of NO_3 to N_2.

- Almost as good is transfer to a different medium or phase, such as by volatilization or physical removal, when the other medium is not sensitive to the target substance. The Fenton overland flow beds transfer most of the leachate's inorganic nitrogen to the atmosphere, a medium much less vulnerable to ammonia than the tiny receiving stream. This type of transfer or chemical destruction (as in all nitrification) may be considered "loss" processes.

- Long-term accumulation can be effective if the accumulated material does not interfere with other system functions and if it is unlikely to be re-released. Iron accumulation in the aerobic overland flow beds may fit this mold.

- Short-term accumulation is the least desirable form of treatment that removes material from solution. The above discussions of metal behavior in the subsurface flow beds suggested that conditions there would favor only shorter-term accumulation of iron, manganese, and other metals subject to easily reversible redox reactions. Similarly, plant uptake is a temporary storage process, requiring harvesting to have much beneficial effect. Neither short-nor long-term accumulation represents a loss from the system.

- Dilution reduces average concentrations (but not mass loadings) for most substances, since atmospheric precipitation has much lower concentrations of the same substances than the untreated leachate and since there is a substantial excess of atmospheric precipitation over evaporation. The effect varies seasonally. During wetter and cooler periods, the atmosphere adds water to the system yielding more effluent than influent and reducing the concentrations of most substances. The increased flow holds solutes in the system for a shorter time, thus providing less opportunity for chemical and biological effects to destroy or accumulate the materials, offsetting some of the concentration drop from the extra flow volume. During a hot, dry period, the system can evaporate much more water than falls as rain or enters as leachate. The system yields less effluent than it receives in influent. Longer residence times and higher temperatures assist loss processes and some accumulation processes. The seasonal rhythm of net dilution appears to coincide beneficially with the seasonal vulnerability of the receiving water. Hotter and drier seasons should bring out the overland flow beds' best oxidation performance and the greatest ammonia volatilization(in both cases due to higher temperature and longer residence time), coinciding with the lowest flow and highest temperatures in the receiving water, which make it most vulnerable to discharges of oxygen demanding material and toxic ammonia.

All of these processes occur much more unevenly in an outdoor system like a constructed wetland than in an indoor system with controlled ambient conditions.

The effects of loss and accumulation processes shift over time as the biological and chemical constituencies of the beds change from their initial state toward something in dynamic equilibrium with the incoming leachate. Ecosystems (both natural and engineered) tend to exhibit capacity limits when accumulating different kinds of material, a capacity determined by how easy it is to immobilize and remobilize the material and how rapidly any loss processes operate. In immature systems starting relatively "empty", like the Fenton case, materials generally accumulate. As the system matures, there is remobilization of some of the material accumulated earlier; at some point averaged output will equal averaged input minus losses. While this makes accumulation processes seem less favorable in mature systems, accumulation provides three possibly valuable opportunities. First, if the substance can be degraded, holding a larger amount of it in storage will lead to additional losses by chemical and biological degradation. (Obviously, a metal is not degradable, but a recalcitrant synthetic organic may well show significant losses if held for several years instead of just passing through quickly to the receiving water.) Second, holding material in storage provides an opportunity to physically remove it from the system. Plant harvesting is the best short-term example. A longer term example could be to re-excavate the subsurface flow beds when they build up substantial storage of metals, depositing the old substrate in a secure location and refilling the beds with fresh substrate. This is analogous to

recharging an activated carbon filter after its absorption capacity becomes saturated. Finally, accumulation processes tend to average out peaks in the influent. This dampening can be beneficial if a substance is acutely toxic in the receiving water. In some cases, all three benefits can be realized.

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Section 5

BENEFITS OF THE CONSTRUCTED WETLAND SYSTEM

ECONOMIC BENEFITS

The total estimated economic benefit as a result of construction and operation of the leachate treatment system using constructed wetlands at the Town of Fenton Sanitary Landfill is based on a comparison of annual transportation and treatment costs associated with hauling 1.89 m^3 (500 gallons) per day of leachate to the Village of Endicott Sewage Treatment Plant versus the total annual cost of the on-site leachate treatment system using constructed wetlands. This comparison is shown in Table 5-1.

The total estimated annual economic benefit of the on-site leachate treatment system using constructed wetlands as opposed to hauling and off-site treatment is approximately $1,233.50 or 6 percent of off-site treatment costs. If the off-site treatment plant were closer to the landfill, the economic benefit of having an on-site wetland treatment system would decrease. If the off-site treatment plant were farther away from the landfill, the economic benefit would increase.

ENERGY BENEFITS

The total estimated energy benefits as a result of construction and operation of the Fenton constructed wetlands project is based on a comparison of the energy consumption costs for the transport and treatment of 1.89 m^3 (500 gallons) per day of leachate to the Village of Endicott Sewage Treatment Plant versus the estimated energy consumption of the on-site leachate treatment system using constructed wetlands. The energy comparison is shown in Table 5-2.

ENVIRONMENTAL BENEFITS

Construction and operation of the Town of Fenton Sanitary Landfill leachate treatment system using constructed wetlands benefits the environment in the following ways:

- Reduction of contaminant concentrations in the liquid discharged,

Table 5–1. Estimated economic costs and benefits.

DESCRIPTION	ANNUAL QUANTITY	UNIT	UNIT COST	ANNUAL COST	
A. Hauling & Treatment Costs					
1. Operation and Maintenance of Pond 1	1	Lump Sum	$1,300.00	1,300.00	
2. Monitoring	1	Lump Sum	$1,700.00	1,700.00	
3. Transportation of Leachate	182,500	Gallon	$0.070	12,775.00	
4. Treatment of Leachate	182,500	Gallon	$0.015	2,737.50	
5. Legal Agreements	1	Lump Sum	500.00	500.00	
TOTAL ESTIMATED OFF–SITE TREATMENT ANNUAL COST:					$19,012.50
B. Leachate Treatment System Using Constructed Wetlands					
1. Annualized Capital Cost	1	Lump Sum	$11,679.00	11,679.00	
2. Operation and Maintenance	1	Lump Sum	$1,300.00	1,300.00	
3. SPDES Permit Monitoring	1	Lump Sum	$4,300.00	4,300.00	
4. Legal Agreements	1	Lump Sum	500.00	500.00	
TOTAL ESTIMATED ON–SITE TREATMENT ANNUAL COST:					17,779.00
TOTAL ESTIMATED ANNUAL ECONOMIC BENEFIT:					$1,233.50

Notes:

Base year for costs: 1989

A.1. Based on one laborer two hours per week at $13.00 per hour.

A.2. Based on one Baseline and three Routine analyses of leachate per year (6NYCRR Part 360–2.11(c)(6)).

A.3. Based on 46-mile round-trip distance to the Treatment Plant and 500 gallons (1.8927m^3) per day of leachate.

A.4. Based on treatment cost of $15.00 per 1000 gallons (3.7854 m^3) of leachate.

A.5. Based on executing leachate hauling and treatment agreements.

B.1. Based on the following capital costs:

Materials	$25,000.00
Installation	$66,200.00
Engineering	$9,240.00
Construction Mgt.	$6,170.00
Total	$106,610.00

Debt retirement factor based on 9 percent annual interest rate for 20 years: 0.10955

B.2. Based on one laborer two hours per week at $13.00 per hour.

B.3. Based on monthly monitoring of SPDES Permit parameters.

B.4. Based on executing leachate hauling and treatment agreements.

Table 5-2. Estimated energy benefits.

DECRIPTION	ESTIMATED ANNUAL ENERGY CONSUMPTION
A. Treatment Plant	
1. Transportation of Leachate	4.16×10^7 kJ (11,556kWh)
2. Leachate Treatment at Endicott STP	5.79×10^5 kJ (161 kWh)
Total	4.22×10^7 kJ (11,722 kWh)
B. Leachate Treatment System Using Constructed Wetlands	0 kJ (0 kWh)
Total	0 kJ (0 kWh)
C. Total Estimated Annual Energy Benefit	
Total Treatment Plant:	4.22×10^7 kJ (11,722 kWh)
Less: Constructed Wetlands:	0 kJ (0 kWh)
Total Energy Benefit	4.22×10^7 kJ (11,722 kWh)

ASSUMPTIONS:
Density of diesel fuel: 875 kg/m^3 (54.6 lbm/ft^3)
Energy Value of diesel fuel: 44,750 kJ/kg (19,240 Btu/lbm)
Hauling distance round trip: 74 km (46 miles)
Mileage of haul vehicle: 0.06092 km/m^3 (10 miles/gallon)
Number of trips per year: 61 trips/year
Volume of leachate per day: 1.8927 m^3/day (500 gallons/day)
Volume of leachate per trip: 11.356 m^3/trip (3,000 gallons/trip)
Volume of diesel fuel per trip: 0.0174129 m^3/trip (4.6 gallons/trip)
Energy consumption Endicott STP 1991: 7.365757×10^9 kJ/yr. (2,046,060 kwh/yr)
Volume of wastewater at Endicott STP 1991: 8,787,457 m^3 (2,321,400,000 gallons/yr)
Energy consumption rate at Endicott STP 1991: 838.2 kJ/m^3 (8.814×10^{-4} kWh/gallon)

CONVERSION FACTORS:
1 kJ = 0.9478 Btu
1 kJ = 2.7778×10^{-4} kWh
1 km = 0.6214 miles
1 kWh = 3600 kJ
1 m^3 = 264.1720 gallons
1 mile = 1.6093 km
1 lb/ft^3 = 16.01846 kg/m^3
1 Btu/lbm = 2.326 kJ/kg

CALCULATIONS:

A.1. Transportation of Leachate
Estimated Annual Energy Consumption
= volume of diesel fuel/trip x trips/yr x density of diesel fuel x energy value of diesel fuel
= 0.0174129 m^3/trip x 61 trips/yr x 875 kg/m^3 x 44,750 KJ/kg
= 4.16×10^7 kJ (11,556 kWh)

A.2. Leachate Treatment at Endicott STP
Estimated Annual Energy Consumption
= rate of energy required x volume leachate/day x 365 days/yr for treatment
= 838.2 kJ/m^3 x 1.8927 m^3/day x 365 days/yr
= 579,000 kJ (161 kWH)

- **On-site treatment avoids the impacts associated with the consumption and combustion of fossil fuels necessary to transport and treat the leachate at a wastewater treatment facility, and**

- **If testing indicates the treated leachate must be transported to a wastewater treatment facility, the constructed wetlands provides a low-energy-cost pretreatment system.**

Section 6

APPLICABILITY OF DESIGN TO OTHER LANDFILLS

This section provides recommendations for the design, construction, and operation of a leachate treatment system using constructed wetlands in the Northeast United States, based on the successes and failures of the Fenton project in New York State. For regions having different climatic conditions such as low rainfall and high year round temperatures, pilot projects and additional research are required for a proper understanding of system dynamics.

LEACHATE CHARACTERISTICS

An overview of typical landfill leachate characteristics is given in Table 6-1 to show the variability and range in concentrations of contaminants in leachate from municipal solid waste landfills as compared to the Fenton Landfill.

The concentrations of contaminants in leachate are dependent on a variety of factors which include the age of the landfill, the type of waste landfilled (municipal, commercial, industrial) and percentages of waste components such as paper, glass, metals, plastics, organic wastes, leaves, wood, etc. Additional factors include site hydrology, presence or absence of a liner system, operation procedures, daily soil cover used, and final cover.

Historical and current data on leachate composition should be evaluated prior to design of a constructed wetland leachate treatment system.

EFFLUENT LIMITATIONS

In New York State, the law requires that a permit be obtained before construction or use of an outlet or discharge pipe of wastewater discharging into surface waters or groundwaters of the State, or construction or operation of disposal systems such as sewage treatment plants.

In New York State, water quality-based effluent limitations for use in the State Pollutant Discharge Elimination System (SPDES) permit program are derived from ambient water quality standards and guidance values as compiled in the NYSDEC Division of Water Technical and Operational Guidance

Table 6–1. Contaminant concentration ranges in leachate reported in the literature.
(All concentrations in mg/l except pH [std units] and Sp. Cond. [umhos/cm]).

Parameter	George (1972)	Chian/ DeWalle (1977)	Metry/ Cross (1975)	Cameron (1978)	Wisconsin Report (20 sites)	Sobotka Report (44 sites)	Fenton Landfill (1991)	Parameter
pH	3.7–8.5	3.7–8.5	3.7–8.5	3.7–8.5	5–8.9	5.4–8.0	6.31–8.13	pH
Alkalinity	0–20,850	0–20,850	310–9,500	0–20,900	ND–15,050	0–7,375	1,100–1,730	Alkalinity
Total Solids	–	0–59,200	–	–	–	1,900–25,873	–	Total Solids
TDS	0–42,276	584–44,900	100–51,000	0–42,300	584–50,430	1,400–16,120	458–1,870	TDS
TSS	6–2,685	10–700	13–26,500	–	2–140,900	28–2,835	–	TSS
Spec. Conductance	–	2,810–16,800	100–1,200	–	480–72,500	–	2,900–4,000	Spec. Conductance
BOD	9–54,610	81–33,360	2,200–720,000	9–55,000	ND–195,000	7–21,600	39	BOD
COD	0–89,520	40–89,520	800–750,000	0–9,000	6.6–97,900	440–50,450	257–497	COD
TOC	–	256–28,000	–	–	ND–30,500	5–6,884	73.5_–1,130	TOC
Hardness	0–22,800	0–22,800	35–8,700	0–22,800	52–225,000	0.8–9,380	503–815	Hardness
Chlorides	34–28,00	4.7–2,467	47–2,350	34–2,800	2–11,375	120–5,475	33–498	Chlorides
Florides	–	–	–	0–2.13	0–0.74	0.12–0.790	–	Florides
Sulfates	1–1,826	1–1,558	20–1,370	0–1,826	ND–1,850	8–500	ND–11	Sulfates
Sulfide	–	–	–	0–0.13	–	–	–	Sulfide
Total K–Nitrogen	0–1,416	–	–	–	2–3,320	47.3–9380	95.1	Total K–Nitrogen
NH3–Nitrogen	1–1,106	0–1,106	0.2–845	0–1,106	10–1,120	11.3–1,200	0.46–109	NH3–Nitrogen
Organic Nitrogen	–	–	2.4–550	–	–	4.5–78.2	–	Organic Nitrogen
NO3–Nitrogen	0–1,300	0.2–10.29	4.5–18	–	10–250	0–50.95	ND–92.5	NO3–Nitrogen
Total Phosphorous	1–154	0–130	–	–	ND–234	–	–	Total Phosphorous
Ortho–Phosphorus	–	6.5–85	0.3–136	0–154	–	–	–	Ortho–Phosphorus
Aluminum	–	–	–	0–122	ND–85	0.010_5.07	0.345	Aluminum
Arsenic	–	–	–	0–11.6	ND–70.2	0–0.08	0.002–0.004	Arsenic
Barium	–	–	–	0–5.4	ND–12.5	0.01–10	0.136	Barium
Beryllium	–	–	–	0–0.3	ND–0.36	0.001–0.01	–	Beryllium
Boron	–	–	–	0.3–73	0.867–13	–	1.45	Boron
Cadmium	–	0.03–17	–	0–0.19	ND–0.04	0–0.1	ND–0.005	Cadmium
Calcium	5–4,080	60–7,200	240–2,570	5–4,000	200–2,500	95.5–2,100	115–164	Calcium
Total Chromium	–	–	–	0–33.4	ND–5.6	0.001–1.0	0.016	Total Chromium
Copper	0–9.9	0–9.9	–	0–10	ND–4.06	0.003–0.32	0.004	Copper
Cyanide	–	–	–	0–0.11	ND–6	0–4.0	–	Cyanide
Iron	0.2–5,500	0–2,820	0.12–1,700	0.2–5,500	ND–1,500	0.22–1,400	5.4–34.3	Iron
Lead	0–5.0	<0.10–2.0	–	0–5.0	0–14.2	0.001–1.11	ND–0.022	Lead
Magnesium	16.5–15,600	17–15,600	64–547	16.5–15,600	ND–780	76–927	65.1–109	Magnesium
Manganese	0.06–1,400	0.09–125	13	0.06–1,400	ND–31.1	0.03–43	0.883–3.93	Manganese
Mercury	–	–	–	0–0.064	ND–0.01	0–0.02	–	Mercury
Molybdenum	–	–	–	0–0.52	0.01–1.43	–	–	Molybdenum
Nickel	–	–	–	0.01–0.8	ND–7.5	0.01–1.25	0.029	Nickel
Potassium	2.8–3,770	2.8–3,770	2.8–3,800	2.8–3,770	ND_2,800	30–1,375	152–256	Potassium
Sodium	0–7,700	0–7,700	85–3,800	0–7,700	12–6,010	–	262–455	Sodium
Titanium	–	–	–	0–5.0	<0.01	–	–	Titanium
Vanadium	–	–	–	0–1.4	0.01	–	–	Vanadium
Zinc	0–1,000	0–370	0.03–135	0–1,000	ND–731	0.01–67	0.074	Zinc

ND = Not Detected
Sources: USEPA, 1987; FLI, 1992a; FLI, 1991b; FLI, 1991c; & FLI, 1991d.

Series (TOGS 1.1.1) (NYSDEC, November 15, 1991). TOGS 1.3.1 describes procedures for use of these criteria in SPDES permits.

A standard is an ambient water quality value that has been placed into regulation. The New York State standards for surface and groundwater quality are promulgated under 6 NYCRR Parts 700-705 Water Quality Regulations for Surface Waters and Groundwaters, effective September 1, 1991 (NYSDEC, September 1, 1991). A guidance value is used where a standard for a substance has not been established.

Parameter selection and effluent limitations compiled by the regulatory agency for a specific SPDES permit are based on the classification of the receiving water and numerical criteria derived to protect designated water uses such as fishing and swimming.

DESIGN

Regardless of location, every landfill has a different combination of site, climatic, hydrogeologic, design, construction, and operation factors. Therefore, design of a constructed wetland for treatment of landfill leachate must be approached on a site-specific basis. Design considerations include site selection, leachate loading rate, pretreatment and treatment requirements, system configuration, dimensions, liners, inlet/outlet structures and distribution system, vegetation, and substrate. Comprehensive construction plans should be provided to the contractor responsible for building the system.

Site Selection

To implement a low-cost, low-maintenance system, the site should be located downgradient from and close to the source of leachate to avoid hauling, extensive piping, or pumping of leachate to the treatment system. Since the treatment beds must be flat, a site that is gravity-fed, is relatively flat (to avoid large amounts of excavation or fill), and is near a receiving stream will keep construction and operation costs to a minimum.

Depth to groundwater and bedrock are also important considerations and should be evaluated with respect to liner depths. If the normal groundwater table is above the liner depth, then groundwater relief drains must be provided to eliminate uplift forces on the bed liner systems.

System Configuration

The configuration of the wetland treatment system will affect the hydrologic factors which control system efficiency and performance. Flow rate, water depth, detention time, and distribution patterns are some of these factors. The configuration should promote an even distribution of leachate throughout the system to maximize treatment efficiencies and minimize channeling. Considerations for configuration design include degree of pretreatment, required treatment area, available land area and slope, length to width ratio, desired bed slope, required excavation and grading, substrate type, internal dikes, distribution piping, and operation and maintenance flexibility (Steiner and Freeman 1989).

The goal of configuration design is to maximize loading rates and treatment efficiency while minimizing required treatment area and costs. Pretreatment to remove solids may require a settling pond or tank. In general, single or multiple cells in series or in parallel or in series/parallel combinations can be used. Various configurations for bed layout are shown in Figure 6-1. The choice of overland flow beds, root zone beds, or a mixture of the two in series depends on the treatment goals. Overland flow beds worked well to volatilize ammonia and oxidize iron (and oxygen-demanding substances). The overland flow beds may have also helped to maintain permeability in subsequent root-zone beds by allowing sediments and particulate matter to settle out.

A typical wetland plan and profile are shown in Figure 6-2 and typical sections are shown in Figure 6-2 and Figure 6-3.

Dimensions

Surface Area. The required surface area of a wetland treatment system is determined by dividing the leachate flow rate by the leachate loading rate criteria for the type of system being designed - overland flow or root-zone.

Surface Area = leachate flow rate divided by leachate loading rate.
$(m^2) = (l/day)/(l/m^2\text{-}d)$

The leachate flow rate is the volume of leachate per day which requires treatment. The leachate loading rate is the amount of surface area required per day per liter of leachate.

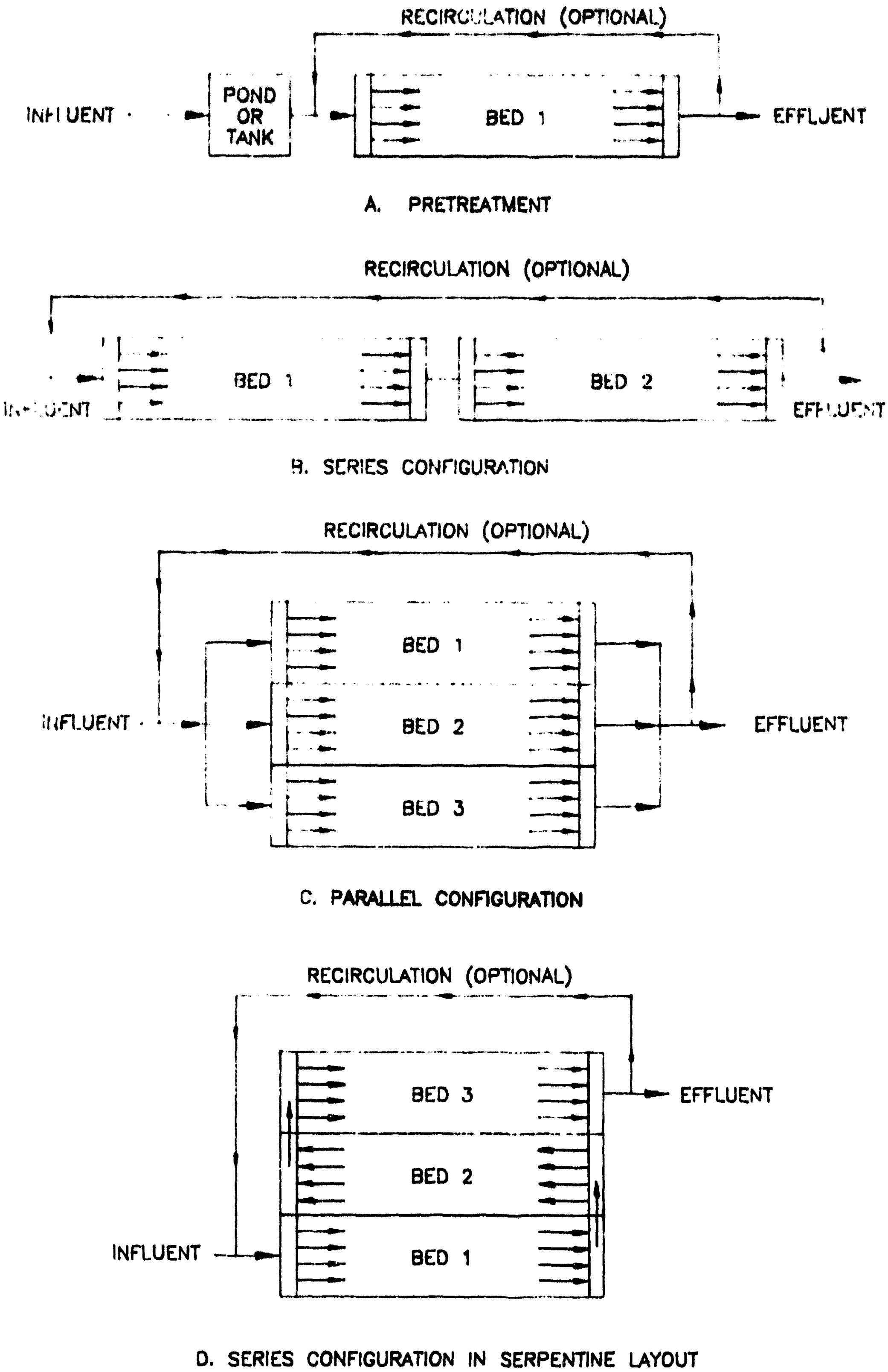


Figure 6 - 1. Alternate configurations.

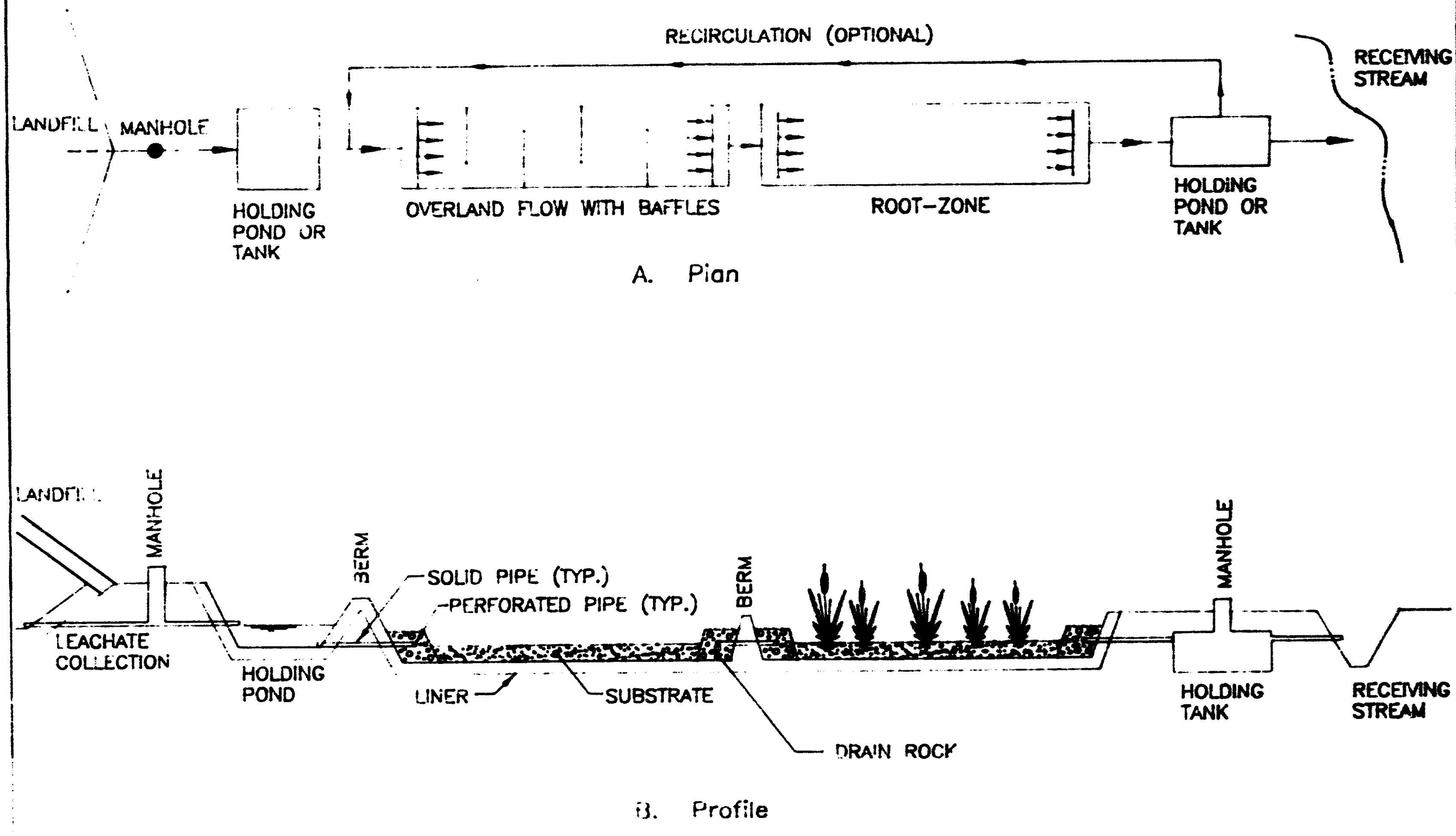
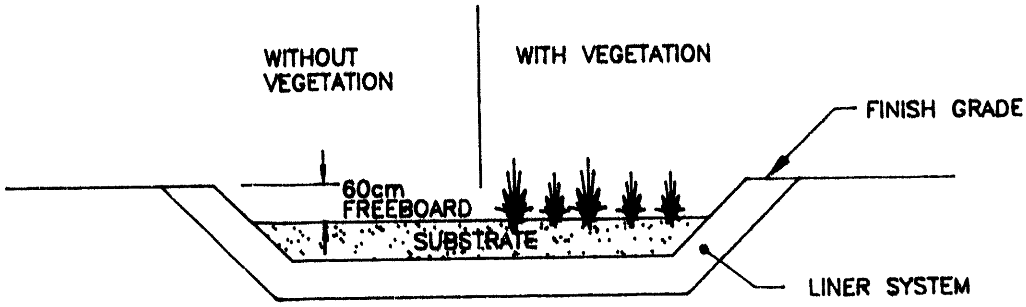
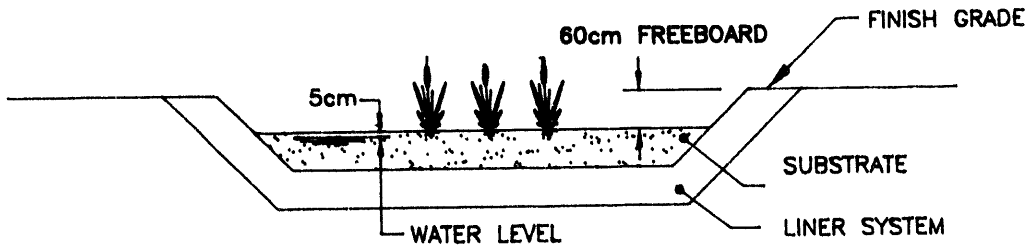


Figure 6 - 2. Typical constructed wetland plan and profile.



A. OVERLAND FLOW BED



B. ROOT ZONE BED

Figure 6 - 3. Typical constructed wetland sections.

For example, if the leachate flow rate is 1000 l/day and the leachate loading rate is 3.4 l/m^2-d, the required surface area is 290 m^2. The required surface area can be rounded up to 300 m^2.

Length and Width. Once the required surface area has been determined, choose a length and width of the bed that will meet surface area requirements and site constraints and allow for proper flow without channeling. In general, a high length to width ratio such as 10 to 1 is desirable.

For example, if the required surface is 300 m^2, a 10 to 1 length to width ratio will require a bed length of 75 m if a width of 4 m is selected to minimize channeling.

Substrate Depth. For overland flow and root-zone systems with vegetation, the substrate depth should be sufficient to allow full root development to avoid root penetration of any liner system.

For overland flow systems without vegetation, the substrate depth should be sufficient to protect any liner system from root penetration by any alien vegetation that may become established.

In general, substrate depths of 30 to 60 cm should be sufficient for root development and liner protection.

Seasonal Considerations

Leachate Flow Rate. In the Northeast, leachate flow rates will be higher in the early spring and late fall seasons when precipitation rates are greater. For design purposes, the higher leachate flow rates are recommended to be used in determining the surface area requirements.

Precipitation, Evaporation, and Transpiration. During wetter and cooler periods, precipitation will result in a higher volume of effluent than influent and will reduce the concentrations of most substances by dilution. The increased flow will decrease residence time of leachate in the system and provide less opportunity for chemical and biological processes to reduce contaminants, offsetting somewhat the effect of dilution.

During hot, dry periods, evaporation and transpiration water losses can exceed precipitation in the system. Residence time will increase and effluent rates will be less than influent rates.

To account for seasonal changes in flow rates, the system should be designed to handle maximum hydraulic loadings by use of a 60-cm (24-inches) freeboard (distance from highest water level to top of containment berm) and piping and channels that will allow full flows to discharge without backing up the system. To provide moisture required for the survival of vegetation during hot dry periods with little or no leachate flow, the ability to hold and recirculate treated leachate by pumping from a holding tank or pond at the end of the system may be necessary.

Temperature. In northern climates, plant dormancy and freezing are factors which reduce the efficiency of biological and chemical treatment processes. In subfreezing temperatures, ice forms on the surface of overland flow beds but allows leachate flow under the ice. If sufficient distance is maintained between the water level and substrate surface of root-zone beds (5 cm minimum) leachate flow will also be maintained.

Contaminant Considerations

Nitrogen Compounds. The nitrogen compounds in the leachate may undergo some of the following transformations as the leachate flows through the treatment system. The nitrogen in organic compounds may be transformed to ammonical N by microbial activity; this process is referred to as mineralization. The ammoniacal nitrogen may undergo any of the following three transformations: a) it may be oxidized to NO_2 and then to NO_3; this process is referred to as nitrification, b) it may be volatilized to the atmosphere, or c) it may be taken up by plants. The nitrate may undergo either of the following two transformations: a) it may be denitrified to N_2 gas in the absence of oxygen, or b) it may be taken up by plants. Only in the cases of denitrification and ammonia volatilization is the nitrogen lost from the system. In the case of plant uptake, if the plants are harvested and removed from the system then their nitrogen is also lost from the system.

The following is the best interpretation of the importance of the various transformations observed in the Fenton system as it was operated. Ammoniacal nitrogen was the major nitrogen compound in the leachate as it emerged from the landfill, and hence mineralization was not a very important transformation. Volatilization of ammonia from the overland flow beds appeared to be a major avenue of loss. Denitrification did not appear to be very important for reasons not well understood. The loss of N from the root-zone beds did not appear to be very important.

Ammonia volatilization is primarily dependent on pH and temperature and was an important avenue of loss of inorganic N in the wetland treatment system at Fenton. The best removal rate occurred in summer and the least removal rate in winter. The importance of temperature is likely the result of the following:

- **Increased temperature enhances the volatilization of NH_3 because of the temperature effect on the chemistry of the solutions.**

- **Increased temperature probably enhances photosynthesis by algae and this increases the pH and then potential for NH_3 volatilization.**

An important factor in NH_3 volatilization is the presence or absence of emergent plants in overland flow beds. Three ways in which emergent plant species reduce NH_3 volatilization are:

- **They reduce algal photosynthesis and hence reduce pH during the day.**

- **The vegetation severely reduces turbulence at the air-water interface and hence reduces loss of NH_3.**

- **Respiration by the increased biomass increases CO_2 concentrations in solution and thereby reduces pH.**

The conclusion is that emergent plants inhibit NH_3 volatilization severely. If the objective is to enhance NH_3 volatilization, emergent plants should be kept out of the overland flow beds.

If emergent plants are part of the overland flow treatment system, their biomass will eventually decompose, re-releasing inorganic N from the system. Thus, harvesting is required for removal of N.

In root-zone beds where the pH is normally below 7.5, the potential for NH_3 volatilization is much less than for the overland flow beds. Therefore, the presence or absence of emergent plants in the root-zone beds is not a concern as far as NH_3 volatilization is concerned.

In summary, at the Fenton wetland treatment site, reductions in inorganic N concentrations were primarily the result of volatilization of NH_3 in the overland flow beds. NH_3 concentrations are also reduced by dilution resulting from precipitation.

Iron and Manganese. Particulate forms of iron can be separated from the leachate solution by sedimentation in holding ponds, overland flow beds, and root-zone beds. The best conditions for rapid oxidation of iron and manganese are high pH and molecular O_2. In overland flow beds, molecular oxygen is provided by algal photosynthesis and exposure to atmospheric O_2. In root-zone beds, emergent plants promote O_2 transport into the root zone. However, there is still some question as to the sufficiency of transported O_2 to promote iron oxidation. An important factor is the O_2 transport relative to O_2 consumption in the substrate. Under high temperatures and/or high organic matter contents, the bulk of the soil will be anaerobic, and under low temperatures and/or low organic matter the bulk of the soil will be aerobic.

Compared to manganese, the oxidation of iron in the presence of oxygen is more rapid.

The best conditions for the oxidation of manganese are high temperature and oxygen. However, oxidation and precipitation of manganese tends to occur slowly in overland flow beds. The best treatment is prolonged residence time.

When first constructed, wetland systems contain the least amount of plant material and organic matter. Over time, the quantities of plant material and organic matter increase. Correspondingly, oxygen demand (to decompose organic matter) and oxygen supply (via plants) both begin at low levels and increase with time. Research indicates that plants cannot supply enough oxygen to maintain more than a small fraction of the root zone in an aerobic condition as the organic matter increases. Therefore, the ability of root zone beds to immobilize iron and manganese will likely decrease over time.

Organic Matter and BOD. European experiences indicate that when landfill leachate contains large amounts of readily decomposable organic matter (i.e., have a high BOD), then overland flow beds unplanted or planted with reed canary grass, cattails, or *Phragmites* can be effective in removal of BOD (Cooper and Findlater 1990).

pH. One of the most important factor in influencing treatment in the system is pH. As discussed above, pH is a key variable in chemical processes that remove inorganic N, iron, and manganese from leachate.

Liner Systems

The objective of a liner system is to prevent the migration of leachate into groundwater. Liner systems can consist of clay barrier layers, geomembranes such as a polyethylene (PVC), chlorosulfonated polyethylene (CSPE), high-density polyethylene (HDPE), or clay/geomembrane combinations. The liner system should be designed and constructed in accordance with regulatory requirements and site conditions.

Inlet/Outlet Structures and Distribution System

The inlet structure can be very simple, consisting of a PVC pipe embedded in stone drain material, or it can be a concrete channel with v-notch weirs located across the width of the bed. The weirs must be leveled to assure a uniform distribution of leachate across the width of the bed. Baffles placed inside the beds will lengthen the flow path. Internal piping, if necessary, can consist of perforated PVC pipe and solid PVC pipe for transferring leachate between beds. The outlet structure can consist of perforated PVC pipe placed in drain rock across the width of the bed and solid PVC pipe to the discharge point. Unless buried a minimum of five feet deep, valves are not recommended for flow control due to the potential for freezing in the winter (in cold weather climates).

Substrate

For overland or surface flow beds, the substrate or rooting medium for vegetation should be a finely textured topsoil. The finer texture allows root penetration, but limits the flow of subsurface water.

For root-zone beds, a gravel substrate such as No. 2 stone 3.8 cm (1-1/2 inch) to No. 1A stone 0.32 - 1.27 cm (1/8-1/2-inch) in size should allow proper shoot and root development and subsurface flow without clogging.

Vegetation.

Vegetation used in the constructed wetland should be species that will naturally grow in the area and will root and thrive in the specified substrate and water depth. Recommended species for root-zone systems in upstate New York include *Typha spp.* (cattails), *Phalaris arundinacea* (reed canary grass), or *Phragmites spp.* Planting should be done in early spring to early fall to maximize root and shoot growth prior to winter.

The most effective planting unit for cattails is a large clump (1 m x 3 m) including roots and rhizomes, rather than a small clump.

If an objective of the system is to enhance NH_3 volatilization, emergent plants should be kept out of overland flow beds.

MONITORING

In order to assess the effectiveness of the wetland leachate treatment system, data should be gathered on a periodic basis (daily, weekly, monthly, or quarterly). A monitoring plan in which observations on weather conditions, flow rates, water quality, and vegetation growth are taken will provide a basis for operation and maintenance of the system. The information also provides a means to evaluate system performance, efficiency, and long-term viability (Hicks and Stober 1989).

Preparation of a comprehensive monitoring protocol will include a detailed description of the goals of the project, objectives of monitoring, assignment of responsibilities, tasks and methods, quality assurance, schedules, reporting procedures, and budgets.

When discharge from the wetland treatment system is into public waters, effluent limitations are established in a wastewater discharge permit such as those issued under SPDES in New York. Monitoring requirements and effluent limitations are developed to assure that the receiving stream water quality standards are maintained. A water quality monitoring protocol is prepared to address chemical and biochemical parameter testing, chain-of-custody, data quality assurance, and reporting responsibilities.

Performance, efficiency, and long-term viability monitoring will include measurements of inflow rates, hydraulic loading, detention times, outflow rates, species composition, plant vigor, and accumulation of dead plant material. Overall, the monitoring plan should provide enough data to evaluate the effectiveness of the system and serve as a basis to make operating decisions, and meet regulatory recording and reporting requirements.

EXAMPLE OF CONSTRUCTED WETLAND DESIGN

Background.

The designer should keep in mind the variability of landfill types and characteristics of waste which affect the presence and concentrations of contaminants in the leachate to be treated. In some cases, constructed wetlands can be used as the primary and only type of treatment for landfill leachates which have relatively low concentrations of contaminants. In other cases, where contaminant concentrations are relatively high, constructed wetlands may be only one phase of a series of treatments such as air stripping, activated sludge processes, or others.

The design example provided herein should be used only as a guide in developing a system design. A specific project may require different or additional concerns and treatment requirements not presented here.

A pilot project to determine the effectiveness of a proposed constructed wetland system is recommended prior to development of a full scale system.

Assumptions.

Leachate Contents.
Leachate contains high ammonia nitrogen, high iron, high manganese, high pH, low BOD, and no volatile organics.

Effluent Limits.

- NH_3 - 2 mg/l

- Fe - 0.3 mg/l
- Mn - 0.3 mg/l

Effluent Concentrations.

- NH_3 - 150 mg/l
- Fe - 6 mg/l
- Mn - 5 mg/l

Leachate Flow.

1,000 l/day

Leachate Loading Rate Criteria.

3.4 l/m^2-d

Site Characteristics.

- Low flat area downgradient from landfill.
- Silty/Clayey soils with low permeability.
- Small intermittent receiving stream.
- Northeastern United States climate.

Design

System Components and Configuration.

- Include holding pond upgradient from constructed wetland system to settle out any particulate matter.
- Include overland flow beds without emergent wetland plants to maintain high pH and oxygen and enhance ammonia volatilization and iron and manganese oxidation.
- Include root-zone beds for subsurface flow to promote filtering action.
- Use beds in series to achieve the greatest amount of residence time.
- Provide a holding tank at the end of the system to allow for monitoring, holding, and recirculation, if necessary.

Dimensions.

- Determine required surface area for each type of bed:

  Surface area = (leachate flow rate)/(leachate loading rate)

  = (1000 l/day)/(3.4 l/m^2-d)

  = 294 m^2 (say 300 m^2)

- Determine length and width for each type of bed. Use a length-to-width ratio of 10 to 1 for both overland flow beds and root-zone beds. Choose a width of 3 m to minimize channeling.

  Length = 10 (3 m)

  = 30 m

- Determine number of beds required.

  No. of beds = (area required)/(area per bed)

  = (300 m_2)/(30 m x 3 m)

  = 3.33 beds

Therefore, use four beds for overland flow treatment and four beds for root-zone treatment.

- Choose substrate depth of 50 cm to allow sufficient rooting depth and avoid root penetration of liners.

Liner System.

Design liner system to prevent migration of leachate into groundwater and comply with regulatory requirements for surface impoundments. Regulations require a top geosynthetic liner (0.15 cm/min. minimum thickness), a leak detection and removal system, and a bottom composite liner consisting of a minimum 61 cm of compacted soil with a permeability of 1 x 10^{-7} cm/sec or less overlain by a geosynthetic liner (0.15 cm/min.).

Provide a minimum 61 cm of freeboard to prevent water levels from overtopping containment berms.

Inlet/Outlet Structures and Distribution System.

- Choose Schedule 80 PVC piping for strength and ease of installation.

- Choose perforated PVC pipe embedded in No. 2 or No. 3 stone at bed inlets and outlets to promote and even distribution of leachate across the width of the bed.

Substrate.

- For overland flow beds, choose a silty/clayey substrate that will limit subsurface flow.

- For root-zone beds, choose a coarser substrate such as No. 2 or No. 1A stone to allow proper plant root and shoot development and to minimize clogging.

Vegetation.

- Exclude emergent wetland plants from the overland flow beds to maintain high pH and oxygen levels.

- **Choose cattails (*Typha spp.*) and/or *Phragmites* for the root-zone beds. Other native species may invade the beds. After a few years, the beds may then contain species different from those initially planted.**

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Section 7
GLOSSARY

Aerenchymous tissue (Aerenchyma) - A type of plant tissue in which cells are unusually large, resulting in large air spaces in the plant organ; such tissues are often referred to as spongy and usually provide increased buoyancy.

Aerobic - A condition in which molecular oxygen is a part of the environment.

Ammonia Nitrogen (NH_3) - A gas released by the microbiological decay of plant and animal proteins. When ammonia nitrogen is found in waters, it is indicative of incomplete treatment.

Anaerobic - A condition in which molecular oxygen is absent (or effectively so) from the environment.

Annual - Occurring yearly or, as in annual plants, living for only one year.

Axenic - Free from other living organisms.

Chemical Reduction - Any process by which one compound or ion acts as an electron donor; in such cases, the valence state of the electron donor is decreased.

Constructed Wetland - A wetland area that has been purposely created by some activity of man; also called an artificial wetland.

Contour - An imaginary line of constant value on a surface; the corresponding line on a map is called a 'contour line'.

Criteria - technical requirements upon which a judgment or decision may be based.

Denitrification - A biological process in which gaseous nitrogen is produced from nitrate and nitrite.

Density - The number of individuals per unit area.

Dominance - As used in this report, refers to the spatial extent of a species; commonly the most abundant species in each vegetation stratum.

Duration (of inundation or soil saturation) - The length of time that water stands above the soil surface (inundation), or that water fills most soil pores near the soil surface; as used in this report, "duration" refers to a period during the growing season.

Effluent Limitations - Any restriction on quantities, qualities, rates, or concentrations of chemical, physical, biological, and other constituents of effluents that are discharged into or allowed to run from an outlet or point source or any other discharge within the meaning of section 17-0501 of the Environmental Conservation Law into surface waters, groundwater, or unsaturated zones.

Evergreen (plant) - Retaining its leaves at the end of the growing season and usually remaining green through the winter.

Flora - A list of all plant species that may occur in an area.

Groundwater - That portion of the water below the surface of the ground whose pressure is greater than atmospheric pressure.

Growing Season - The portion of the year when soil temperatures are above biologic zero (40°F).

Guidance Value - Such measure of purity or quality for any waters in relation to their reasonable and necessary use as may be established by the NYSDEC.

Hardpan - A very dense soil layer caused by compaction or cementation of soil particles by organic matter, silica, sesquioxides, or calcium carbonate, for example.

Hydrology - The science dealing with the properties, distribution, and circulation of water.

Hydrophyte - Any macrophyte that grows in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content; plants typically found in wetlands and other aquatic habitats.

Hydrophytic Vegetation - Plant life growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content.

Indicator - An event, entity, or condition that typically characterizes a prescribed environment or situation; indicators determine or aid in determining whether or not certain stated circumstances exist or criteria are satisfied.

Inundation - A condition in which water temporarily or permanently covers a land surface.

Macrophyte - Any plant species that can be readily observed without the aid of optical magnification, including all vascular plant species and bryophytes (e.g., *Sphagnum* spp.), as well as large algae (e.g. *Chara* spp., and *Fucus* spp.).

Microbial -Pertaining to work by microorganisms too small to be seen by the naked eye.

Micrograms per Liter (ug/l) - The weight in micrograms of any specific substance or substances contained in one liter of liquid.

Milligrams per Liter (mg/l) - The weight in millig[illegible]ny specific substance or substances contained in one liter of liquid.

Morphological Features - Properties related to the external structure of soil (such as color and texture) or of plants.

Nitrate Nitrogen (NO_3^-) - The final decomposition product of the nitrogen compounds; determination of this parameter indicates the degree of waste treatment.

Nitrification - The conversion of nitrogenous matter into nitrates by bacteria.

Nitrite Nitrogen (NO_2^-) - An intermediate stage in the decomposition of organic nitrogen to the nitrate form; tests for nitrite nitrogen can determine whether an applied treatment is sufficient.

Nitrogen Cycle - Organic nitrogen in waste is oxidized by bacteria into ammonia (NH_3). If oxygen is present, ammonia is bacterially oxidized first into nitrite (NO_2^-) and then into nitrate (NO_3^-). If oxygen is not present, nitrite and nitrate are bacterially reduced to nitrogen gas. The conversion to nitrogen gas (N_2) is called "denitrification".

Oxidation-Reduction Process -A complex of biochemical reactions in soil that influences the valence state of elements and their ions found in the soil; long periods of soil saturation during the growing season tend to elicit anaerobic conditions that shift the overall process to a reducing condition.

Perennial (plant) - Living for many years.

Permeability - The quality of the soil that enables water to move downward through the profile, measured as the distance per unit time that water moves downward through the saturated soil.

Physiological Adaption - A peculiarity of the basic physical and chemical activities that occur in cells and tissues of a species, which results in the species being better fitted to its environment (e.g., ability to absorb nutrients under low oxygen tensions).

Plant Community - The plant populations existing in a shared habitat or environment.

Ponded - A condition in which free water covers the soil surface, for example, in a closed depression; the water is removed only by percolation, evaporation, or transpiration.

Poorly Drained - A condition in which water is removed from the soil so slowly that the soil is saturated periodically during the growing season or remains wet for periods greater than seven days.

Profile - Vertical section of the soil through all its horizons and extending into the parent material.

Quantitative - Precise measurement or determination expressed numerically.

Range - The set of conditions throughout which an organism (e.g., a plant species) naturally occurs.

Reduction - The process of changing an element from a higher to a lower oxidation state, as in the reduction of ferric (Fe^{3+}) iron into ferrous iron (Fe^{2+}).

Rhizophere - The zone of soil in which interactions between living plant roots and microorganisms occur.

Saturated - A condition in which all easily drained voids (pores) between soil particles are temporarily or permanently filled with water; significant saturation during the growing season is considered to be usually one week or more.

Soil - Unconsolidated material on the earth's surface that supports or is capable of supporting plants out-of-doors.

Soil Permeability - The ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil.

Soil Pore - An area within soil occupied by either air or water, resulting from the arrangement of individual soil particles or peds.

Soil Structure - The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Soil Texture - The relative proportions of the various sizes of particles (silt, sand, and clay) in a soil.

Standards - Such measures of purity or quality for any waters in relation to their reasonable and necessary use as may be established by the NYSDEC pursuant to section 17-0301 of the Environmental Conservation Law.

Stolon - A horizontal branch from the base of a plant that produces new plants from buds at its tip or nodes.

Stratum - A layer of vegetation used to determine dominant species in a plant community.

Substrate - Rooting medium for wetland plants.

Surface Water - Water present above the substrate or soil surface.

Topography - The configuration of a surface, including its relief and the position of its natural and manmade features.

Toxic Pollutant - Those pollutants, or combination of pollutants, including disease-causing agents, that after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly through food chains, will cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, including malfunctions in reproduction, or physical deformations, in such organisms or their offspring.

Transpiration - The process in plants by which water is released into the gaseous environment (atmosphere), primarily through stomata.

Typical - That which normally, usually, or commonly occurs.

Upland - Any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands. Such areas occurring in flood plains are more appropriately termed nonwetlands.

Vascular (plant) - Possessing a well-developed system of conducting tissue to transport water, mineral salts, and foods within the plant.

Vegetation - The sum total of macrophytes that occupy a given area.

Water Table - The zone of saturation at the highest average depth during the wettest season; it is at least 15 cm (six inches) thick and persists in the soil for more than a few weeks.

Wetlands - As used in this report, areas that under normal circumstances have hydrophytic vegetation, hydric soils, and wetland hydrology.

Wetland Hydrology - In general terms, permanent or periodic inundation or prolonged soil saturation sufficient to create anaerobic conditions in the soil.

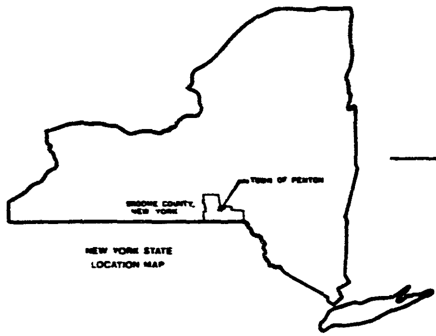
REFERENCES CITED IN SECTION 7

Government Institutes, Inc., 1989, Wetlands identification federal manual for identifying and delineating jurisdictional wetlands, Rockville, Maryland: Government Institutes, Inc.

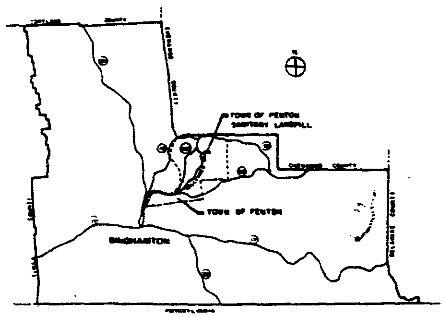
Liptak, B.G., Ed., 1974, Environmental Engineers Handbook, Volume 1, Water Pollution, Radnor, Pennsylvania: Chilton Book Company.

New York Code of Rules and Regulations, Title 6, Parts 700-705 (6NYCRR Parts 700-705), September 1, 1991, Water Quality Regulations for Surface Waters and Groundwaters.

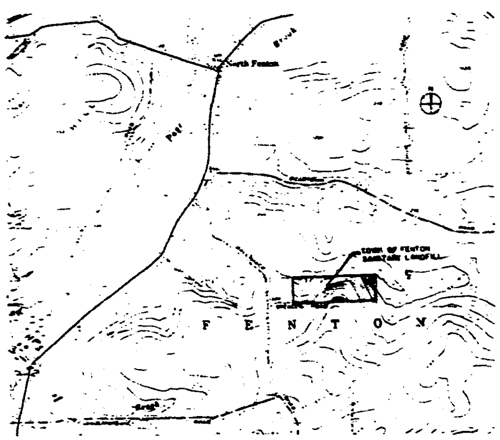
APPENDIX A
CONSTRUCTION PLANS



NEW YORK STATE
LOCATION MAP



BROOME COUNTY
LOCATION MAP
NOT TO SCALE



TOWN OF FENTON
SANITARY LANDFILL
LOCATION MAP
SCALE 1"=2,000

CONSTRUCTION PLANS

LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS

TOWN OF FENTON SANITARY LANDFILL

TOWN OF FENTON   BROOME COUNTY
NEW YORK STATE

PLANS AND SPECIFICATIONS
PREPARED BY

HAWK
ENGINEERING, p.c.

P.O. BOX 427
BINGHAMTON, NEW YORK
(607) 648-4168

MARCH 1989

INDEX OF DRAWINGS

DWG. NO.	TITLE
1	OVERALL SITE PLAN
2	SITE PLAN
3	PROFILES
4	PROFILES & SECTIONS
5	DETAILS
6	DETAILS

PROJECT SPONSORS:

NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY
TWO ROCKEFELLER PLAZA
ALBANY NEW YORK 12223

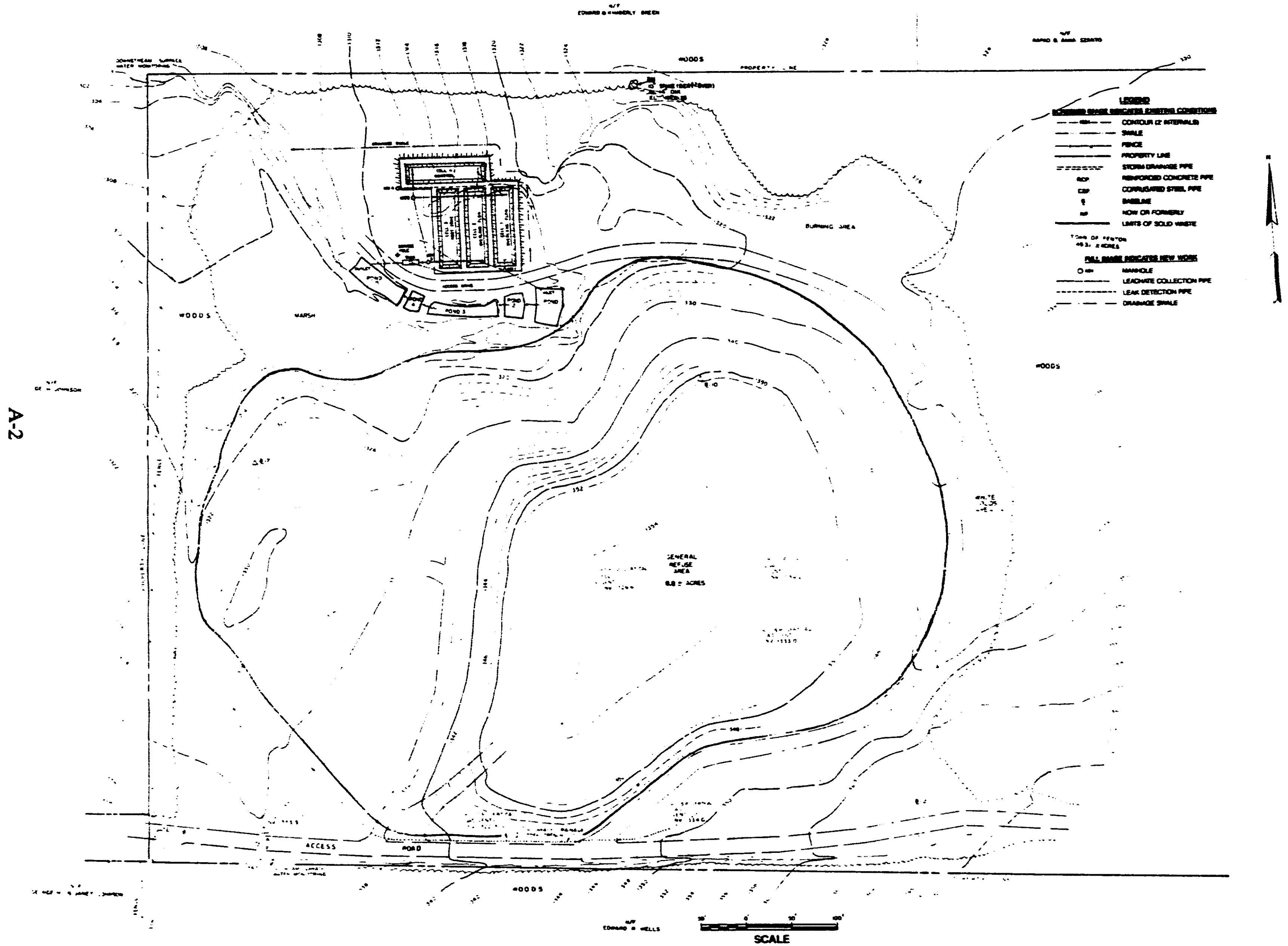
TOWN OF FENTON TOWN BOARD
TOWN HALL
P O BOX 246
PORT CRANE NEW YORK 13833

PROJECT TEAMS:

HAWK ENGINEERING, p.c.
P O BOX 427
BINGHAMTON NEW YORK 13902

CORNELL UNIVERSITY
NEW YORK STATE WATER RESOURCES INSTITUTE
DEPT. OF AGRONOMY
ITHACA NEW YORK 14850

ITHACA COLLEGE
DEPT. OF BIOLOGY
ITHACA NEW YORK 14853



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- ENVIRONMENTAL SERVICES
- LAND DEVELOPMENT SERVICES
- SURVEYING & MAPPING SERVICES

WARNING

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CONSTRUCTION PLANS
LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS
TOWN OF FENTON SANITARY LANDFILL
TOWN OF FENTON BROOME COUNTY
NEW YORK STATE

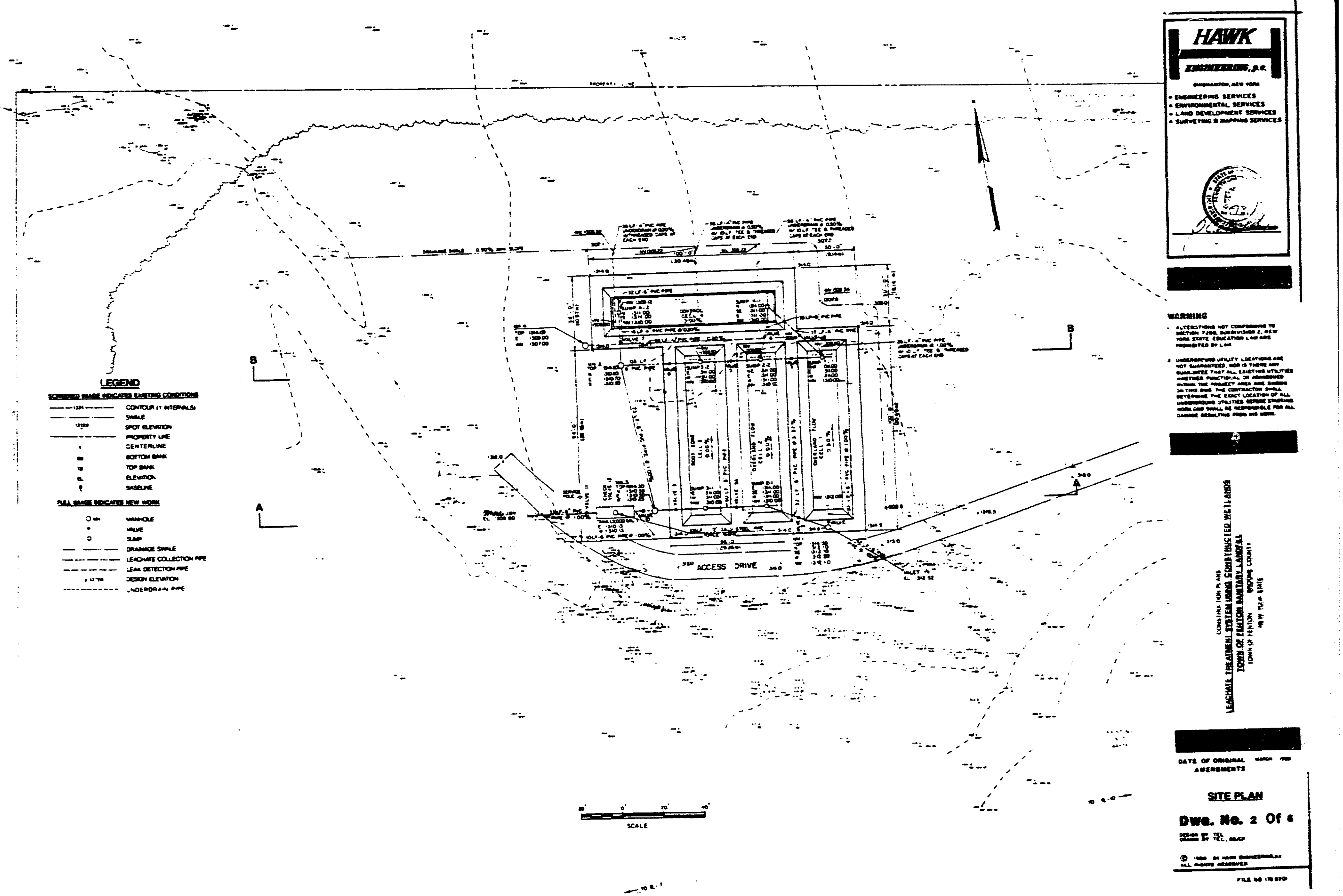
DATE OF ORIGINAL MARCH 1988
AMENDMENTS

OVERALL SITE PLAN

Dwg. No. 1 Of 6

FILE NO

A-3


HAWK
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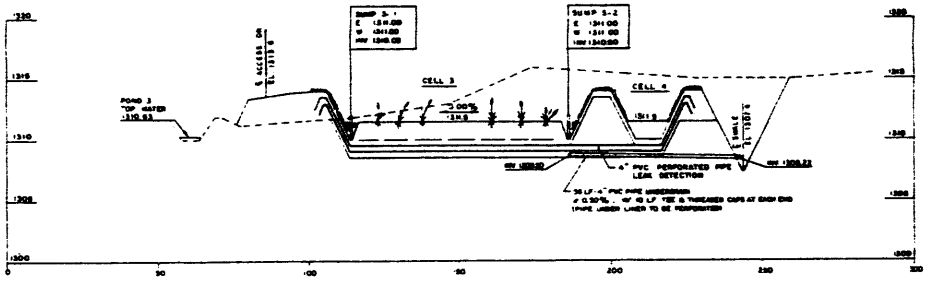
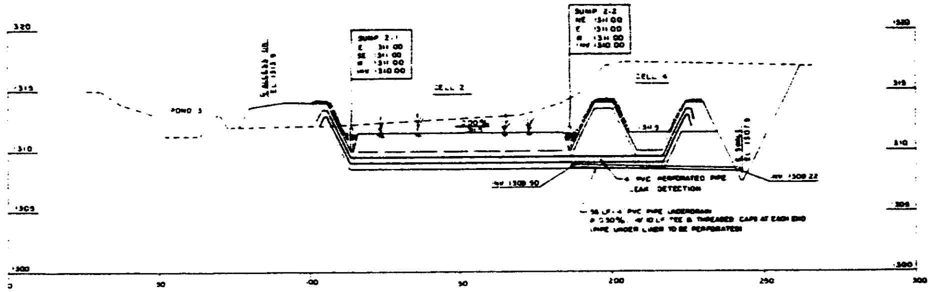
LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS
TOWN OF FENTON SANITARY LANDFILL
TOWN OF FENTON BROOME COUNTY NEW YORK STATE
DATE OF ORIGINAL MARCH 1989
AMENDMENTS
SITE PLAN
Dwg. No. 2 Of 6
LEGEND
SCREENED IMAGE INDICATES EXISTING CONDITIONS
CONTOUR (1' INTERVALS)
SWALE
SPOT ELEVATION
PROPERTY LINE
CENTERLINE
BOTTOM BANK
TOP BANK
ELEVATION
BASELINE
FULL IMAGE INDICATES NEW WORK
MANHOLE
VALVE
SUMP
DRAINAGE SWALE
LEACHATE COLLECTION PIPE
LEAK DETECTION PIPE
DESIGN ELEVATION
UNDERDRAIN PIPE
CONTROL CELL 4
ROOT CELL 1
OVERLAND FLOW CELL 2
OVERLAND FLOW CELL 3
ACCESS DRIVE
SCALE
A
B



PROFILE - CELL 3



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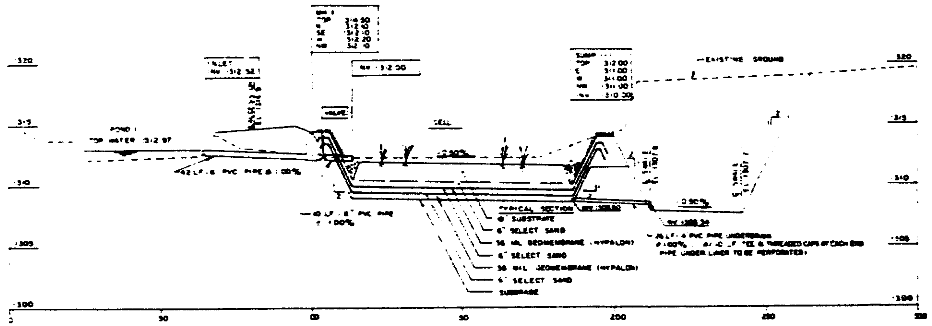

PROFILE - CELL 1

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CONSTRUCTION PLANS

LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS

TOWN OF FENTON SANITARY LANDFILL

TOWN OF FENTON BROOME COUNTY

NEW YORK STATE

DATE OF ORIGINAL

AMENDMENTS

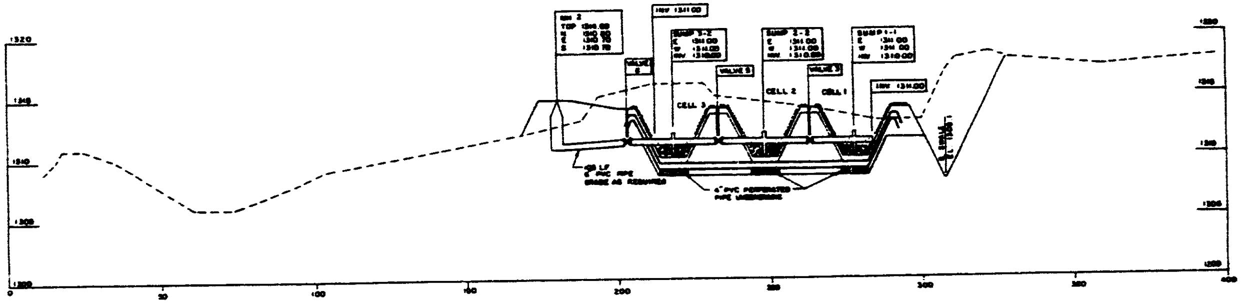
PROFILES

Dwg. No. 3 Of 6

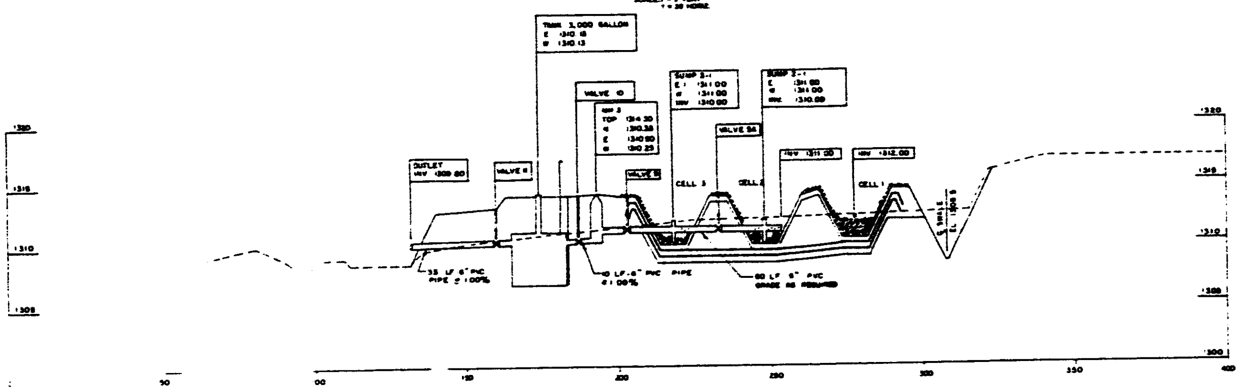
DESIGN BY TEL

DRAWN BY TB

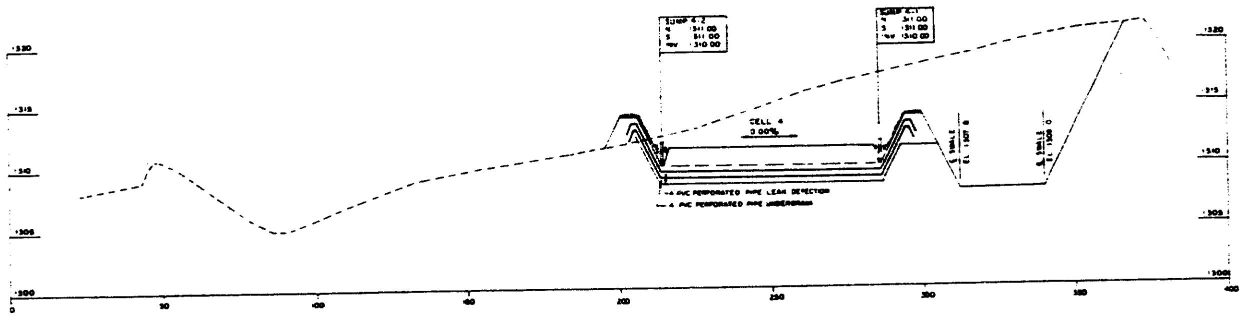
A-5



SECTION B-B



SECTION A-A



PROFILE CELL - 4

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CONSTRUCTION PLANS

LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS

TOWN OF FENTON SANITARY LANDFILL

TOWN OF FENTON BROOME COUNTY

NEW YORK STATE

[redacted]

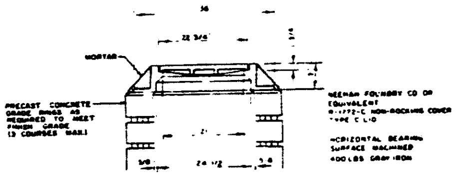
DATE OF ORIGINAL MARCH 1989

AMENDMENTS

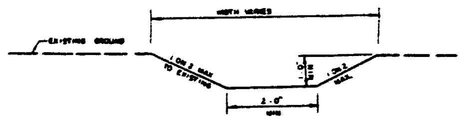
PROFILES & SECTIONS

Dwg. No. 4 Of 6

A-6

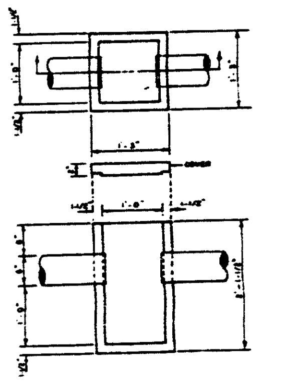


STANDARD MANHOLE COVER DETAIL



TYPICAL DRAINAGE SWALE

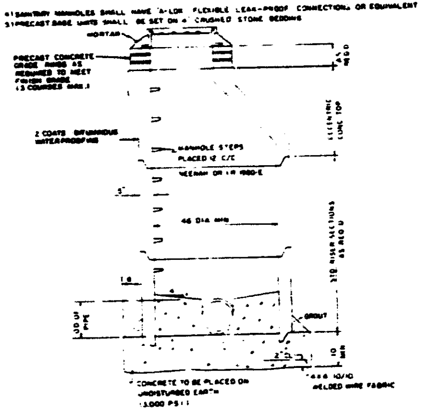
(NOT TO SCALE)



CONCRETE SUMP PIT DETAIL

NOT TO SCALE

NOTES
1) PRECAST CONCRETE MANHOLE COMPONENTS SHALL CONFORM TO ASTM C478
2) SANITARY MANHOLE SECTIONS SHALL HAVE JOINTS CONFORMING TO ASTM C443
3) LIFTING HOLES AND PIPE CUTOUTS TO BE GROUTED WITH EXPANDING MORTAR
4) SANITARY MANHOLES SHALL HAVE A-LOK FLEXIBLE LEAK-PROOF CONNECTIONS OR EQUIVALENT
5) PRECAST BASE UNITS SHALL BE SET ON 4" CRUSHED STONE BEDDING

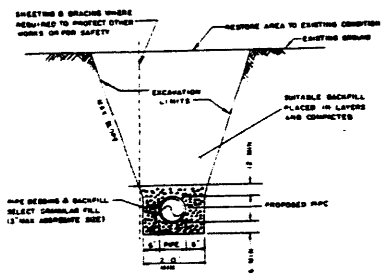


ITEM 02514.1

PRECAST CONCRETE MANHOLE

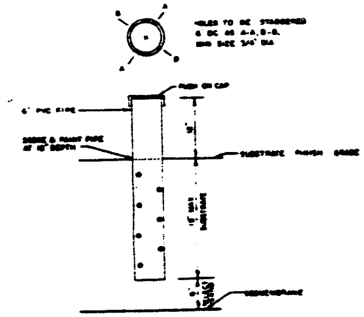
(FOR PIPES 24" DIAMETER OR LESS)

NO SCALE



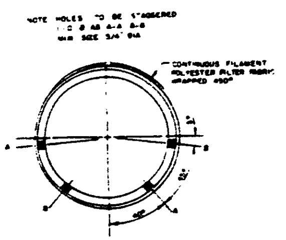
PIPE BEDDING & TRENCH DETAIL

(N.T.S)



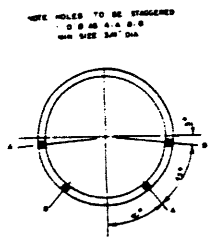
MONITORING PIPE DETAIL

NOT TO SCALE



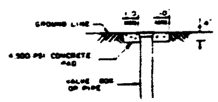
4" PVC PERFORATED PIPE DETAIL

(NOT TO SCALE)



6" PVC PERFORATED PIPE DETAIL

(NOT TO SCALE)



CONCRETE PAD DETAIL

(N.T.S.)

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CONSTRUCTION PLANS

LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS

TOWN OF FENTON SANITARY LANDFILL

TOWN OF FENTON BROOME COUNTY

NEW YORK STATE

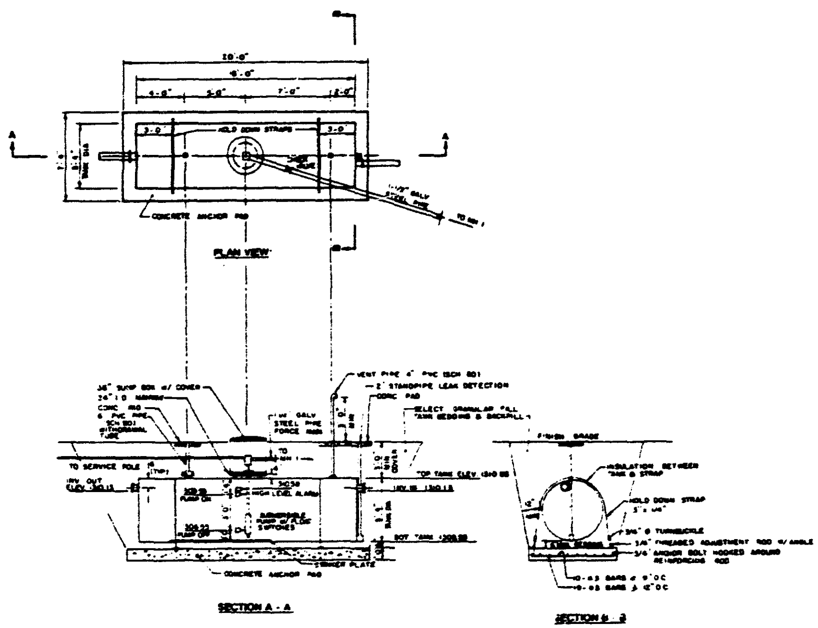
[redacted]

DATE OF ORIGINAL
AMENDMENTS

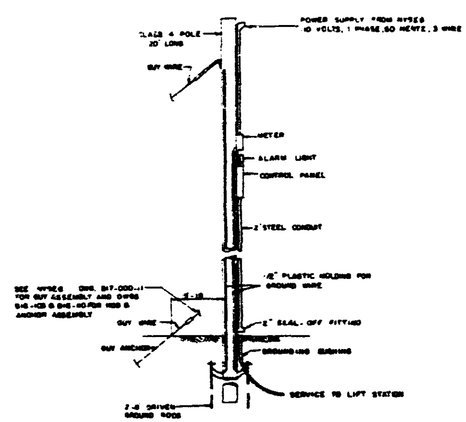
DETAILS

Dwg. No. 5 Of 6

A-7

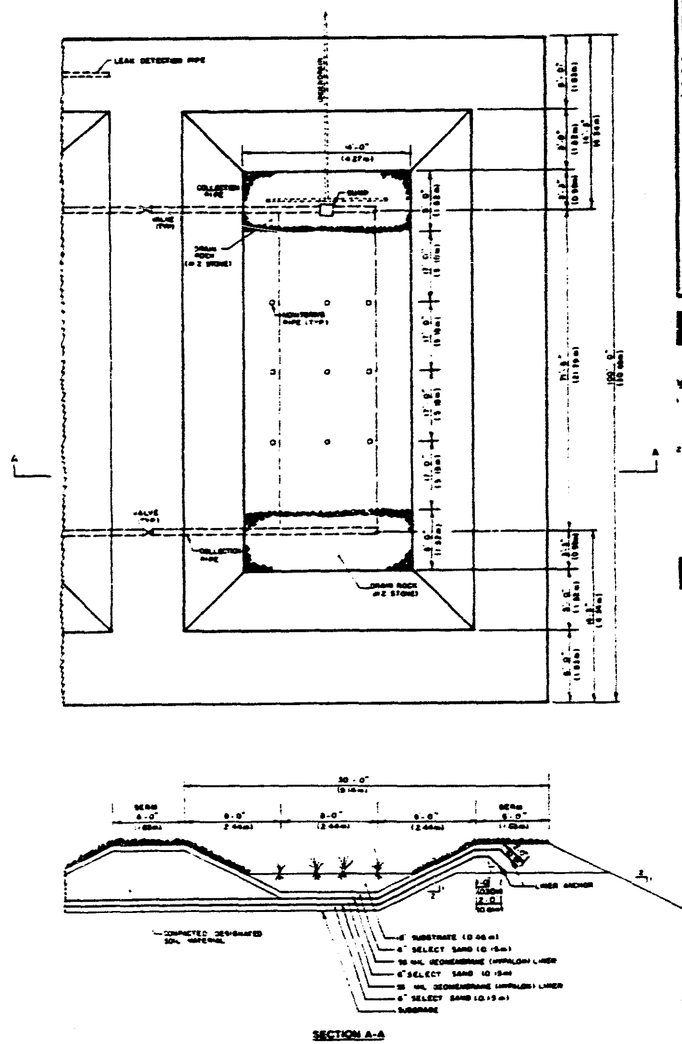


TANK DETAIL



SERVICE POLE DETAIL

NO SCALE



CELL DETAIL

NOT TO SCALE

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BINGHAMTON, NEW YORK

- ENGINEERING SERVICES
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[redacted]

CONSTRUCTION PLANS
LEACHATE TREATMENT SYSTEM USING CONSTRUCTED WETLANDS
TOWN OF FENTON SANITARY LANDFILL
TOWN OF FENTON BROOME COUNTY
NEW YORK STATE

[redacted]

DATE OF ORIGINAL MARCH 1990
AMENDMENTS

DETAILS

Dwg. No. 6 Of 6

DESIGN BY TEL
DRAWN BY TEL

FILE NO. 10 STO1

APPENDIX B

LEACHATE QUALITY ANALYSES

AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

APPENDIX B

LEACHATE QUALITY ANALYSIS

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Table B-1

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 91786003
Date: September 17, 1986

Client I.D.: Costello's Laboratory, Inc. - Town of Fenton Landfill #1 Pond, PO #090178832

ULI I.D.: 21286024

Parameters	Results
Odor	50 units
Total Kjeldahl Nitrogen	38
Ammonia-Nitrogen	29
Nitrate-Nitrogen	0.52
Sulfate	<1
Hexavalent Chromium	<0.01
BOD_5	91
COD	250
TOC	<1
Total Dissolved Solids	680
Alkalinity *	720
Color	8 units
Total Hardness *	420
Total Boron	0.7
Detergent **	<1
Chloride	210
Turbidity	16 NTU
Total Cyanide	<0.01
Total Metals ***	
Total Aluminum	<0.6
Total Antimony	<0.4
Total Arsenic	0.014
Total Beryllium	0.015
Total Cadmium	<0.005
Total Calcium	130
Total Chromium	<0.05
Total Copper	<0.03
Total Iron	3.5
Total Lead	<0.1
Total Manganese	4.2

(cont. on next page)

All results are expressed as ppm unless otherwise stated.
*Results expressed as mg/1 $CaCO_3$.
**Higher detection limit due to matrix interferences.
***Dissolved Metals could not be run because sample preserved upon receipt. In order to run this sample as Dissolved Metals, sample must be filtered in the field.

Approved: [signature]

Date: 9/17/86

Table B-1

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 91786003
Date: September 17, 1986

Client I.D.: Costello's Laboratory, Inc. - Town of Fenton Landfill #1 Pond, PO #090178832

ULI I.D.: 21286024

Parameters	Results
Total Metals (cont.) ***	
Total Mercury	<0.0004
Total Nickel	0.03
Total Selenium	<0.001
Total Silver	<0.02
Total Sodium	120
Total Thallium	<0.3
Total Zinc	0.12

All results are expressed as ppm unless otherwise stated.
***Dissolved Metals could not be run because sample preserved upon receipt. In order to run this sample as Dissolved Metals, sample must be filtered in the field.

Approved: A Scala

Date: 9/17/86

Table B-1

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 91786003
Date: September 17, 1986

EPA 624

CLIENT I.D. - Costello's Laboratory Inc.	Town of Fenton Landfill #1 Pond			
ULI I.D.	21286024			
Chloromethane	<1			
Bromomethane	<1			
Dichlorodifluoromethane	<1			
Vinyl Chloride	<1			
Chloroethane	<1			
Methylene Chloride	<1			
Trichlorofluoromethane	<1			
1,1-Dichloroethylene	<1			
1,1-Dichloroethane	<1			
t-1,2-Dichloroethylene	<1			
Chloroform	<1			
1,2-Dichloroethane	<1			
1,1,1-Trichloroethane	<1			
Carbon Tetrachloride	<1			
Bromodichloromethane	<1			
1,2-Dichloropropane	<1			
t-1,3-Dichloropropylene	<1			
Trichloroethylene	<1			
Dibromochloromethane	<1			
1,1,2-Trichloroethane	<1			
c-1,3-Dichloropropylene	<1			
1,1,2,2-Tetrachloroethane	<1			
Tetrachloroethylene	<1			
Bromoform	<10			
2-Chloroethylvinyl ether	<10			
Chlorobenzene	<1			
1,2-Dichlorobenzene	<1			
1,3-Dichlorobenzene	<1			
1,4-Dichlorobenzene	<1			
Benzene	14			
Toluene	<1			
Ethylbenzene	<1			
Xylenes	<1			

All results are expressed as ppm unless otherwise stated.

Results are expressed as ppb.

Approved: A. Scala

Date: 9/17/86

Disclaimer: The test results and procedures utilized, and laboratory interpretations of data obtained by ULI as contained in this report are believed by ULI to be accurate and reliable for sample(s) tested. In accepting this report, the customer agrees that the full extent of any and all liability for actual and consequential damages of ULI for the services performed shall be equal to the fee charged to the customer for the services as liquidated damages.

Table B-1

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 91786003
Date: September 17, 1986

PESTICIDES/PCBs

CLIENT I.D.- Costello's Laboratory Inc.	Town of Fenton Landfill #1 Pond			
ULI I.D.	21286024			
BHC (a-isomer)	<0.01			
BHC (g-isomer)	<0.01			
BHC (b-isomer)	<0.01			
Heptachlor	<0.01			
BHC (d-isomer)	<0.01			
Aldrin	<0.01			
Heptachlor Epoxide	<0.1			
Endosulfan (a-isomer)	<0.02			
Dieldrin	<0.02			
4,4'-DDE	<0.01			
4,4'-DDD	<0.02			
Endrin	<0.01			
Endosulfan (b-isomer)	<0.01			
4,4'-DDT	<0.02			
Endrin Aldehyde	<0.04			
Endosulfan Sulfate	<0.1			
Chlordane	<0.03			
Toxaphene	<0.3			
Aroclor 1016	<0.1			
Aroclor 1221	<0.1			
Aroclor 1232	<0.1			
Aroclor 1242	<0.1			
Aroclor 1248	<0.1			
Aroclor 1254	<0.1			
Aroclor 1260	<0.1			

All results are expressed as ppb.

Table B-1

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 91786003
Date: September 17, 1986

BASE/NEUTRAL EXTRACTABLES

CLIENT I.D. - Costello's Laboratory Inc.	Town of Fenton Landfill #1 Pond			
ULI I.D.	21286024			
N-Nitrosodimethylamine	<20			
Bis(2-chloroethyl) ether	<5			
1,3-Dichlorobenzene	<5			
1,4-Dichlorobenzene	<5			
1,2-Dichlorobenzene	<5			
Bis(2-chloroisopropyl) ether	<5			
Hexachloroethane	<5			
Nitrobenzene	<5			
N-Nitrosodipropylamine	<5			
Isophorone	<5			
Bis(2-chloroethoxy) methane	<5			
1,2,4-Trichlorobenzene	<5			
Naphthalene	<5			
Hexachlorobutadiene	<5			
Hexachlorocyclopentadiene	<5			
2-Chloronaphthalene	<5			
Dimethylphthalate	<5			
Acenaphthylene	<5			
2,6-Dinitrotoluene	<5			
Acenaphthene	<5			
2,4-Dinitrotoluene	<5			
Fluorene	<5			
Diethyl phthalate	<5			

All results are expressed as ppb.

Table B-1

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 91786003
Date: September 17, 1986

BASE/NEUTRAL EXTRACTABLES

CLIENT I.D. - Costello's Laboratory Inc.	Town of Fenton Landfill #1 Pond			
ULI I.D.	21286024			
4-Chlorophenylphenyl ether	<5			
N-Nitrosodiphenylamine	<5			
4-Bromophenylphenyl ether	<5			
Hexachlorobenzene	<5			
Phenanthrene	<5			
Anthracene	<5			
Dibutyl phthalate	<5			
Fluoranthene	<5			
Benzidine	<50			
Pyrene	<5			
Butyl benzyl phthalate	<5			
3,3'-Dichlorobenzidine	<20			
Chrysene	<5			
Benzo(a)anthracene	<10			
Bis(2-ethylhexyl) phthalate	16			
Dioctyl phthalate	<5			
Benzo(b)fluoranthene	<5			
Benzo(k)fluoranthene	<5			
Benzo(a)pyrene	<5			
Indeno(1,2,3-cd)pyrene	<5			
Dibenzo(a,h)anthracene	<5			
Benzo(ghi)perylene	<5			

All results are expressed as ppb.

Table B-1

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 91786003
Date: September 17, 1986

ACID EXTRACTABLES

CLIENT I.D. - Costello's Laboratory Inc.	Town of Fenton Landfill #1 Pond			
ULI I.D.	21286024			
Phenol	<5			
2-Chlorophenol	<5			
2-Nitrophenol	<5			
2,4-Dimethylphenol	<5			
2,4-Dichlorophenol	<5			
4-Chloro-3-Methylphenol	<5			
2,4,6-Trichlorophenol	<5			
2,4-Dinitrophenol	<50			
4-Nitrophenol	<5			
2-Methyl-4,6-Dinitrophenol	<50			
Pentachlorophenol	<5			

All results are expressed as ppb.

Approved: [signature] 9/17/86

Disclaimer: The test results and procedures utilized, and laboratory interpretations of data obtained by ULI as contained in this report are believed by ULI to be accurate and reliable for sample(s) tested. In accepting this report, the customer agrees that the full extent of any and all liability for actual and consequential damages of ULI for the services performed shall be equal to the fee charged to the customer for the services as liquidated damages.

Table B-2

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 082889013
Date: August 28, 1989

CLIENT I.D.: Costello's Laboratory, Inc. (Town of Fenton Landfill) - Water Sample, 7/26/89, GRAB

ULI I.D.: 20889089

Parameters	Results
BOD_5	50
Hexavalent Chromium *	<0.10
Nitrate-Nitrogen	12
Turbidity	19 NTU
Color	1000 Units
Sulfate	7
Total Dissolved Solids	2700
Alkalinity	2300 mg/l $CaCO_3$
Chloride	510
Total Hardness	1000 mg/l $CaCO_3$
Total Kjeldahl Nitrogen	240
Ammonia Nitrogen	210
COD	580
TOC	200
Total Phenols	0.037
Total Cyanide	<0.01
Total Boron	2.0
Dissolved Boron	1.8

All results are expressed as mg/l unless otherwise stated.
*Higher detection limit due to Matrix Interference.
Sampled by client.

Approved: ______________ 8/28/89

Note: See disclaimer on cover letter.

Table B-2

UPSTATE LABORATORIES, INC.
Analysis Results
Report Number 082889013
Date: August 28, 1989

CLIENT I.D.: Costello's Laboratory (Town of Fenton Landfill) - Water Sample, 7/26/89, GRAB

ULI I.D.: 20889089

Parameters	Results
TOTAL:	
Aluminum	0.5
Antimony *	<0.01
Arsenic *	0.005
Barium	0.4
Beryllium	<0.005
Cadmium	0.017
Calcium	290
Chromium	<0.05
Copper	<0.02
Iron	32
Lead *	0.011
Magnesium	140
Manganese	5.0
Mercury	0.0012
Nickel	0.10
Potassium	260
Selenium *	0.001
Silver	<0.05
Sodium	490
Thallium *	0.029
Zinc	0.34

All results are expressed as mg/l. *Analysis by Furnace AA.
Sampled by client.

Approved: [signature] 8/28/89

Note: See disclaimer on cover letter.

Table B-2

UPSTATE LABORATORIES, INC.

Analysis Results
Report Number 082889013
Date: August 28, 1989

CLIENT I.D.: Costello's Laboratory, Inc. (Town of Fenton Landfill) - Water Sample, 7/26/89, GRAB

ULI I.D.: 20889089

Parameters	Results
DISSOLVED:	
Aluminum	0.7
Antimony *	<0.01
Arsenic *	0.006
Barium	0.4
Beryllium	<0.005
Cadmium	0.009
Calcium	310
Chromium	<0.05
Copper	<0.02
Iron	17
Lead *	0.004
Magnesium	140
Manganese	4.8
Mercury	0.005
Nickel	0.03
Potassium	260
Selenium *	0.006
Silver	<0.05
Sodium	480
Thallium *	0.022
Zinc	0.26

All results are expressed as mg/l. *Analysis by Furnace AA.
Sampled by client.

Approved: ____________________ 8/28/89

Note: See disclaimer on cover letter.

Table B-2

UPSTATE LABORATORIES, INC.
Analysis Results
Report Number 082889013
Date: August 28, 1989

EPA 624

CLIENT I.D. Costello's Laboratory, Inc. (Town Fenton Landfill)	Water Sample 7/26/89 GRAB			
ULI I.D.	20889089			
Chloromethane	<3			
Bromomethane	<3			
Vinyl Chloride	<3			
Chloroethane	<3			
Methylene Chloride	<3			
Trichlorofluoromethane	<3			
1,1-Dichloroethylene	<3			
t-1,2-Dichloroethylene	<3			
1,1-Dichloroethane	13			
Chloroform	<3			
1,2-Dichloroethane	<3			
1,1,1-Trichloroethane	<3			
Benzene	<3			
Carbon Tetrachloride	<3			
1,2-Dichloropropane	<3			
Bromodichloromethane	<3			
Trichloroethylene	<3			
c-1,3-Dichloropropene	<3			
t-1,3-Dichloropropene	<3			
1,1,2-Trichloroethane	<3			
Toluene	13			
Dibromochloromethane	<3			
Tetrachloroethylene	<3			
2-Chloroethylvinyl Ether	<3			
Chlorobenzene	<3			
Ethylbenzene	3			
Bromoform	<3			
1,1,2,2-Tetrachloroethane	<3			
1,2-Dichlorobenzene	<3			
1,3-Dichlorobenzene	<3			
1,4-Dichlorobenzene	<3			
Total Xylenes	11			

All results are expressed as ug/l.
Sampled by client.

Approved: ______________________ 8/28/89

Note: See disclaimer on cover letter.

Table B-2

UPSTATE LABORATORIES, INC.
Analysis Results
Report Number 082889013
Date: August 28, 1989

SE/NEUTRAL EXTRACTABLES

IENT I.D. stello's Laboratory, Inc. own of Fenton Landfill)	Water Sample 7/26/89 GRAB			
I I.D.	20889089			
s(2-chloroethyl)Ether	<5			
3-Dichlorobenzene	<5			
4-Dichlorobenzene	<5			
2-Dichlorobenzene	<5			
s(2-chloroisopropyl)Ether	<5			
xachloroethane	<5			
trobenzene	<5			
-Nitrosodipropylamine	<5			
sophorone	<5			
s(2-chloroethoxy)Methane	<5			
2,4-Trichlorobenzene	<5			
phthalene	<5			
xachlorobutadiene	<5			
xachlorocyclopentadiene	<5			
-Chloronaphthalene	<5			
methylphthalate	<5			
enaphthylene	<5			
6-Dinitrotoluene	<5			
enaphthene	<5			
4-Dinitrotoluene	<5			
uorene	<5			
ethyl Phthalate	7			
-Chlorophenylphenyl Ether	<5			
-Nitrosodiphenylamine	<5			
-Bromophenylphenyl Ether	<5			
xachlorobenzene	<5			
enanthrene	<5			
thracene	<5			
butyl Phthalate	<5			

l results are expressed as ug/l.
mpled by client.

proved: ________________ 8/28/89

te: See disclaimer on cover letter.

Table B-2

UPSTATE LABORATORIES, INC.
Analysis Results
Report Number 082889013
Date: August 28, 1989

BASE NEUTRAL EXTRACTABLES (cont)

CLIENT I.D. Costello's Laboratory, Inc. (Town of Fenton Landfill)	Water Sample 7/26/89 GRAB			
ULI I.D.	20889089			
Fluoranthene	<5			
Benzidine	<5			
Pyrene	<5			
Butyl Benzyl Phthalate	<5			
3,3'-Dichlorobenzidine	<5			
Chrysene	<5			
Benzo(a)Anthracene	<5			
Bis(2-ethylhexyl)Phthalate	12			
Dioctyl Phthalate	<5			
Benzo(b)Fluoranthene	<5			
Benzo(k)Fluoranthene	<5			
Benzo(a)Pyrene	<5			
Indeno(1,2,3-cd)Pyrene	<10			
Dibenzo(a,h)Anthracene	<10			
Benzo(ghi)Perylene	<10			

All results are expressed as ug/l.
Sampled by client.

Approved: ______________________ 8/28/89

Note: See disclaimer on cover letter.

Table B-2

UPSTATE LABORATORIES, INC.
Analysis Results
Report Number 082889013
Date: August 28, 1989

PESTICIDES/PCBs

CLIENT I.D. Costello's Laboratory, Inc. (Town of Fenton Landfill)	Water Sample 7/26/89 GRAB			
ULI I.D.	20889089			
BHC (a-isomer)	<0.01			
BHC (g-isomer)	<0.01			
BHC (b-isomer)	<0.01			
Heptachlor	<0.01			
BHC (d-isomer)	<0.01			
Aldrin	<0.01			
Heptachlor Epoxide	<0.1			
Endosulfan (a-isomer)	<0.01			
Dieldrin	<0.01			
4,4'-DDE	<0.01			
4,4'-DDD	<0.01			
Endrin	<0.01			
Endosulfan (b-isomer)	<0.01			
4,4'-DDT	<0.01			
Endrin Aldehyde	<0.03			
Endosulfan Sulfate	<0.1			
Chlordane	<0.03			
Toxaphene	<0.5			
Aroclor 1016	<0.1			
Aroclor 1221	<0.1			
Aroclor 1232	<0.1			
Aroclor 1242	<0.1			
Aroclor 1248	<0.1			
Aroclor 1254	<0.1			
Aroclor 1260	<0.1			

All results are expressed as ug/l.
Sampled by client.

Approved: [signature] 8/28/89

Note: See disclaimer on cover letter.

Table B-2

UPSTATE LABORATORIES, INC.
Analysis Results
Report Number 082889013
Date: August 28, 1989

ACID EXTRACTABLES

CLIENT I.D. Costello's Laboratory, Inc. (Town of Fenton Landfill)	Water Sample 7/26/89 GRAB			
ULI I.D.	20889089			
Phenol	<5			
2-Chlorophenol	<5			
2-Nitrophenol	<5			
2,4-Dimethylphenol	<5			
2,4-Dichlorophenol	<5			
4-Chloro-3-Methylphenol	<5			
2,4,6-Trichlorophenol	<5			
2,4-Dinitrophenol	<50			
4-Nitrophenol	<50			
2-Methyl-4,6-Dinitrophenol	<50			
Pentachlorophenol	<10			

All results are expressed as ug/l.
Sampled by client.
NYS DOH I.D.: 10170

Approved: ________________ 8/28/89

Note: See disclaimer on cover letter.

Table B-3

ANALYTICAL SUMMARY
ROUTINE PARAMETERS
FENTON LANDFILL
GTA-89-65
JANUARY 8, 1990

	W-1	W-2	W-3D	W-3S	UPSTREAM	DOWNSTREAM	LEACHATE	JOHNSON	MCGOWAN	DUPLICATE LEACHATE	BLANK	DETECTION LIMITS	NYSDEC STANDARD & GUIDANCE (mg/l)
Alkalinity **	62	63	302	246	7.2	231	2170	226	128	2090	1.0	0.5 - 25	---
Ammonia Nitrate	<DL	<DL	0.11	0.06	<DL	4.43	197	0.07	0.06	200	0.11	0.05 - 10	---
TOC	1.9	1.3	2.8	4.9	2.8	7.2	156	0.19	0.17	160	0.29	0.10	---
COD	<DL	10.6	41	129	7.5	22	741	<DL	6.7	638	<DL	5.00 - 50.0	---
Chloride	1.8	57	49	63	<DL	57	464	21	2.8	495	<DL	1.00 - 10.00	250 (S)
Total Hardness **	122	146	354	367	24	226	992	128	120	1014	<DL	1.00 - 10.00	---
Nitrate	<DL	0.26	<DL	<DL	<DL	<DL	0.38	<DL	<DL	0.41	<DL	0.20	---
Total Phenolics	<DL	<DL	<DL	<DL	<DL	0.008	0.036	<DL	<DL	0.034	<DL	0.006	0.001 (S)
TDS	145	201	342	223	64	284	2770	274	161	2560	<DL	10.0	---
Sulfate	70	37	31	26	12	18	26	19	14	26	<DL	10.0	250 (S)
Turbidity *	27	68	341	1043	18	47	151	0.64	0.83	170	0.36	0.05	---
Cadmium	<DL	<DL	<DL	0.02	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.005 - 0.05	0.01 (S)
Calcium	30.7	34.4	82.5	47.0	6.44	48.5	211	29.1	30.7	213	0.67	0.05 - 0.5	---
Iron	1.79	2.17	14.5	176	1.04	6.64	7.47	<DL	1.16	11.6	<DL	0.02 - 0.2	0.3 (S)
Lead	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.05	0.025 (S)
Magnesium	6.95	11.1	25.6	46.9	1.54	18.4	118	8.99	7.62	118	0.07	0.03 - 0.3	35 (G)
Manganese	0.12	0.33	4.43	5.16	0.05	4.04	3.72	0.20	0.12	3.83	<DL	0.01 - 0.1	0.3 (S)
Potassium	<DL	<DL	<DL	20.7	<DL	6.42	273	<DL	<DL	274	<DL	5.0 - 50.0	---
Sodium	10.9	20.4	33.2	15.8	2.86	55.5	768	97.8	16.9	773	0.37	0.125 - 1.25	---

NOTES:

All results in mg/l unless otherwise specified
Metals are total concentrations except for W-3S which was filtered.
<DL = Less than detection limit
* = Units in NTU
** = mg/l as CaCo3

Reference: Empire Soils Investigations, Inc. October 1989, Revised: January 1990.
Hydrogeologic Investigation, Town of Fenton Landfill Closure, Fenton, New York.
Empire Soils Investigations, Inc. Groton, New York.

Table B-4

ANALYTICAL SUMMARY
ROUTINE PARAMETERS
FENTON LANDFILL
GTA-89-65
FEBRUARY 28, 1990

	W-1	W-2	W-3D	DUPLICATE W-3D	W-3S	UPSTREAM	DOWNSTREAM	LEACHATE	JOHNSON	MCGOWAN	BLANK	DETECTION LIMITS	NYSDEC STANDARD & GUIDANCE (mg/l)
Alkalinity **	46.0	49.0	352	334	306	5.6	311	2260	268	124	---	0.5	---
Ammonia Nitrate	<DL	<DL	0.17	0.16	0.55	<DL	9.9	186	0.26	0.26	0.14	0.05	---
TOC	1.5	2.1	6.1	5.7	6.2	1.8	13.4	206	1.4	0.70	0.30	0.10	---
COD	14	17	47	63	40	<DL	49	596	7.9	<DL	6.3	5.00	---
Chloride	1.3	60	82	82	97	<DL	69	512	23	3.2	---	1.00	250 (S)
Total Hardness **	90	145	434	432	404	21	260	1005	184	119	5.9	1.00	---
Nitrate	<DL	<DL	<DL	<DL	<DL	<DL	0.49	<DL	<DL	<DL	---	0.20	---
Total Phenolics	<DL	<DL	<DL	0.008	<DL	<DL	0.016	0.20	0.006	<DL	---	0.006	0.001 (S)
TDS	15	113	540	530	288	55	380	2702	316	131	---	2.0	---
Sulfate	55	45	32	39	30	11	14	<DL	24	12	---	10.0	250 (S)
Turbidity *	102	124	1200	1200	1200	10	22	270	0.93	0.80	---	0.05 - 1.5	---
Cadmium	<DL	<DL	0.019	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.005 - 0.05	0.01 (S)
Calcium	21.8	33.3	99.3	99.5	86.4	4.77	60.0	222	44.4	29.7	2.62	0.05 - 0.50	---
Iron	0.23	0.51	39.7	34.6	0.20	0.97	2.82	41.8	0.14	0.12	0.16	0.02 - 0.20	0.3 (S)
Lead	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.05 - 0.50	0.025 (S)
Magnesium	5.00	11.0	34.8	33.9	32.2	1.69	20.0	119	13.2	7.08	0.08	0.03 - 0.30	35 (G)
Manganese	0.12	0.32	5.86	5.84	5.96	0.04	4.36	3.07	0.25	0.13	<DL	0.01 - 0.10	0.3 (S)
Potassium	<DL	<DL	9.47	7.70	<DL	<DL	15.0	307	<DL	<DL	<DL	5.0 - 50.0	---
Sodium	5.41	13.1	28.6	27.9	29.8	2.66	46.0	528	59.2	9.89	1.18	0.13 - 1.25	---

NOTES:

All results in mg/l unless otherwise specified
Metals are total concentrations except for W-3S which was filtered.
<DL = Less than detection limit
* = Units in NTU
** = mg/l as CaCo3

Table B-5

ANALYTICAL SUMMARY
ROUTINE PARAMETERS
FENTON LANDFILL
GTA-89-65
May 30, 1990

	W-1	W-2	W-3S	W-3D	W-4S	W-4D	DUPLICATE W-4D	UPSTREAM	DOWNSTREAM	LEACHATE	MCGOWAN	BLANK	DETECTION LIMITS	NYSDEC STANDARD & GUIDANCE (mg/l)
Alkalinity **	55	61	311	355	116	94	91	8	1162	1110	113	<10	10.0	---
Ammonia Nitrogen	0.12	0.06	0.28	0.18	0.08	0.06	0.10	<0.05	5	80	1.08	<0.05	0.05	---
TOC	2.9	5.8	9.3	89#	2.4	2.4	1.8	3.8	9.2	100	0.33	0.53	0.10	---
COD	8.0	13	47	22	28	34	51	<5.0	29	364	<5.0	6.0	5.0	---
Chloride	1.5	39	97	85	12	11	11	<1.00	31	228	2	<1.00	1.00	250 (S)
Total Hardness **	84	229	437	575	146	121	140	24	205	844	123	<1.00	1.00	---
Nitrate Nitrogen	<0.20	0.22	0.34	<0.20	<0.20	<0.20	<0.20	<0.20	0.56	<0.20	<0.20	<0.20	0.20	---
Total Phenolics	[0.012]	<0.006	[0.009]	<0.006	<0.006	[0.008]	[0.008]	<0.006	[0.006]	[0.131]	<0.006	<0.006	0.006	0.001 (S)
TDS	197	355	576	540	170	169	193	52	195	1320	140	<2.0	2.0	---
Sulfate	43	159	31	33	15	13	12	11	<10.0	<10.0	13	<10.0	10.0	250 (S)
Turbidity *	890	120	2300	900	730	850	1300	12	11	280	1.3	0.2	0.1	---
Cadmium (Total)	<DL	0.009	0.020	0.022	0.013	0.019	0.013	<DL	0.006	0.012	<DL	<DL	0.005	***
Cadmium (Dissolved)	0.007	[0.014]	[0.012]	[0.013]	0.009	<DL	<DL	[0.013]	0.007	[0.025]	<DL	---	0.005	0.01 (S)
Calcium (Total)	25.1	59.7	99.6	123	35.6	30.3	29.9	5.41	51.6	162	31.7	0.19	0.05	---
Calcium (Dissolved)	22.8	59.1	95.1	111	30.9	24.1	22.8	3.94	48.7	128	31.7	---	0.05	---
Iron (Total)	7.53	18.0	83.9	119	55.4	109	88.7	0.97	2.20	28.3	0.38	0.06	0.02	***
Iron (Dissolved)	0.16	0.10	[0.32]	[0.34]	0.30	0.18	0.17	0.19	[0.54]	[0.43]	0.18	---	0.02	0.3 (S)
Lead (Total)	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.05	***
Lead (Dissolved)	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	---	0.05	0.025 (S)
Magnesium (Total)	6.49	20.1	45.8	51.4	17.9	24.6	21.2	1.62	15.8	56.0	7.17	<DL	0.03	***
Magnesium (Dissolved)	5.57	17.7	32.3	29.9	9.53	7.85	7.59	1.41	14.9	[53.3]	7.25	---	0.03	35 (G)
Manganese (Total)	0.73	0.64	7.75	8.45	1.83	3.08	2.82	0.09	2.58	7.37	0.13	<DL	0.01	***
Manganese (Dissolved)	0.05	0.23	[6.40]	[6.06]	[0.96]	[1.47]	[1.46]	0.07	[2.40]	[4.27]	0.13	---	0.01	0.3 (S)
Potassium (Total)	<DL	9.39	11.0	16.3	9.62	17.6	12.7	<DL	13.0	101	<DL	<DL	5.0	---
Potassium (Dissolved)	<DL	7.08	<DL	<DL	<DL	<DL	<DL	<DL	12.6	96.3	<DL	---	5.0	---
Sodium (Total)	5.17	20.7	41.9	36.5	10.6	12.2	12	1.70	36.6	182	9.77	0.20	0.13	---
Sodium (Dissolved)	6.36	22.2	40.2	35.6	12.3	11.8	12.2	4.62	37.5	179	10.0	---	0.13	---

NOTES:

All results in mg/l unless otherwise specified
<DL = Less than detection limit
* = Units in NTU
** = mg/l as CaCO3
*** = Standard and Guidance values for metals listed with dissolved analysis
# = Result suspect due to laboratory error
[ ] = Result above NYSDEC standard or guidance value

APPENDIX C

FIELD SAMPLING RESULTS

APPENDIX C
FIELD SAMPLING RESULTS

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APPENDIX C

FIELD SAMPLING RESULTS

Appendix Tables C-1 through C-5 present sampling and analysis methods, field and laboratory analysis results, and daily weather data for the study period. All of the data are also provided in Lotus 1-2-3™ spreadsheet files (.WK1 format) on the companion diskette.

Tables C-2 through C-4 present individual sampling results from the Cornell work at the experimental site. Weekly samples between June, 1990 and August, 1991 form the core of the field data generated in the research project. Tables C-2 through C-4 begin with three columns:

- sampling location,
- sample identification number, and
- sampling date.

Dashes indicate missing data points. Samples with concentrations below the detection limit are indicated in the tables, for example <0.04 means less than the detection limit of 0.04 ppm.

The sample identification numbers may be used to match data from different files. (The auxilliary ID numbers are not important; they were used for internal tracking of laboratory samples). Location codes are as follows (see main text for details of sampling arrangements and a site map):

mh1	raw landfill leachate near entrance to treatment bed 1
bd1	outflow from bed 1
bd2	outflow from bed 2
bd3	outflow from bed 3
bd4	outflow from bed 4
mh4	manhole between bd4 and htk
htk	holding tank
s14	surface water upstream from landfill influence
s19	surface water upstream from landfill influence
gwn	groundwater discharge to stream
s18	surface water downstream from landfill influence, representing future receiving water for treated leachate

Results from bd4, mh4, and htk are very close; there is no intentional treatment or dilution after bd4. However, the holding tank provides a compositing effect, thus smoothing the bd4 effluent quality and providing additional retention time for chemical or biological reactions. The body of the report generally uses bd4 or mh4 as indicative of the full effect of the treatment system.

Table C-1, identical to Table 4-16 in the body of the report, summarizes field and laboratory methods used to collect and analyze the leachate and water samples.

Table C-2 contains field data plus laboratory-derived oxygen consumption and nitrogen results. Data are contained in eight columns, the first three from onsite measurements:

- pH
- water temperature
- dissolved oxygen

and the remaining five from laboratory results:

- oxygen consumption
- ammonium plus ammonia as N,
- nitrate plus nitrite as N,
- total inorganic N (computed as the sum of the earlier two columns), and
- total Kjeldahl N (interpretable as organic nitrogen plus ammonium and ammonium).

The TKN column contains values only for the mh1 location because interference from nitrate present in the tests invalidated TKN results for the other locations. Mh1 had minimal nitrate.

Table C-3 contains cation concentrations and is broken into two parts. Table C-3a includes Cd, Cu, Ni, Cr, Co, Zn, Ca, and Mg. Table C-3b covers Mn, Al, Fe, Pb, K, As, and Na. These cation concentrations were measured using an Inductively Coupled Plasma (ICP) Spectrometer.

Table C-4 contains site hydrological measurements:

- mh1 flow, indicating inflow to the treatment system
- weekly total precipitation

Table C-5 contains daily weather data from the nearby Binghamton, NY airport (Weather Station Binghamton WS) AP 30-0687):

- maximimum and minimum daily air temperatures,
- total and snow precipitation, and
- snow on the ground.

Tables C-6 and C-7 report supplemental wide-spectrum scans of final treatment system effluent.

Figures C-1 thrugh C-6 provide synoptic views of the overall system performance in terms of twelve quality parameters. C-1 through C-3 summarize raw leachate (at mh1) and C-4 through C-6 compare average water quality at entry to and exit from the treatment system. Table C-8 documents the specific data used in constructing these Figures.

Table C-1. Summary of sampling and analytical methods used in field program.

Parameter	Analysis location	Sample handling	Analysis methods
O_2	field	measure with meter and probe *in-situ*	Yellow Springs model 54A meter, YSI 5700 series electrode
Water temperature	field	(as for O_2)	Beckman model 11 meter
pH	field	(as for O_2)	Beckman model 11 meter
Oxygen consumption	lab	collect 2 l sample in plastic bottle (no chemical additives)	Custom method: Begin same day as sampled; aerate vigorously for 30 min to oxidize ferric iron; measure initial oxygen content; seal, excluding air bubbles; unseal and measure oxygen content 8-16 hr later
$NH_4^+ + NH_3$	lab	(part of sample for oxygen consumption; refrigerate until analysis)	Agronomic standard method: Begin within two days after sample collection. Steam-distill with excess MgO, collect distillate into borate buffer, titrate using HCl. (Keeney and Nelson, 1982)
$NO_3^- + NO_2^-$	lab	(part of sample for oxygen consumption; refrigerate until analysis)	Agronomic standard method: Add Dvarda's alloy to solution used to titrate NH_3, reducing any NO_3 and NO_2 to NH_3. Then redistill and retitrate as above. (Keeney and Nelson, 1982)
Total Kjeldahl N (TKN) (organic nitrogen plus ammonia and ammonium)	lab	Add 2 ml conc. HCl to 250 ml plastic sample bottle; then fill bottle with sample (resulting pH approx. 1). Freeze until analysis.	APHA-AWWA-WPCF Standard Method 4500-N_{org}
Total Ca, Mg, K, Mn, Fe, Zn, Na, Al, Ni, Cu, Cd, Co, Cr	lab	(part of sample for TKN analysis)	APHA-AWWA-WPCF Standard Method 3120: Inductively Coupled Plasma (ICP) Spectrometer

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
mh1	1	05-Jun-90		-	-	-	43	224	0	224	-
mh1	9	18-Jun-90		6.9	1.1	22.0	8	224	0	224	-
mh1	19	25-Jun-90		7.3	1.4	19.0	9	237	0	237	-
mh1	29	02-Jul-90		7.0	1.7	20.0	7	228	0	228	-
mh1	39	09-Jul-90		7.2	3.7	20.0	5	91	3	94	-
mh1	49	16-Jul-90		7.0	0.6	20.7	-	238	5	243	-
mh1	60	23-Jul-90		7.2	0.7	24.3	5	249	0	249	-
mh1	75	30-Jul-90		7.1	-	-	10	261	1	262	256
mh1	86	06-Aug-90		7.5	2.7	21.0	20	135	3	137	138
mh1	101	13-Aug-90		7.1	0.4	22.7	7	251	1	252	-
mh1	112	20-Aug-90		7.3	1.8	18.0	10	239	1	240	-
mh1	127	27-Aug-90		7.3	1.6	23.4	13	265	4	269	283
mh1	142	04-Sep-90		7.2	2.8	24.2	13	219	0	219	266
mh1	150	10-Sep-90		7.4	2.7	18.0	13	267	3	270	290
mh1	162	17-Sep-90		7.5	2.7	16.1	5	260	5	266	-
mh1	176	24-Sep-90		7.7	2.6	13.4	6	239	0	239	-
mh1	190	01-Oct-90		7.5	0.7	15.2	6	202	3	205	217
mh1	205	08-Oct-90		7.2	1.3	17.0	9	234	1	234	-
mh1	220	15-Oct-90		7.0	1.4	15.4	25	108	1	109	-
mh1	235	22-Oct-90		7.2	1.0	13.6	30	233	0	233	-
mh1	251	29-Oct-90		7.4	2.2	8.5	8	230	0	230	-
mh1	267	05-Nov-90		7.2	1.6	13.2	8	246	0	246	-
mh1	282	12-Nov-90		6.8	2.2	7.0	13	169	1	170	-
mh1	297	19-Nov-90		7.2	2.5	5.9	10	206	0	206	173
mh1	312	26-Nov-90		6.9	1.7	8.9	6	102	0	102	-
mh1	327	04-Dec-90		7.1	4.0	6.1	23	92	1	93	-
mh1	342	10-Dec-90		7.0	2.3	9.0	4	189	0	189	186
mh1	357	17-Dec-90		7.5	4.1	6.0	1	165	3	167	-
mh1	372	02-Jan-91		6.9	2.7	3.6	14	155	1	156	125
mh1	387	07-Jan-91		6.9	3.4	2.2	6	152	0	152	-
mh1	400	14-Jan-91		7.2	4.1	2.5	5	143	0	143	-
mh1	410	21-Jan-91		6.9	-	0.9	3	156	0	156	-
mh1	421	28-Jan-91		7.2	4.9	2.2	2	161	3	163	-
mh1	432	04-Feb-91		7.5	4.4	4.8	6	122	1	124	123
mh1	446	11-Feb-91		7.1	3.6	0.8	1	103	3	106	-
mh1	457	18-Feb-91		7.3	-	1.2	4	86	2	88	-
mh1	470	25-Feb-91		7.5	7.1	2.2	3	127	1	128	-
mh1	481	06-Mar-91		-	-	-	-	33	2	35	-
mh1	492	11-Mar-91		7.4	1.6	6.2	8	169	0	169	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
mh1	504	18-Mar-91		7.5	4.5	5.4	6	140	0	140	-
mh1	515	25-Mar-91		7.4	4.0	6.1	15	110	2	112	-
mh1	527	02-Apr-91		7.3	2.4	7.4	5	157	2	159	141
mh1	545	08-Apr-91		7.1	2.5	15.1	16	169	1	170	-
mh1	563	15-Apr-91		6.9	3.8	10.8	5	166	2	168	-
mh1	578	23-Apr-91		7.0	1.3	13.7	21	112	0	112	-
mh1	593	29-Apr-91		7.1	2.0	14.3	3	161	3	164	-
mh1	604	13-May-91		7.0	2.0	18.6	12	175	2	177	180
mh1	622	20-May-91		7.1	1.9	17.4	8	154	0	154	-
mh1	633	28-May-91		7.0	1.7	22.5	3	177	0	177	-
mh1	651	03-Jun-91		7.3	1.4	21.6	6	163	0	163	177
mh1	670	10-Jun-91		7.2	2.2	20.8	8	175	1	176	-
mh1	688	17-Jun-91		7.1	2.1	21.1	6	172	0	172	-
mh1	706	24-Jun-91		7.0	0.8	22.7	3	177	0	177	-
mh1	724	01-Jul-91		7.2	1.5	23.5	6	195	0	195	182
mh1	738	08-Jul-91		7.1	1.7	23.2	6	196	3	199	-
mh1	756	15-Jul-91		7.0	2.7	21.5	5	191	19	210	-
mh1	774	22-Jul-91		7.2	2.5	24.5	6	205	0	205	-
mh1	792	29-Jul-91		7.1	3.1	22.0	7	205	0	205	-
mh1	810	05-Aug-91		7.1	0.6	22.5	6	200	1	201	183
mh1	828	12-Aug-91		7.3	1.8	21.5	5	197	0	197	-
mh1	846	19-Aug-91		-	-	-	-	-	-	-	-
mh1	864	26-Aug-91		-	-	-	-	-	-	-	-
mh1	882	03-Sep-91		-	-	-	-	197	2	199	-
mh1	900	09-Sep-91		7.3	1.7	21.3	5	197	11	208	-
mh1	918	16-Sep-91		7.5	1.8	22.0	5	189	3	192	-
mh1	936	23-Sep-91		-	-	-	-	-	-	-	-
mh1	954	30-Sep-91		7.6	4.2	11.9	3	189	5	195	-
mh1	972	07-Oct-91		7.5	4.0	12.5	6	143	9	151	-
mh1	990	14-Oct-91		7.6	6.7	10.0	3	154	10	164	-
mh1	1008	21-Oct-91		7.0	3.0	13.8	2	182	0	182	-
mh1	1026	28-Oct-91		7.4	5.2	14.0	6	181	4	185	-
mh1	1044	04-Nov-91		7.7	5.9	8.8	3	181	0	181	-
mh1	1062	11-Nov-91		7.4	11.3	4.2	5	21	5	26	-
mh1	1080	18-Nov-91		7.1	2.9	6.4	7	159	0	159	-
mh1	1098	25-Nov-91		6.8	1.0	7.3	19	119	0	119	-
bd1	2	05-Jun-90		-	8.8	15.5	11	96	0	96	-
bd1	10	18-Jun-90		7.4	2.5	23.0	10	121	0	121	-
bd1	20	25-Jun-90		8.2	5.2	18.0	5	111	0	111	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd1	30	02-Jul-90		7.8	7.8	21.0	9	95	0	95	-
bd1	40	09-Jul-90		7.8	2.9	20.6	4	70	3	72	-
bd1	50	16-Jul-90		7.5	3.1	23.6	4	88	0	88	-
bd1	61	23-Jul-90		8.1	2.1	24.3	5	129	0	129	-
bd1	76	30-Jul-90		7.9	-	-	3	118	0	118	-
bd1	87	06-Aug-90		7.9	6.0	20.0	13	42	1	42	-
bd1	102	13-Aug-90		7.9	8.7	22.6	11	108	0	108	-
bd1	113	20-Aug-90		8.2	5.0	16.0	8	175	1	175	-
bd1	128	27-Aug-90		8.2	7.2	25.3	10	142	3	144	-
bd1	143	04-Sep-90		8.2	11.0	21.0	6	70	7	77	-
bd1	151	10-Sep-90		8.3	9.3	20.2	9	93	91	183	-
bd1	163	17-Sep-90		8.6	11.8	12.3	2	50	30	80	-
bd1	177	24-Sep-90		8.6	11.0	10.5	2	49	25	74	-
bd1	191	01-Oct-90		8.5	12.6	15.3	9	3	16	18	-
bd1	206	08-Oct-90		8.2	9.8	17.1	11	128	0	128	-
bd1	221	15-Oct-90		8.4	16.3	14.0	16	28	1	29	-
bd1	236	22-Oct-90		8.1	16.0	11.4	11	42	1	42	-
bd1	252	29-Oct-90		7.5	9.5	6.0	16	67	0	67	-
bd1	268	05-Nov-90		7.7	7.6	13.6	8	133	0	133	-
bd1	283	12-Nov-90		7.1	7.2	3.2	7	69	0	70	-
bd1	298	19-Nov-90		7.7	6.3	1.2	3	135	0	135	-
bd1	313	26-Nov-90		7.8	6.9	4.2	6	123	0	123	-
bd1	328	04-Dec-90		7.9	9.9	6.3	7	31	2	32	-
bd1	343	10-Dec-90		7.4	3.5	5.1	15	127	0	127	-
bd1	358	17-Dec-90		7.0	3.3	1.4	3	127	0	127	-
bd1	373	02-Jan-91		7.4	16.4	1.7	2	67	0	67	-
bd1	388	07-Jan-91		7.5	19.2	0.5	10	145	0	145	-
bd1	401	14-Jan-91		6.9	4.3	1.9	3	157	0	157	-
bd1	411	21-Jan-91		6.9	-	0.0	3	71	0	71	-
bd1	422	28-Jan-91		7.4	4.5	0.5	4	147	0	147	-
bd1	433	04-Feb-91		7.2	2.9	2.0	7	148	0	148	-
bd1	447	11-Feb-91		7.4	15.4	0.6	1	43	0	43	-
bd1	458	18-Feb-91		7.6	18.2	0.3	6	107	0	107	-
bd1	471	25-Feb-91		7.8	20.0	2.3	3	73	0	73	-
bd1	482	06-Mar-91		8.6	20.0	8.1	14	20	0	21	-
bd1	493	11-Mar-91		8.4	20.0	4.2	5	76	0	76	-
bd1	505	18-Mar-91		8.4	19.2	5.1	3	62	0	63	-
bd1	516	25-Mar-91		8.4	12.1	5.7	3	71	0	71	-
bd1	528	02-Apr-91		8.3	17.8	6.1	5	74	0	74	-
bd1	546	08-Apr-91		8.3	20.0	17.7	28	85	0	85	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Loca-tion	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd1	564	15-Apr-91		8.3	20.0	8.4	16	69	0	69	-
bd1	579	23-Apr-91		8.7	20.0	13.5	9	56	1	58	-
bd1	594	29-Apr-91		8.6	20.0	15.3	13	42	1	43	-
bd1	605	13-May-91		7.8	5.6	23.1	11	39	0	39	-
bd1	623	20-May-91		7.9	8.1	23.5	8	47	0	47	-
bd1	634	28-May-91		8.0	6.1	25.9	4	64	0	64	-
bd1	652	03-Jun-91		8.2	6.5	27.7	7	67	0	67	-
bd1	671	10-Jun-91		8.1	3.3	24.4	7	62	0	62	-
bd1	689	17-Jun-91		8.3	8.2	21.1	9	43	0	43	-
bd1	707	24-Jun-91		8.3	13.1	23.9	15	39	0	39	-
bd1	725	01-Jul-91		8.5	13.9	23.2	12	40	0	40	-
bd1	739	08-Jul-91		8.4	10.5	24.5	13	40	0	40	-
bd1	757	15-Jul-91		8.2	9.1	21.2	10	38	2	40	-
bd1	775	22-Jul-91		8.6	16.2	26.5	12	16	0	16	-
bd1	793	29-Jul-91		8.3	9.0	22.0	7	19	0	19	-
bd1	811	05-Aug-91		8.4	8.8	23.3	4	20	0	21	-
bd1	829	12-Aug-91		8.7	13.4	21.0	7	5	0	5	-
bd1	847	19-Aug-91		8.6	6.7	20.9	5	2	0	2	-
bd1	865	26-Aug-91		8.7	18.6	23.5	15	8	1	9	-
bd1	883	03-Sep-91		8.6	11.2	20.0	13	5	0	5	-
bd1	901	09-Sep-91		8.5	10.9	21.9	12	11	0	11	-
bd1	919	16-Sep-91		8.8	-	24.6	12	3	0	3	-
bd1	937	23-Sep-91		8.4	7.6	13.0	8	5	0	5	-
bd1	955	30-Sep-91		8.3	7.1	7.9	4	13	0	13	-
bd1	973	07-Oct-91		8.4	11.6	11.8	5	17	0	17	-
bd1	991	14-Oct-91		8.3	13.1	9.4	5	18	0	18	-
bd1	1009	21-Oct-91		8.2	11.9	8.5	4	29	0	29	-
bd1	1027	28-Oct-91		7.9	10.4	13.1	9	50	0	50	-
bd1	1045	04-Nov-91		8.2	12.8	5.5	7	67	0	67	-
bd1	1063	11-Nov-91		8.2	18.4	2.8	13	50	0	50	-
bd1	1081	18-Nov-91		7.6	-	3.1	8	101	0	101	-
bd1	1099	25-Nov-91		7.1	3.6	3.1	29	93	0	93	-
bd2	3	05-Jun-90		-	2.8	16.0	5	31	1	32	-
bd2	11	18-Jun-90		7.7	2.4	22.0	9	111	0	111	-
bd2	21	25-Jun-90		8.0	1.6	17.0	2	13	18	31	-
bd2	31	02-Jul-90		7.3	2.3	19.0	4	25	0	25	-
bd2	41	09-Jul-90		7.4	2.7	20.0	2	1	11	12	-
bd2	51	16-Jul-90		7.0	1.7	21.3	2	9	2	11	-
bd2	62	23-Jul-90		7.2	1.9	23.4	2	18	1	19	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd2	77	30-Jul-90		7.2	-	-	4	20	3	24	-
bd2	88	06-Aug-90		7.2	4.1	19.0	5	4	3	7	-
bd2	103	13-Aug-90		7.5	2.2	20.6	5	19	1	20	-
bd2	114	20-Aug-90		7.7	2.6	15.0	8	128	2	130	-
bd2	129	27-Aug-90		7.5	3.4	21.4	7	106	3	109	-
bd2	144	04-Sep-90		7.7	4.3	16.8	7	44	8	52	-
bd2	152	10-Sep-90		7.7	3.9	16.2	8	30	28	58	-
bd2	164	17-Sep-90		7.7	3.9	12.1	2	19	12	31	-
bd2	178	24-Sep-90		8.0	5.4	9.7	3	7	31	37	-
bd2	192	01-Oct-90		6.7	3.7	13.3	5	2	15	16	-
bd2	207	08-Oct-90		7.4	2.8	15.5	7	52	4	56	-
bd2	222	15-Oct-90		7.2	3.6	13.8	6	9	2	10	-
bd2	237	22-Oct-90		7.1	5.5	10.6	3	2	3	5	-
bd2	253	29-Oct-90		7.5	6.5	3.8	1	3	2	6	-
bd2	269	05-Nov-90		7.5	8.4	10.5	6	69	0	70	-
bd2	284	12-Nov-90		7.7	8.8	2.0	5	9	2	11	-
bd2	299	19-Nov-90		7.7	5.5	0.9	4	68	1	69	-
bd2	314	26-Nov-90		7.7	8.5	6.4	4	88	1	89	-
bd2	329	04-Dec-90		7.7	6.1	5.5	7	26	5	31	-
bd2	344	10-Dec-90		7.8	7.7	4.0	10	31	3	34	-
bd2	359	17-Dec-90		7.8	10.7	3.8	2	27	1	28	-
bd2	374	02-Jan-91		7.8	6.2	1.5	2	9	1	10	-
bd2	389	07-Jan-91		7.7	4.7	2.0	16	49	0	49	-
bd2	402	14-Jan-91		6.3	3.2	2.0	27	52	0	52	-
bd2	412	21-Jan-91		7.4	-	0.0	5	22	0	22	-
bd2	423	28-Jan-91		7.5	2.5	0.8	16	65	0	65	-
bd2	434	04-Feb-91		7.1	3.6	2.4	19	59	0	59	-
bd2	448	11-Feb-91		6.7	5.8	0.6	2	5	1	6	-
bd2	459	18-Feb-91		7.3	5.5	0.6	4	29	0	29	-
bd2	472	25-Feb-91		7.3	12.8	1.4	4	22	0	22	-
bd2	483	06-Mar-91		7.9	20.0	7.8	11	24	0	24	-
bd2	494	11-Mar-91		7.8	20.0	4.0	4	22	0	22	-
bd2	506	18-Mar-91		8.0	20.0	4.6	4	38	0	38	-
bd2	517	25-Mar-91		9.3	20.0	5.5	0	14	0	14	-
bd2	529	02-Apr-91		8.0	11.4	6.8	5	41	0	41	-
bd2	547	08-Apr-91		7.8	8.9	17.6	6	41	0	41	-
bd2	565	15-Apr-91		8.2	15.6	7.7	5	36	1	37	-
bd2	580	23-Apr-91		8.6	20.0	15.6	11	24	3	26	-
bd2	595	29-Apr-91		8.7	20.0	15.4	3	25	19	44	-
bd2	606	13-May-91		8.1	14.5	21.2	12	12	0	13	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Loca-tion	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd2	624	20-May-91		8.0	11.8	19.6	8	3	0	3	-
bd2	635	28-May-91		7.9	6.9	24.3	6	5	0	5	-
bd2	653	03-Jun-91		8.1	5.2	25.6	10	21	0	21	-
bd2	672	10-Jun-91		8.2	10.2	22.9	11	15	0	15	-
bd2	690	17-Jun-91		8.3	8.6	20.5	11	5	0	5	-
bd2	708	24-Jun-91		8.1	10.4	21.4	14	2	0	2	-
bd2	726	01-Jul-91		8.1	9.2	20.5	9	2	0	2	-
bd2	740	08-Jul-91		8.2	8.1	24.0	9	8	0	8	-
bd2	758	15-Jul-91		7.9	7.9	21.1	9	5	3	8	-
bd2	776	22-Jul-91		8.0	1.8	25.3	7	5	0	5	-
bd2	794	29-Jul-91		7.7	3.3	21.2	8	5	0	5	-
bd2	812	05-Aug-91		8.0	5.6	21.5	4	2	0	2	-
bd2	830	12-Aug-91		8.0	4.2	20.0	2	1	0	1	-
bd2	848	19-Aug-91		7.8	1.9	21.0	2	-	0	0	-
bd2	866	26-Aug-91		7.8	4.4	21.5	9	-	0	0	-
bd2	884	03-Sep-91		7.7	5.3	19.7	6	-	0	0	-
bd2	902	09-Sep-91		7.6	5.2	19.8	2	-	0	0	-
bd2	920	16-Sep-91		7.7	9.7	23.0	12	-	0	0	-
bd2	938	23-Sep-91		7.7	4.2	13.0	6	-	0	0	-
bd2	956	30-Sep-91		7.9	8.9	8.6	6	-	0	0	-
bd2	974	07-Oct-91		7.7	8.3	12.0	2	-	0	0	-
bd2	992	14-Oct-91		7.9	7.4	8.9	3	-	0	0	-
bd2	1010	21-Oct-91		7.7	5.6	8.4	3	-	0	0	-
bd2	1028	28-Oct-91		7.6	5.0	13.1	7	-	0	0	-
bd2	1046	04-Nov-91		8.0	6.5	5.5	3	5	0	5	-
bd2	1064	11-Nov-91		7.5	13.6	2.6	19	3	0	3	-
bd2	1082	18-Nov-91		8.1	-	2.4	5	13	0	13	-
bd2	1100	25-Nov-91		7.5	4.1	1.9	3	19	0	19	-
bd3	4	05-Jun-90		-	1.6	13.1	6	18	7	24	-
bd3	12	18-Jun-90		7.4	1.1	22.0	1	26	6	32	-
bd3	22	25-Jun-90		7.2	0.9	18.0	0	9	19	28	-
bd3	32	02-Jul-90		7.2	0.8	20.0	1	21	5	26	-
bd3	42	09-Jul-90		7.2	1.3	20.8	2	18	5	22	-
bd3	52	16-Jul-90		7.2	7.2	22.3	1	18	2	20	-
bd3	63	23-Jul-90		7.2	1.0	23.5	1	14	3	17	-
bd3	78	30-Jul-90		7.2	-	-	1	10	2	11	-
bd3	89	06-Aug-90		7.4	3.1	20.0	3	5	1	6	-
bd3	104	13-Aug-90		-	-	-	-	-	-	-	-
bd3	115	20-Aug-90		7.3	1.4	19.5	2	75	0	76	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd3	130	27-Aug-90		7.5	1.2	23.5	3	76	8	84	-
bd3	145	04-Sep-90		7.5	1.2	19.5	5	48	1	49	-
bd3	153	10-Sep-90		7.5	1.0	17.2	8	47	46	93	-
bd3	165	17-Sep-90		7.8	1.3	14.0	2	37	4	41	-
bd3	179	24-Sep-90		7.7	2.1	11.8	4	29	6	36	-
bd3	193	01-Oct-90		6.9	1.8	14.6	3	19	6	25	-
bd3	208	08-Oct-90		7.5	1.8	16.8	2	8	9	17	-
bd3	223	15-Oct-90		7.4	2.5	14.5	4	18	0	18	-
bd3	238	22-Oct-90		8.0	4.8	11.6	2	1	4	5	-
bd3	254	29-Oct-90		7.4	2.8	6.5	1	11	0	11	-
bd3	270	05-Nov-90		7.2	2.2	12.3	3	39	0	39	-
bd3	285	12-Nov-90		7.5	5.1	3.1	3	34	1	35	-
bd3	300	19-Nov-90		7.5	3.4	2.4	4	42	1	44	-
bd3	315	26-Nov-90		7.1	3.3	5.3	4	46	4	49	-
bd3	330	04-Dec-90		7.6	4.5	6.0	5	22	4	26	-
bd3	345	10-Dec-90		7.7	3.2	6.7	2	31	3	34	-
bd3	360	17-Dec-90		7.9	4.6	3.1	1	22	3	25	-
bd3	375	02-Jan-91		7.2	2.5	1.6	8	41	0	41	-
bd3	390	07-Jan-91		7.6	3.3	0.5	15	40	0	40	-
bd3	403	14-Jan-91		7.5	7.9	2.4	11	38	0	38	-
bd3	413	21-Jan-91		6.8	-	0.0	16	49	0	49	-
bd3	424	28-Jan-91		7.4	4.2	0.6	15	51	0	51	-
bd3	435	04-Feb-91		7.3	2.9	0.8	13	50	0	50	-
bd3	449	11-Feb-91		7.4	4.5	0.4	9	37	1	37	-
bd3	460	18-Feb-91		7.6	3.5	0.2	10	48	0	48	-
bd3	473	25-Feb-91		7.6	3.6	0.9	7	27	0	28	-
bd3	484	06-Mar-91		7.5	3.5	7.1	10	26	1	26	-
bd3	495	11-Mar-91		7.8	16.1	5.1	5	26	0	26	-
bd3	507	18-Mar-91		8.4	13.1	6.5	5	19	0	19	-
bd3	518	25-Mar-91		8.9	14.6	5.3	1	14	0	15	-
bd3	530	02-Apr-91		7.6	3.7	4.5	5	51	0	51	-
bd3	548	08-Apr-91		7.2	2.0	13.6	7	52	0	52	-
bd3	566	15-Apr-91		7.3	2.4	7.2	4	46	0	46	-
bd3	581	23-Apr-91		7.6	3.7	9.9	3	24	2	26	-
bd3	596	29-Apr-91		7.6	2.5	13.9	2	20	0	20	-
bd3	607	13-May-91		7.3	2.1	19.5	5	17	0	17	-
bd3	625	20-May-91		7.3	2.0	17.8	4	16	1	16	-
bd3	636	28-May-91		7.2	2.0	26.1	0	10	0	10	-
bd3	654	03-Jun-91		7.6	2.4	22.3	7	7	0	7	-
bd3	673	10-Jun-91		7.4	2.0	19.9	6	6	0	6	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Loca-tion	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd3	691	17-Jun-91		7.2	1.9	20.4	5	5	0	5	-
bd3	709	24-Jun-91		7.0	2.0	21.6	2	6	0	6	-
bd3	727	01-Jul-91		7.2	1.8	22.5	-	2	0	2	-
bd3	741	08-Jul-91		6.9	2.2	23.9	5	1	0	1	-
bd3	759	15-Jul-91		6.9	2.4	21.5	1	1	1	2	-
bd3	777	22-Jul-91		7.0	2.1	24.6	3	1	0	1	-
bd3	795	29-Jul-91		7.0	2.7	22.4	9	0	0	0	-
bd3	813	05-Aug-91		7.2	2.5	21.6	2	1	0	1	-
bd3	831	12-Aug-91		7.2	2.1	21.0	4	-	0	0	-
bd3	849	19-Aug-91		7.0	2.8	21.8	2	1	0	1	-
bd3	867	26-Aug-91		6.8	2.2	23.3	8	-	0	0	-
bd3	885	03-Sep-91		6.9	3.3	20.9	2	-	0	0	-
bd3	903	09-Sep-91		6.9	2.5	21.6	3	1	0	1	-
bd3	921	16-Sep-91		7.2	3.2	21.9	13	1	0	1	-
bd3	939	23-Sep-91		7.1	3.4	14.6	1	-	0	0	-
bd3	957	30-Sep-91		7.4	4.7	10.9	3	-	0	0	-
bd3	975	07-Oct-91		7.3	4.8	12.0	1	0	0	0	-
bd3	993	14-Oct-91		7.5	5.4	9.0	1	-	0	0	-
bd3	1011	21-Oct-91		7.1	4.4	8.8	3	0	0	0	-
bd3	1029	28-Oct-91		7.0	4.4	12.9	6	-	0	0	-
bd3	1047	04-Nov-91		7.3	6.3	4.9	2	-	0	0	-
bd3	1065	11-Nov-91		7.5	12.4	2.8	4	-	0	0	-
bd3	1083	18-Nov-91		7.4	4.7	3.2	6	8	0	8	-
bd3	1101	25-Nov-91		7.7	6.3	2.8	2	24	0	24	-
bd4	5	05-Jun-90		-	2.0	12.0	4	-	21	21	-
bd4	13	18-Jun-90		7.3	2.3	22.0	1	17	10	26	-
bd4	23	25-Jun-90		7.3	3.3	19.0	1	-	18	18	-
bd4	33	02-Jul-90		7.3	1.2	19.0	1	0	17	17	-
bd4	43	09-Jul-90		7.4	2.8	20.0	1	4	9	12	-
bd4	53	16-Jul-90		7.4	1.1	21.6	1	5	4	10	-
bd4	64	23-Jul-90		7.3	1.1	24.1	3	5	5	10	-
bd4	79	30-Jul-90		7.2	-	-	3	6	3	8	-
bd4	90	06-Aug-90		7.2	3.1	21.0	3	3	2	5	-
bd4	105	13-Aug-90		7.1	4.7	22.1	0	3	1	4	-
bd4	116	20-Aug-90		7.2	1.6	20.0	2	7	1	8	-
bd4	131	27-Aug-90		7.3	1.7	23.0	7	36	5	41	-
bd4	146	04-Sep-90		7.6	1.6	20.7	2	27	11	37	-
bd4	154	10-Sep-90		7.6	2.0	18.2	2	22	21	43	-
bd4	166	17-Sep-90		7.7	2.6	15.5	4	19	12	30	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Loca-tion	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd4	180	24-Sep-90		8.0	4.2	12.5	2	21	7	28	-
bd4	194	01-Oct-90		7.6	1.2	14.7	4	11	8	19	-
bd4	209	08-Oct-90		7.6	2.5	16.7	2	8	10	18	-
bd4	224	15-Oct-90		7.6	1.8	15.0	5	2	2	4	-
bd4	239	22-Oct-90		7.5	2.1	11.9	3	1	5	6	-
bd4	255	29-Oct-90		7.6	2.7	6.3	1	3	3	6	-
bd4	271	05-Nov-90		7.4	2.2	12.1	4	12	2	14	-
bd4	286	12-Nov-90		7.6	3.6	4.2	3	4	5	9	-
bd4	301	19-Nov-90		7.3	2.7	3.4	2	20	4	23	-
bd4	316	26-Nov-90		7.2	3.0	5.2	4	27	5	32	-
bd4	331	04-Dec-90		7.7	3.3	5.6	4	11	6	17	-
bd4	346	10-Dec-90		7.7	3.2	4.7	3	13	9	22	-
bd4	361	17-Dec-90		7.8	3.5	3.8	1	12	10	22	-
bd4	376	02-Jan-91		7.0	3.3	1.9	3	24	1	25	-
bd4	391	07-Jan-91		7.7	2.9	1.2	7	31	0	31	-
bd4	414	21-Jan-91		7.1	-	0.0	8	33	0	33	-
bd4	425	28-Jan-91		7.3	4.6	0.5	4	38	0	38	-
bd4	436	04-Feb-91		7.5	3.1	0.6	6	43	0	43	-
bd4	450	11-Feb-91		7.6	3.3	1.0	3	26	1	26	-
bd4	461	18-Feb-91		7.6	4.3	0.0	6	37	0	37	-
bd4	474	25-Feb-91		7.6	3.1	0.5	3	20	0	21	-
bd4	485	06-Mar-91		7.6	4.3	4.9	5	10	2	12	-
bd4	496	11-Mar-91		7.8	4.4	1.6	6	21	0	21	-
bd4	508	18-Mar-91		7.7	4.7	6.5	5	14	3	17	-
bd4	519	25-Mar-91		7.6	4.7	4.8	1	13	3	16	-
bd4	531	02-Apr-91		7.8	4.4	5.0	5	35	2	37	-
bd4	549	08-Apr-91		7.3	2.0	13.6	6	29	4	34	-
bd4	567	15-Apr-91		7.3	2.6	7.3	4	29	1	30	-
bd4	582	23-Apr-91		7.6	2.7	8.8	5	15	3	18	-
bd4	597	29-Apr-91		7.6	3.5	13.0	1	14	1	16	-
bd4	608	13-May-91		7.5	3.1	19.1	1	8	3	11	-
bd4	626	20-May-91		7.5	2.8	16.0	4	3	0	4	-
bd4	637	28-May-91		7.4	2.5	23.9	3	5	0	5	-
bd4	655	03-Jun-91		7.7	2.9	21.9	5	2	0	3	-
bd4	674	10-Jun-91		7.6	2.7	20.0	5	1	0	1	-
bd4	692	17-Jun-91		7.5	2.1	20.2	5	1	0	1	-
bd4	710	24-Jun-91		7.4	2.2	20.5	2	1	0	1	-
bd4	728	01-Jul-91		7.6	2.2	21.9	2	1	0	1	-
bd4	742	08-Jul-91		7.3	2.3	23.3	1	2	0	2	-
bd4	760	15-Jul-91		7.1	2.9	21.1	1	2	1	3	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Loca-tion	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
bd4	778	22-Jul-91		7.1	2.7	24.5	3	2	0	2	-
bd4	796	29-Jul-91		7.2	3.4	22.7	9	1	0	1	-
bd4	814	05-Aug-91		7.2	2.7	21.3	3	1	0	1	-
bd4	832	12-Aug-91		7.4	2.6	20.9	2	0	0	1	-
bd4	850	19-Aug-91		7.2	2.9	21.5	-	1	0	1	-
bd4	868	26-Aug-91		7.1	2.6	22.0	10	0	0	0	-
bd4	886	03-Sep-91		7.0	2.2	20.7	1	1	0	1	-
bd4	904	09-Sep-91		7.1	2.7	22.0	5	1	0	1	-
bd4	922	16-Sep-91		7.2	2.3	22.1	4	1	0	1	-
bd4	940	23-Sep-91		7.0	3.3	14.0	2	0	0	0	-
bd4	958	30-Sep-91		7.4	4.2	9.2	1	0	0	0	-
bd4	976	07-Oct-91		7.3	5.5	11.9	0	1	0	1	-
bd4	994	14-Oct-91		7.4	8.5	8.7	1	0	0	0	-
bd4	1012	21-Oct-91		7.3	6.2	9.0	3	0	0	0	-
bd4	1030	28-Oct-91		7.0	5.5	13.6	6	-	0	0	-
bd4	1048	04-Nov-91		7.5	5.3	5.5	1	1	0	1	-
bd4	1066	11-Nov-91		7.1	9.0	3.4	4	-	0	0	-
bd4	1084	18-Nov-91		7.2	4.5	2.8	2	-	0	0	-
bd4	1102	25-Nov-91		7.7	10.6	3.1	2	18	0	18	-
mh4	6	05-Jun-90		-	3.4	12.0	16	-	20	20	-
mh4	14	18-Jun-90		7.4	3.2	20.0	2	5	16	20	-
mh4	24	25-Jun-90		7.4	4.9	18.0	1	-	15	15	-
mh4	34	02-Jul-90		7.3	4.4	20.0	1	6	9	15	-
mh4	44	09-Jul-90		7.5	4.3	21.5	1	-	11	11	-
mh4	54	16-Jul-90		7.3	4.1	20.4	2	4	5	8	-
mh4	65	23-Jul-90		7.6	4.3	22.7	1	3	8	10	-
mh4	80	30-Jul-90		7.7	-	-	1	0	7	7	-
mh4	91	06-Aug-90		7.3	5.5	20.0	2	2	3	4	-
mh4	106	13-Aug-90		7.1	4.4	21.3	2	1	2	3	-
mh4	117	20-Aug-90		7.5	5.2	19.0	1	1	2	3	-
mh4	132	27-Aug-90		7.8	4.4	21.5	1	37	5	42	-
mh4	147	04-Sep-90		7.9	5.1	18.0	2	25	10	35	-
mh4	155	10-Sep-90		7.8	4.5	17.3	8	20	19	38	-
mh4	167	17-Sep-90		7.5	5.3	15.9	-	14	12	27	-
mh4	181	24-Sep-90		7.9	5.3	13.4	3	17	8	25	-
mh4	195	01-Oct-90		7.2	5.0	14.2	2	9	9	18	-
mh4	210	08-Oct-90		7.4	5.8	16.6	3	8	8	16	-
mh4	225	15-Oct-90		7.5	5.7	15.1	0	2	2	4	-
mh4	240	22-Oct-90		7.3	6.2	11.7	2	1	4	5	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Loca-tion	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
mh4	256	29-Oct-90		7.6	5.4	6.2	2	2	4	6	-
mh4	272	05-Nov-90		7.5	5.7	11.2	3	10	3	13	-
mh4	287	12-Nov-90		6.3	5.8	5.2	2	3	6	8	-
mh4	302	19-Nov-90		6.8	5.9	5.1	1	17	4	21	-
mh4	317	26-Nov-90		7.2	5.7	5.2	1	24	6	30	-
mh4	332	04-Dec-90		7.7	6.7	6.6	3	8	5	13	-
mh4	347	10-Dec-90		7.8	6.5	6.7	2	11	10	21	-
mh4	362	17-Dec-90		7.1	6.8	5.7	0	11	10	20	-
mh4	377	02-Jan-91		7.3	4.9	1.8	3	19	0	19	-
mh4	392	07-Jan-91		7.4	6.3	0.8	0	28	0	28	-
mh4	404	14-Jan-91		7.8	8.7	5.6	2	31	0	32	-
mh4	415	21-Jan-91		6.8	-	0.9	6	31	0	31	-
mh4	426	28-Jan-91		7.9	6.0	1.8	4	34	0	34	-
mh4	437	04-Feb-91		7.7	5.4	1.7	5	35	0	35	-
mh4	451	11-Feb-91		7.8	5.8	0.6	1	20	2	22	-
mh4	462	18-Feb-91		7.9	6.1	2.0	4	31	0	31	-
mh4	475	25-Feb-91		8.0	8.7	1.7	3	14	1	15	-
mh4	486	06-Mar-91		8.0	7.9	5.7	5	7	2	9	-
mh4	497	11-Mar-91		7.9	6.1	2.3	6	20	0	20	-
mh4	509	18-Mar-91		7.8	6.5	8.2	3	16	2	18	-
mh4	520	25-Mar-91		7.8	7.8	3.8	-	12	4	16	-
mh4	532	02-Apr-91		7.9	5.9	6.5	5	32	1	32	-
mh4	550	08-Apr-91		8.2	5.9	8.1	4	28	4	33	-
mh4	568	15-Apr-91		7.8	7.8	7.2	3	17	4	22	-
mh4	583	23-Apr-91		7.7	5.8	10.9	5	14	3	17	-
mh4	598	29-Apr-91		8.1	6.4	10.5	2	10	6	16	-
mh4	609	13-May-91		7.9	3.3	14.4	2	2	7	9	-
mh4	627	20-May-91		8.0	4.7	15.8	1	0	8	8	-
mh4	638	28-May-91		8.1	5.4	18.2	2	-	3	3	-
mh4	656	03-Jun-91		8.2	1.5	19.5	0	0	1	2	-
mh4	675	10-Jun-91		8.4	5.7	18.4	1	-	2	2	-
mh4	693	17-Jun-91		8.3	5.5	18.6	1	-	1	1	-
mh4	711	24-Jun-91		-	-	-	-	-	-	-	-
mh4	743	08-Jul-91		-	-	-	-	-	-	-	-
mh4	761	15-Jul-91		-	-	-	-	-	-	-	-
mh4	779	22-Jul-91		-	-	-	-	-	-	-	-
mh4	797	29-Jul-91		-	-	-	-	-	-	-	-
mh4	815	05-Aug-91		-	-	-	-	-	-	-	-
mh4	833	12-Aug-91		-	-	-	-	-	-	-	-
mh4	851	19-Aug-91		-	-	-	-	-	-	-	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
mh4	869	26-Aug-91		-	-	-	-	-	-	-	-
mh4	887	03-Sep-91		-	-	-	-	-	-	-	-
mh4	905	09-Sep-91		-	-	-	-	-	-	-	-
mh4	923	16-Sep-91		-	-	-	-	-	-	-	-
mh4	941	23-Sep-91		-	-	-	-	-	-	-	-
mh4	959	30-Sep-91		-	-	-	-	-	-	-	-
mh4	977	07-Oct-91		-	-	-	-	-	-	-	-
mh4	995	14-Oct-91		-	-	-	-	-	-	-	-
mh4	1013	21-Oct-91		8.2	9.7	11.4	3	-	0	0	-
mh4	1031	28-Oct-91		7.9	9.3	12.7	2	-	0	0	-
mh4	1049	04-Nov-91		8.4	10.4	8.2	3	-	0	0	-
mh4	1067	11-Nov-91		7.2	11.0	3.2	4	-	0	0	-
mh4	1085	18-Nov-91		7.6	9.1	4.0	5	0	0	0	-
mh4	1105	25-Nov-91		7.6	9.6	2.6	1	18	0	18	-
htk	18.5	18-Jun-90		-	-	-	-	-	-	0	-
htk	28.5	25-Jun-90		-	-	-	-	-	-	0	-
htk	38.5	02-Jul-90		-	-	-	-	-	-	0	-
htk	48.5	09-Jul-90		-	-	-	-	-	-	0	-
htk	59	16-Jul-90		6.7	5.5	20.6	2	2	6	8	-
htk	70	23-Jul-90		7.6	2.7	23.2	5	0	9	9	-
htk	85	30-Jul-90		7.7	-	-	1	0	7	8	-
htk	96	06-Aug-90		7.4	4.6	20.0	1	1	4	5	-
htk	111	13-Aug-90		6.9	5.1	21.2	1	-	4	4	-
htk	122	20-Aug-90		7.7	4.5	20.3	2	15	1	16	-
htk	137	27-Aug-90		7.7	2.2	21.7	2	25	3	28	-
htk	149	04-Sep-90		7.8	3.6	20.0	4	22	10	32	-
htk	157	10-Sep-90		7.9	5.1	16.9	2	17	16	34	-
htk	172	17-Sep-90		7.7	2.9	16.8	3	12	15	27	-
htk	185	24-Sep-90		7.6	2.6	13.7	3	11	12	24	-
htk	200	01-Oct-90		7.5	5.2	15.4	3	11	1	12	-
htk	215	08-Oct-90		6.7	4.0	15.8	3	8	8	15	-
htk	230	15-Oct-90		7.4	5.2	16.0	1	3	1	4	-
htk	245	22-Oct-90		7.1	5.1	12.3	2	1	3	4	-
htk	250	25-Oct-90		7.7	7.2	12.8	-	0	3	3	-
htk	261	29-Oct-90		7.6	7.2	7.4	2	1	3	4	-
htk	266	02-Nov-90		7.0	6.4	12.2	-	6	3	9	-
htk	277	05-Nov-90		7.5	6.0	11.4	2	8	2	10	-
htk	292	12-Nov-90		6.6	6.8	6.8	2	9	4	12	-
htk	307	19-Nov-90		7.3	5.6	6.2	1	13	4	17	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
htk	322	26-Nov-90		7.2	5.2	6.5	3	19	6	24	-
htk	337	04-Dec-90		7.7	8.0	7.6	1	14	7	21	-
htk	352	10-Dec-90		7.5	5.6	8.1	1	11	8	19	-
htk	367	17-Dec-90		6.7	8.3	5.1	0	11	10	21	-
htk	382	02-Jan-91		7.0	4.5	3.1	2	15	1	15	-
htk	397	07-Jan-91		7.0	2.9	1.5	1	19	0	19	-
htk	409	14-Jan-91		8.0	7.7	5.7	3	27	0	27	-
htk	420	21-Jan-91		7.2	-	1.7	5	24	0	24	-
htk	431	28-Jan-91		7.3	2.6	2.6	2	32	0	32	-
htk	441	04-Feb-91		7.8	5.8	2.7	1	-	0	0	-
htk	456	11-Feb-91		7.8	6.1	1.3	0	20	1	21	-
htk	469	18-Feb-91		7.9	6.7	2.5	2	50	47	96	-
htk	480	25-Feb-91		7.9	6.3	2.2	2	15	1	16	-
htk	491	06-Mar-91		7.9	6.8	6.0	-	10	2	12	-
htk	502	11-Mar-91		8.0	6.4	3.6	2	16	0	16	-
htk	514	18-Mar-91		7.9	7.5	5.2	1	19	1	20	-
htk	525	25-Mar-91		7.7	6.5	3.8	0	15	2	16	-
htk	537	02-Apr-91		7.9	6.1	5.7	1	28	1	29	-
htk	555	08-Apr-91		7.7	4.9	8.0	2	31	1	33	-
htk	573	15-Apr-91		7.6	5.1	7.6	1	21	5	27	-
htk	588	23-Apr-91		7.6	5.9	12.4	1	14	3	18	-
htk	603	29-Apr-91		7.7	4.8	11.2	0	12	3	15	-
htk	614	13-May-91		7.5	3.7	14.2	2	7	4	11	-
htk	632	20-May-91		-	-	-	-	-	-	-	-
htk	643	28-May-91		7.8	3.2	16.5	1	1	2	4	-
htk	661	03-Jun-91		8.0	3.2	20.4	2	1	2	3	-
htk	680	10-Jun-91		7.7	3.2	18.5	1	0	1	2	-
htk	698	17-Jun-91		7.9	4.3	18.0	1	1	0	1	-
htk	716	24-Jun-91		7.8	3.5	19.1	1	-	1	1	-
htk	748	08-Jul-91		-	-	-	-	-	-	-	-
htk	766	15-Jul-91		-	-	-	-	-	-	-	-
htk	784	22-Jul-91		-	-	-	-	-	-	-	-
htk	802	29-Jul-91		-	-	-	-	-	-	-	-
htk	820	05-Aug-91		-	-	-	-	-	-	-	-
htk	838	12-Aug-91		-	-	-	-	-	-	-	-
htk	856	19-Aug-91		-	-	-	-	-	-	-	-
htk	874	26-Aug-91		-	-	-	-	-	-	-	-
htk	892	03-Sep-91		-	-	-	-	-	-	-	-
htk	910	09-Sep-91		-	-	-	-	-	-	-	-
htk	928	16-Sep-91		-	-	-	-	-	-	-	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
htk	946	23-Sep-91		-	-	-	-	-	-	-	-
htk	964	30-Sep-91		-	-	-	-	-	-	-	-
htk	982	07-Oct-91		-	-	-	-	-	-	-	-
htk	1000	14-Oct-91		-	-	-	-	-	-	-	-
htk	1018	21-Oct-91		8.0	7.6	12.1	2	0	0	0	-
htk	1036	28-Oct-91		7.9	7.2	12.6	2	-	0	0	-
htk	1054	04-Nov-91		8.2	8.1	8.2	-	0	0	0	-
htk	1072	11-Nov-91		7.4	12.5	3.9	2	-	0	0	-
htk	1090	18-Nov-91		7.4	8.2	5.5	4	0	0	0	-
htk	1110	25-Nov-91		7.7	8.4	4.2	3	15	0	15	-
s14	16	18-Jun-90		-	-	-	1	-	0	0	-
s14	26	25-Jun-90		-	-	-	1	0	0	0	-
s14	36	02-Jul-90		-	-	-	1	0	0	0	-
s14	46	09-Jul-90		-	-	-	1	-	0	0	-
s14	56	16-Jul-90		-	-	-	1	-	0	0	-
s14	67	23-Jul-90		-	-	-	5	0	0	0	-
s14	82	30-Jul-90		6.9	-	-	1	-	0	0	-
s14	93	06-Aug-90		-	-	-	2	0	0	0	-
s14	108	13-Aug-90		-	-	-	2	0	0	0	-
s14	119	20-Aug-90		-	-	-	2	-	0	0	-
s14	134	27-Aug-90		-	-	-	1	-	0	0	-
s14	169	17-Sep-90		7.7	-	11.7	1	0	0	0	-
s14	183	24-Sep-90		8.4	7.4	10.9	0	-	0	0	-
s14	197	01-Oct-90		6.4	6.1	12.5	3	-	0	0	-
s14	212	08-Oct-90		6.7	3.5	14.1	2	0	0	0	-
s14	227	15-Oct-90		7.4	7.5	13.8	1	0	0	0	-
s14	242	22-Oct-90		7.2	9.0	11.4	2	-	0	0	-
s14	258	29-Oct-90		7.8	10.8	6.0	1	0	0	0	-
s14	274	05-Nov-90		7.6	10.2	10.1	2	0	0	0	-
s14	289	12-Nov-90		6.3	11.1	4.1	2	-	0	0	-
s14	304	19-Nov-90		7.4	10.9	2.9	1	-	0	0	-
s14	319	26-Nov-90		6.8	10.6	4.7	2	-	0	0	-
s14	334	04-Dec-90		7.5	10.6	5.0	-	-	1	1	-
s14	349	10-Dec-90		8.1	10.3	6.3	1	-	0	0	-
s14	364	17-Dec-90		7.4	11.6	6.5	-	-	0	0	-
s14	379	02-Jan-91		6.1	12.2	3.0	1	0	0	0	-
s14	394	07-Jan-91		8.2	11.9	0.0	0	0	0	0	-
s14	406	14-Jan-91		8.7	11.2	5.9	2	-	0	0	-
s14	417	21-Jan-91		6.8	-	0.7	3	-	0	0	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
s14	428	28-Jan-91		6.8	11.1	2.3	0	0	0	0	-
s14	438	04-Feb-91		6.0	12.0	2.7	0	-	-	-	-
s14	453	11-Feb-91		6.4	12.3	0.0	0	0	0	0	-
s14	464	18-Feb-91		6.9	12.5	2.0	1	0	0	0	-
s14	477	25-Feb-91		6.6	12.9	1.9	1	-	0	0	-
s14	488	06-Mar-91		7.1	11.4	7.4	0	0	0	0	-
s14	499	11-Mar-91		8.1	12.8	1.9	2	-	0	0	-
s14	511	18-Mar-91		7.8	12.2	4.3	2	-	0	0	-
s14	522	25-Mar-91		7.6	11.2	4.5	1	0	0	0	-
s14	534	02-Apr-91		8.1	11.1	4.7	1	0	0	0	-
s14	552	08-Apr-91		5.8	9.7	13.2	1	-	0	0	-
s14	570	15-Apr-91		7.7	10.8	6.7	1	0	0	0	-
s14	585	23-Apr-91		7.7	10.4	13.3	1	0	0	0	-
s14	600	29-Apr-91		7.8	9.7	12.8	1	0	0	0	-
s14	611	13-May-91		6.2	9.4	17.4	0	-	0	0	-
s14	629	20-May-91		7.2	10.3	14.0	0	-	0	0	-
s14	640	28-May-91		7.3	9.1	18.5	0	0	0	0	-
s14	658	03-Jun-91		7.2	8.9	19.8	0	-	0	0	-
s14	677	10-Jun-91		7.4	6.6	18.9	0	0	0	0	-
s14	695	17-Jun-91		7.3	3.8	20.0	1	0	0	0	-
s14	713	24-Jun-91		-	-	-	-	-	-	-	-
s14	745	08-Jul-91		-	-	-	-	-	-	-	-
s14	763	15-Jul-91		-	-	-	-	-	-	-	-
s14	781	22-Jul-91		-	-	-	-	-	-	-	-
s14	799	29-Jul-91		7.5	6.8	17.7	2	0	0	0	-
s14	817	05-Aug-91		7.3	5.8	20.4	1	-	0	0	-
s14	835	12-Aug-91		7.4	6.3	20.7	1	-	0	0	-
s14	853	19-Aug-91		7.4	6.4	19.9	-	-	0	0	-
s14	871	26-Aug-91		7.3	6.4	20.0	2	-	0	0	-
s14	889	03-Sep-91		-	-	-	-	-	-	-	-
s14	907	09-Sep-91		-	-	-	-	-	-	-	-
s14	925	16-Sep-91		-	-	-	-	-	-	-	-
s14	943	23-Sep-91		7.5	4.6	12.5	3	0	0	0	-
s14	961	30-Sep-91		7.3	4.4	6.0	5	-	0	0	-
s14	979	07-Oct-91		7.8	7.5	10.8	1	0	0	0	-
s14	997	14-Oct-91		7.5	7.3	9.4	3	-	0	0	-
s14	1015	21-Oct-91		7.1	7.1	9.6	3	0	0	0	-
s14	1033	28-Oct-91		7.0	6.3	11.2	3	0	0	0	-
s14	1051	04-Nov-91		-	-	-	-	-	-	-	-
s14	1069	11-Nov-91		7.0	14.0	2.3	2	0	0	0	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
s14	1087	18-Nov-91		7.9	10.6	2.6	4	0	0	0	-
s14	1107	25-Nov-91		7.8	9.8	3.0	-	-	0	0	-
s19	8	05-Jun-90		-	8.0	11.0	3	-	-	-	-
s19	18	18-Jun-90		-	-	-	-	-	-	-	-
s19	28	25-Jun-90		-	-	-	1	0	0	0	-
s19	38	02-Jul-90		-	-	-	0	0	0	0	-
s19	48	09-Jul-90		-	-	-	1	-	0	0	-
s19	58	16-Jul-90		-	-	-	-	-	-	-	-
s19	69	23-Jul-90		-	-	-	-	-	-	-	-
s19	84	30-Jul-90		-	-	-	-	-	-	-	-
s19	95	06-Aug-90		-	-	-	2	0	0	0	-
s19	110	13-Aug-90		-	-	-	-	-	-	-	-
s19	121	20-Aug-90		-	-	-	-	-	-	-	-
s19	136	27-Aug-90		-	-	-	2	0	0	0	-
s19	171	17-Sep-90		8.5	7.3	11.6	0	-	0	0	-
s19	199	01-Oct-90		6.2	8.3	11.8	1	-	0	0	-
s19	214	08-Oct-90		6.1	6.3	15.4	2	-	0	0	-
s19	229	15-Oct-90		7.3	6.3	14.2	3	10	0	10	-
s19	244	22-Oct-90		7.1	9.4	10.6	1	-	0	0	-
s19	260	29-Oct-90		7.9	11.2	5.2	1	-	0	0	-
s19	276	05-Nov-90		6.9	10.2	9.1	2	0	0	0	-
s19	291	12-Nov-90		6.2	10.7	3.2	2	-	0	0	-
s19	306	19-Nov-90		7.9	11.8	1.3	1	-	0	0	-
s19	321	26-Nov-90		6.9	11.1	5.4	2	-	0	0	-
s19	336	04-Dec-90		7.9	11.0	6.2	-	-	0	0	-
s19	351	10-Dec-90		7.8	9.8	6.6	1	0	0	0	-
s19	366	17-Dec-90		7.3	12.1	3.1	0	0	0	0	-
s19	381	02-Jan-91		7.2	11.4	0.7	2	-	0	0	-
s19	396	07-Jan-91		8.2	11.8	0.3	1	0	0	0	-
s19	408	14-Jan-91		8.5	12.6	2.9	3	-	0	0	-
s19	419	21-Jan-91		6.9	-	0.0	3	-	0	0	-
s19	430	28-Jan-91		7.6	12.6	0.6	1	0	0	0	-
s19	440	04-Feb-91		6.9	11.5	1.9	0	5	0	6	-
s19	455	11-Feb-91		6.8	11.6	0.0	1	0	0	0	-
s19	466	18-Feb-91		-	-	-	-	-	0	0	-
s19	468	18-Feb-91		7.6	13.7	0.8	1	-	0	0	-
s19	479	25-Feb-91		7.4	13.9	1.3	1	0	0	0	-
s19	490	06-Mar-91		7.5	11.3	4.7	-	0	0	0	-
s19	501	11-Mar-91		7.9	12.7	2.5	2	0	0	0	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
s19	513	18-Mar-91		8.0	12.0	5.0	2	0	0	0	-
s19	524	25-Mar-91		7.7	11.3	4.1	0	0	0	0	-
s19	536	02-Apr-91		8.0	11.5	5.2	0	0	0	0	-
s19	554	08-Apr-91		7.6	9.7	14.8	1	0	0	0	-
s19	572	15-Apr-91		7.7	10.9	6.6	1	0	0	0	-
s19	587	23-Apr-91		7.6	10.4	12.3	0	0	0	0	-
s19	602	29-Apr-91		7.7	6.9	13.0	-	0	0	0	-
s19	613	13-May-91		7.4	8.4	18.4	1	-	0	0	-
s19	631	20-May-91		-	-	-	-	-	-	-	-
s19	642	28-May-91		-	-	-	-	-	-	-	-
s19	660	03-Jun-91		-	-	-	-	-	-	-	-
s19	679	10-Jun-91		-	-	-	-	-	-	-	-
s19	697	17-Jun-91		-	-	-	-	-	-	-	-
s19	715	24-Jun-91		-	-	-	-	-	-	-	-
s19	747	08-Jul-91		-	-	-	-	-	-	-	-
s19	765	15-Jul-91		-	-	-	-	-	-	-	-
s19	783	22-Jul-91		-	-	-	-	-	-	-	-
s19	801	29-Jul-91		-	-	-	-	-	-	-	-
s19	819	05-Aug-91		-	-	-	-	-	-	-	-
s19	837	12-Aug-91		-	-	-	-	-	-	-	-
s19	855	19-Aug-91		-	-	-	-	-	-	-	-
s19	873	26-Aug-91		-	-	-	-	-	-	-	-
s19	891	03-Sep-91		-	-	-	-	-	-	-	-
s19	909	09-Sep-91		-	-	-	-	-	-	-	-
s19	927	16-Sep-91		-	-	-	-	-	-	-	-
s19	945	23-Sep-91		-	-	-	-	-	-	-	-
s19	963	30-Sep-91		-	-	-	-	-	-	-	-
s19	981	07-Oct-91		-	-	-	-	-	-	-	-
s19	999	14-Oct-91		-	-	-	-	-	-	-	-
s19	1017	21-Oct-91		-	-	-	-	-	-	-	-
s19	1035	28-Oct-91		-	-	-	-	-	-	-	-
s19	1053	04-Nov-91		-	-	-	-	-	-	-	-
s19	1071	11-Nov-91		7.5	13.2	3.6	3	-	2	2	-
s19	1089	18-Nov-91		-	-	-	-	-	-	-	-
s19	1109	25-Nov-91		8.2	11.9	3.2	3	-	0	0	-
s18	17	18-Jun-90		-	-	-	1	8	1	9	-
s18	27	25-Jun-90		-	-	-	2	6	4	11	-
s18	37	02-Jul-90		-	-	-	1	8	2	10	-
s18	47	09-Jul-90		-	-	-	1	0	5	5	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
s18	57	16-Jul-90		-	-	-	1	10	1	10	-
s18	68	23-Jul-90		-	-	-	1	10	0	10	-
s18	83	30-Jul-90		7.3	-	-	1	14	0	14	-
s18	94	06-Aug-90		-	-	-	4	2	1	3	-
s18	109	13-Aug-90		-	-	-	2	10	0	10	-
s18	120	20-Aug-90		-	-	-	1	11	0	11	-
s18	135	27-Aug-90		-	-	-	1	10	0	10	-
s18	148	04-Sep-90		7.6	6.0	16.6	3	11	0	11	-
s18	156	10-Sep-90		7.9	7.9	16.7	2	10	9	18	-
s18	170	17-Sep-90		7.7	6.8	11.7	-	11	1	11	-
s18	184	24-Sep-90		7.5	7.5	10.6	0	12	0	13	-
s18	198	01-Oct-90		6.8	7.6	12.8	2	6	1	8	-
s18	213	08-Oct-90		6.8	6.0	15.8	2	9	1	9	-
s18	228	15-Oct-90		7.3	7.7	14.3	0	-	0	0	-
s18	243	22-Oct-90		6.9	8.5	10.6	2	4	0	5	-
s18	259	29-Oct-90		7.6	11.6	4.7	2	3	0	3	-
s18	275	05-Nov-90		6.7	9.4	9.3	2	6	0	6	-
s18	290	12-Nov-90		7.2	11.3	4.3	1	2	0	2	-
s18	305	19-Nov-90		7.3	11.3	1.1	1	3	0	3	-
s18	320	26-Nov-90		7.4	10.7	4.1	2	4	0	4	-
s18	335	04-Dec-90		7.1	10.7	6.1	-	1	1	2	-
s18	350	10-Dec-90		7.4	10.4	6.7	2	2	0	2	-
s18	365	17-Dec-90		7.2	12.1	2.6	0	3	0	3	-
s18	380	02-Jan-91		6.9	12.0	1.0	2	2	0	3	-
s18	395	07-Jan-91		6.5	10.6	1.0	0	4	0	5	-
s18	407	14-Jan-91		7.5	11.6	2.6	2	6	0	7	-
s18	418	21-Jan-91		6.6	-	0.0	3	2	0	2	-
s18	429	28-Jan-91		7.2	12.3	1.0	1	6	1	6	-
s18	439	04-Feb-91		7.3	9.4	2.5	-	-	0	0	-
s18	454	11-Feb-91		7.4	11.6	1.1	0	1	0	2	-
s18	467	18-Feb-91		7.6	12.9	0.5	1	24	1	24	-
s18	465	18-Feb-91		-	-	-	-	3	1	3	-
s18	478	25-Feb-91		7.6	13.1	1.3	1	1	0	1	-
s18	489	06-Mar-91		7.7	11.5	4.8	0	1	0	2	-
s18	500	11-Mar-91		7.5	12.7	2.8	2	3	0	3	-
s18	512	18-Mar-91		7.5	12.2	6.3	2	1	2	3	-
s18	523	25-Mar-91		7.6	11.3	4.6	0	2	0	3	-
s18	535	02-Apr-91		7.7	11.6	7.0	1	2	1	3	-
s18	553	08-Apr-91		7.6	10.6	15.1	2	3	1	3	-
s18	571	15-Apr-91		7.6	11.0	6.3	1	2	1	3	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Loca-tion	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
s18	586	23-Apr-91		7.4	10.4	13.7	1	2	0	2	-
s18	601	29-Apr-91		7.5	9.8	12.7	1	1	1	2	-
s18	612	13-May-91		7.4	7.9	19.4	0	2	1	3	-
s18	630	20-May-91		7.2	7.6	19.9	1	5	0	5	-
s18	641	28-May-91		7.4	7.1	21.1	2	7	0	7	-
s18	659	03-Jun-91		7.5	6.6	20.1	1	10	0	10	-
s18	678	10-Jun-91		7.3	6.0	17.9	1	15	0	15	-
s18	696	17-Jun-91		7.3	6.5	18.4	1	13	0	13	-
s18	714	24-Jun-91		7.3	7.2	17.9	3	13	0	13	-
s18	730	01-Jul-91		7.5	6.3	17.7	3	24	0	24	-
s18	746	08-Jul-91		7.7	5.6	21.9	2	15	0	15	-
s18	764	15-Jul-91		7.5	5.3	17.2	1	18	1	19	-
s18	782	22-Jul-91		7.7	5.0	22.5	-	16	1	18	-
s18	800	29-Jul-91		7.5	4.8	18.7	1	16	2	18	-
s18	818	05-Aug-91		7.5	4.4	18.5	2	11	3	14	-
s18	836	12-Aug-91		7.6	5.3	19.1	2	10	2	12	-
s18	854	19-Aug-91		7.3	5.6	20.0	1	12	2	14	-
s18	872	26-Aug-91		7.5	5.2	20.7	2	11	3	15	-
s18	890	03-Sep-91		7.4	4.8	18.4	2	15	4	19	-
s18	908	09-Sep-91		7.5	5.0	20.9	2	15	3	18	-
s18	926	16-Sep-91		7.7	5.5	22.4	2	12	3	15	-
s18	944	23-Sep-91		7.1	6.3	13.0	-	11	1	12	-
s18	962	30-Sep-91		7.3	7.6	8.1	1	11	2	13	-
s18	980	07-Oct-91		7.4	7.7	11.8	3	7	1	9	-
s18	998	14-Oct-91		7.3	8.7	10.4	8	7	2	9	-
s18	1016	21-Oct-91		7.5	9.6	9.7	2	6	3	9	-
s18	1034	28-Oct-91		7.4	8.0	11.6	3	5	1	6	-
s18	1052	04-Nov-91		7.7	9.9	5.5	1	2	0	2	-
s18	1070	11-Nov-91		7.6	13.2	3.1	4	0	1	2	-
s18	1088	18-Nov-91		7.4	12.4	3.1	3	8	0	8	-
s18	1108	25-Nov-91		7.8	12.8	2.9	1	9	0	9	-
gwn	7	05-Jun-90		-	1.3	11.0	4	9	7	16	-
gwn	15	18-Jun-90		-	-	-	1	19	0	19	-
gwn	25	25-Jun-90		6.6	1.7	15.0	1	19	0	19	-
gwn	35	02-Jul-90		-	-	-	0	19	0	19	-
gwn	45	09-Jul-90		-	-	-	1	18	0	18	-
gwn	55	16-Jul-90		-	-	-	1	20	0	20	-
gwn	66	23-Jul-90		-	-	-	3	21	0	21	-
gwn	81	30-Jul-90		6.3	-	-	0	20	0	20	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
gwn	92	06-Aug-90		-	-	-	1	16	0	16	-
gwn	107	13-Aug-90		-	-	-	1	19	0	19	-
gwn	118	20-Aug-90		-	-	-	1	20	0	20	-
gwn	133	27-Aug-90		-	-	-	0	20	0	20	-
gwn	168	17-Sep-90		6.6	2.3	17.6	-	20	0	20	-
gwn	182	24-Sep-90		6.7	2.0	15.5	0	21	0	21	-
gwn	196	01-Oct-90		6.4	2.3	15.8	0	17	0	17	-
gwn	211	08-Oct-90		6.1	2.6	15.9	1	19	0	19	-
gwn	226	15-Oct-90		6.8	2.4	15.8	1	14	0	14	-
gwn	241	22-Oct-90		6.4	2.7	14.6	2	16	0	16	-
gwn	257	29-Oct-90		6.6	4.1	11.7	2	16	0	16	-
gwn	273	05-Nov-90		5.9	2.4	12.1	2	17	0	17	-
gwn	288	12-Nov-90		5.5	3.2	9.8	2	12	0	12	-
gwn	303	19-Nov-90		6.5	3.9	9.4	1	14	0	15	-
gwn	318	26-Nov-90		6.2	2.5	4.7	2	14	0	14	-
gwn	333	04-Dec-90		7.1	4.2	8.2	1	9	4	13	-
gwn	348	10-Dec-90		7.0	3.6	8.4	1	14	0	14	-
gwn	363	17-Dec-90		6.5	1.9	7.7	0	13	0	13	-
gwn	378	02-Jan-91		6.6	3.9	5.5	1	8	1	9	-
gwn	393	07-Jan-91		7.0	3.3	3.8	-	10	1	10	-
gwn	405	14-Jan-91		7.3	4.8	4.7	2	11	0	11	-
gwn	416	21-Jan-91		6.4	-	3.4	2	6	0	7	-
gwn	427	28-Jan-91		6.8	3.1	4.1	0	11	0	11	-
gwn	438	04-Feb-91		6.5	3.9	5.0	1	10	0	10	-
gwn	452	11-Feb-91		6.7	3.9	3.8	1	8	1	9	-
gwn	463	18-Feb-91		6.7	5.3	3.3	1	11	0	11	-
gwn	476	25-Feb-91		6.7	4.6	3.6	0	9	1	10	-
gwn	487	06-Mar-91		6.7	4.5	5.8	1	8	1	9	-
gwn	498	11-Mar-91		6.8	4.6	5.1	2	11	0	11	-
gwn	510	18-Mar-91		6.7	4.5	7.0	1	8	0	8	-
gwn	521	25-Mar-91		6.7	3.4	4.6	2	9	1	9	-
gwn	533	02-Apr-91		6.8	4.4	5.8	1	10	0	10	-
gwn	551	08-Apr-91		6.6	3.1	9.0	1	10	0	10	-
gwn	569	15-Apr-91		6.4	3.6	7.6	1	13	0	13	-
gwn	584	23-Apr-91		6.6	2.6	12.6	1	10	0	10	-
gwn	599	29-Apr-91		6.5	6.7	9.5	1	12	0	12	-
gwn	610	13-May-91		6.4	2.5	12.7	-	16	0	16	-
gwn	628	20-May-91		6.4	2.8	14.2	0	18	0	18	-
gwn	639	28-May-91		6.4	3.2	15.5	2	21	0	21	-
gwn	657	03-Jun-91		6.6	3.1	17.4	0	22	0	22	-

Table C-2. Water Chemistry, Town of Fenton Landfill Leachate Treatment Demonstration.

Location	Sample ID	Date	Comment	pH	O2 (mg/l)	Temp (degr. C)	Oxygen Consumption (mg/l/day)	NH4 (mg/l)	NO3 (mg/l)	Total inorg N (mg/l)	Kjel N (mg/l)
gwn	676	10-Jun-91		6.5	2.6	16.6	0	22	0	22	-
gwn	694	17-Jun-91		6.6	5.3	17.9	1	22	0	22	-
gwn	712	24-Jun-91		6.5	4.3	18.5	2	14	0	14	-
gwn	729	01-Jul-91		6.4	3.6	18.7	2	-	-	-	-
gwn	744	08-Jul-91		6.4	2.7	19.5	2	24	0	24	-
gwn	762	15-Jul-91		6.3	3.3	18.7	1	23	0	23	-
gwn	780	22-Jul-91		6.4	2.8	20.5	1	24	0	24	-
gwn	798	29-Jul-91		6.5	3.2	19.8	2	21	0	21	-
gwn	816	05-Aug-91		6.4	2.5	19.4	2	19	0	19	-
gwn	834	12-Aug-91		6.8	3.9	19.4	1	17	0	17	-
gwn	852	19-Aug-91		6.6	4.0	20.0	-	20	0	20	-
gwn	870	26-Aug-91		6.5	3.7	20.2	1	20	0	20	-
gwn	888	03-Sep-91		6.5	3.3	20.3	2	21	0	21	-
gwn	906	09-Sep-91		6.4	4.4	23.5	2	21	0	21	-
gwn	924	16-Sep-91		6.5	3.2	20.6	1	20	0	20	-
gwn	942	23-Sep-91		6.6	5.2	16.1	2	18	0	18	-
gwn	960	30-Sep-91		6.1	4.2	14.2	10	18	0	18	-
gwn	978	07-Oct-91		6.7	5.0	12.8	-	18	0	18	-
gwn	996	14-Oct-91		6.6	4.5	13.6	1	18	0	18	-
gwn	1014	21-Oct-91		6.5	5.3	13.0	2	17	0	17	-
gwn	1032	28-Oct-91		6.4	4.1	13.1	2	18	0	18	-
gwn	1050	04-Nov-91		6.3	5.3	9.4	-	20	0	20	-
gwn	1068	11-Nov-91		6.6	5.9	7.5	1	15	0	15	-
gwn	1086	18-Nov-91		6.7	5.0	8.3	3	16	0	16	-
gwn	1106	25-Nov-91		6.9	4.9	5.5	-	11	0	11	-

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
mh1	9	18-Jun-90			<0.01	0.0	0.0	0.0	<0.01	0.1	135	75
mh1	19	25-Jun-90			<0.01	0.0	0.0	0.0	<0.01	0.2	184	112
mh1	29	02-Jul-90			<0.01	0.0	0.0	0.0	<0.01	0.2	172	106
mh1	39	09-Jul-90			<0.01	0.0	0.0	0.0	<0.01	0.1	88	43
mh1	49	16-Jul-90			<0.01	<0.01	0.0	<0.01	<0.01	0.6	404	198
mh1	60	23-Jul-90		15147.01	<0.01	<0.01	0.0	<0.01	<0.01	0.5	425	247
mh1	75	30-Jul-90			<0.01	<0.01	0.0	<0.01	<0.01	0.3	303	20
mh1	86	06-Aug-90	flooded	15147.06	<0.01	<0.01	<0.01	<0.01	<0.01	0.1	148	96
mh1	101	13-Aug-90			<0.01	<0.01	0.1	<0.01	<0.01	0.5	315	167
mh1	112	20-Aug-90			<0.01	<0.01	0.0	<0.01	<0.01	0.2	162	112
mh1	127	27-Aug-90			<0.004	<0.04	0.0	<0.04	<0.04	0.2	198	145
mh1	142	04-Sep-90		15147.11	<0.004	<0.04	0.0	<0.04	<0.04	0.2	206	134
mh1	150	10-Sep-90			<0.004	<0.04	0.0	<0.04	<0.04	0.0	137	124
mh1	162	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	54	40
mh1	176	24-Sep-90			<0.004	0.0	0.0	<0.04	<0.04	0.2	149	138
mh1	190	01-Oct-90		15147.16	<0.004	0.0	0.1	<0.04	<0.04	0.1	116	136
mh1	205	08-Oct-90			<0.004	<0.04	<0.04	0.0	<0.04	0.1	127	73
mh1	220	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	4	6
mh1	235	22-Oct-90			<0.004	<0.04	0.0	<0.04	<0.04	0.3	296	134
mh1	251	29-Oct-90			0.0	0.1	<0.04	<0.04	<0.04	0.2	144	64
mh1	267	05-Nov-90			<0.004	<0.04	0.1	<0.04	<0.04	0.4	266	165
mh1	282	12-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	0.3	165	69
mh1	297	19-Nov-90		15147.21	<0.004	<0.04	<0.04	<0.04	<0.04	0.3	198	109
mh1	312	26-Nov-90			<0.004	<0.04	0.0	<0.04	<0.04	0.3	214	119
mh1	327	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.1	102	58
mh1	342	10-Dec-90		15147.26	<0.004	<0.04	0.1	<0.04	<0.04	0.2	191	111
mh1	357	17-Dec-90			<0.004	<0.04	0.1	<0.04	<0.04	0.1	157	93
mh1	372	02-Jan-91		15147.31	-	<0.1	<0.1	-	-	0.4	252	83
mh1	432	04-Feb-91		15147.36	-	<0.1	<0.1	-	-	0.1	144	65
mh1	481	06-Mar-91		15147.41	-	<0.1	<0.1	-	-	0.3	48	22
mh1	527	02-Apr-91		15147.46	-	<0.1	<0.1	-	-	0.4	225	84
mh1	604	13-May-91		15147.51	-	<0.1	0.1	-	-	0.4	235	97
mh1	651	03-Jun-91		15147.56	-	<0.1	0.1	-	-	0.1	245	100
mh1	724	01-Jul-91		15147.61	-	<0.1	0.1	-	-	0.1	238	116
mh1	810	05-Aug-91		15147.66	-	<0.1	<0.1	-	-	0.1	195	114
mh1	828	12-Aug-91		15155.01	-	0.0	0.1	-	-	0.1	193	104
mh1	882	03-Sep-91	dry???	15155.09	-	<0.01	0.0	-	-	0.1	172	94
mh1	[illegible]	07-Oct-91		15155.16	-	<0.01	0.0	-	-	0.1	149	75
mh1	[illegible]	11-Nov-91		15155.24	-	<0.01	0.0	-	-	0.0	38	17
mh1	[illegible]	18-Nov-91		15155.34	-	0.0	0.0	-	-	0.3	170	69
mh1	1096	25-Nov-91		15155.44	-	0.0	0.0	-	-	0.5	167	52

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
bd1	10	18-Jun-90			<0.01	0.0	0.0	0.0	<0.01	0.1	83	107
bd1	20	25-Jun-90			<0.01	0.0	0.0	0.0	<0.01	0.1	76	96
bd1	30	02-Jul-90			<0.01	0.0	0.0	0.0	<0.01	0.1	57	86
bd1	40	09-Jul-90			<0.01	0.0	0.0	0.0	<0.01	0.0	41	58
bd1	50	16-Jul-90			<0.01	<0.01	0.1	<0.01	<0.01	0.0	132	127
bd1	61	23-Jul-90		15147.02	<0.01	<0.01	0.0	<0.01	<0.01	0.1	85	159
bd1	76	30-Jul-90			<0.01	<0.01	0.1	<0.01	<0.01	0.0	64	163
bd1	87	06-Aug-90		15147.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	39	93
bd1	102	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.1	165	177
bd1	113	20-Aug-90			<0.01	<0.01	0.1	<0.01	<0.01	0.1	58	164
bd1	128	27-Aug-90			<0.004	<0.04	0.0	<0.04	<0.04	0.2	54	142
bd1	143	04-Sep-90		15147.12	<0.004	<0.04	0.0	<0.04	<0.04	0.0	43	130
bd1	151	10-Sep-90			<0.004	<0.04	0.0	<0.04	<0.04	0.0	16	60
bd1	163	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	11	46
bd1	177	24-Sep-90			<0.004	<0.04	0.0	<0.04	<0.04	0.2	52	130
bd1	191	01-Oct-90		15147.17	<0.004	<0.04	<0.04	<0.04	<0.04	0.0	27	68
bd1	206	08-Oct-90			<0.004	<0.04	0.0	0.0	<0.04	0.1	79	148
bd1	221	15-Oct-90			<0.004	<0.04	<0.04	0.0	<0.04	<0.04	23	39
bd1	236	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	55	48
bd1	252	29-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	0.0	80	43
bd1	268	05-Nov-90			<0.004	<0.04	0.1	<0.04	<0.04	<0.04	146	124
bd1	283	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	53	47
bd1	298	19-Nov-90		15147.22	0.0	<0.04	0.1	<0.04	<0.04	0.1	156	106
bd1	313	26-Nov-90			<0.004	<0.04	0.0	<0.04	<0.04	0.1	138	99
bd1	328	04-Dec-90			0.0	<0.04	<0.04	<0.04	<0.04	0.0	32	29
bd1	343	10-Dec-90		15147.27	<0.004	<0.04	0.1	<0.04	<0.04	0.1	158	95
bd1	358	17-Dec-90			<0.004	<0.04	0.1	<0.04	<0.04	0.1	141	87
bd1	373	02-Jan-91		15147.32	-	<0.1	<0.1	-	-	<0.1	98	45
bd1	433	04-Feb-91		15147.37	-	<0.1	<0.1	-	-	0.1	223	98
bd1	482	06-Mar-91		15147.42	-	<0.1	<0.1	-	-	0.1	116	54
bd1	528	02-Apr-91		15147.47	-	<0.1	<0.1	-	-	<0.1	94	55
bd1	605	13-May-91		15147.52	-	<0.1	<0.1	-	-	<0.1	55	54
bd1	652	03-Jun-91		15147.57	-	<0.1	<0.1	-	-	<0.1	142	94
bd1	725	01-Jul-91		15147.62	-	<0.1	<0.1	-	-	<0.1	42	116
bd1	811	05-Aug-91		15147.67	-	<0.1	<0.1	-	-	<0.1	34	123
bd1	829	12-Aug-91		15155.02	-	<0.01	0.1	-	-	0.1	49	99
bd1	883	03-Sep-91		15155.10	-	<0.01	0.1	-	-	<0.01	41	89
bd1	973	07-Oct-91		15155.17	-	<0.01	0.0	-	-	<0.01	60	81
bd1	1063	11-Nov-91		15155.25	-	<0.01	0.0	-	-	<0.01	61	59
bd1	1081	18-Nov-91		15155.35	-	0.0	0.1	-	-	0.3	104	73

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
bd1	1099	25-Nov-91		15155.45	-	0.0	0.1	-	-	0.4	129	51
bd2	11	18-Jun-90			<0.01	0.0	0.0	0.0	<0.01	0.0	79	109
bd2	21	25-Jun-90			<0.01	0.0	0.0	<0.01	<0.01	0.0	52	57
bd2	31	02-Jul-90			<0.01	0.0	0.0	<0.01	<0.01	0.0	53	57
bd2	41	09-Jul-90			<0.01	0.0	0.0	<0.01	<0.01	0.0	34	34
bd2	51	16-Jul-90			<0.01	<0.01	0.0	<0.01	<0.01	0.0	65	72
bd2	62	23-Jul-90		15147.03	<0.01	<0.01	0.0	<0.01	<0.01	0.0	82	89
bd2	77	30-Jul-90			<0.01	<0.01	0.0	<0.01	<0.01	0.0	81	116
bd2	88	06-Aug-90		15147.08	<0.01	<0.01	<0.01	<0.01	<0.01	0.1	36	48
bd2	103	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	57	67
bd2	114	20-Aug-90			<0.01	<0.01	0.1	<0.01	<0.01	0.3	65	167
bd2	129	27-Aug-90			<0.004	<0.04	0.0	<0.04	<0.04	0.0	60	130
bd2	144	04-Sep-90		15147.13	<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	39	94
bd2	152	10-Sep-90			<0.004	<0.04	0.0	<0.04	<0.04	<0.04	26	67
bd2	164	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	9	31
bd2	178	24-Sep-90			<0.004	<0.04	0.0	<0.04	<0.04	<0.04	40	115
bd2	192	01-Oct-90		15147.18	<0.004	<0.04	<0.04	<0.04	<0.04	0.0	27	66
bd2	207	08-Oct-90			<0.004	<0.04	<0.04	0.0	<0.04	<0.04	24	50
bd2	222	15-Oct-90			<0.004	<0.04	<0.04	0.0	<0.04	0.1	127	53
bd2	237	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	16	15
bd2	253	29-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	14	10
bd2	269	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	90	90
bd2	284	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	14	10
bd2	299	19-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	89	83
bd2	314	26-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.1	102	86
bd2	329	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	41	35
bd2	344	10-Dec-90		15147.28	0.0	<0.04	0.0	<0.04	<0.04	<0.04	56	52
bd2	359	17-Dec-90			<0.004	<0.04	0.0	<0.04	<0.04	0.0	55	41
bd2	374	02-Jan-91		15147.33	-	<0.1	<0.1	-	-	0.1	11	8
bd2	434	04-Feb-91		15147.38	-	<0.1	<0.1	-	-	<0.1	65	30
bd2	483	06-Mar-91		15147.43	-	<0.1	<0.1	-	-	<0.1	37	18
bd2	529	02-Apr-91		15147.48	-	<0.1	<0.1	-	-	0.1	63	33
bd2	606	13-May-91		15147.53	-	0.1	<0.1	-	-	<0.1	59	51
bd2	653	03-Jun-91		15147.58	-	<0.1	<0.1	-	-	<0.1	72	79
bd2	726	01-Jul-91		15147.63	-	<0.1	<0.1	-	-	<0.1	36	93
bd2	812	05-Aug-91		15147.68	-	<0.1	<0.1	-	-	<0.1	33	108
bd2	830	12-Aug-91		15155.03	-	<0.01	0.0	-	-	<0.01	57	91
bd2	884	03-Sep-91		15155.11	-	<0.01	0.0	-	-	<0.01	56	87
bd2	974	07-Oct-91		15155.18	-	<0.01	0.0	-	-	<0.01	54	79
bd2	1064	11-Nov-91		15155.26	-	<0.01	<0.01	-	-	<0.01	22	38

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
bd2	1082	18-Nov-91		15155.36	-	0.0	0.0	-	-	0.2	25	51
bd2	1100	25-Nov-91		15155.46	-	0.0	0.0	-	-	0.2	18	20
bd3	12	18-Jun-90			<0.01	0.0	0.0	0.0	<0.01	0.0	60	31
bd3	22	25-Jun-90			<0.01	0.0	0.0	<0.01	<0.01	0.0	76	41
bd3	32	02-Jul-90			<0.01	0.0	0.0	<0.01	<0.01	0.0	63	34
bd3	42	09-Jul-90			<0.01	0.0	0.0	0.0	<0.01	<0.01	57	31
bd3	52	16-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	97	53
bd3	63	23-Jul-90		15147.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	91	49
bd3	78	30-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	78	43
bd3	89	06-Aug-90		15147.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	60	33
bd3	115	20-Aug-90			<0.01	0.0	0.1	<0.01	<0.01	<0.01	105	135
bd3	130	27-Aug-90			<0.004	<0.04	0.0	<0.04	<0.04	<0.04	64	91
bd3	145	04-Sep-90		15147.14	<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	48	71
bd3	153	10-Sep-90			0.0	<0.04	0.0	<0.04	<0.04	<0.04	44	66
bd3	165	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	18	30
bd3	179	24-Sep-90			<0.004	<0.04	0.0	<0.04	<0.04	<0.04	59	87
bd3	193	01-Oct-90		15147.19	<0.004	<0.04	0.0	<0.04	<0.04	0.0	40	65
bd3	208	08-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	22	19
bd3	223	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	46	70
bd3	238	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	29	14
bd3	254	29-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	37	33
bd3	270	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	80	77
bd3	285	12-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	36	37
bd3	300	19-Nov-90		15147.24	0.0	<0.04	<0.04	<0.04	<0.04	<0.04	52	45
bd3	315	26-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	62	57
bd3	330	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	39	33
bd3	345	10-Dec-90		15147.29	0.0	<0.04	0.1	<0.04	<0.04	0.0	45	42
bd3	360	17-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	38	29
bd3	375	02-Jan-91		15147.34	-	<0.1	<0.1	-	-	<0.1	83	44
bd3	435	04-Feb-91		15147.39	-	<0.1	<0.1	-	-	0.1	101	50
bd3	484	06-Mar-91		15147.44	-	<0.1	<0.1	-	-	<0.1	45	22
bd3	530	02-Apr-91		15147.49	-	<0.1	<0.1	-	-	<0.1	99	50
bd3	607	13-May-91		15147.54	-	<0.1	<0.1	-	-	<0.1	43	23
bd3	654	03-Jun-91		15147.59	-	<0.1	<0.1	-	-	0.1	76	60
bd3	727	01-Jul-91		15147.64	-	<0.1	<0.1	-	-	<0.1	81	74
bd3	813	05-Aug-91		15147.69	-	<0.1	0.1	-	-	0.1	77	62
bd3	831	12-Aug-91		15155.04	-	0.0	0.0	-	-	0.0	76	41
bd3	885	03-Sep-91		15155.12	-	<0.01	0.0	-	-	<0.01	93	55
bd3	975	07-Oct-91		15155.19	-	0.0	0.0	-	-	<0.01	70	34
bd3	1065	11-Nov-91		15155.27	-	<0.01	<0.01	-	-	<0.01	27	15

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
bd3	1083	18-Nov-91		15155.37	-	0.0	0.1	-	-	0.2	48	67
bd3	1101	25-Nov-91		15155.47	-	0.0	0.1	-	-	0.2	48	55
bd4	13	18-Jun-90			0.0	0.0	0.3	0.2	0.0	0.5	79	31
bd4	23	25-Jun-90			<0.01	0.0	<0.01	0.0	<0.01	<0.01	51	19
bd4	33	02-Jul-90			<0.01	0.0	<0.01	0.0	<0.01	<0.01	40	14
bd4	43	09-Jul-90			<0.01	0.0	<0.01	0.0	<0.01	<0.01	41	14
bd4	53	16-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	48	15
bd4	64	23-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	52	16
bd4	79	30-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	52	17
bd4	105	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	46	14
bd4	116	20-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	100	43
bd4	131	27-Aug-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	112	76
bd4	146	04-Sep-90			<0.004	<0.04	0.0	<0.04	<0.04	0.0	69	51
bd4	154	10-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	54	39
bd4	166	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	16	14
bd4	180	24-Sep-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	59	44
bd4	194	01-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	33	28
bd4	209	08-Oct-90			<0.004	<0.04	0.0	<0.04	<0.04	<0.04	29	49
bd4	224	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	17	11
bd4	239	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	18	10
bd4	255	29-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	42	23
bd4	271	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	78	68
bd4	286	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	28	14
bd4	301	19-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	45	35
bd4	316	26-Nov-90			<0.004	<0.04	0.1	<0.04	<0.04	<0.04	75	64
bd4	331	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	32	22
bd4	346	10-Dec-90			0.0	<0.04	0.1	<0.04	<0.04	0.0	43	32
bd4	361	17-Dec-90			<0.004	<0.04	0.0	<0.04	<0.04	0.0	40	29
bd4	728	01-Jul-91		15147.65	-	<0.1	<0.1	-	-	<0.1	68	31
bd4	814	05-Aug-91		15147.70	-	0.1	<0.1	-	-	<0.1	62	28
bd4	832	12-Aug-91		15155.05	-	<0.01	0.0	-	-	<0.01	78	25
bd4	886	03-Sep-91		15155.13	-	<0.01	0.0	-	-	<0.01	93	32
bd4	976	07-Oct-91		15155.20	-	<0.01	0.0	-	-	<0.01	89	30
bd4	1066	11-Nov-91		15155.28	-	<0.01	<0.01	-	-	<0.01	50	19
bd4	1084	18-Nov-91		15155.38	-	0.0	0.1	-	-	0.2	86	53
bd4	1102	25-Nov-91		15155.48	-	0.0	0.0	-	-	0.2	38	33
mh4	14	18-Jun-90			<0.01	0.0	0.0	0.0	<0.01	0.0	47	17
mh4	24	25-Jun-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	30	9
mh4	34	02-Jul-90			<0.01	0.0	0.0	0.0	<0.01	0.0	50	17

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
mh4	44	09-Jul-90			<0.01	0.0	<0.01	0.0	<0.01	<0.01	34	11
mh4	54	16-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	56	16
mh4	65	23-Jul-90		15147.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	49	14
mh4	80	30-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	52	14
mh4	91	06-Aug-90		15147.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	40	10
mh4	106	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	54	14
mh4	117	20-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	50	14
mh4	132	27-Aug-90			0.0	<0.04	0.0	<0.04	<0.04	<0.04	111	81
mh4	147	04-Sep-90		15147.15	<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	71	52
mh4	155	10-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	29	20
mh4	167	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	13	9
mh4	181	24-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	58	46
mh4	195	01-Oct-90		15147.20	<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	38	31
mh4	210	08-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	36	31
mh4	225	15-Oct-90	Cu was 5.4		<0.004	-	<0.04	<0.04	<0.04	2.8	19	11
mh4	240	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	19	10
mh4	256	29-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	40	20
mh4	272	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	66	55
mh4	287	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	16	6
mh4	302	19-Nov-90		15147.25	<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	44	34
mh4	317	26-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	81	67
mh4	332	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.1	32	19
mh4	347	10-Dec-90		15147.30	<0.004	<0.04	0.0	<0.04	<0.04	<0.04	39	28
mh4	362	17-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	34	22
mh4	377	02-Jan-91		15147.35	-	<0.1	<0.1	-	-	<0.1	63	27
mh4	437	04-Feb-91		15147.40	-	<0.1	<0.1	-	-	<0.1	84	43
mh4	486	06-Mar-91		15147.45	-	<0.1	<0.1	-	-	<0.1	25	9
mh4	532	02-Apr-91		15147.50	-	<0.1	<0.1	-	-	<0.1	100	43
mh4	609	13-May-91		15147.55	-	<0.1	<0.1	-	-	<0.1	66	20
mh4	656	03-Jun-91		15147.60	-	<0.1	<0.1	-	-	<0.1	84	31
mh4	1067	11-Nov-91		15155.29	-	0.0	0.0	-	-	0.2	33	15
mh4	1085	18-Nov-91		15155.39	-	0.0	0.1	-	-	0.2	84	52
mh4	1105	25-Nov-91		15155.49	-	0.0	0.0	-	-	0.2	39	35
htk	59	16-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	52	15
htk	70	23-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	37	10
htk	85	30-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	49	14
htk	96	06-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	46	12
htk	111	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	47	12
htk	122	20-Aug-90			<0.01	<0.01	0.0	<0.01	<0.01	0.0	57	43
htk	137	27-Aug-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	109	70

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
htk	149	04-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	60	47
htk	157	10-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	34	25
htk	172	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	9	6
htk	185	24-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	57	46
htk	200	01-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	47	38
htk	215	08-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	14	11
htk	230	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	24	20
htk	245	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	9	5
htk	250	25-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	15	4
htk	261	29-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	35	16
htk	266	02-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	40	28
htk	277	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	69	57
htk	292	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	20	14
htk	307	19-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	44	31
htk	322	26-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	54	43
htk	337	04-Dec-90			<0.004	<0.04	0.0	<0.04	<0.04	0.1	28	22
htk	352	10-Dec-90			<0.004	<0.04	0.1	<0.04	<0.04	0.0	26	20
htk	367	17-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	40	26
htk	1072	11-Nov-91		15155.33	-	0.0	0.0	-	-	0.2	36	16
htk	1090	18-Nov-91		15155.43	-	0.0	0.0	-	-	0.2	69	39
htk	1110	25-Nov-91		15155.54	-	0.0	0.0	-	-	0.2	38	34
s14	16	18-Jun-90			<0.01	0.0	<0.01	0.0	<0.01	<0.01	4	2
s14	26	25-Jun-90			<0.01	0.0	<0.01	0.0	<0.01	0.0	7	2
s14	36	02-Jul-90			<0.01	0.0	<0.01	<0.01	<0.01	0.0	12	3.
s14	46	09-Jul-90			<0.01	0.0	<0.01	<0.01	<0.01	0.0	12	2
s14	56	16-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	8	<0.1
s14	67	23-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	9	<0.1
s14	82	30-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11	<0.1
s14	108	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	26	0
s14	119	20-Aug-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	34	2
s14	134	27-Aug-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	23	3
s14	169	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	26	4
s14	183	24-Sep-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	21	3
s14	197	01-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	35	5
s14	212	08-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	34	4
s14	227	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	8	<0.04
s14	242	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
s14	258	29-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
s14	274	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	2	<0.04
s14	289	12-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
s14	304	19-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	1	<0.04
s14	319	26-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	2	<0.04
s14	334	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
s14	349	10-Dec-90			<0.004	<0.04	0.1	<0.04	<0.04	<0.04	<0.04	<0.04
s14	364	17-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	4	<0.04
s14	835	12-Aug-91		15155.07	-	0.0	<0.01	-	-	0.4	48	10
s14	979	07-Oct-91		15155.22	-	0.0	<0.01	-	-	0.3	22	7
s14	1087	18-Nov-91		15155.41	-	0.0	0.0	-	-	0.4	10	3
s14	1107	25-Nov-91		15155.51	-	0.0	0.0	-	-	0.2	<0.01	1
s19	28	25-Jun-90			<0.01	0.0	<0.01	0.0	<0.01	0.0	15	5
s19	38	02-Jul-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	14	4
s19	48	09-Jul-90			<0.01	0.0	<0.01	0.0	<0.01	0.0	13	4
s19	95	06-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	7	<0.1
s19	136	27-Aug-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	18	6
s19	171	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	5	1
s19	199	01-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	11	4
s19	214	08-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	10	2
s19	229	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	79	33
s19	244	22-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	0.0	5	<0.04
s19	260	29-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	3	<0.04
s19	276	05-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	5	<0.04
s19	291	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	2	<0.04
s19	306	19-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	4	<0.04
s19	321	26-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	5	<0.04
s19	336	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.1	4	<0.04
s19	351	10-Dec-90			<0.004	<0.04	0.1	<0.04	<0.04	<0.04	2	<0.04
s19	366	17-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.1	7	<0.04
s19	1071	11-Nov-91		15155.32	-	0.0	0.0	-	-	0.2	0	4
s19	1109	25-Nov-91		15155.53	-	<0.01	0.0	-	-	0.2	<0.01	2
s18	17	18-Jun-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	97	37
s18	27	25-Jun-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	78	29
s18	37	02-Jul-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	92	35
s18	47	09-Jul-90			<0.01	0.0	<0.01	0.0	<0.01	<0.01	61	21
s18	57	16-Jul-90			<0.01	<0.01	0.0	<0.01	<0.01	<0.01	141	55
s18	68	23-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	129	44
s18	83	30-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	128	52
s18	94	06-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	53	16
s18	109	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	127	50
s18	120	20-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	119	47

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
s18	135	27-Aug-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	113	46
s18	148	04-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	5.7	124	53
s18	156	10-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	65	39
s18	170	17-Sep-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	27	11
s18	184	24-Sep-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	105	44
s18	198	01-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	80	33
s18	213	08-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	94	42
s18	228	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	9	1
s18	243	22-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	33	11
s18	259	29-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	37	11
s18	275	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	51	18
s18	290	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	17	4
s18	305	19-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	41	14
s18	320	26-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	38	14
s18	335	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	0.0	19	4
s18	350	10-Dec-90			<0.004	<0.04	0.1	<0.04	<0.04	0.0	12	4
s18	365	17-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	30	9
s18	836	12-Aug-91		15155.08	-	<0.01	<0.01	-	-	0.0	138	40
s18	890	03-Sep-91		15155.15	-	0.0	0.3	-	-	0.1	494	57
s18	980	07-Oct-91		15155.23	-	<0.01	0.0	-	-	<0.01	119	38
s18	1070	11-Nov-91		15155.31	-	0.0	0.0	-	-	0.3	3	5
s18	1088	18-Nov-91		15155.42	-	0.0	0.0	-	-	0.2	94	34
s18	1108	25-Nov-91		15155.52	-	0.0	0.0	-	-	0.2	52	19
gwn	15	18-Jun-90			<0.01	0.0	0.0	<0.01	<0.01	<0.01	90	39
gwn	25	25-Jun-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	143	54
gwn	35	02-Jul-90			<0.01	0.0	<0.01	<0.01	<0.01	<0.01	166	59
gwn	45	09-Jul-90			<0.01	0.0	0.0	<0.01	<0.01	0.0	143	53
gwn	55	16-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	214	88
gwn	66	23-Jul-90			<0.01	0.0	<0.01	<0.01	<0.01	0.0	167	70
gwn	81	30-Jul-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	199	85
gwn	92	06-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	126	48
gwn	107	13-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	173	71
gwn	118	20-Aug-90			<0.01	<0.01	<0.01	<0.01	<0.01	0.0	152	64
gwn	133	27-Aug-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	159	68
gwn	168	17-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	58	25
gwn	182	24-Sep-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	157	66
gwn	196	01-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	133	54
gwn	211	08-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	144	63
gwn	226	15-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	122	50
gwn	241	22-Oct-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	117	49

Table C-3a. Cation Concentrations (Additional cations are listed in Table C-3b).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Cd	Cu	Ni	Cr	Co	Zn	Ca	Mg
gwn	257	29-Oct-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	104	44
gwn	273	05-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	118	54
gwn	288	12-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	89	37
gwn	303	19-Nov-90			0.0	<0.04	<0.04	<0.04	<0.04	<0.04	105	46
gwn	318	26-Nov-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	121	55
gwn	333	04-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	85	35
gwn	348	10-Dec-90			0.0	<0.04	0.1	<0.04	<0.04	<0.04	94	49
gwn	363	17-Dec-90			<0.004	<0.04	<0.04	<0.04	<0.04	<0.04	94	42
gwn	834	12-Aug-91		15155.06	-	0.0	0.0	-	-	0.0	165	49
gwn	888	03-Sep-91		15155.14	-	<0.01	<0.01	-	-	<0.01	163	52
gwn	978	07-Oct-91		15155.21	-	<0.01	0.0	-	-	<0.01	146	49
gwn	1068	11-Nov-91		15155.30	-	0.0	0.0	-	-	0.2	91	32
gwn	1086	18-Nov-91		15155.40	-	0.0	0.0	-	-	0.2	118	42
gwn	1106	25-Nov-91		15155.50	-	0.0	0.0	-	-	0.2	87	30

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
mh1	9	18-Jun-90			-	0.2	21.6	0	207.0	<0.2	-
mh1	19	25-Jun-90			-	0.4	27.3	<0.01	256.0	<0.2	-
mh1	29	02-Jul-90			-	0.3	27.9	<0.01	250.0	<0.2	-
mh1	39	09-Jul-90			-	0.3	7.8	0	96.0	<0.2	-
mh1	49	16-Jul-90			-	0.6	102.0	<0.01	403.0	-	762.0
mh1	60	23-Jul-90		15147.01	2.4	1.5	69.3	<0.01	422.0	-	959.0
mh1	75	30-Jul-90			-	0.7	33.9	<0.01	407.0	-	705.0
mh1	86	06-Aug-90	flooded	15147.06	1.8	0.3	17.8	<0.01	189.0	-	404.0
mh1	101	13-Aug-90			-	0.6	58.6	0	369.0	-	728.0
mh1	112	20-Aug-90			-	0.5	13.9	<0.01	196.0	-	462.0
mh1	127	27-Aug-90			-	0.4	17.6	<0.04	155.0	-	675.0
mh1	142	04-Sep-90		15147.11	1.8	0.3	25.9	<0.04	216.0	-	557.0
mh1	150	10-Sep-90			-	0.2	0.9	<0.04	150.0	-	580.0
mh1	162	17-Sep-90			-	0.1	2.4	<0.04	94.8	-	260.0
mh1	176	24-Sep-90			-	0.3	6.8	<0.04	146.0	-	574.0
mh1	190	01-Oct-90		15147.16	0.4	0.2	16.1	0	200.0	-	430.0
mh1	205	08-Oct-90			-	0.2	19.7	<0.04	134.0	-	360.0
mh1	220	15-Oct-90			-	<0.04	0.4	<0.04	29.6	-	56.0
mh1	235	22-Oct-90			-	0.6	62.1	<0.04	197.0	-	500.0
mh1	251	29-Oct-90			-	0.2	20.7	<0.04	101.0	-	280.0
mh1	267	05-Nov-90			-	0.5	41.9	<0.04	215.0	-	700.0
mh1	282	12-Nov-90			-	0.3	48.0	<0.04	124.0	-	356.0
mh1	297	19-Nov-90		15147.21	2.0	0.3	45.8	<0.04	208.0	-	468.0
mh1	312	26-Nov-90			-	0.5	51.0	0	172.0	-	548.0
mh1	327	04-Dec-90			-	0.4	14.8	<0.04	93.6	-	228.0
mh1	342	10-Dec-90		15147.26	3.0	0.2	24.9	0	185.0	-	436.0
mh1	357	17-Dec-90			-	0.3	11.9	0	138.0	-	340.0
mh1	372	02-Jan-91		15147.31	3.6	-	97.0	<0.1	188.0	-	340.0
mh1	432	04-Feb-91		15147.36	1.3	-	5.0	<0.1	140.0	-	280.0
mh1	481	06-Mar-91		15147.41	0.6	-	<0.1	<0.1	56.0	-	91.0
mh1	527	02-Apr-91		15147.46	3.2	-	74.0	<0.1	180.0	-	320.0
mh1	604	13-May-91		15147.51	2.7	-	68.0	<0.1	195.0	-	380.0
mh1	651	03-Jun-91		15147.56	2.3	-	54.0	<0.1	200.0	-	380.0
mh1	724	01-Jul-91		15147.61	1.8	-	40.0	0	240.0	-	440.0
mh1	810	05-Aug-91		15147.66	1.0	-	11.0	0	250.0	-	460.0
mh1	828	12-Aug-91		15155.01	1.9	-	5.2	0	220.0	-	450.0
mh1	882	03-Sep-91	dry???	15155.09	1.8	-	4.3	<0.01	230.0	-	470.0
mh1	972	07-Oct-91		15155.16	1.7	-	5.0	0	140.0	-	300.0
mh1	1062	11-Nov-91		15155.24	<0.01	-	4.8	<0.01	35.0	-	55.0
mh1	1080	18-Nov-91		15155.34	1.5	-	25.9	0	150.0	-	310.0
mh1	1098	25-Nov-91		15155.44	3.3	-	95.5	<0.01	110.0	-	230.0

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
bd1	10	18-Jun-90			-	0.7	53.0	0	245.0	<0.2	-
bd1	20	25-Jun-90			-	0.6	42.6	<0.01	226.0	<0.2	-
bd1	30	02-Jul-90			-	0.6	28.2	<0.01	206.0	<0.2	-
bd1	40	09-Jul-90			-	0.3	5.5	0	163.0	<0.2	-
bd1	50	16-Jul-90			-	0.3	24.2	<0.01	210.0	-	474.0
bd1	61	23-Jul-90		15147.02	0.6	1.8	39.9	<0.01	298.0	-	638.0
bd1	76	30-Jul-90			-	0.5	25.4	-	385.0	-	635.0
bd1	87	06-Aug-90		15147.07	0.5	0.2	7.2	<0.01	219.0	-	463.0
bd1	102	13-Aug-90			-	0.5	32.5	<0.01	340.0	-	728.0
bd1	113	20-Aug-90			-	0.7	12.5	<0.01	371.0	-	739.0
bd1	128	27-Aug-90			-	3.1	52.0	0	160.0	-	674.0
bd1	143	04-Sep-90		15147.12	0.2	0.4	4.8	<0.04	221.0	-	570.0
bd1	151	10-Sep-90			-	0.1	1.5	<0.04	120.0	-	330.0
bd1	163	17-Sep-90			-	0.3	2.2	<0.04	96.0	-	250.0
bd1	177	24-Sep-90			-	4.3	43.8	<0.04	145.0	-	580.0
bd1	191	01-Oct-90		15147.17	0.5	1.5	10.3	<0.04	137.0	-	316.0
bd1	206	08-Oct-90			-	1.5	20.2	0	200.0	-	628.0
bd1	221	15-Oct-90			-	0.0	5.5	<0.04	76.4	-	188.0
bd1	236	22-Oct-90			-	0.2	8.5	<0.04	86.8	-	212.0
bd1	252	29-Oct-90			-	0.1	16.5	0	81.6	-	196.0
bd1	268	05-Nov-90			-	0.3	37.7	0	171.0	-	520.0
bd1	283	12-Nov-90			-	0.1	4.7	0	88.8	-	240.0
bd1	298	19-Nov-90		15147.22	1.5	2.7	28.0	0	177.0	-	418.0
bd1	313	26-Nov-90			-	0.3	8.8	0	148.0	-	472.0
bd1	328	04-Dec-90			-	1.2	4.5	0	53.6	-	132.0
bd1	343	10-Dec-90		15147.27	4.9	0.4	12.6	<0.04	143.0	-	364.0
bd1	358	17-Dec-90			-	1.3	10.9	<0.04	119.0	-	308.0
bd1	373	02-Jan-91		15147.32	1.7	-	0.9	<0.1	115.0	-	180.0
bd1	433	04-Feb-91		15147.37	4.9	-	23.0	<0.1	195.0	-	380.0
bd1	482	06-Mar-91		15147.42	2.4	-	0.8	<0.1	95.0	-	200.0
bd1	528	02-Apr-91		15147.47	0.1	-	3.2	<0.1	135.0	-	220.0
bd1	605	13-May-91		15147.52	1.7	-	7.8	<0.1	127.0	-	220.0
bd1	652	03-Jun-91		15147.57	1.6	-	20.0	<0.1	175.0	-	340.0
bd1	725	01-Jul-91		15147.62	0.3	-	23.0	<0.01	240.0	-	460.0
bd1	811	05-Aug-91		15147.67	0.1	-	6.3	0	265.0	-	520.0
bd1	829	12-Aug-91		15155.02	1.1	-	6.3	<0.01	200.0	-	470.0
bd1	883	03-Sep-91		15155.10	1.1	-	10.5	<0.01	210.0	-	500.0
bd1	973	07-Oct-91		15155.17	1.1	-	8.0	<0.01	160.0	-	400.0
bd1	1063	11-Nov-91		15155.25	0.2	-	1.8	<0.01	100.0	-	260.0
bd1	1081	18-Nov-91		15155.35	0.4	-	11.7	0	150.0	-	330.0

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
bd1	1099	25-Nov-91		15155.45	2.7	-	37.7	0	100.0	-	220.0
bd2	11	18-Jun-90			-	0.3	35.0	0	252.0	<0.2	-
bd2	21	25-Jun-90			-	0.2	9.6	<0.01	136.0	<0.2	-
bd2	31	02-Jul-90			-	0.3	13.1	<0.01	136.0	<0.2	-
bd2	41	09-Jul-90			-	0.6	3.3	<0.01	68.3	<0.2	-
bd2	51	16-Jul-90			-	1.2	13.6	<0.01	112.0	-	323.0
bd2	62	23-Jul-90		15147.03	0.9	0.3	7.7	<0.01	162.0	-	392.0
bd2	77	30-Jul-90			-	0.2	5.5	<0.01	213.0	-	462.0
bd2	88	06-Aug-90		15147.08	0.5	1.1	3.7	<0.01	119.0	-	263.0
bd2	103	13-Aug-90			-	0.2	5.6	<0.01	138.0	-	347.0
bd2	114	20-Aug-90			-	0.8	11.6	<0.01	372.0	-	705.0
bd2	129	27-Aug-90			-	0.2	7.4	<0.04	157.0	-	645.0
bd2	144	04-Sep-90		15147.13	0.4	0.2	2.7	<0.04	172.0	-	427.0
bd2	152	10-Sep-90			-	0.2	0.9	<0.04	125.0	-	396.0
bd2	164	17-Sep-90			-	0.0	0.4	<0.04	76.8	-	192.0
bd2	178	24-Sep-90			-	0.2	1.0	<0.04	151.0	-	646.0
bd2	192	01-Oct-90		15147.18	0.4	0.2	0.6	<0.04	147.0	-	318.0
bd2	207	08-Oct-90			-	0.1	1.3	<0.04	104.0	-	272.0
bd2	222	15-Oct-90			-	0.3	58.9	<0.04	86.8	-	220.0
bd2	237	22-Oct-90			-	0.1	0.8	<0.04	39.2	-	84.0
bd2	253	29-Oct-90			-	0.0	0.4	<0.04	30.3	-	64.0
bd2	269	05-Nov-90			-	0.3	16.0	0	135.0	-	420.0
bd2	284	12-Nov-90			-	0.1	0.7	0	33.0	-	64.0
bd2	299	19-Nov-90			-	0.2	7.0	<0.04	126.0	-	404.0
bd2	314	26-Nov-90			-	0.2	9.7	0	132.0	-	420.0
bd2	329	04-Dec-90			-	1.5	3.7	<0.04	59.2	-	148.0
bd2	344	10-Dec-90		15147.28	1.9	0.3	1.3	0	81.1	-	178.0
bd2	359	17-Dec-90			-	0.5	2.1	<0.04	53.2	-	148.0
bd2	374	02-Jan-91		15147.33	0.2	-	<0.1	<0.1	18.0	-	34.0
bd2	434	04-Feb-91		15147.38	2.6	-	3.9	<0.1	107.0	-	140.0
bd2	483	06-Mar-91		15147.43	1.4	-	<0.1	<0.1	30.0	-	81.0
bd2	529	02-Apr-91		15147.48	0.0	-	<0.1	<0.1	90.0	-	140.0
bd2	606	13-May-91		15147.53	0.8	-	2.7	<0.1	120.0	-	220.0
bd2	653	03-Jun-91		15147.58	2.4	-	7.4	<0.1	165.0	-	320.0
bd2	726	01-Jul-91		15147.63	1.7	-	14.0	<0.01	170.0	-	360.0
bd2	812	05-Aug-91		15147.68	0.7	-	3.5	0	220.0	-	480.0
bd2	830	12-Aug-91		15155.03	1.6	-	7.4	<0.01	170.0	-	440.0
bd2	884	03-Sep-91		15155.11	1.4	-	6.6	0	150.0	-	390.0
bd2	974	07-Oct-91		15155.18	1.4	-	6.2	<0.01	140.0	-	390.0
bd2	1064	11-Nov-91		15155.26	0.3	-	<0.01	<0.01	106.0	-	180.0

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
bd2	1082	18-Nov-91		15155.36	<0.01	-	<0.01	0	100.0	-	260.0
bd2	1100	25-Nov-91		15155.46	<0.01	-	<0.01	0	62.0	-	110.0
bd3	12	18-Jun-90			-	0.2	1.7	<0.01	57.5	<0.2	-
bd3	22	25-Jun-90			-	0.2	1.5	<0.01	71.7	<0.2	-
bd3	32	02-Jul-90			-	0.2	1.4	<0.01	63.9	<0.2	-
bd3	42	09-Jul-90			-	0.2	1.7	0	58.6	<0.2	-
bd3	52	16-Jul-90			-	0.2	2.1	<0.01	90.9	-	277.0
bd3	63	23-Jul-90		15147.04	1.8	0.3	2.6	<0.01	97.5	-	300.0
bd3	78	30-Jul-90			-	0.1	1.1	<0.01	82.8	-	266.0
bd3	89	06-Aug-90		15147.09	1.1	1.6	4.2	<0.01	67.2	-	241.0
bd3	115	20-Aug-90			-	0.5	3.8	0	228.0	-	531.0
bd3	130	27-Aug-90			-	0.3	1.7	<0.04	132.0	-	490.0
bd3	145	04-Sep-90		15147.14	1.1	0.2	1.5	<0.04	132.0	-	330.0
bd3	153	10-Sep-90			-	0.2	1.4	<0.04	102.0	-	332.0
bd3	165	17-Sep-90			-	0.0	0.6	<0.04	60.0	-	186.0
bd3	179	24-Sep-90			-	0.3	0.9	<0.04	110.0	-	440.0
bd3	193	01-Oct-90		15147.19	1.1	0.2	0.5	0	128.0	-	307.0
bd3	208	08-Oct-90			-	0.0	0.2	<0.04	52.4	-	148.0
bd3	223	15-Oct-90			-	0.1	0.8	<0.04	116.0	-	328.0
bd3	238	22-Oct-90			-	0.0	0.2	<0.04	35.2	-	80.0
bd3	254	29-Oct-90			-	0.1	1.0	<0.04	62.4	-	140.0
bd3	270	05-Nov-90			-	0.1	1.8	0	110.0	-	312.0
bd3	285	12-Nov-90			-	0.1	0.8	<0.04	72.8	-	188.0
bd3	300	19-Nov-90		15147.24	0.7	0.4	1.7	<0.04	105.0	-	214.0
bd3	315	26-Nov-90			-	0.4	1.5	0	95.2	-	280.0
bd3	330	04-Dec-90			-	0.6	1.7	<0.04	55.6	-	124.0
bd3	345	10-Dec-90		15147.29	0.8	0.2	0.9	0	85.1	-	156.0
bd3	360	17-Dec-90			-	0.6	2.1	<0.04	53.2	-	108.0
bd3	375	02-Jan-91		15147.34	5.9	-	3.1	0	105.0	-	200.0
bd3	435	04-Feb-91		15147.39	8.9	-	14.0	0	114.0	-	180.0
bd3	484	06-Mar-91		15147.44	4.6	-	3.1	<0.1	67.0	-	84.0
bd3	530	02-Apr-91		15147.49	6.4	-	5.5	<0.1	112.0	-	200.0
bd3	607	13-May-91		15147.54	2.8	-	<0.1	<0.1	60.0	-	114.0
bd3	654	03-Jun-91		15147.59	6.3	-	1.8	<0.1	119.0	-	280.0
bd3	727	01-Jul-91		15147.64	7.6	-	5.7	0	137.0	-	380.0
bd3	813	05-Aug-91		15147.69	6.9	-	6.1	0	115.0	-	360.0
bd3	831	12-Aug-91		15155.04	5.5	-	6.1	0	97.0	-	290.0
bd3	885	03-Sep-91		15155.12	9.6	-	12.8	<0.01	112.0	-	320.0
bd3	975	07-Oct-91		15155.19	5.2	-	5.8	0	78.0	-	200.0
bd3	1065	11-Nov-91		15155.27	<0.01	-	<0.01	<0.01	20.0	-	49.0

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
bd3	1083	18-Nov-91		15155.37	0.6	-	<0.01	0	110.0	-	350.0
bd3	1101	25-Nov-91		15155.47	0.5	-	<0.01	<0.01	140.0	-	250.0
bd4	13	18-Jun-90			-	1.3	4.8	0	55.3	<0.2	-
bd4	23	25-Jun-90			-	0.1	0.1	<0.01	49.3	<0.2	-
bd4	33	02-Jul-90			-	0.1	0.2	<0.01	33.7	<0.2	-
bd4	43	09-Jul-90			-	0.2	0.3	0	31.7	<0.2	-
bd4	53	16-Jul-90			-	0.3	0.5	<0.01	40.6	-	104.0
bd4	64	23-Jul-90			-	0.2	0.3	<0.01	43.3	-	116.0
bd4	79	30-Jul-90			-	0.2	0.4	<0.01	42.6	-	139.0
bd4	105	13-Aug-90			-	1.0	0.3	<0.01	35.6	-	127.0
bd4	116	20-Aug-90			-	0.4	0.2	0	61.8	-	231.0
bd4	131	27-Aug-90			-	0.6	1.5	<0.04	88.8	-	404.0
bd4	146	04-Sep-90			-	0.8	2.1	<0.04	78.0	-	304.0
bd4	154	10-Sep-90			-	1.0	2.7	<0.04	69.6	-	240.0
bd4	166	17-Sep-90			-	0.3	0.7	<0.04	39.2	-	106.0
bd4	180	24-Sep-90			-	1.2	4.3	<0.04	70.8	-	252.0
bd4	194	01-Oct-90			-	0.0	0.8	<0.04	54.4	-	184.0
bd4	209	08-Oct-90			-	0.1	0.5	0	104.0	-	304.0
bd4	224	15-Oct-90			-	0.1	0.4	0	40.0	-	72.0
bd4	239	22-Oct-90			-	0.1	0.2	<0.04	38.5	-	64.0
bd4	255	29-Oct-90			-	0.1	0.8	<0.04	40.4	-	108.0
bd4	271	05-Nov-90			-	0.2	0.8	<0.04	86.8	-	264.0
bd4	286	12-Nov-90			-	0.2	0.8	<0.04	32.9	-	60.0
bd4	301	19-Nov-90			-	0.1	0.3	<0.04	66.8	-	168.0
bd4	316	26-Nov-90			-	0.1	0.3	0	82.8	-	260.0
bd4	331	04-Dec-90			-	0.2	0.8	<0.04	41.6	-	92.0
bd4	346	10-Dec-90			-	0.1	0.5	0	51.2	-	122.0
bd4	361	17-Dec-90			-	0.5	1.6	<0.04	48.4	-	96.0
bd4	728	01-Jul-91		15147.65	3.2	-	<0.1	0	65.0	-	200.0
bd4	814	05-Aug-91		15147.70	3.6	-	0.4	0	56.0	-	180.0
bd4	832	12-Aug-91		15155.05	3.9	-	4.1	0	50.0	-	160.0
bd4	886	03-Sep-91		15155.13	4.7	-	3.9	0	56.0	-	190.0
bd4	976	07-Oct-91		15155.20	3.6	-	2.7	<0.01	44.0	-	180.0
bd4	1066	11-Nov-91		15155.28	1.5	-	<0.01	<0.01	26.0	-	94.0
bd4	1084	18-Nov-91		15155.38	1.8	-	<0.01	0	88.0	-	310.0
bd4	1102	25-Nov-91		15155.48	<0.01	-	<0.01	<0.01	91.0	-	160.0
mh4	14	18-Jun-90			-	0.1	0.1	<0.01	36.0	<0.2	-
mh4	24	25-Jun-90			-	0.1	0.1	<0.01	26.1	<0.2	-
mh4	34	02-Jul-90			-	0.1	0.2	<0.01	41.1	<0.2	-

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
mh4	44	09-Jul-90			-	0.2	0.4	0	25.9	<0.2	-
mh4	54	16-Jul-90			-	0.1	<0.01	<0.01	39.4	-	116.0
mh4	65	23-Jul-90		15147.05	0.4	0.1	0.1	<0.01	40.5	-	93.0
mh4	80	30-Jul-90			-	0.1	<0.01	<0.01	40.5	-	127.0
mh4	91	06-Aug-90		15147.10	0.3	0.2	0.3	<0.01	26.0	-	92.0
mh4	106	13-Aug-90			-	0.1	0.5	<0.01	32.4	-	127.0
mh4	117	20-Aug-90			-	0.2	<0.01	<0.01	29.6	-	127.0
mh4	132	27-Aug-90			-	0.2	0.4	<0.04	90.8	-	430.0
mh4	147	04-Sep-90		15147.15	0.7	0.1	0.2	<0.04	104.0	-	293.0
mh4	155	10-Sep-90			-	0.1	0.1	<0.04	49.6	-	168.0
mh4	167	17-Sep-90			-	<0.04	<0.04	<0.04	31.2	-	86.0
mh4	181	24-Sep-90			-	0.1	0.1	<0.04	71.2	-	264.0
mh4	195	01-Oct-90		15147.20	0.4	0.1	0.2	0	67.7	-	183.0
mh4	210	08-Oct-90			-	0.1	0.3	<0.04	68.8	-	208.0
mh4	225	15-Oct-90			-	0.1	0.3	<0.04	38.8	-	76.0
mh4	240	22-Oct-90			-	0.0	0.1	<0.04	37.3	-	64.0
mh4	256	29-Oct-90			-	0.0	0.6	0	40.6	-	92.0
mh4	272	05-Nov-90			-	0.1	0.7	<0.04	76.8	-	228.0
mh4	287	12-Nov-90			-	0.1	0.2	<0.04	23.4	-	32.0
mh4	302	19-Nov-90		15147.25	0.4	0.1	0.3	<0.04	75.5	-	155.0
mh4	317	26-Nov-90			-	0.2	0.5	<0.04	80.8	-	248.0
mh4	332	04-Dec-90			-	0.9	2.2	<0.04	36.9	-	74.0
mh4	347	10-Dec-90		15147.30	0.5	0.3	0.9	0	55.2	-	102.0
mh4	362	17-Dec-90			-	0.1	0.5	<0.04	42.0	-	76.0
mh4	377	02-Jan-91		15147.35	1.1	-	<0.1	<0.1	54.0	-	95.0
mh4	437	04-Feb-91		15147.40	4.9	-	<0.1	<0.1	93.0	-	174.0
mh4	486	06-Mar-91		15147.45	0.3	-	<0.1	<0.1	26.0	-	25.0
mh4	532	02-Apr-91		15147.50	1.1	-	<0.1	<0.1	88.0	-	140.0
mh4	609	13-May-91		15147.55	0.1	-	<0.1	<0.1	50.0	-	135.0
mh4	656	03-Jun-91		15147.60	0.3	-	<0.1	<0.1	56.0	-	140.0
mh4	1067	11-Nov-91		15155.29	0.2	-	<0.01	<0.01	24.0	-	94.0
mh4	1085	18-Nov-91		15155.39	2.4	-	<0.01	0	90.0	-	320.0
mh4	1105	25-Nov-91		15155.49	<0.01	-	<0.01	<0.01	93.0	-	160.0
htk	59	16-Jul-90			-	0.1	0.4	0	34.4	-	104.0
htk	70	23-Jul-90			-	0.1	0.2	0	33.7	-	80.8
htk	85	30-Jul-90			-	0.1	0.1	<0.01	35.6	-	116.0
htk	96	06-Aug-90			-	0.2	0.7	<0.01	32.6	-	116.0
htk	111	13-Aug-90			-	0.1	0.2	<0.01	30.2	-	116.0
htk	122	20-Aug-90			-	0.3	2.1	<0.01	93.3	-	219.0
htk	137	27-Aug-90			-	0.6	0.5	<0.04	79.2	-	396.0

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
htk	149	04-Sep-90			-	0.2	0.4	<0.04	71.2	-	276.0
htk	157	10-Sep-90			-	0.1	0.4	<0.04	56.8	-	196.0
htk	172	17-Sep-90			-	<0.04	0.1	<0.04	21.6	-	50.0
htk	185	24-Sep-90			-	0.2	0.4	<0.04	70.8	-	564.0
htk	200	01-Oct-90			-	0.1	0.3	<0.04	60.8	-	222.0
htk	215	08-Oct-90			-	0.1	0.2	<0.04	32.1	-	92.0
htk	230	15-Oct-90			-	0.2	0.6	0	50.4	-	128.0
htk	245	22-Oct-90			-	0.1	0.4	<0.04	18.9	-	40.0
htk	250	25-Oct-90			-	0.1	0.4	<0.04	20.5	-	28.0
htk	261	29-Oct-90			-	0.0	0.6	<0.04	34.8	-	80.0
htk	266	02-Nov-90			-	0.2	0.4	0	49.6	-	128.0
htk	277	05-Nov-90			-	0.1	0.5	0	78.8	-	236.0
htk	292	12-Nov-90			-	0.1	0.2	<0.04	36.8	-	80.0
htk	307	19-Nov-90			-	0.1	0.3	0	56.4	-	132.0
htk	322	26-Nov-90			-	0.1	0.4	<0.04	69.2	-	192.0
htk	337	04-Dec-90			-	0.3	1.3	0	36.2	-	84.0
htk	352	10-Dec-90			-	0.0	0.6	0	37.7	-	76.0
htk	367	17-Dec-90			-	0.1	0.8	0	44.4	-	100.0
htk	1072	11-Nov-91		15155.33	<0.01	-	<0.01	0	27.0	-	123.0
htk	1090	18-Nov-91		15155.43	1.5	-	<0.01	0	68.0	-	240.0
htk	1110	25-Nov-91		15155.54	<0.01	-	<0.01	0	90.0	-	170.0
s14	16	18-Jun-90			-	0.3	0.6	0	<0.1	<0.2	-
s14	26	25-Jun-90			-	0.3	0.5	<0.01	<0.1	<0.2	-
s14	36	02-Jul-90			-	0.3	0.8	<0.01	1.0	<0.2	-
s14	46	09-Jul-90			-	0.3	0.7	<0.01	1.8	<0.2	-
s14	56	16-Jul-90			-	0.7	1.4	0	2.0	-	<0.1
s14	67	23-Jul-90			-	0.8	2.8	<0.01	1.1	-	<0.1
s14	82	30-Jul-90			-	0.3	1.6	<0.01	1.8	-	<0.1
s14	108	13-Aug-90			-	0.2	1.0	<0.01	4.6	-	11.6
s14	119	20-Aug-90			-	1.3	3.1	<0.01	7.1	-	46.2
s14	134	27-Aug-90			-	0.4	1.3	<0.04	3.4	-	13.6
s14	169	17-Sep-90			-	0.2	0.5	<0.04	4.0	-	12.0
s14	183	24-Sep-90			-	0.3	1.2	<0.04	4.2	-	12.0
s14	197	01-Oct-90			-	0.3	0.8	<0.04	11.6	-	14.0
s14	212	08-Oct-90			-	0.2	0.6	0	10.4	-	16.0
s14	227	15-Oct-90			-	0.1	0.3	<0.04	2.2	-	4.0
s14	242	22-Oct-90			-	0.1	0.2	0	0.4	-	<0.004
s14	258	29-Oct-90			-	0.2	0.3	<0.04	0.6	-	<0.004
s14	274	05-Nov-90			-	0.2	0.3	<0.04	0.7	-	<0.004
s14	289	12-Nov-90			-	0.1	0.1	0	0.4	-	<0.004

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
s14	304	19-Nov-90			-	0.1	0.1	0	0.4	-	<0.004
s14	319	26-Nov-90			-	0.6	0.5	<0.04	0.4	-	<0.004
s14	334	04-Dec-90			-	0.3	1.3	<0.04	0.4	-	<0.004
s14	349	10-Dec-90			-	<0.04	0.4	0	0.3	-	<0.004
s14	364	17-Dec-90			-	0.4	1.4	0	0.4	-	<0.004
s14	835	12-Aug-91		15155.07	1.2	-	2.5	<0.01	2.0	-	9.0
s14	979	07-Oct-91		15155.22	0.6	-	8.6	0	3.0	-	7.0
s14	1087	18-Nov-91		15155.41	<0.01	-	<0.01	0	2.0	-	7.0
s14	1107	25-Nov-91		15155.51	<0.01	-	<0.01	0	1.0	-	2.0
s19	28	25-Jun-90			-	1.0	2.0	<0.01	0.7	<0.2	-
s19	38	02-Jul-90			-	0.2	0.3	<0.01	0.9	<0.2	-
s19	48	09-Jul-90			-	0.4	0.7	0	1.8	<0.2	-
s19	95	06-Aug-90			-	3.6	7.8	<0.01	1.1	-	<0.1
s19	136	27-Aug-90			-	1.4	3.1	<0.04	2.1	-	7.2
s19	171	17-Sep-90			-	0.3	0.6	<0.04	0.9	-	2.0
s19	199	01-Oct-90			-	0.5	1.0	<0.04	2.0	-	7.2
s19	214	08-Oct-90			-	0.3	0.7	<0.04	1.8	-	4.0
s19	229	15-Oct-90			-	0.1	2.5	<0.04	27.2	-	84.0
s19	244	22-Oct-90			-	0.1	0.2	<0.04	1.3	-	<0.004
s19	260	29-Oct-90			-	0.1	0.2	<0.04	1.1	-	<0.004
s19	276	05-Nov-90			-	0.1	0.4	<0.04	0.8	-	<0.004
s19	291	12-Nov-90			-	0.2	0.4	<0.04	0.6	-	<0.004
s19	306	19-Nov-90			-	0.1	0.3	0	0.6	-	<0.004
s19	321	26-Nov-90			-	0.1	0.2	<0.04	0.6	-	<0.004
s19	336	04-Dec-90			-	0.1	0.9	0	1.0	-	4.0
s19	351	10-Dec-90			-	<0.04	0.3	0	0.5	-	<0.004
s19	366	17-Dec-90			-	0.2	1.2	<0.04	0.6	-	<0.004
s19	1071	11-Nov-91		15155.32	<0.01	-	<0.01	<0.01	2.0	-	5.0
s19	1109	25-Nov-91		15155.53	<0.01	-	<0.01	<0.01	1.0	-	4.0
s18	17	18-Jun-90			-	0.2	1.3	<0.01	14.7	<0.2	-
s18	27	25-Jun-90			-	0.1	1.3	<0.01	13.2	<0.2	-
s18	37	02-Jul-90			-	0.2	1.3	<0.01	14.2	<0.2	-
s18	47	09-Jul-90			-	0.2	1.5	<0.01	12.4	<0.2	-
s18	57	16-Jul-90			-	0.3	1.9	<0.01	22.9	-	139.0
s18	68	23-Jul-90			-	0.2	5.3	<0.01	15.4	-	116.0
s18	83	30-Jul-90			-	0.4	2.2	<0.01	17.2	-	127.0
s18	94	06-Aug-90			-	0.9	3.5	<0.01	15.9	-	57.8
s18	109	13-Aug-90			-	0.4	1.1	<0.01	18.7	-	127.0
s18	120	20-Aug-90			-	0.4	0.5	0	16.4	-	127.0

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
s18	135	27-Aug-90			-	0.2	0.7	<0.04	15.6	-	105.0
s18	148	04-Sep-90			-	0.3	0.6	<0.04	17.7	-	130.0
s18	156	10-Sep-90			-	0.5	1.8	<0.04	44.0	-	194.0
s18	170	17-Sep-90			-	0.0	0.1	<0.04	6.0	-	31.2
s18	184	24-Sep-90			-	0.1	0.3	<0.04	15.4	-	254.0
s18	198	01-Oct-90			-	0.1	0.9	<0.04	21.9	-	84.8
s18	213	08-Oct-90			-	0.3	0.9	<0.04	23.5	-	116.0
s18	228	15-Oct-90			-	0.4	1.0	0	1.7	-	4.0
s18	243	22-Oct-90			-	0.1	0.4	<0.04	10.3	-	32.0
s18	259	29-Oct-90			-	0.1	0.7	<0.04	11.6	-	32.0
s18	275	05-Nov-90			-	0.1	0.8	<0.04	14.3	-	50.0
s18	290	12-Nov-90			-	0.1	0.5	<0.04	5.3	-	12.0
s18	305	19-Nov-90			-	0.1	0.6	<0.04	11.2	-	38.0
s18	320	26-Nov-90			-	0.2	0.4	<0.04	10.4	-	38.0
s18	335	04-Dec-90			-	0.3	1.4	<0.04	6.1	-	12.0
s18	350	10-Dec-90			-	<0.04	0.5	0	3.2	-	12.0
s18	365	17-Dec-90			-	0.2	1.8	<0.04	7.1	-	20.0
s18	836	12-Aug-91		15155.08	7.7	-	2.1	0	15.0	-	91.0
s18	890	03-Sep-91		15155.15	55.6	-	5.5	<0.01	26.0	-	110.0
s18	980	07-Oct-91		15155.23	5.6	-	<0.01	0	17.0	-	86.0
s18	1070	11-Nov-91		15155.31	<0.01	-	5.6	0	5.0	-	10.0
s18	1088	18-Nov-91		15155.42	4.2	-	<0.01	<0.01	20.0	-	100.0
s18	1108	25-Nov-91		15155.52	1.4	-	<0.01	0	24.0	-	59.0
gwn	15	18-Jun-90			-	0.2	7.2	0	13.9	<0.2	-
gwn	25	25-Jun-90			-	0.2	12.9	<0.01	22.0	<0.2	-
gwn	35	02-Jul-90			-	0.2	11.7	<0.01	23.3	<0.2	-
gwn	45	09-Jul-90			-	0.2	7.8	0	23.8	<0.2	-
gwn	55	16-Jul-90			-	0.4	13.8	<0.01	27.4	-	173.0
gwn	66	23-Jul-90			-	0.8	13.3	<0.01	23.4	-	162.0
gwn	81	30-Jul-90			-	0.4	14.2	<0.01	29.6	-	185.0
gwn	92	06-Aug-90			-	0.4	4.3	0	18.7	-	127.0
gwn	107	13-Aug-90			-	0.3	12.0	<0.01	24.6	-	162.0
gwn	118	20-Aug-90			-	0.4	11.3	<0.01	22.6	-	150.0
gwn	133	27-Aug-90			-	0.2	10.2	<0.04	19.2	-	174.0
gwn	168	17-Sep-90			-	0.4	5.1	<0.04	11.2	-	74.0
gwn	182	24-Sep-90			-	0.2	10.1	<0.04	20.7	-	168.0
gwn	196	01-Oct-90			-	0.2	2.8	<0.04	17.2	-	126.0
gwn	211	08-Oct-90			-	0.2	8.2	<0.04	20.5	-	152.0
gwn	226	15-Oct-90			-	0.2	10.2	<0.04	15.9	-	116.0
gwn	241	22-Oct-90			-	0.3	2.8	<0.04	18.3	-	116.0

Table C-3b. Cation Concentrations (Additional cations are listed in Table C-3a).
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	AuxID	Mn	Al	Fe	Pb	K	As	Na
gwn	257	29-Oct-90			-	0.1	2.0	0	16.7	-	104.0
gwn	273	05-Nov-90			-	0.2	6.8	0	18.8	-	128.0
gwn	288	12-Nov-90			-	0.2	0.9	0	13.5	-	92.0
gwn	303	19-Nov-90			-	0.2	2.0	0	15.8	-	112.0
gwn	318	26-Nov-90			-	0.3	4.2	<0.04	16.8	-	116.0
gwn	333	04-Dec-90			-	0.5	3.2	<0.04	10.8	-	72.0
gwn	348	10-Dec-90			-	<0.04	3.4	0	15.2	-	96.0
gwn	363	17-Dec-90			-	0.1	0.9	0	13.7	-	84.0
gwn	834	12-Aug-91		15155.06	12.4	-	4.2	0	22.0	-	110.0
gwn	888	03-Sep-91		15155.14	13.0	-	4.4	0	25.0	-	110.0
gwn	978	07-Oct-91		15155.21	12.3	-	<0.01	<0.01	22.0	-	120.0
gwn	1068	11-Nov-91		15155.30	8.4	-	<0.01	0	16.0	-	76.0
gwn	1086	18-Nov-91		15155.40	10.9	-	<0.01	0	19.0	-	111.0
gwn	1106	25-Nov-91		15155.50	7.8	-	<0.01	<0.01	13.0	-	74.0

Table C-4. Site Hydrological Characteristics,
Town of Fenton Landfill Leachate Treatment Demonstration

Loca-tion	Sample ID	Date	Comment	Inflow (l/day)	Inflow (gal/day)	Precip (in)
mh1	1	05-Jun-90		626	165	-
mh1	9	18-Jun-90		626	165	-
mh1	19	25-Jun-90		580	153	-
mh1	29	02-Jul-90		513	135	-
mh1	39	09-Jul-90		1411	373	-
mh1	49	16-Jul-90		1310	346	-
mh1	60	23-Jul-90		1202	318	0.44
mh1	75	30-Jul-90		709	187	0
mh1	86	06-Aug-90	Flooded	-	-	1.4
mh1	101	13-Aug-90		1289	341	0.5
mh1	112	20-Aug-90		1642	434	0.35
mh1	127	27-Aug-90		1142	302	0.04
mh1	142	04-Sep-90		619	164	0.2
mh1	150	10-Sep-90		749	198	0.44
mh1	162	17-Sep-90		634	167	0.68
mh1	176	24-Sep-90		360	95	0.34
mh1	190	01-Oct-90		439	116	1.2
mh1	205	08-Oct-90		922	243	0.56
mh1	220	15-Oct-90		529	140	2.35
mh1	235	22-Oct-90		677	179	1.45
mh1	251	29-Oct-90		812	215	3.15
mh1	267	05-Nov-90		768	203	0
mh1	282	12-Nov-90		752	199	2.9
mh1	297	19-Nov-90		781	206	0.2
mh1	312	26-Nov-90		796	210	0.35
mh1	327	04-Dec-90		-	-	1.6
mh1	342	10-Dec-90		1836	485	0.05
mh1	357	17-Dec-90		2880	761	0.75
mh1	372	02-Jan-91		817	216	3.25
mh1	387	07-Jan-91		778	205	0
mh1	400	14-Jan-91		598	158	0.9
mh1	410	21-Jan-91		310	82	1.25
mh1	421	28-Jan-91		547	145	0.2
mh1	432	04-Feb-91		940	248	0.6
mh1	446	11-Feb-91		554	146	0.5
mh1	457	18-Feb-91		698	185	0.6
mh1	470	25-Feb-91		324	86	0.75
mh1	481	06-Mar-91		0	0	1.75
mh1	492	11-Mar-91		1310	346	0
mh1	504	18-Mar-91		821	217	-
mh1	515	25-Mar-91		382	101	0.7

Table C-4. Site Hydrological Characteristics,
Town of Fenton Landfill Leachate Treatment Demonstration

Location	Sample ID	Date	Comment	Inflow (l/day)	Inflow (gal/day)	Precip (in)
mh1	527	02-Apr-91		792	209	0.9
mh1	545	08-Apr-91		904	239	0.25
mh1	563	15-Apr-91		864	228	0.8
mh1	578	23-Apr-91		817	216	2
mh1	593	29-Apr-91		842	223	0.4
mh1	604	13-May-91		904	239	1.3
mh1	622	20-May-91		1174	310	0.25
mh1	633	28-May-91		1692	447	0.4
mh1	651	03-Jun-91		1062	281	0.55
mh1	670	10-Jun-91		1040	275	0.9
mh1	688	17-Jun-91		644	170	0.95
mh1	706	24-Jun-91		1440	380	0
mh1	724	01-Jul-91		850	224	0
mh1	738	08-Jul-91		1019	269	0.55
mh1	756	15-Jul-91		511	135	0.4
mh1	774	22-Jul-91		490	129	0.3
mh1	792	29-Jul-91		522	138	0.8
mh1	810	05-Aug-91		216	57	0.7
mh1	828	12-Aug-91		0	0	1
mh1	846	19-Aug-91		554	146	0.8
mh1	864	26-Aug-91		0	0	0.8
mh1	882	02-Sep-91		0	0	0
mh1	900	09-Sep-91		94	25	0.13
mh1	918	16-Sep-91		94	25	0.6
mh1	936	23-Sep-91		0	0	1.3
mh1	954	30-Sep-91		122	32	0.75
mh1	972	07-Oct-91		266	70	0.6
mh1	990	14-Oct-91		288	76	0.6
mh1	1008	21-Oct-91		324	86	0.73
mh1	1026	28-Oct-91		396	105	0.23
mh1	1044	04-Nov-91		389	103	0
mh1	1062	11-Nov-91		3456	913	1.1
mh1	1080	18-Nov-91		2160	571	0.4
mh1	1098	25-Nov-91		3456	913	2.6

Table C-5. Daily Weather Data for Binghamton, NY.

	--- Binghamton, NY Airport Weather Data ---				
	Air temperature		Total	Snow	Snow on
	Max.	Min.	Precip.	Precip.	Ground
Date	(Degr F)	(Degr F)	(in. water)	(in.)	(in.)
01-Jun-90	73	48	0	0	0
02-Jun-90	77	58	0	0	0
03-Jun-90	79	62	0.04	0	0
04-Jun-90	63	42	0.05	0	0
05-Jun-90	63	39	0	0	0
06-Jun-90	73	48	-	0	0
07-Jun-90	72	55	-	0	0
08-Jun-90	64	48	0.15	0	0
09-Jun-90	74	61	0.02	0	0
10-Jun-90	67	55	0.05	0	0
11-Jun-90	60	50	0.01	0	0
12-Jun-90	74	45	0	0	0
13-Jun-90	76	51	0	0	0
14-Jun-90	79	61	0.36	0	0
15-Jun-90	78	60	0	0	0
16-Jun-90	81	61	0	0	0
17-Jun-90	83	65	0	0	0
18-Jun-90	77	63	0.57	0	0
19-Jun-90	73	57	-	0	0
20-Jun-90	74	56	0	0	0
21-Jun-90	77	59	0.02	0	0
22-Jun-90	79	58	0.22	0	0
23-Jun-90	74	60	0.13	0	0
24-Jun-90	66	56	-	0	0
25-Jun-90	64	54	-	0	0
26-Jun-90	77	53	0	0	0
27-Jun-90	75	61	-	0	0
28-Jun-90	74	57	0	0	0
29-Jun-90	82	57	0.49	0	0
30-Jun-90	74	58	0.39	0	0
01-Jul-90	67	55	-	0	0
02-Jul-90	75	54	0	0	0
03-Jul-90	78	55	0	0	0
04-Jul-90	91	63	0	0	0
05-Jul-90	81	60	0.02	0	0
06-Jul-90	66	52	0.33	0	0
07-Jul-90	72	47	0	0	0
08-Jul-90	72	52	0	0	0
09-Jul-90	80	66	0.4	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
10-Jul-90	77	60	0	0	0
11-Jul-90	66	56	0.02	0	0
12-Jul-90	57	53	1.21	0	0
13-Jul-90	73	54	0	0	0
14-Jul-90	75	57	-	0	0
15-Jul-90	77	67	0.11	0	0
16-Jul-90	76	63	0.02	0	0
17-Jul-90	82	62	0	0	0
18-Jul-90	83	65	0	0	0
19-Jul-90	82	65	0.01	0	0
20-Jul-90	83	66	0.27	0	0
21-Jul-90	80	65	0	0	0
22-Jul-90	82	61	0.11	0	0
23-Jul-90	74	61	0.34	0	0
24-Jul-90	76	60	0	0	0
25-Jul-90	78	55	0	0	0
26-Jul-90	80	57	0	0	0
27-Jul-90	84	61	0	0	0
28-Jul-90	84	62	0	0	0
29-Jul-90	83	61	0	0	0
30-Jul-90	83	62	0	0	0
31-Jul-90	68	57	0.23	0	0
01-Aug-90	72	53	0	0	0
02-Aug-90	77	52	0	0	0
03-Aug-90	82	60	0	0	0
04-Aug-90	83	60	0	0	0
05-Aug-90	71	60	1.29	0	0
06-Aug-90	71	62	0.43	0	0
07-Aug-90	73	60	0	0	0
08-Aug-90	75	59	0.05	0	0
09-Aug-90	71	55	0.04	0	0
10-Aug-90	67	59	0.22	0	0
11-Aug-90	78	62	0	0	0
12-Aug-90	80	57	0	0	0
13-Aug-90	81	61	0.33	0	0
14-Aug-90	73	57	0	0	0
15-Aug-90	75	53	0	0	0
16-Aug-90	79	58	-	0	0
17-Aug-90	82	62	0	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
18-Aug-90	83	66	0.06	0	0
19-Aug-90	69	54	0.07	0	0
20-Aug-90	58	53	0.07	0	0
21-Aug-90	60	54	0.43	0	0
22-Aug-90	69	58	0.07	0	0
23-Aug-90	63	59	0.41	0	0
24-Aug-90	76	61	-	0	0
25-Aug-90	80	62	0	0	0
26-Aug-90	79	61	0	0	0
27-Aug-90	80	62	0.44	0	0
28-Aug-90	79	63	1.66	0	0
29-Aug-90	73	61	0	0	0
30-Aug-90	74	56	0	0	0
31-Aug-90	76	49	0	0	0
01-Sep-90	77	54	-	0	0
02-Sep-90	78	61	0.17	0	0
03-Sep-90	67	52	0	0	0
04-Sep-90	72	47	0	0	0
05-Sep-90	71	59	0.1	0	0
06-Sep-90	74	62	0	0	0
07-Sep-90	70	51	0.07	0	0
08-Sep-90	67	43	0	0	0
09-Sep-90	56	47	0.41	0	0
10-Sep-90	73	56	0.01	0	0
11-Sep-90	75	61	0	0	0
12-Sep-90	77	63	0	0	0
13-Sep-90	80	54	0	0	0
14-Sep-90	73	60	0	0	0
15-Sep-90	67	52	0.38	0	0
16-Sep-90	58	44	0.03	0	0
17-Sep-90	50	38	-	0	0
18-Sep-90	57	35	0	0	0
19-Sep-90	52	39	0.24	0	0
20-Sep-90	59	46	0	0	0
21-Sep-90	64	43	0	0	0
22-Sep-90	61	49	0.13	0	0
23-Sep-90	54	43	0.01	0	0
24-Sep-90	58	42	0	0	0
25-Sep-90	62	44	0	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
26-Sep-90	59	50	0.4	0	0
27-Sep-90	62	47	-	0	0
28-Sep-90	71	46	0	0	0
29-Sep-90	73	55	0.72	0	0
30-Sep-90	67	48	0.16	0	0
01-Oct-90	57	43	0	0	0
02-Oct-90	55	44	-	0	0
03-Oct-90	65	42	0	0	0
04-Oct-90	63	48	0.56	0	0
05-Oct-90	69	46	-	0	0
06-Oct-90	77	57	0	0	0
07-Oct-90	76	59	0	0	0
08-Oct-90	67	53	-	0	0
09-Oct-90	71	52	0.21	0	0
10-Oct-90	76	52	0	0	0
11-Oct-90	67	47	0.65	0	0
12-Oct-90	72	47	0.26	0	0
13-Oct-90	69	56	1.57	0	0
14-Oct-90	58	52	0	0	0
15-Oct-90	61	46	0	0	0
16-Oct-90	57	40	0	0	0
17-Oct-90	68	44	0	0	0
18-Oct-90	68	42	0.85	0	0
19-Oct-90	45	37	0.01	-	0
20-Oct-90	56	32	0	0	0
21-Oct-90	57	40	0	0	0
22-Oct-90	59	48	0.02	0	0
23-Oct-90	57	45	2.94	0	0
24-Oct-90	52	42	-	0	0
25-Oct-90	53	35	-	0	0
26-Oct-90	39	29	-	0	0
27-Oct-90	49	25	0	0	0
28-Oct-90	47	33	0.12	0.2	0
29-Oct-90	39	30	-	0.1	-
30-Oct-90	56	27	0	0	0
31-Oct-90	58	39	0	0	0
01-Nov-90	63	39	0	0	0
02-Nov-90	68	51	0	0	0
03-Nov-90	69	52	0	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
04-Nov-90	64	44	-	0	0
05-Nov-90	59	41	0.03	0	0
06-Nov-90	54	35	0.6	0.1	0
07-Nov-90	39	31	0.09	-	0
08-Nov-90	35	26	0.02	0.4	-
09-Nov-90	40	21	0.24	0.2	0
10-Nov-90	39	34	1.46	-	0
11-Nov-90	37	28	0.06	1.6	-
12-Nov-90	33	24	0.06	3.3	2
13-Nov-90	30	22	0.01	1	4
14-Nov-90	39	24	0	0	2
15-Nov-90	64	37	0	0	-
16-Nov-90	65	47	0.02	0	0
17-Nov-90	50	28	0.2	-	0
18-Nov-90	33	21	0	0	0
19-Nov-90	32	19	0	0	0
20-Nov-90	41	26	0	0	0
21-Nov-90	48	31	0	0	0
22-Nov-90	51	38	0.22	0	0
23-Nov-90	47	39	0.17	0	0
24-Nov-90	40	30	0.01	0.2	0
25-Nov-90	54	33	0	0	-
26-Nov-90	45	28	0	0	0
27-Nov-90	54	40	-	0	0
28-Nov-90	70	48	0.01	0	0
29-Nov-90	48	29	-	0.2	0
30-Nov-90	37	27	-	0.2	-
01-Dec-90	47	29	0	0	0
02-Dec-90	45	27	0	0	0
03-Dec-90	45	27	0.77	3.4	0
04-Dec-90	50	25	0.69	0.2	0
05-Dec-90	28	20	-	1.1	-
06-Dec-90	34	23	0	0	-
07-Dec-90	35	30	0	0	0
08-Dec-90	42	27	-	-	0
09-Dec-90	41	31	0	0	0
10-Dec-90	42	24	0	0	0
11-Dec-90	27	18	-	0.1	0
12-Dec-90	47	25	0	0	-

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
13-Dec-90	50	25	0.03	0.3	0
14-Dec-90	28	14	0.01	0.3	1
15-Dec-90	36	21	0.37	1.6	-
16-Dec-90	37	29	0.19	0.2	1
17-Dec-90	36	28	-	-	-
18-Dec-90	40	34	0.9	0	-
19-Dec-90	40	29	-	-	0
20-Dec-90	38	20	0	0	0
21-Dec-90	52	36	0.28	0	0
22-Dec-90	55	50	-	0	0
23-Dec-90	59	34	0.53	0	0
24-Dec-90	35	13	0.24	0.4	-
25-Dec-90	24	10	0	0	-
26-Dec-90	24	10	-	0.4	0
27-Dec-90	20	8	0.05	0.5	-
28-Dec-90	31	17	0.51	5.2	5
29-Dec-90	46	31	0.02	0	4
30-Dec-90	53	33	0.59	-	0
31-Dec-90	33	14	0.04	0.8	1
01-Jan-91	31	14	-	-	1
02-Jan-91	36	23	0	0	-
03-Jan-91	29	20	-	-	-
04-Jan-91	27	13	-	-	-
05-Jan-91	31	16	0.01	0.4	0
06-Jan-91	32	26	0.02	0.1	0
07-Jan-91	27	7	-	-	-
08-Jan-91	24	2	-	-	-
09-Jan-91	33	20	0.13	1.7	2
10-Jan-91	31	12	-	-	1
11-Jan-91	22	11	0.62	6.2	1
12-Jan-91	33	22	0.07	-	6
13-Jan-91	22	12	-	0.5	5
14-Jan-91	31	11	0.01	0.3	5
15-Jan-91	44	31	0	0	5
16-Jan-91	40	34	0.91	0	3
17-Jan-91	39	29	0.05	0.2	2
18-Jan-91	32	24	-	0.7	1
19-Jan-91	40	27	-	-	1
20-Jan-91	38	27	0.03	0.4	-

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
21-Jan-91	28	2	0.08	1	1
22-Jan-91	10	-3	-	0.1	1
23-Jan-91	26	4	-	-	1
24-Jan-91	27	9	0.03	0.8	1
25-Jan-91	15	2	-	0.1	2
26-Jan-91	23	6	-	0.6	2
27-Jan-91	33	15	-	-	3
28-Jan-91	37	28	0.01	0.3	3
29-Jan-91	39	24	0	0	2
30-Jan-91	39	24	0.1	0.5	2
31-Jan-91	24	14	0.04	1.1	2
01-Feb-91	23	13	-	0.4	3
02-Feb-91	45	19	0	0	3
03-Feb-91	53	32	0	0	2
04-Feb-91	55	35	0	0	-
05-Feb-91	55	40	0	0	0
06-Feb-91	41	35	0.17	0	0
07-Feb-91	39	33	0.21	0	0
08-Feb-91	39	32	0	0	0
09-Feb-91	42	27	0	0	0
10-Feb-91	33	19	-	-	0
11-Feb-91	22	11	0.01	0.8	-
12-Feb-91	19	0	0.01	0.4	1
13-Feb-91	31	18	0.39	3.3	1
14-Feb-91	36	27	0.46	2.5	6
15-Feb-91	31	3	0.02	1.8	5
16-Feb-91	18	2	0.01	0.6	3
17-Feb-91	29	13	0.06	3.1	5
18-Feb-91	32	25	0.16	-	4
19-Feb-91	46	32	0.29	0	3
20-Feb-91	47	27	0.19	-	0
21-Feb-91	47	25	-	-	0
22-Feb-91	45	21	0.01	0.4	0
23-Feb-91	21	6	-	0.3	1
24-Feb-91	35	11	-	0.2	-
25-Feb-91	32	24	-	-	0
26-Feb-91	32	19	-	0.2	-
27-Feb-91	26	15	-	-	-
28-Feb-91	35	18	0.14	2.1	-

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
01-Mar-91	57	33	0	0	2
02-Mar-91	63	48	0.53	0	0
03-Mar-91	56	45	0.61	0	0
04-Mar-91	47	28	0.35	-	0
05-Mar-91	40	25	-	-	-
06-Mar-91	55	29	0.06	0	0
07-Mar-91	44	22	-	-	0
08-Mar-91	27	17	-	0.2	-
09-Mar-91	35	17	0	0	0
10-Mar-91	31	19	0	0	0
11-Mar-91	23	13	-	-	0
12-Mar-91	34	16	-	-	-
13-Mar-91	42	20	0	0	0
14-Mar-91	32	28	0.22	5.9	-
15-Mar-91	36	29	0.21	1.8	6
16-Mar-91	44	24	0	0	6
17-Mar-91	50	27	0	0	2
18-Mar-91	41	33	0.24	0.3	-
19-Mar-91	48	33	0.01	0.1	-
20-Mar-91	43	30	-	-	0
21-Mar-91	50	27	-	0	0
22-Mar-91	44	34	0.23	0	0
23-Mar-91	36	31	0.28	0	0
24-Mar-91	46	34	0.21	-	0
25-Mar-91	40	35	0.02	-	0
26-Mar-91	50	33	0	0	0
27-Mar-91	54	41	0.43	0	0
28-Mar-91	61	38	0	0	0
29-Mar-91	47	27	0	0	0
30-Mar-91	34	21	0.02	1.6	2
31-Mar-91	44	18	0	0	0
01-Apr-91	39	30	0.16	1.4	-
02-Apr-91	39	30	-	0.2	-
03-Apr-91	49	27	0	0	0
04-Apr-91	65	34	0	0	0
05-Apr-91	60	47	0.07	0	0
06-Apr-91	72	44	0.05	0	0
07-Apr-91	83	55	0	0	0
08-Apr-91	80	60	0.39	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
09-Apr-91	75	60	0.6	-	0
10-Apr-91	61	33	0.01	-	0
11-Apr-91	44	31	-	-	0
12-Apr-91	46	28	0	0	0
13-Apr-91	48	34	0.02	0.1	0
14-Apr-91	56	33	0.13	0	0
15-Apr-91	48	34	0.22	0	0
16-Apr-91	62	45	-	0	0
17-Apr-91	58	36	-	0	0
18-Apr-91	51	35	0	0	0
19-Apr-91	59	36	-	0	0
20-Apr-91	44	36	0.58	0	0
21-Apr-91	41	33	1	0.3	0
22-Apr-91	41	31	0.24	2	2
23-Apr-91	61	37	0	0	0
24-Apr-91	61	43	0.33	0	0
25-Apr-91	63	41	0	0	0
26-Apr-91	70	41	-	0	0
27-Apr-91	73	53	-	0	0
28-Apr-91	69	51	0	0	0
29-Apr-91	59	45	-	0	0
30-Apr-91	75	53	0.42	0	0
01-May-91	76	46	0.34	0	0
02-May-91	51	41	0.02	-	0
03-May-91	47	37	-	0	0
04-May-91	58	35	0	0	0
05-May-91	70	37	-	0	0
06-May-91	63	45	0.84	0	0
07-May-91	54	44	-	0	0
08-May-91	59	42	0	0	0
09-May-91	53	42	0.04	0	0
10-May-91	67	49	0.08	0	0
11-May-91	74	46	0	0	0
12-May-91	80	56	0	0	0
13-May-91	81	58	0	0	0
14-May-91	78	61	0.06	0	0
15-May-91	77	54	0	0	0
16-May-91	82	53	0	0	0
17-May-91	80	45	0.16	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
18-May-91	61	42	0	0	0
19-May-91	67	38	0	0	0
20-May-91	71	44	0	0	0
21-May-91	78	50	0	0	0
22-May-91	80	58	0	0	0
23-May-91	85	57	0	0	0
24-May-91	83	61	0.24	0	0
25-May-91	82	65	0	0	0
26-May-91	80	62	0	0	0
27-May-91	83	66	0.02	0	0
28-May-91	81	61	0	0	0
29-May-91	82	56	0	0	0
30-May-91	82	63	0.05	0	0
31-May-91	82	66	0.05	0	0
01-Jun-91	72	56	0	0	0
02-Jun-91	74	52	0	0	0
03-Jun-91	76	52	0.68	0	0
04-Jun-91	64	49	0.24	0	0
05-Jun-91	64	47	0.02	0	0
06-Jun-91	67	45	0	0	0
07-Jun-91	75	46	0	0	0
08-Jun-91	78	52	0	0	0
09-Jun-91	79	58	0	0	0
10-Jun-91	84	55	0	0	0
11-Jun-91	78	61	0.8	0	0
12-Jun-91	74	48	0.62	0	0
13-Jun-91	63	43	0	0	0
14-Jun-91	77	44	0	0	0
15-Jun-91	87	59	-	0	0
16-Jun-91	80	68	-	0	0
17-Jun-91	71	61	0	0	0
18-Jun-91	78	62	0	0	0
19-Jun-91	81	60	0	0	0
20-Jun-91	84	63	0	0	0
21-Jun-91	82	62	0	0	0
22-Jun-91	76	57	-	0	0
23-Jun-91	74	55	-	0	0
24-Jun-91	78	51	0	0	0
25-Jun-91	82	54	0	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
26-Jun-91	84	61	0	0	0
27-Jun-91	89	63	0	0	0
28-Jun-91	92	65	0	0	0
29-Jun-91	85	69	0	0	0
30-Jun-91	74	58	-	0	0
01-Jul-91	76	54	0	0	0
02-Jul-91	69	58	0.21	0	0
03-Jul-91	74	61	-	0	0
04-Jul-91	74	61	-	0	0
05-Jul-91	67	58	0.3	0	0
06-Jul-91	86	62	0.01	0	0
07-Jul-91	82	64	0.15	0	0
08-Jul-91	83	63	0	0	0
09-Jul-91	75	57	0	0	0
10-Jul-91	80	53	0	0	0
11-Jul-91	78	56	0	0	0
12-Jul-91	83	51	0	0	0
13-Jul-91	70	62	0.35	0	0
14-Jul-91	77	60	0.01	0	0
15-Jul-91	80	54	0	0	0
16-Jul-91	87	54	0	0	0
17-Jul-91	91	60	0	0	0
18-Jul-91	90	67	0.01	0	0
19-Jul-91	91	67	0.08	0	0
20-Jul-91	93	67	0	0	0
21-Jul-91	89	71	0.32	0	0
22-Jul-91	85	66	0.03	0	0
23-Jul-91	86	65	0.02	0	0
24-Jul-91	82	59	0	0	0
25-Jul-91	86	61	0	0	0
26-Jul-91	72	58	0.46	0	0
27-Jul-91	76	53	0	0	0
28-Jul-91	78	52	0	0	0
29-Jul-91	80	59	0	0	0
30-Jul-91	76	56	0.01	0	0
31-Jul-91	80	62	-	0	0
01-Aug-91	88	60	0.04	0	0
02-Aug-91	85	60	0	0	0
03-Aug-91	76	61	0.23	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
04-Aug-91	78	60	0.01	0	0
05-Aug-91	73	56	0.02	0	0
06-Aug-91	72	52	0	0	0
07-Aug-91	82	53	0	0	0
08-Aug-91	82	57	0.05	0	0
09-Aug-91	70	61	1.46	0	0
10-Aug-91	78	59	0.12	0	0
11-Aug-91	72	57	-	0	0
12-Aug-91	79	58	0.01	0	0
13-Aug-91	84	60	0	0	0
14-Aug-91	83	60	0	0	0
15-Aug-91	77	62	0.3	0	0
16-Aug-91	85	60	0.16	0	0
17-Aug-91	85	62	0	0	0
18-Aug-91	78	65	0.29	0	0
19-Aug-91	73	59	-	0	0
20-Aug-91	65	57	1.09	0	0
21-Aug-91	75	62	0	0	0
22-Aug-91	79	57	0	0	0
23-Aug-91	79	61	-	0	0
24-Aug-91	76	58	0	0	0
25-Aug-91	73	55	0	0	0
26-Aug-91	80	57	0	0	0
27-Aug-91	85	62	0	0	0
28-Aug-91	87	66	0	0	0
29-Aug-91	86	66	0	0	0
30-Aug-91	89	67	0	0	0
31-Aug-91	75	51	0	0	0
01-Sep-91	66	43	0	0	0
02-Sep-91	73	44	0	0	0
03-Sep-91	79	51	0	0	0
04-Sep-91	69	60	0.11	0	0
05-Sep-91	73	53	0	0	0
06-Sep-91	77	50	0	0	0
07-Sep-91	80	53	0	0	0
08-Sep-91	82	58	0	0	0
09-Sep-91	84	56	0	0	0
10-Sep-91	79	66	0.34	0	0
11-Sep-91	66	50	0.01	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
12-Sep-91	70	47	0	0	0
13-Sep-91	77	46	0	0	0
14-Sep-91	78	56	0	0	0
15-Sep-91	75	62	0.22	0	0
16-Sep-91	90	68	0	0	0
17-Sep-91	81	59	0.26	0	0
18-Sep-91	78	55	0.03	0	0
19-Sep-91	67	45	1.02	0	0
20-Sep-91	56	42	-	0	0
21-Sep-91	55	40	0	0	0
22-Sep-91	65	35	0	0	0
23-Sep-91	60	49	0.03	0	0
24-Sep-91	62	42	0.24	0	0
25-Sep-91	55	47	0.31	0	0
26-Sep-91	61	42	0.04	0	0
27-Sep-91	54	37	-	0	0
28-Sep-91	53	33	0	0	0
29-Sep-91	61	35	0	0	0
30-Sep-91	61	29	0	0	0
01-Oct-91	72	51	-	0	0
02-Oct-91	77	60	0	0	0
03-Oct-91	76	55	0.01	0	0
04-Oct-91	71	50	0.05	0	0
05-Oct-91	75	54	0.02	0	0
06-Oct-91	58	38	0.21	0	0
07-Oct-91	50	35	-	-	0
08-Oct-91	59	34	0	0	0
09-Oct-91	67	46	0	0	0
10-Oct-91	69	43	0.1	0	0
11-Oct-91	53	37	0.2	0	0
12-Oct-91	45	32	-	0	0
13-Oct-91	49	34	0.05	-	0
14-Oct-91	51	29	0	0	0
15-Oct-91	59	42	0.53	0	0
16-Oct-91	50	35	0.02	0	0
17-Oct-91	56	33	0.18	0	0
18-Oct-91	67	42	-	0	0
19-Oct-91	53	36	0.02	0	0
20-Oct-91	45	33	-	-	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
21-Oct-91	51	34	0	0	0
22-Oct-91	65	39	0	0	0
23-Oct-91	72	48	0	0	0
24-Oct-91	67	52	0	0	0
25-Oct-91	71	53	0	0	0
26-Oct-91	73	57	0	0	0
27-Oct-91	73	51	0.26	0	0
28-Oct-91	52	35	-	0	0
29-Oct-91	54	29	0	0	0
30-Oct-91	62	30	0	0	0
31-Oct-91	59	38	0	0	0
01-Nov-91	66	44	0		0
02-Nov-91	57	36	-		0
03-Nov-91	44	27	0		0
04-Nov-91	35	21	0		0
05-Nov-91	36	19	0		0
06-Nov-91	43	25	0	0	0
07-Nov-91	35	30	0.04	0.4	0
08-Nov-91	34	23	-	-	-
09-Nov-91	35	19	0	0	0
10-Nov-91	44	23	0.31	0	0
11-Nov-91	35	30	1.17	0.8	-
12-Nov-91	34	31	0.01	-	-
13-Nov-91	37	33	0.01	0.1	-
14-Nov-91	52	35	-	0	0
15-Nov-91	53	37	0.17	0	0
16-Nov-91	52	30	0.01	-	0
17-Nov-91	36	22	0	0	0
18-Nov-91	49	22	0	0	0
19-Nov-91	70	42	-	0	0
20-Nov-91	73	57	-	0	0
21-Nov-91	64	44	0.72	0	0
22-Nov-91	49	45	1.75	0	0
23-Nov-91	49	44	0.01	0	0
24-Nov-91	50	30	0.2	-	0
25-Nov-91	31	26	0.02	0.3	0
26-Nov-91	31	22	0.04	2.3	1
27-Nov-91	34	23	0	0	1
28-Nov-91	47	32	0.01	0	0

Table C-5. Daily Weather Data for Binghamton, NY.

--- Binghamton, NY Airport Weather Data ---

Date	Air temperature Max. (Degr F)	Air temperature Min. (Degr F)	Total Precip. (in. water)	Snow Precip. (in.)	Snow on Ground (in.)
29-Nov-91	53	40	0.02	0	0
30-Nov-91	60	49	0.01	0	0

Source: Northeast Regional Climate Center, Cornell University, Ithaca, NY.
Data are from the Binghamton WSO AP 30-0687 weather station.

Table C–6. Contaminant Concentrations in Leachate (MH–1)
(all concentrations in mg/l unless otherwise noted)

Parameter	January 16, 1991	April 9, 1991	July 7, 1991	October 29, 1991	Minumum	Maximum	Parameter
pH	6.31	7.74	7.91	8.13	6.31	8.13	pH
Alkalinity	1560	1100	1730	1260	1100	1730	Alkalinity
Total Solids	–	–	–	–	–	–	Total Solids
TDS	1720	458	828	1870	458	1870	TDS
TSS	–	–	–	–	–	–	TSS
Spec. Conductance	4000	2900	3770	3480	2900	4000	Spec. Conductance
BOD	–	39	–	–	39	39	BOD
COD	369	257	497	341	257	497	COD
TOC	1130	73.5	90.5	106	73.5	1130	TOC
Hardness	813	503	815	643	503	815	Hardness
Chlorides	33.0	268	498	411	33	498	Chlorides
Florides	–	–	–	–	–	–	Florides
Sulfates	ND<5.0	7.3	11	ND<5.0	0	11	Sulfates
Sulfide	–	–	–	–	–	–	Sulfide
Total K–Nitrogen	–	95.1	–	–	95.1	95.1	Total K–Nitrogen
NH3–Nitrogen	109	0.46	92.1	66	0.46	109	NH3–Nitrogen
Organic Nitrogen	–	–	–	–	–	–	Organic Nitrogen
NO3–Nitrogen	ND<0.05	92.5	1.72	0.73	0.00	92.50	NO3–Nitrogen
Total Phosphorous	–	–	–	–	–	–	Total Phosphorous
Ortho–Phosphorus	–	–	–	–	–	–	Ortho–Phosphorus
Aluminum	–	0.345	–	–	0.345	0.345	Aluminum
Arsenic	–	0.002	–	0.004	0.002	0.004	Arsenic
Barium	–	0.136	–	–	0.136	0.136	Barium
Beryllium	–	ND<0.002	–	–	–	–	Beryllium
Boron	–	1.45	–	–	1.45	1.45	Boron
Cadmium	0.005	ND<0.002	ND<0.002	ND<0.002	0	0.005	Cadmium
Calcium	164	115	134	119	115	164	Calcium
Total Chromium	–	0.016	–	–	0.016	0.016	Total Chromium
Copper	–	0.004	–	–	0.004	0.004	Copper
Cyanide	–	ND<0.20	–	–	0	0	Cyanide
Iron	34.3	14.2	23.9	5.4	5.4	34.3	Iron
Lead	ND<0.005	ND<0.005	0.022	0.02	0	0.022	Lead
Magnesium	77.1	65.1	109	83.9	65.1	109	Magnesium
Manganese	3.93	1.07	1.25	0.883	0.883	3.93	Manganese
Mercury	–	ND<0.002	–	–	–	–	Mercury
Molybdenum	–	–	–	–	–	–	Molybdenum
Nickel	–	0.029	–	–	0.029	0.029	Nickel
Potassium	165	152	256	191	152	256	Potassium
Sodium	282	264	455	321	264	455	Sodium
Titanium	–	–	–	–	–	–	Titanium
Vanadium	–	–	–	–	–	–	Vanadium
Zinc	–	0.074	–	–	0.074	0.074	Zinc
Phenols, Total	0.074	0.012	0.054	0.092	0.012	0.092	Phenols, Total
Benzene	–	ND<1	ND<1	–	0	0	Benzene

Table C-6. Contaminant Concentrations in Leachate (MH-1)
(all concentrations in mg/l unless otherwise noted)

Parameter	January 16, 1991	April 9, 1991	July 7, 1991	October 29, 1991	Minumum	Maximum	Parameter
Dissolved Metals:							Dissolved Metals:
Aluminum	–	ND<0.029	–	–	0	0	Aluminum
Arsenic	–	0.002	–	ND<0.002	0	0.002	Arsenic
Barium	–	0.071	–	–	0.071	0.071	Barium
Beryllium	–	ND<0.002	–	–	–	–	Beryllium
Boron	–	1.4	–	–	1.4	1.4	Boron
Cadmium	ND<0.003	ND<0.002	ND<0.002	ND<0.002	0	0	Cadmium
Calcium	160	88.2	91.1	52.1	52.1	160	Calcium
Total Chromium	–	0.01	–	–	0.01	0.01	Total Chromium
Copper	–	0.004	–	–	0.004	0.004	Copper
Cyanide	–	–	–	–	–	–	Cyanide
Iron	1.9	0.159	1.19	0.895	0.159	1.9	Iron
Lead	ND<0.005	ND<0.005	ND<0.005	ND<0.005	0	0	Lead
Magnesium	78.2	61.8	114	84.2	61.8	114	Magnesium
Manganese	3.7	0.728	0.489	0.106	0.106	3.7	Manganese
Mercury	–	ND<0.002	–	–	–	–	Mercury
Molybdenum	–	–	–	–	–	–	Molybdenum
Nickel	–	0.031	–	–	0.031	0.031	Nickel
Potassium	165	145	282	198	145	282	Potassium
Sodium	283	255	478	348	255	478	Sodium
Titanium	–	–	–	–	–	–	Titanium
Vanadium	–	–	–	–	–	–	Vanadium
Zinc	–	0.007	–	–	0.007	0.007	Zinc

All concentrations in mg/l except pH (std units and Sp. Cond. (umhos/cm
ND = Not Detected

References: FLI Environmental Services. January 1991. Report, Quarterly Analylsis of Monitoring Wells at Town of Fenton Landfill. FLI. Waverly, New York.

FLI Environmental Services. April 1991. Report, Baseline Analylsis of Monitoring Wells at Town of Fenton Landfill. FLI. Waverly, New York.

FLI Environmental Services. July 1991. Report, Routine Analylsis of Monitoring Wells at Town of Fenton Landfill. FLI. Waverly, New York.

FLI Environmental Services. October 1991. Report, Routine Analylsis of Monitoring Wells at Town of Fenton Landfill. FLI. Waverly, New York.

Table C–7. Summary of Contaminant Concentrations in Post–treatment Leachate (MH–4)
(all concentrations in mg/l unless otherwise noted)

Parameter	January 16, 1991	April 9, 1991	July 7, 1991	October 29, 1991	Minumum	Maximum	SPDES Permit	Parameter
pH	7.76	7.76	8.57	8.55	7.76	8.57	6.0–9.0	pH
Alkalinity	484	512	346	292	292	512	–	Alkalinity
Total Solids	–	–	–	–	–	–	–	Total Solids
TDS	656	795	828	661	656	828	Monitor	TDS
TSS	–	–	–	–	–	–	10	TSS
Spec. Conductance	1500	1335	1375	1082	0	1500	–	Spec. Conductance
BOD	–	11	–	–	11	11	Monitor	BOD
COD	108	105	99	31.8	31.8	108	–	COD
TOC	1500	41.3	21.7	18.3	18.3	1500	–	TOC
Hardness	316	349	170	228	170	349	–	Hardness
Chlorides	122	139	201	159	122	201	–	Chlorides
Florides	–	–	–	–	–	–	–	Florides
Sulfates	ND<05.0	10	11	8.2	0	11	–	Sulfates
Sulfide	–	–	–	–	–	–	–	Sulfide
Total K–Nitrogen	–	27.7	–	–	27.7	27.7	Monitor	Total K–Nitrogen
NH3–Nitrogen	21.2	21.4	0.33	0.1	0.1	21.4	Monitor	NH3–Nitrogen
Organic Nitrogen	–	–	–	–	–	–	–	Organic Nitrogen
NO3–Nitrogen	0.8	8.17	3.69	0.06	0.06	8.17	–	NO3–Nitrogen
Total Phosphorous	–	–	–	–	–	–	–	Total Phosphorous
Ortho–Phosphorus	–	–	–	–	–	–	–	Ortho–Phosphorus
Aluminum	–	0.044	–	–	0.044	0.044	0.25	Aluminum
Arsenic	–	0.003	–	ND<0.002	0.000	0.003	–	Arsenic
Barium	–	0.208	–	–	0.208	0.208	1.0	Barium
Beryllium	–	ND<0.002	–	–	–	–	–	Beryllium
Boron	–	0.452	–	–	0.452	0.452	2.0	Boron
Cadmium	ND<0.003	ND<0.005	ND<0.002	0.002	0	0.002	–	Cadmium
Calcium	55.1	78.4	36.6	57.4	36.6	78.4	–	Calcium
Total Chromium	–	0.007	–	–	0.007	0.007	–	Total Chromium
Copper	–	0.008	–	–	0.007	0.008	–	Copper
Cyanide	–	ND<0.020	–	–	0	0	–	Cyanide
Iron	3.43	0.39	1.66	0.489	0.39	3.43	0.3	Iron
Lead	0.008	ND<0.002	0.011	0.05	0	3.43	–	Lead
Magnesium	30.6	31.6	19.9	20.6	19.9	31.6	–	Magnesium
Manganese	2.41	1.51	0.527	0.182	0.182	2.41	2.0	Manganese
Mercury	–	ND<0.002	–	–	0	0	–	Mercury
Molybdenum	–	–	–	–	–	–	–	Molybdenum
Nickel	–	0.026	–	–	0.026	0.026	0.13	Nickel
Potassium	55.9	61.3	88	29.6	29.6	88	–	Potassium
Silver	–	0.017	–	–	0.017	0.017	0.004	Silver
Sodium	99.2	125	202	126	99.2	202	–	Sodium
Titanium	–	–	–	–	–	–	–	Titanium
Vanadium	–	–	–	–	–	–	–	Vanadium
Zinc	–	0.006	–	–	0.006	0.006	–	Zinc
Phenols, Total	0.044	0.004	0.008	0.031	0.004	0.044	0.005	Phenols, Total
Benzene	–	ND<1	ND<1	–	0	0	0.006	Benzene
Bis(2 Ethylhexyl) Phathalate	–	–	–	–	–	–	3.0	Bis(2 Ethylhexyl) Phathalate

Table C-7. Summary of Contaminant Concentrations in Post-treatment Leachate (MH-4)
(all concentrations in mg/l unless otherwise noted)

Parameter	January 16, 1991	April 9, 1991	July 7, 1991	October 29, 1991	Minumum	Maximum	SPDES Permit	Parameter
Dissolved Metals:								Dissolved Metals:
Aluminum	–	ND<0.029	–	–	0	0	0.25	Aluminum
Arsenic	–	ND<0.002	–	ND<0.002	0	0	–	Arsenic
Barium	–	0.184	–	–	0.184	0.184	–	Barium
Beryllium	–	ND<0.002	–	–	–	–	–	Beryllium
Boron	–	0.473	–	–	0.473	0.473	2.0	Boron
Cadmium	ND<0.003	ND<0.002	ND<0.002	ND<0.002	0	0	–	Cadmium
Calcium	57.6	74.9	30.6	57.3	30.6	74.9	–	Calcium
Total Chromium	–	0.006	–	–	0.006	0.006	–	Total Chromium
Copper	–	0.008	–	–	0.008	0.008	–	Copper
Cyanide	–	–	–	–	–	–	–	Cyanide
Iron	0.727	ND<0.015	ND<0.015	ND<0.015	0	0.727	0.3	Iron
Lead	ND<0.005	ND<0.005	0.006	ND<0.005	0	0.006	–	Lead
Magnesium	32.9	30.6	19.1	20.5	19.1	32.9	–	Magnesium
Manganese	1.54	1.13	0.008	0.008	0.008	1.54	2.0	Manganese
Mercury	–	ND<0.002	–	–	–	–	–	Mercury
Molybdenum	–	–	–	–	–	–	–	Molybdenum
Nickel	–	0.021	–	–	0.021	0.021	0.13	Nickel
Potassium	62.4	60.3	82.1	28.8	28.8	82.1	–	Potassium
Silver	–	ND<0.003	–	–	0	0	0.004	Silver
Sodium	111	122	196	129	111	196	–	Sodium
Titanium	–	–	–	–	–	–	–	Titanium
Vanadium	–	–	–	–	–	–	–	Vanadium
Zinc	–	0.005	–	–	0.005	0.005	–	Zinc

All concentrations in mg/l except pH (std units and Sp. Cond. (umhos/cm
ND = Not Detected

References: FLI Environmental Services. January 1991. Report, Quarterly Analylsis of Monitoring Wells at Town of Fenton Landfill. FLI. Waverly, New York.

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Table C-8. Concentration of contaminants in MH-1 (pre-treatment) and MH-4 (post-treatment) from 1989 to 1991 at Fenton Landfill. Concentrations are in mg/l ± 1 S.E. of the mean.

	1989	1990		1991	
		manhole 1	manhole 4	manhole 1	manhole 4
Ca	245	187 ± 19	45 ± 4	176 ± 19	64 ± 9.3
Mg	122	103 ± 11	3 ± 4	78 ± 9	30 ± 5
K	457	198 ± 19	47 ± 5	166 ± 18	57 ± 7
Na	458	494 ± 43	150 ± 19	321 ± 35	151 ± 23
Fe	28	29 ± 5	0.4 ± 0.1	34 ± 10	0.1 ± 0.2
Mn	4.4	1.9 ± 0.4	0.5 ± 0.1	1.9 ± 0.3	1.0 ± 0.5
Zn	0.2	0.2 ± 0.02	0.1 ± 0.1	0.2 ± 0.04	0.1 ± 0.02
Al	0.5	0.4 ± 0.05	0.1 ± 0.03	-	-
NH_4	-	208 ± 10	10 ± 2	150 ± 8	19 ± 3
NO_3	-	1.3 ± 0.3	7.8 ± 0.9	2.2 ± 0.5	2.3 ± 0.5
Total N_i	-	204 ± 10	145 ± 13	159 ± 6	19 ± 2
O_2	-	11.7 ± 1.8	2.4 ± 0.6	6.5 ± 0.7	2.9 ± 0.4

Figure C-1 **Average yearly concentration of calcium, magnesium, potassium, and sodium in untreated landfill leachate at the Fenton Landfill Project. Error bars for 1990 and 1991 represent ± 1 S.E.**

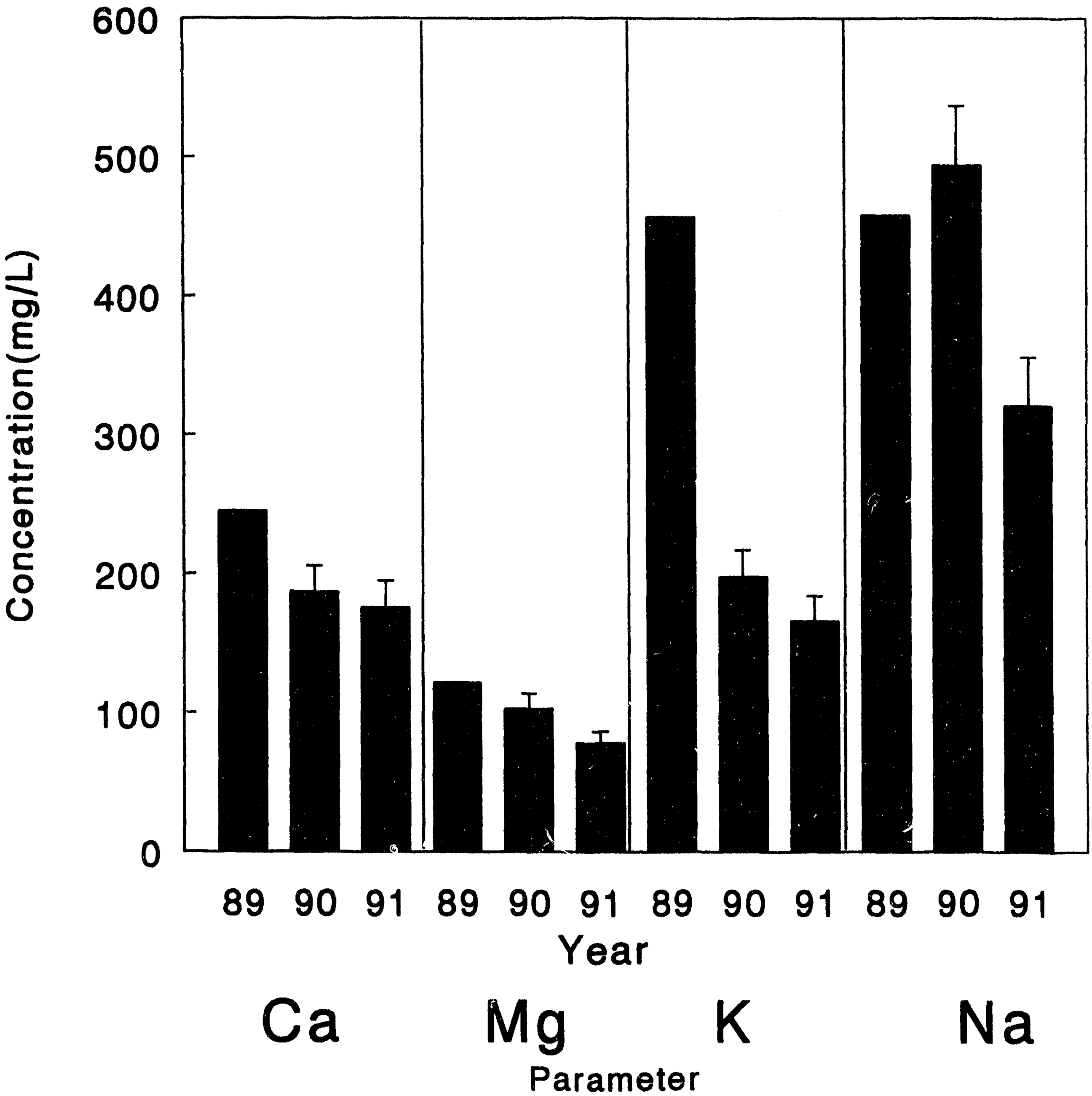
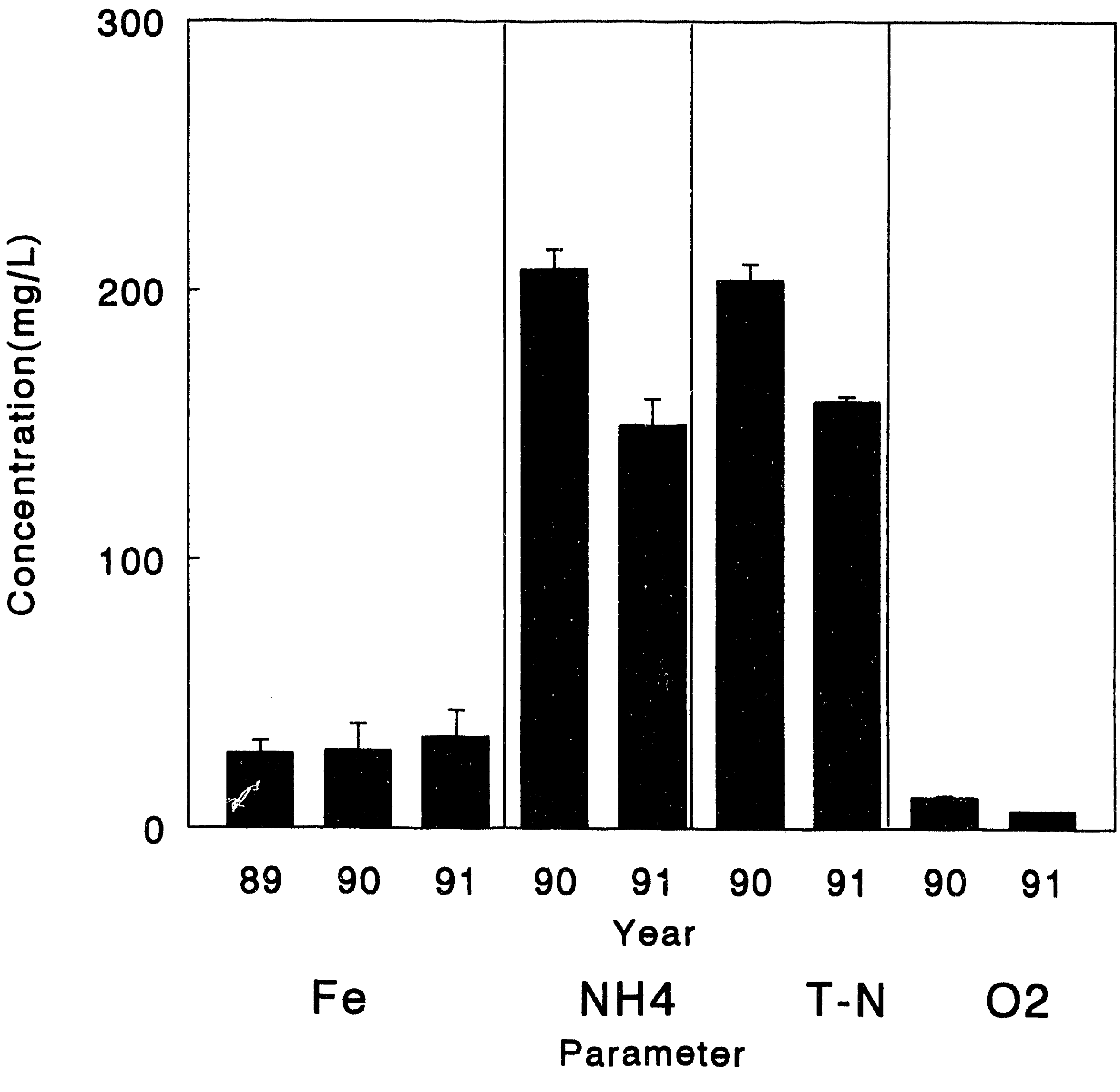


Figure C-2 Average yearly concentration of iron, ammonia, total nitrogen, and oxygen in untreated landfill leachate at the Fenton Landfill Project. Error bars for 1990 and 1991 represent ± 1 S.E.



gure C-3 Average yearly concentration of Mn, Zn, Al, and NO3 in untreated landfill leachate at the Fenton Landfill Project. Error bars for 1990 and 1991 represent ± 1 S.E.

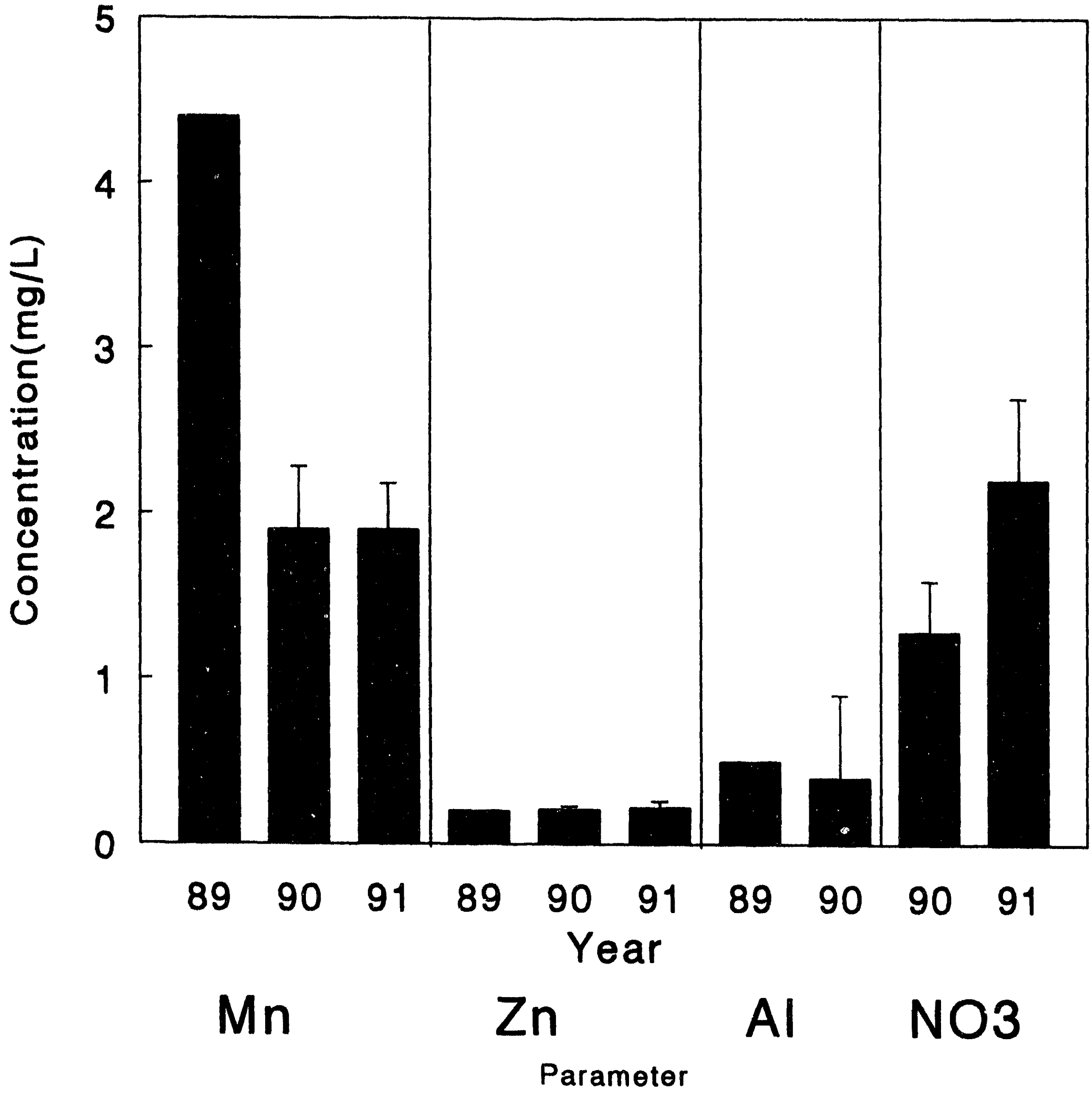


Figure C-4 Average yearly concentration of Ca, Mg, K, and Na in untreated (U) and treated (T) landfill leachate at the Fenton Landfill Project.

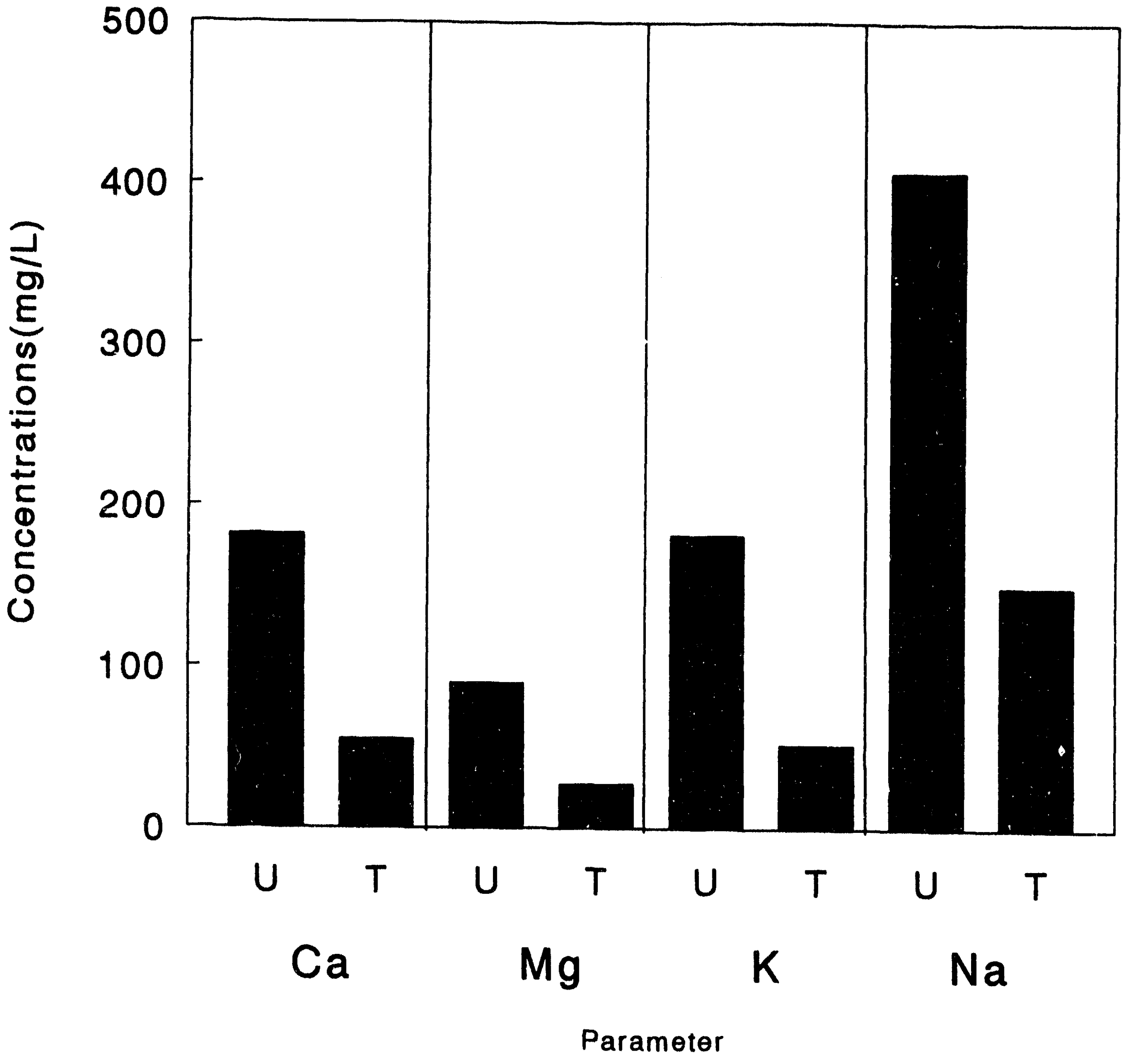


Figure C-5 Average yearly concentration of Fe, Mn, Zn, and Al in untreated (U) and treated (T) landfill leachate at the Fenton Landfill Project.

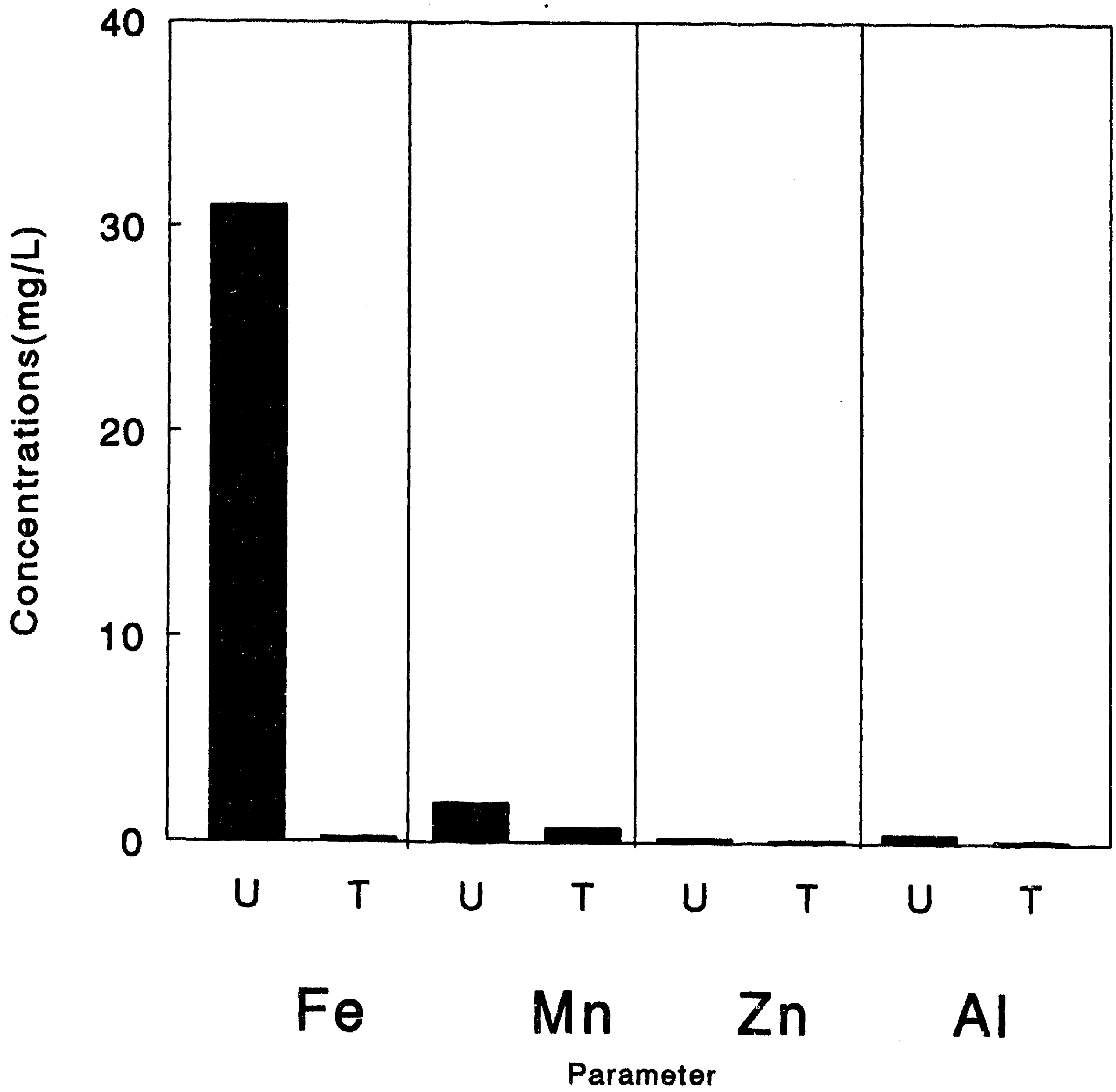
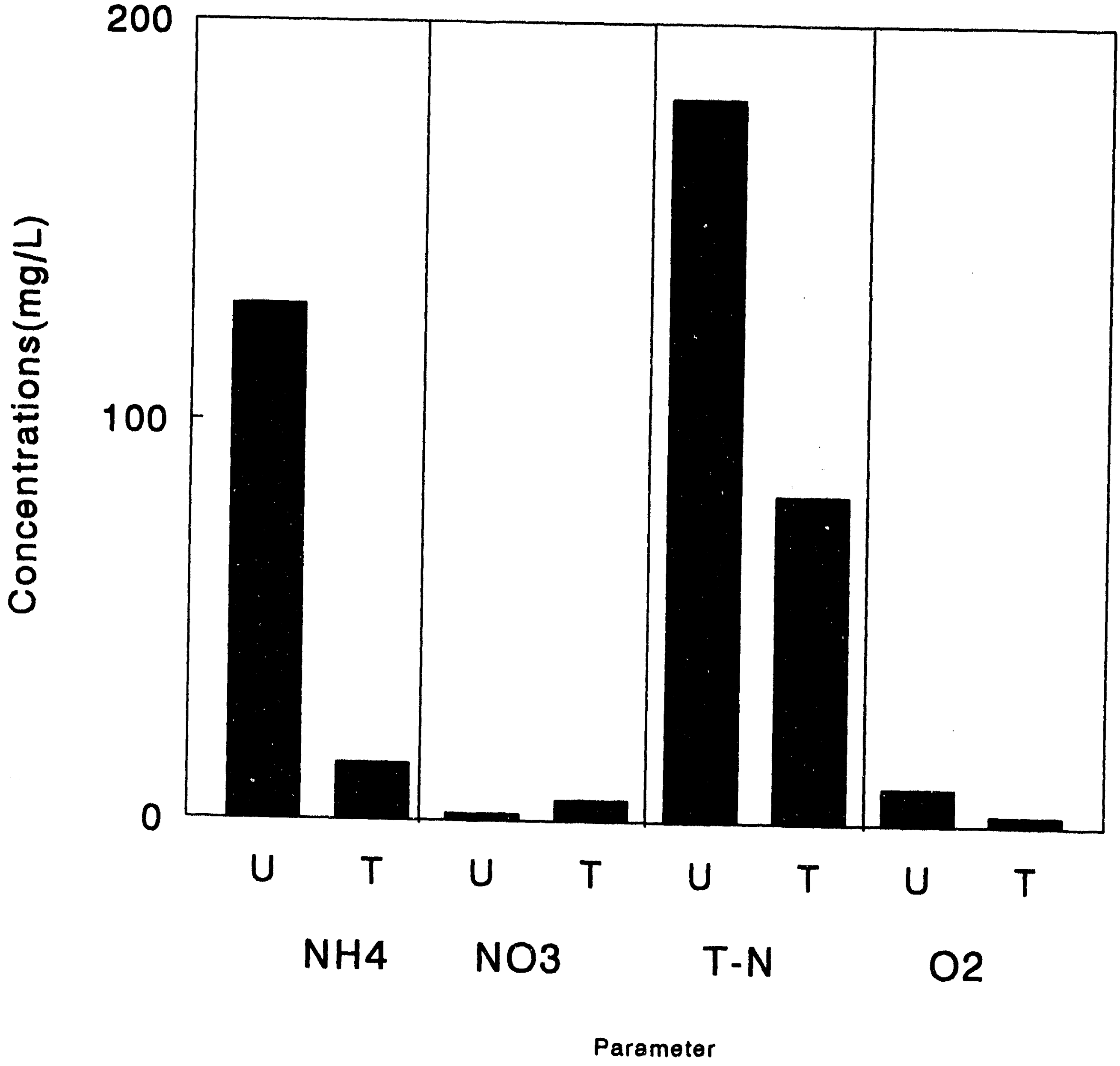


Figure C-6 Average yearly concentration of NH4, NO3, Total N, and O2 untreated (U) and treated (T) landfill leachate at the Fent Landfill Project.



APPENDIX D

EUROPEAN EXPERIENCES USING WETLAND PLANTS FOR WASTEWATER TREATMENT

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European Experiences Using Wetland Plants for Wastewater Treatment

by N.M. Trautmann, W. Hegemann, and K.S. Porter

Abstract

Artificially-constructed beds of wetland plants have received much attention in Europe within recent years for treatment of domestic wastewater, especially from rural areas or sites with seasonally fluctuating loads. Theoretically, wastewater flows horizontally through the root zone, which the plants supply with oxygen and channels for wastewater flow. The efficacy and cost effectiveness of this method of treatment is highly controversial. Although many sites are in operation, the tremendous variation in site design, soil type, loading rate, and wastewater characteristics has made comparisons difficult. Results presented from two sites in West Germany show satisfactory wastewater treatment to be possible, although additional research is needed before reliable guidelines for design and operation can be developed.

Keywords: artificial wetlands, hydrophyte treatment, Phragmites, Root Zone Method, wastewater treatment, wetland treatment

Treatment Systems

Over the past twenty years, a method has been developed in Germany for treatment of wastewater by horizontal flow through artificially constructed beds of wetland plants, usually reeds (Phragmites sp.), but often also including rushes (Scirpus sp.), cattails (Typha sp.), or sedges (Carex sp.). These systems, called Emergent Hydrophyte Treatment Systems (EHTS), are seen as a potentially inexpensive and effective means of treating wastewater in rural areas where conventional treatment is impracticable. Capital costs have been estimated to be from 25 to 75 percent of those for conventional wastewater treatment for populations less than 1000, and operating costs only 10 to 25 percent of those for conventional processes[1]. A recent comparison between EHTS and conventional wastewater treatment methods concluded that the EHTS is not cost-effective [2], but this conclusion is subject to critical assumptions such as the use of gravel rather than soil, and the provision of relatively large bed sizes to provide sufficient treatment during very cold winters typical of New York State.

Although the capability of wetlands to treat wastewater is widely recognized [3,4], Emergent Hydrophyte Treatment Systems differ in that they rely on percolation of wastewater through the soil rather than over the surface. Theoretically, the soil surface remains unsaturated and porous, allowing exchange of oxygen with the atmosphere. According to Kickuth[5], the extensive rhizome network of Phragmites both enhances the hydraulic conductivity of the soil and adds oxygen to what would otherwise be a saturated, anaerobic soil environment. Based on the theories of Kickuth and the apparent success of his pilot site in Othfresen, West Germany, many other European countries have within the past few years begun construction of EHTS sites for wastewater treatment. Since 1984, for example, over 100 EHTS sites have been built in Denmark, and 25 in the United Kingdom. The EHTS method is not well known in the United States, although interest has begun to develop within the past few years.

Although many types of EHTS systems have evolved, most are based on the work in the 1960's of Kickuth[6] and Seidel[7]. Kickuth recommends feeding raw or pretreated wastewater to a single bed of Phragmites planted in soil with a hyraulic conductivity ranging from 10^{-3} to 10^{-5} m/s. According to Kickuth, soil hydraulic conductivities of 10^{-3} m/s, comparable to that of a coarse sand, will develop within the first few years of plant operation, after the rhizomes and roots are fully established. Theoretically, living and dead rhizomes create channels and pores through which wastewater can flow. A primary tenet of Kickuth's theory is that release of oxygen from Phragmites roots creates a mosaic of oxygenated and deoxygenated micro-areas within the root zone, providing sites for both aerobic and anaerobic decomposition of organic matter and nutrients[5]. Details of the recommended system designs can be found in a summary by the British Water Research Centre[8].

The system developed by Seidel[7] differs in that raw sewage is fed onto the surface of a Phragmites bed for primary treatment, then to a series of Scirpus beds for secondary treatment. The system consists of a series of containers made out of concrete, fiberglass, or other impermeable materials. Gravel and sand are used rather than the finer-grained soils recommended by Kickuth. Another major difference between the two systems is that Seidel recommends a yearly harvest of the reeds and rushes, while in Kickuth's method they never are cut. Summarizing experience with five Seidel-type EHTS sites built in the United States in the 1970's, Lewis et al.[9] conclude that for typical domestic wastewater these systems are relatively easy to operate, low in initial cost, and low in the cost of maintenance and operation. However, problems may be encountered with industrial wastes or in areas with prolonged periods of subfreezing weather.

The methods recommended by Kickuth and Seidel, as well as the many related EHTS systems that have evolved, rely on several basic premises about wastewater treatment. Sludge is aerobically composted in the layer of plant litter at the soil surface. Pathogens are filtered out by the soil, and organic matter is broken down by soil microorganisms, just as in other forms of land treatment of wastewater. The wetland plants, although essential to the treatment process, are not thought to play a significant role in removing nutrients from the wastewater. Rather, they provide the root structure which theoretically maintains or increases soil hydraulic conductivity and supplies oxygen which soil microorganisms can use in decomposing organic matter and converting ammonium into nitrite and nitrate. Phosphate reduction occurs through precipitation and adsorption to soil particles. EHTS systems theoretically work well even in winter, since the Phragmites root network continues to provide oxygen and channels through which wastewater can flow.

EHTS Effectiveness

The good treatment performances claimed by Kickuth at his Othfresen site have within recent years come under attack. From 1974 to 1984, there was no well-defined outlet to the system, and the pipe from which outlet samples had been taken was shown through dye tests in 1984 to be hydraulically unconnected to the wastewater flow[10,11]. Most wastewater flow occurs over rather than through the soil, refuting Kickuth's claim that the Phragmites roots would open up the soil pores and increase soil conductivity enough to maintain high flows through the root zone. In winter months, problems have developed with hydrogen sulfide odors and visible layers of sulfide bacteria in the outlet zone.

Hydraulic problems have also been encountered at other sites. Experiences in Denmark, for example, have shown the soil hydraulic conductivities to be lower than expected, resulting in surface runoff of wastewater rather than treatment in the root zone[12]. In spite of this surface flow, BOD typically is reduced 60 to 80 percent. Nutrient reduction occurs mostly through sedimentation rather than microbial decomposition or chemical precipitation, resulting in Total-N removal in the range of 25-50 percent, and Total-P only 20-40 percent.

In articles summarizing experiences with 20 Bavarian EHTS sites ranging in size from 5 to 500 p.e., Bucksteeg[13,14] reaches the following conclusions:

> EHTS beds with sand/gravel substrates and 3-5 m^2/p.e. may achieve an 80-95 percent reduction in the organic load of domestic sewage but generally less than 50 percent N removal and negligible P elimination.
>
> EHTS beds with soil substrates, sized 1-4 m^2/p.e., have had many problems because the Phragmites root networks have not increased the soil hydraulic conductivities as predicted by Kickuth. The result is that most of the wastewater flows over the soil surface rather than through the root zone, resulting in generally inadequate treatment

results. Larger surface areas (probably >10 m^2/p.e.) would be needed to allow adequate root zone flow.

In spite of these problems, European interest in EHTS treatment remains high, and there are a number of successful sites. In this article, two German sites are described, one built privately and the other as a pilot research station by the Technical University of Munich.

The See EHTS

Description

In the small village of See, east of Nuremberg, West Germany, an EHTS site was built in 1984 to treat the wastewater from 100 inhabitants of a religious community*. The 940 m^2 bed is 0.6m deep and sealed on the bottom and sides by the impermeable clay soils of the site. Although many EHTS sites are built using on-site soils, the success in See is due in large part to the fact that a fine- to medium-grained sand was brought in. This soil was chosen for its hydraulic conductivity (7×10^{-5} m/s) and its high iron content for phosphorus adsorption[15].

Mechanically pretreated sewage enters the site through a 41-meter-long perforated pipe, buried in gravel (Figure 1). The percolation bed is divided into two regions (Figure 2). The infiltration area, with a surface area of 410 m^2, has standing-water over the soil surface and is planted primarily with cattails (Typha latifolia), chosen for their quick growth and ability to keep the soil pores open for infiltration. A soil dam separates this region from the following 530 m^2 zone, through which wastewater flows horizontally before seeping into an underground drainage pipe

----

* Although the design population was 100, because of sparse water use the actual wastewater load is equal to 80 p.e.

and finally being discharged into a collecting pond. The zone of horizontal flow has an unsaturated soil surface and is planted with reeds (Phragmites communis). Phragmites are the favored plant for EHTS sites because of their deep root networks and reported ability to enhance soil hydraulic conductivity and oxygen content[5]. Although Phragmites communities take several years to mature, once established they produce hardy stands which can survive in either dry or flooded conditions. Phragmites at the See site are now spreading into the infiltration zone, outcompeting the existing Typha stand.

The SEE site treats septic system effluent representing a concentrated domestic wastewater, with BOD_5 values of approximately 300 mg/l, COD 500 mg/l, NH_4-N 100 mg/l, and Total-P 20 mg/l. The volume treated is approximately 8 m^3/d, in an area of about 11.75 m^2/p.e.

Results

In its first three years of operation, the SEE site averaged 90-97% removal of BOD_5 and 84-89% removal of COD, with treatment results remaining relatively constant from summer to winter periods (Table 1)[15]. The high ammonium influent concentrations were 30-50% reduced, with the higher nitrification rates occuring in the summer months. Nitrate values increased from near zero in the influent to as high as 14 mg N/l in the effluent. The rates at which nitrate and nitrite are denitrified have not been quanitified but have not appeared to increase appreciably with time, in spite of vigorous development of the Phragmites root network. Total-P was almost entirely eliminated, from an average of 18 mg/l in the influent to only 0.2 mg/l in the effluent. The hydraulic conductivity of the See soil lies in the range of 10^{-5} and has not markedly changed in the first three years of plant operation.

Results of a 10-day intensive study by the Technical University of Munich are shown in Table 2. In this time period, 95% of the COD and 99% of the BOD_5 load were eliminated, leaving effluent concentrations averaging 55 and 4 mg/l, respectively. Total-P dropped from an influent average of 19.3 mg/l to only 0.1 mg/l in the effluent. Total-N load was reduced by 81%, with ammonium and organic nitrogen concentrations dropping sharply while nitrate and nitrite rose from 0.5 to 25.0 mg/l.

Because of the low water use per person in See and the relatively long retention time of the wastewater in septic tanks, the wastewater entering the reed bed is unusually high in nitrogen, with NH_4-N and TKN concentrations averaging over 100 mg/l. Although these levels were reduced by almost 90% during the study period, the effluent concentrations of 27 and 29 mg/l still are as high as an average untreated domestic wastewater. Samples taken at distances of 10 and 18 m from the inlet show a linear rate of decay for both forms of nitrogen (Figure 3), indicating that with a longer retention time in the bed the effluent concentrations could probably be further reduced.

The Germerswang EHTS

Description

The Germerswang site was designed as a pilot EHTS site by the Technical University of Munich, West Germany. It was planted in the fall of 1985, first received wastewater in July of 1986, and was rebuilt to correct drainage problems in the spring of 1987. Effluent from a presettling pond is sent to two parallel beds, each 50m x 10m and 0.6m deep (Figure 4). The beds differ in soil content: the "fine-grained" bed consisting of 17% gravel, 63% sand, 16% silt, and 4% clay, and the "coarse-grained" bed consisting of 63% gravel, 33% sand, 4% silt, and less than one percent clay. Both beds are planted with reeds (Phragmites) covering 60% of the area, with the remaining 40% covered by bulrushes (Scirpus), cattails (Typha), sedges (Carex), and lilies (Iris)[16].

The beds are lined on the bottom and sides with plastic. Wastewater enters the beds underground through 50m-long perforated pipes. After travelling 10m either through or over the soil mass, it is collected at the outlet by another set of perforated pipes buried in gravel. Dams at the outlet ends of the beds prevent overland flow from draining directly into the outlet gravel.

The Germerswang site treats approximately 60 m^3/d wastewater (275 p.e.), with a surface area of 3.6 m^2/p.e. The presettled wastewater is much more dilute than that in See, with influent BOD_5 concentrations in the range of 100 mg/l, COD 200 mg/l, NH_4-N 50 mg/l, and Total-P 8 mg/l.

Results

The Germerswang site illustrates a problem common to many EHTS sites: the soil hydraulic conductivities are not high enough for all of the wastewater to flow through the soil mass, resulting in surface flow and lowered treatment results. Although dams prevent the surface flow from draining directly into the effluent gravel, wastewater entering the soil in the region of the dams percolates through less than a meter of soil before being collected by the effluent pipes.

Table 3 summarizes the results of a 10-day investigation of the Germerswang site in October, 1987. BOD_5 and COD removal averaged 70-90% and were slightly better in the coarse-grained bed than in the bed with finer-grained soil. This trend was reversed for nutrient removal, with the coarse-grained bed removing an average of only 20% of the Total-N and 37% of the Total-P, compared with 40% of Total-N and 60% of Total-P in the fine-grained bed.

These elimination rates in Germerswang were significantly lower than those in See for several reasons. The Germerswang site has less than a third as much land area per personal equivalent as in See, and because the whole bed is flooded some of the wastewater flows only a short distance through the soil. Another factor contributing to the lower treatment performance in Germerswang during the study period is the fact that 19.5 mm of rain fell on the eighth day of the 10-day study, washing accumulated nutrients from the beds (Figure 5). In the eight days before the rainstorm, 8.8 kg Total-N had been removed from the wastewater by the fine-grained bed, but 22% of this appeared in the effluent in the three days during and after the heavy rainfall. Similarly in the coarse-grained bed, 5.1 kg Total-N was removed in the first seven days, but 34%

of this was released after the heavy rainfall. Total-P followed the same trend, with 1.7 kg accumulated and then 8.4% washed out in the fine-grained bed, and 1.1 kg accumulated and 15.6% washed out in the coarse-grained bed. The extent to which such wash-out occurs at other EHTS sites is not known because few intensive studies of this sort have been carried out.

Discussion and Conclusions

Emergent Hydrophyte Treatment Systems have been receiving widespread attention in European countries as a potentially low-cost, low-technology alternative to conventional wastewater treatment, especially in rural areas where conventional treatment is prohibitively expensive. For rural communities, EHTS sites offer a low-maintenance, natural-appearing form of wastewater treatment, and for camping areas or villages with many summer residents, they offer a means of treating the seasonally fluctuating wastewater loads.

Although hundreds of EHTS sites are in operation, reliable guidelines for design and operation have not yet been developed. Comparisons among existing sites are difficult because of the numerous differences between factors such as soil type, hydraulic design, loading rates, and wastewater characteristics[17]. At the EHTS sites which function well, COD and BOD_5 removal rates of 80 to 95% are common, but nitrogen and phosphorus elimination generally is less successful. Additional research is needed on the mechanisms of nutrient removal in the reed beds, particularly relating to the expected lifetime of such removal and the degree to which accumulated nutrients will wash out of the system during heavy precipitation periods.

The most widespread problem with existing EHTS sites is insufficient hydraulic conductivity, resulting in flow of wastewater over the soil surface rather than through the root zone. Although Phragmites roots may prevent the soil pores from clogging, the theoretical increase in soil hydraulic conductivity with development of the root network has not been shown to occur.

Because most of the existing EHTS sites have been built or rebuilt within recent years, their long-term performance is as yet unknown.

The cost of EHTS sites relative to other low-technology wastewater treatment methods varies according to the land area needed for adequate treatment. In relation to non-aerated lagoons, EHTS sites are likely to be less expensive only if the treatment can be accomplished in specific areas ranging 3-5 m^2/p.e. as planned by Kickuth[18]. Because soil hydraulic conductivities have not been as high as those predicted by Kickuth, however, specific areas up to 10 m^2/p.e. appear to be needed, making EHTS sites cost as much as or more than conventional treatment methods[13,14,19].

As research continues, key questions will include how EHTS sites can best be designed to optimize treatment results, how well they perform under harsh winter conditions, and under what conditions substantial nutrient reduction can be achieved. Only after these questions have been addressed can the long-term utility of the EHTS method be determined.

Acknowledgements

Credits

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Authors

N.M. Trautmann is a Water Resources Scientist and K.S. Porter is Director of the New York State Water Resources Institute at Cornell University. W. Hegemann is Professor of Sanitary Engineering at the Technical University of Berlin. The work described in this paper was conducted while N.M. Trautmann and W. Hegemann were working at the Technical University

of Munich. Correspondence should be addressed to N.M. Trautmann, N.Y.S. Water Resources Institute, 468 Hollister Hall, Cornell University, Ithaca, N.Y. 14853.

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Table 1. Performance of the EHTS site in See, West Germany, during its first two years of operation (from Dafner, 1987).

Phase 1: 10/84-1-/85 (n=6)

Parameter (mg/l)	Influent (mg/l)	Effluent (mg/l)	Elim.-Rate (mg/l)
BOD5	430	16	96
COD	554	58	89
NH4-N	98	41	58
NO3-N	0.3	5.4	++
Total-P	18	0.2	99

Phase 2: 12/85-3/86 (n=8)

Parameter (mg/l)	Influent (mg/l)	Effluent (mg/l)	Elim.-Rate (mg/l)
BOD5	380	17	90
COD	609	74	84
NH4-N	106	54	49
NO3-N	0.5	2	++
Total-P	17	0.3	98

Phase 3: 4/86-6/86 (n=4)

Parameter (mg/l)	Influent (mg/l)	Effluent (mg/l)	Elim.-Rate (mg/l)
BOD5	313	9	97
COD	447	66	85
NH4-N	91	60	34
NO3-N	0.6	14	++
Total-P	18	0.2	99

Table 2. EHTS System in See, West Germany: Average concentration loads, and elimination rates (calculated from loads) (October 17-25, 1987).

	Concentration		Load		
	Influent (mg/l)	Effluent (mg/l)	Influent (mg/l)	Effluent (mg/l)	Elim.-Rate
COD	465	55	3807	206	94.6%
BOD5	268	4	2193	15	99.3%
NH4-N	113.1	27	929	100	89.2%
N-Org.	15.7	2.3	128	8	93.8%
TKN	128.7	29.2	1054	109	89.7%
NOx-N	0.5	25	4	93	---
N-Total	129.3	54.3	1058	201	81.0%
P-Total	19.3	0.1	158	0.2	99.9%

Table 3. EHTS System in Germerswang, West Germany: Average concent loads, and elimination rates (calculated from loads) (Aug. 26 - Sept. 6, 1987).

	Concentration			Elimination-rate	
	Influent (mg/l)	Effluent fine-grained (mg/l)	Effluent coarse-grained (mg/l)	Fine-grained bed	Coarse-grained bed
COD	180	60	44	72.3%	74.1%
BOD5	80	14	8	85.1%	89.6%
NH4-N	47.5	28.1	32.1	45.2%	20.2%
N-Org.	8.7	5.7	4.8	38.7%	33.7%
TKN	56.2	33.8	37	44.2%	22.4%
NOx-N	0.3	2.6	1.5	-620.0%	-450.0%
N-Total	56.5	36.4	38.5	40.3%	19.6%
P-Total	8.3	3.2	4.4	63.9%	37.3%

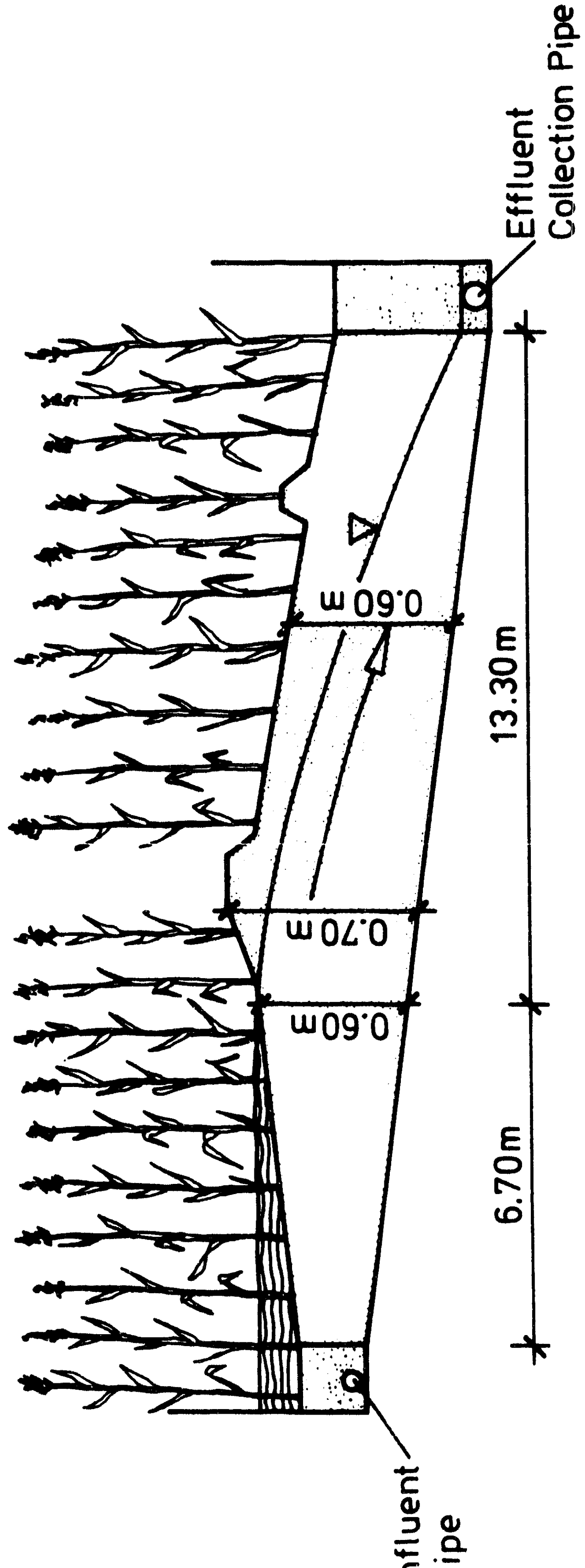
Figure 1. Cross-section of the EHTS in See, West Germany. A soil dam divides the system into two beds, one with standing-water and the other with all water passing horizontally through the soil.

Figure 2. Plan view of the EHTS site in See, West Germany.

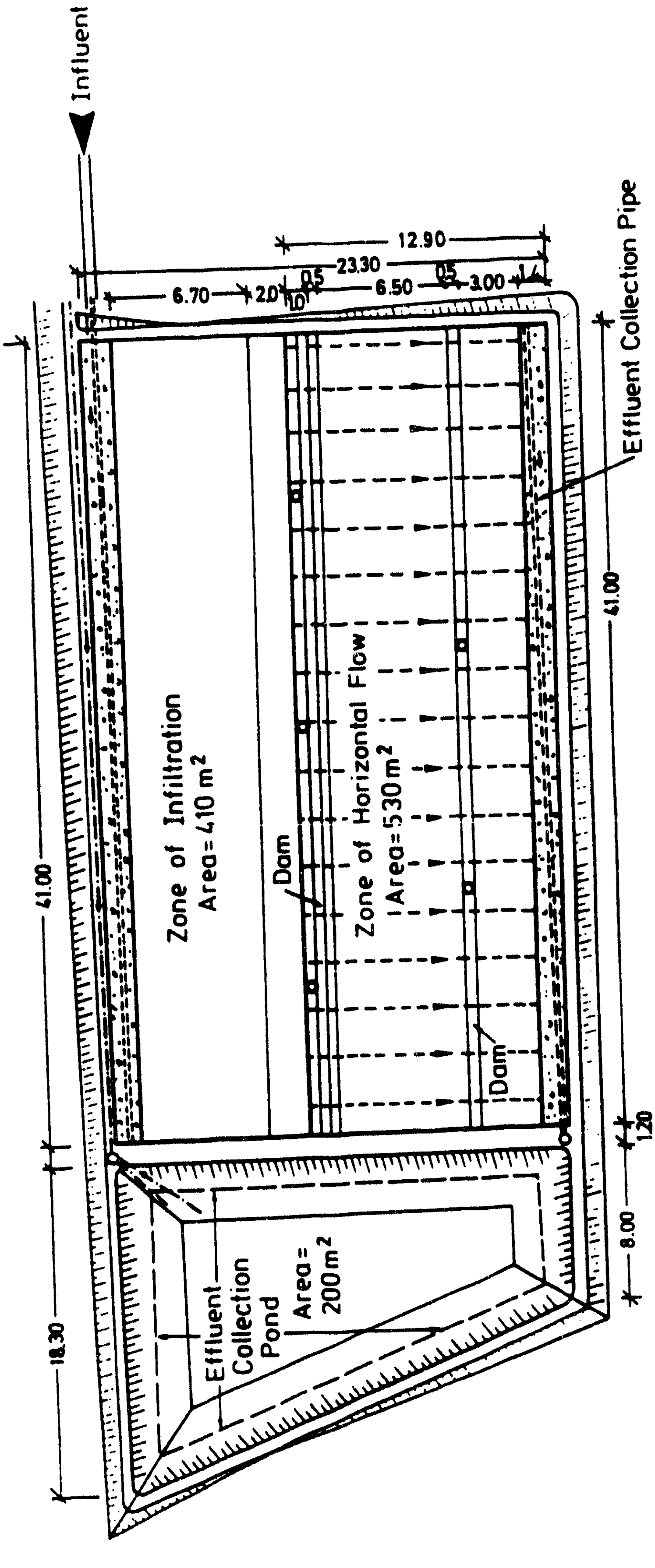
Figure 3. Profile showing decrease in nitrogen concentrations with movement of wastewater through the EHTS site in See, West Germany.

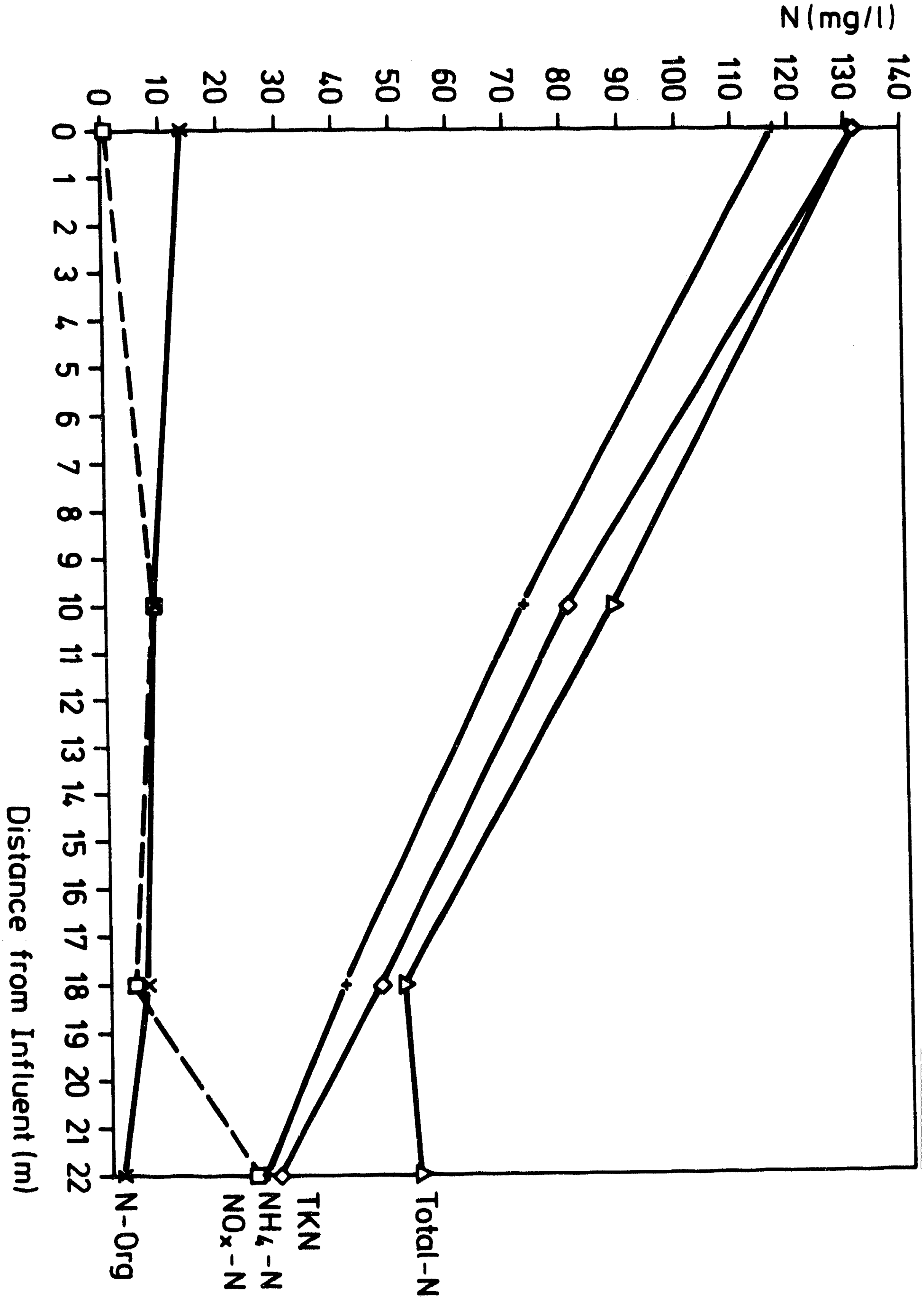
Figure 4. Plan view of the EHTS site in Germerswang, West Germany.

Figure 5. Wash-out of nitrogen and phosphorus after heavy rainfall at the EHTS site in Germerswang, West Germany.

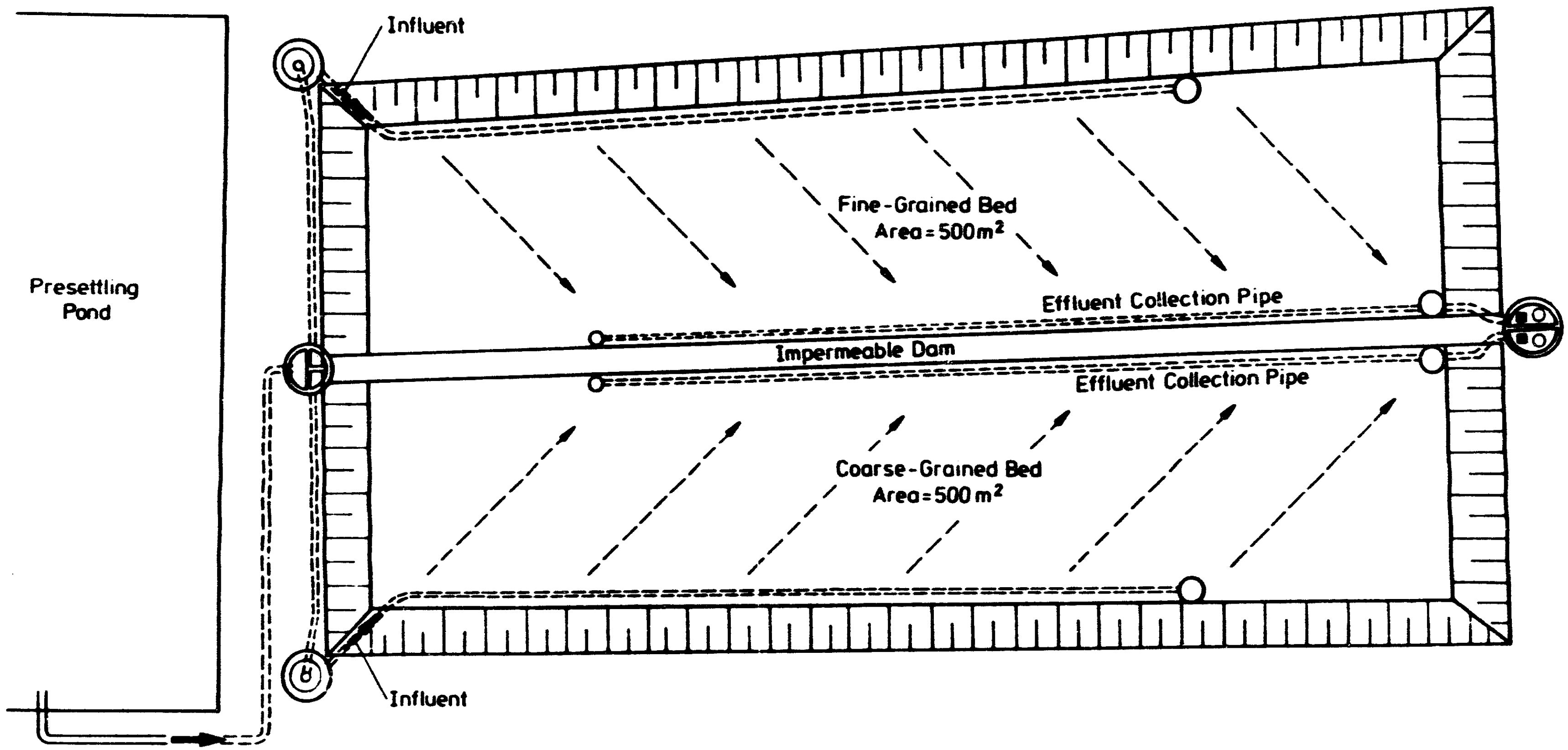


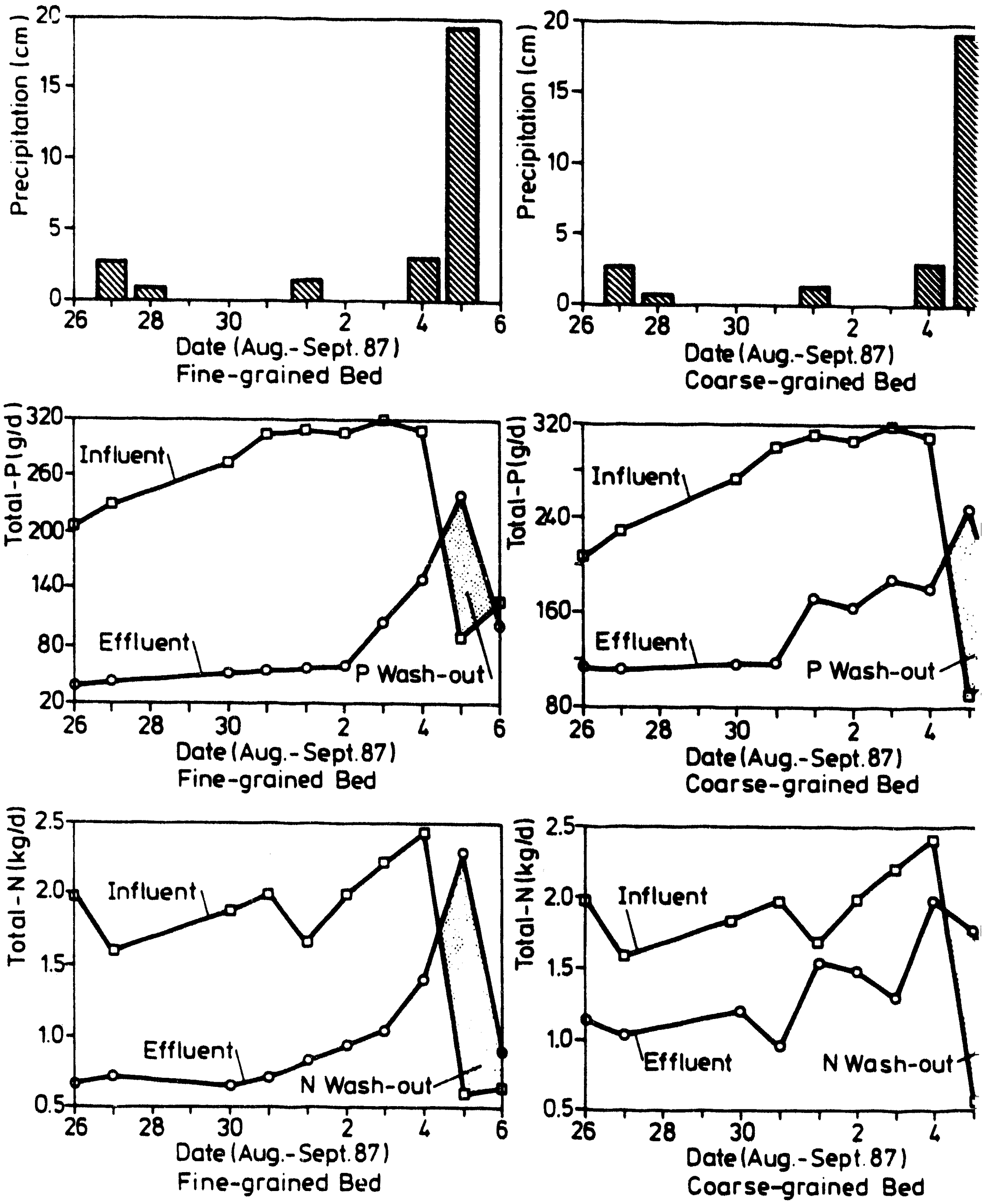
Effluent
Collection Pipe
0.60 m
13.30m
0.70 m
0.60m
6.70m
Influent
Pipe


Influent
Effluent Collection Pipe
12.90
23.30
6.70
2.0
1.0
0.5
6.50
0.5
3.00
41.00
41.00
18.30
8.00
1.20
Zone of Infiltration
Area=410 m²
Dam
Zone of Horizontal Flow
Area=530m²
Dam
Effluent
Collection
Pond
Area=
200m²



N (mg/l)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Distance from Influent (m)
N-Org
NO$_x$-N
NH$_4$-N
TKN
Total-N

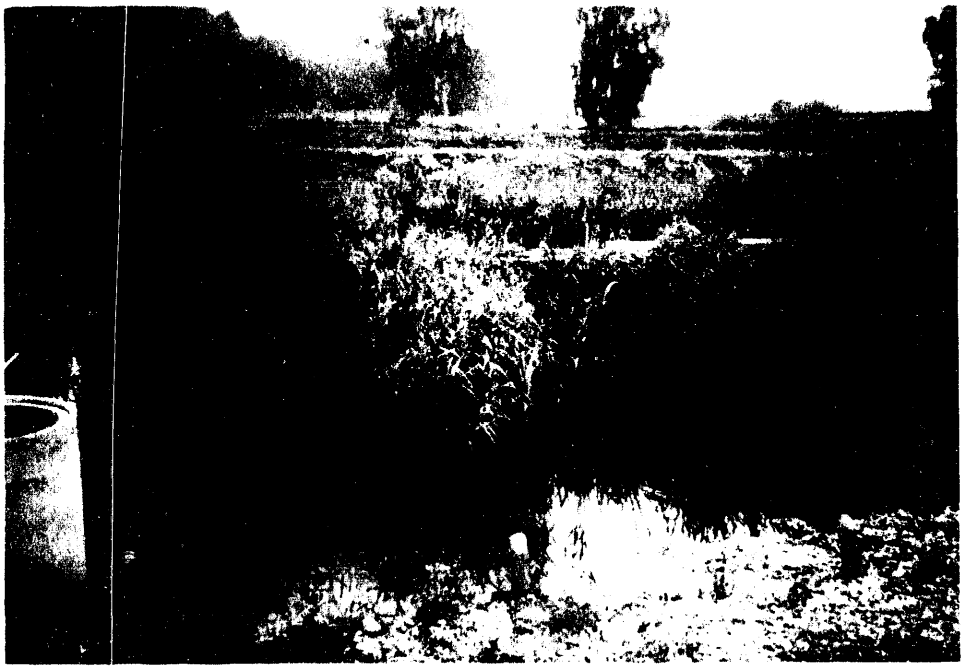

Presettling Pond
Influent
Fine-Grained Bed
Area = 500 m²
Effluent Collection Pipe
Impermeable Dam
Effluent Collection Pipe
Coarse-Grained Bed
Area = 500 m²
Influent



Precipitation (cm)
Date (Aug.-Sept. 87)
Fine-grained Bed
Precipitation (cm)
Date (Aug.-Sept. 87)
Coarse-grained Bed
Total-P (g/d)
Influent
Effluent
P Wash-out
Date (Aug.-Sept. 87)
Fine-grained Bed
Total-P (g/d)
Influent
Effluent
P Wash-out
Date (Aug.-Sept. 87)
Coarse-grained Bed
Total-N (kg/d)
Influent
Effluent
N Wash-out
Date (Aug.-Sept. 87)
Fine-grained Bed
Total-N (kg/d)
Influent
Effluent
N Wash-out
Date (Aug.-Sept. 87)
Coarse-grained Bed

EHTS systems fit in well with the natural landscape. The EHTS site in See, West Germany can be seen in the center of this picture.

The See, West Germany, EHTS site is divided into two zones, one with water ponded at the soil surface and the other in which water flows only underground through the root zone.



Water flowing over the soil surface rather than through the root zone is a common problem of EHTS systems and accounts in many cases for poor treatment performance.

DATE

FILMED

8/3/94

END