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**CONSTRUCTED WETLANDS FOR
MUNICIPAL SOLID WASTE LANDFILL LEACHATE TREATMENT**

Final Report

Prepared for

**THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY**

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ADDENDUM

Please note the following correction in Section 4, IMPLICATIONS OF THE UNCERTAINTY ANALYSIS RESULTS, in the third paragraph on page 4-1:

The heating season simulations of the Winchester home indicated bias and random errors, both about 10 percent of the mean UA. In comparison, measurement error would be about 3 percent of the mean UA. The bias of the heating system efficiency estimate was 18 percent and the scatter was about 9 percent of the mean.

ABSTRACT

Four constructed wetland beds were installed at the Tompkins County municipal solid-waste landfill, located in New York. Each bed measured 3.4 m wide, 30 m long, and 1 m deep and is lined with high-density polyethylene. One bed each is filled with coarse gravel (2-4 cm) and pea gravel (0.5 cm) while the other two beds are filled with a sand/gravel mixture (0.5-1 cm). During the spring of 1990, common reed (*Phragmites australis*) was planted in each of the three substrate types while the second bed of sand/gravel substrate was left unplanted as a control.

Leachate application began in July, 1990 with application rates of 2000-liters per day per bed. Hydraulic controls at the head and foot of each bed maintain continuous sub-surface flow. Leachate residence time was established at approximately 15 days.

Treatment effectiveness was highly variable depending on the type of substrate and bed temperature. The most efficient treatment overall occurred in summer in the sand/gravel substrate, particularly for Fe, Mn, NH_4^+ , and K^+ . Microbial activity and cation exchange are possible mechanisms in reduction of BOD and removal of NH_4^+ , and K^+ , as indicated by the reduced treatment efficiency and even nutrient loss from the beds when bed temperatures dropped.

During the sampling period July 1990 to September 1991, hydraulic conductivity of the substrates decreased from 37 to 80 percent in all substrates except the coarse gravel bed. Overland flow occurred in the sand/gravel beds which resulted in greater Fe removal. The use of coarse gravel provides extremely high conductivity but does not provide acceptable treatment of the leachate. The pea gravel has a sufficiently high hydraulic conductivity to prevent overland flow while also providing acceptable treatment. Specific conductance measurement indicated that significant stratification of the leachate occurs in the substrate due to density differences of the leachate compared to rainwater.

Plants did not alter hydraulic conductivity of the substrate and no increase in root-zone aeration by plants was indicated, other than a greater removal of BOD in the planted sand/gravel bed than in the unplanted sand/gravel bed in summer 1991.

It appears that the energy requirements for this constructed wetland system are approximately the same as the cost for conventional activated sludge treatment. The cost of the constructed wetland system could be decreased by redesigning the system with gravity feed and increased contact time with the substrate and discharging treated water onsite to eliminate hauling costs.

key words: *artificial wetlands, *wetlands, *landfills, *reeds, *leachates, *wastewater treatment, biological wastewater treatment, metals, nutrients, macrophytes

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A. INTRODUCTION

Infiltration of precipitation and migration of pore water through landfills produces leachate that contains varying quantities of toxic organic and inorganic chemicals. Nearly all landfills in humid areas produce leachate, and this leachate has long been a suspected source of groundwater and surface-water contamination.

Problems resulting from the migration of leachate have led to stringent regulations in New York State and elsewhere that require new landfills to be lined and equipped with a leachate collection system (U.S. Congress, Office of Technology Assessment, 1989). However, no economically or environmentally sound system for renovating leachate presently exists.

The need for efficient collection and treatment of leachate from solid-waste landfills to avoid surface-water and groundwater contamination is widely recognized. Traditional approaches (onsite treatment or transport to off-site facilities, usually municipal sewage-treatment plants) are undesirable because (1) on-site plant operation and maintenance is costly and entails labor and services after landfill closing, and (2) transport of concentrated waste on public roads is costly and dangerous, plus the addition of leachate to municipal sewage disrupts the normal biological processes upon which treatment depends.

A method of on-site treatment is needed that is inexpensive and requires little maintenance or power after landfill closure. Constructed wetlands have shown promise for treatment of sewage and municipal waste and have several characteristics that are beneficial for leachate treatment, including high vegetation biomass, large adsorptive surfaces on sediments and plant roots, aerobic-anaerobic interfaces, and diverse and active microbial populations (Wolverton, 1987). The design and operating limits for treatment of landfill leachate in the humid temperate zone are not well documented, however.

The treatment of landfill leachate with constructed wetlands is challenging because the high concentrations of biochemical oxygen demand (42 to 10,000 mg/l), ammonium (0.01 to 1,000 mg/l), iron (0.09 to 678 mg/l), and manganese (0.01 to 550 mg/l), combined with the highly

reduced state of the leachate, normally make the solution too toxic for most plants (Shuckrow and others, 1980). A wetland system generally is most successful for wastewater treatment when only subsurface flow is allowed because this maximizes the contact between the wastewater and the substrate and rhizome or root surfaces and minimizes odors.

Wetland plants, such as the common reed (*Phragmites australis*) and cattail (*Typha latifolia*), have been shown to increase aeration of the substrate by diffusing air from their above-ground shoots to the rhizomes and roots (Armstrong and Armstrong, 1990; Reddy and others, 1989; Brix and Schierup, 1990; Stengel, 1993) and might also sustain the hydraulic conductivity of the substrate through eventual decay of rhizomes (Boon, 1985). These plant functions would seem beneficial for the efficient treatment of landfill leachate because they provide the oxygen for breakdown of organic compounds and ammonium and might offset plugging by large iron and manganese loads in leachate. Plants also might provide a more rapid decrease in leachate volume (through evapotranspiration) than is provided by storage lagoons or ponds without plants.

Plants growing in constructed wetlands used for wastewater treatment have to be tolerant of more extreme chemical conditions such as elevated metals, nutrients, and organic carbon. In the case of landfill leachate, *Phragmites* roots encounter very high levels of ammonium, potassium, sodium, iron and other metals (Staubitz and others, 1989). Under these conditions, concerns about growth, healthy rhizosphere function, tissue accumulation of nutrient and metal elements and maximum water treatment arise.

One of the important design parameters for reed beds is the residence time. The "design" residence time is defined as the average time that leachate remains in the bed and is equal to the time needed for the incoming wastewater to be treated. This calculation assumes, in general, that the added water flows through all the pore spaces and that the whole bed participates in the treatment process. One major problem with wetlands constructed for subsurface flow is the clogging of the substrate, especially if the substrate is a soil or sand, resulting in overland flow and bypassing of the treatment zone within the matrix and rhizosphere of the reeds (Brix, 1987; Cooper and others, 1990; Schierup and others, 1990; Conley and others, 1991; Sanford, 1992). During treatment in constructed wetlands, precipitates form, bio-films are developed, and suspended solids are filtered

out of the wastewater, all of which contribute to the clogging of the substrates. When there is preferential flow, short-circuiting occurs and portions of the bed are bypassed, reducing the residence time to less than the design residence time. The production of odors can also become a problem.

Although in many studies the concentrations of the inflowing and outflowing water from the reed-bed has been measured (see examples in Hammer, 1989), little is known about the flow characteristics and the resulting residence time within the reed-bed systems. Therefore, various types of substrates need to be examined to determine which ones are best at maintaining sufficient hydraulic conductivity. In one experiment using lithium chloride as a tracer, highest concentrations of lithium were found in the effluent one to two days after being introduced for two beds with design retention times of five and eight days (Schierup and others, 1990).

In 1989, the U.S. Geological Survey and Cornell University, in cooperation with the New York State Energy Research and Development Authority and the Tompkins County Solid Waste Department, began a three-year study at a municipal solid-waste landfill near Ithaca, New York, to test the effectiveness of leachate treatment with constructed wetlands and to examine the associated treatment processes. Specific objectives of the study were to examine-

1. treatment efficiency as function of substrate composition and grain size, degree of plant growth, and seasonal changes in evapotranspiration rates and microbial activity
2. effects of leachate and plant growth on the hydraulic characteristics of the substrate
3. chemical, biological, and physical processes by which nutrients, metals, and organic compounds are removed from leachate as it flows through the substrate.

A parallel study at a municipal solid-waste landfill near Fenton, New York was conducted by researchers at Cornell University, Ithaca College, and Hawk Engineering (Trautmann and others, 1989).

Funding for this three-year study was provided by the New York State Energy Research and Development Authority and the U.S. Geological Survey. In-kind contributions were provided by Cornell University and Tompkins County.

B. LITERATURE REVIEW

B.1 HISTORIC USES OF WETLANDS FOR WASTEWATER RENOVATION

Water-quality improvement has been observed in many types of natural wetlands, such as freshwater marshes, northern bogs, southern swamps, bottomland hardwood forests, and brackish and saltwater marshes (U.S. EPA, 1983, 1985; U.S. EPA/DOI, 1984; Godfrey and others, 1985; Reddy and Smith, 1987). In many areas, natural wetlands receive waters from permitted discharges of treated wastewater as well as much of the nation's nonpoint-source surface-water discharge. More than 400 such permitted discharges exist in the Southeast (U.S. EPA, 1984, 1985) and another 100 occur in the Great Lakes states (U.S. EPA, 1983). A number of engineered treatment systems in California, Michigan, Wisconsin, Florida, and elsewhere use natural wetlands to provide part of the wastewater treatment.

Sphagnum (moss) and *Typha* (cattail) wetland systems have been incorporated in the treatment of acid mine drainage (Girts and Kleinmann, 1986a; Snyder and Aharrah, 1984; Wieder and others, 1985). In a survey of more than 25 mine drainage sites, Girts and Kleinmann (1986b) found *Sphagnum* and *Typha* wetland systems consistently neutralized acidity and removed iron while moderately removing manganese and sulfate. Some natural wetland systems have shown greater removals; however, water treatment with natural wetlands is seldom feasible. It is rare that a natural wetland system is available near a permitted mine area.

The use of natural wetlands has several disadvantages. Major costs and energy requirements include preapplication wastewater treatment, land costs, and the wastewater distribution system. Natural wetlands are rarely available on site and are hydrologically complex. In the United States, proposed physical modifications of a natural wetland to allow wastewater application require a permit from the U.S. Army Corps of Engineers (under section 404 of the Clean Water Act) and review under the National Environmental Policy Act. These disadvantages associated with natural systems have led to the use of constructed systems. Constructed wetlands can be built and maintained on site thus lowering costs. They have the capability to treat a variety of wastes at varying application rates. Domestic wastewater, acid mine drainage, urban

stormwater, agricultural wastewater, and industrial wastes have all been successfully treated using constructed systems.

Floating plant and nutrient-film systems have been used to treat wastewater. Water hyacinths (*Eichhornia crassipes*) have been studied in systems treating primary sewage effluents, as the final treatment cells in multiple-cell ponds, and as an advanced waste treatment step after conventional secondary sewage treatment. A small-scale system for treating domestic sewage was installed at the National Space Technologies Laboratory (NSTL) in 1976 (Wolverton and McDonald, 1979). In the late 1970's, Disney World water hyacinth testing facility at Lake Buena Vista, Florida, treated all constituents, with the possible exception of phosphorus, to a tertiary level (Kruzic, 1979). In a three-year pilot study, an advanced hydroponic system, referred to as the "Nutrient Film Technique" (NFT), was shown to be a viable alternative for domestic sewage treatment (Jewel and others, 1983). Small-scale systems for treating domestic sewage were installed in New York and New Hampshire and treated domestic sewage at flow rates of up to 11,000 liters per day per area or length (residence time).

In 1979, the city of Arcata, California, constructed an open water freshwater wetland to polish secondary-treated water (Gearheart and others, 1989). The facility was upgraded in 1986 and serves as an effective and reliable treatment system. An ancillary benefit from the project was the creation of the Arcata Marsh and Wildlife Sanctuary.

Full-scale treatment of raw sewage using the root zone method (RZM) developed by Kickuth at Kassel University, Germany, was started in Othfresen, Germany, in 1974 (Boon, 1986). In the RZM, *Phragmites* is grown in beds of soil. Success at this site led to a capacity increase from serving 2,700 people in 1974 to 10,000 people in 1987. By 1986, 20 RZM systems had been constructed in Bavaria to treat both domestic and industrial wastewaters (Boon, 1986). By 1987, 10 RZM systems had been installed in the United Kingdom while 40 additional systems were under consideration or construction there (Login, 1987). An evaluation of the existing root zone systems provided evidence that the method can meet secondary treatment standards if properly designed and operated (Conley and others, 1991). It was found that the use of coarse substrate media avoided the common operational problems of plugging and overland flow.

Wolverton (1981) developed a rock-reed system using rooted, cold-tolerant plants such as *Phragmites australis* growing on the surface area of a microbial rock filter bed, to treat domestic sewage in Mississippi. This system can be used in colder climates and estuarine environments because of the salt- and cold-tolerant characteristics of the reeds. Several small rock-reed systems and septic-tank rock-plant systems are in operation in Mississippi to treat domestic sewage to advanced secondary levels (Wolverton, Myrick, and Johnson, 1984; Wolverton, 1989). In 1987, Upton and Griffin (1990) constructed a rock-reed system in Little Stretton, United Kingdom, to treat wastewater from 15 dwellings combined with farm waste. Downstream river quality considerably improved after the installation of this treatment system.

Small (1977), of the Brookhaven National Laboratory, pioneered work in the United States treating sewage by a marsh/pond/meadow wetland system. The village of Iselin, Pennsylvania, constructed a marsh/pond/meadow system, based on Small's research, to treat an average daily flow of 45,000 liters per day of wastewater from 62 homes (Conway and Murtha, 1989). The success of this system has led to several similar projects in Pennsylvania.

The Tennessee Valley Authority (TVA) has been a leader in acid mine drainage treatment using constructed wetlands. In 1985, a constructed wetland was designed to treat acid drainage from a coal preparation plant (Brodie and others, 1989). Brodie, Hammer, and Tomljanovich (1988) have found constructed wetlands to be an environmentally effective and cost-effective alternative to conventional treatment of mine drainage. Most recently, the research team at TVA has been incorporating anoxic limestone drains into their aerobic acid drainage treatment wetlands to enhance performance (Brodie and others, 1992).

Industrial wastes have been successfully treated using both the RZM and rock-reed filter systems. Photographic and chemical laboratory wastewaters, treated initially using a water hyacinth system, were later treated with a rock-plant microbial filter at the NSTL in Mississippi (Wolverton, 1987). This upgrade incorporated the more cold-tolerant aquatic plants *Phragmites australis* and *Typha latifolia*. Windel Textiles in Windelsbleiche, Germany, treats their wastewater using a rock-reed filter system (Boon, 1986). The reed/microbial filter system has

been used to remove benzene, toluene, and p-xylene (Wolverton, McDonald, and Marble, 1984) as well as phenols and m-cresol (Wolverton and McDonald, 1981). Rock-*Phragmites* filter systems have also treated river water contaminated with phenol and m-cresol (Wolverton and McDonald, 1981) and biodegradable hazardous organic compounds (Wolverton and McDonald-McCaleb, 1986). Davies, Watson, and Jenkins (1990) used a portable rock-reed filter to treat rail-car and tank-truck cleaning wastewater at Calvert City, Kentucky. This wastewater, containing a wide range of organic and inorganic chemicals such as acids, caustics, solvents, pesticides, antifreeze, oil, paints, and fertilizers, had a substantial reduction in pollutant loads after treatment with the portable rock-reed system.

B.2 THEORY OF OPERATION

Wetland ecosystem properties that contribute to wastewater restoration include high plant productivity, high decomposition rates, large adsorption areas in sediments, and low oxygen contents of sediments (Bastian and Benforado, 1986). The anaerobic conditions often found in wetland sediments enhance retention of many compounds. This, coupled with aerated conditions in the rhizosphere and upper sediment layer, allows many processes to occur simultaneously.

Roots of emergent wetland plants, such as *Phragmites australis*, grow and function in an anaerobic environment. As a result these tissues must tolerate or compensate for low oxygen, elevated concentrations of iron and manganese, and sometimes organic acids and other breakdown products of organic matter. Evidently, strategies to maintain aerobic respiration in root tissue and prevent excessive root absorption of iron, manganese, and other metals have evolved in these plants.

The maintenance of oxygen at the root respiratory sites depends on development of open lacunar space in the stems, roots, and rhizomes. This gaseous space acts as an oxygen conduit from the photosynthetic shoot tissue to the below-ground tissues, where aerobic processes maintain normal root absorptive functions for nutrient uptake (Bedford and others, 1991).

It is also believed that plants can establish an external aerobic microzone around parts of the growing roots (Armstrong and Armstrong, 1990). As a result, iron (and perhaps manganese) is

precipitated and an iron plaque or coating appears. Neither the exact chemical nature of this plaque nor the relative importance of external physical/chemical or internal physiological processes in its formation is well understood. Its effect on root absorptive processes seems apparent, as a filter or chemical adsorptive surface, but little information is available. Overall, wetland plants show adequate nutrient status and vigor under these conditions (Hutchinson, 1975).

A major part of the treatment process is attributed to the microorganisms living on and around the plant root system. Submerged vegetation provides extensive surface area for attached enhanced biological growths. Once microorganisms are established on aquatic plant roots, they form a symbiotic relationship (in most cases) with the plants. This relationship normally produces a synergistic effect, resulting in increased degradation rates and removal of organic chemicals from the wastewater surrounding the plant root system (Wolverton, 1989). The plants absorb and utilize the metabolites produced in this process as well as nitrogen, phosphorus, and other minerals. Microorganisms also use some or all metabolites released through the plant roots as a food source. By each using the other's waste products, the rapid removal of organics from wastewater is sustained (Wolverton, 1987).

The indigenous microbes in wetlands appear to perform all biochemical transformations of wastewater constituents that take place in conventional wastewater treatment plants. The additional processes of absorption of organics and nutrients by plants, adsorption of metals on sediments and plant roots, microbially mediated oxidation of metals, and simultaneous aerobic decomposition and anaerobic digestion of organic compounds result in the transformation and immobilization of a wide range of chemical constituents.

Negative electrical potentials associated with aquatic plant root hairs attract colloidal particles with opposite charges and adsorb them to the plant roots where they are slowly digested and assimilated by the plant and microorganisms. The oxygen pump mechanism utilized by *Typha*, *Phragmites*, and similar plants in saturated soils creates aerobic microsites adjacent to the plant roots in an otherwise anaerobic root zone (Bastian and Benforado, 1986; Armstrong and Armstrong, 1990). Aquatic plant roots also are capable of removing toxic heavy metals and certain radioactive elements from the water column by adsorbing, concentrating, and—in some

cases—translocating them (Wolverton, 1987).

The substrate is an important factor in pollutant removal. The substrate supports vegetation, provides surface area for microorganism attachment, and is associated with the physical and chemical treatment mechanisms (Steiner and Freeman, 1989). Substrates containing iron, calcium, and aluminum can remove significant amounts of phosphorus through coprecipitation. Substrates high in organic material and clay minerals have higher exchange capacities than gravel substrates. While such an increase in adsorptive capacity would appear advantageous, these substrates also have lower hydraulic conductivities (which may decrease over time), reducing permeability to the point of causing overland flow and reduced residence time.

Factors controlling pollutant removal processes in a wetland include water velocity, water depth and fluctuation, detention time, circulation and distribution patterns, and turbulence and wave action (Steiner and Freeman, 1989). Wetlands that maximize contact between wastewater, substrate, and vegetation will enhance the effectiveness of pollutant removal.

C. MATERIALS AND METHODS

C.1 SITE (SYSTEM) DESCRIPTION

C.1.1 Site Use

The Tompkins County Hillview Road Landfill (formerly known as the Landstrom Landfill) is located east of New York State Routes 34 and 96 on Hillview and Michigan Hollow Roads in the Town of Spencer, Tioga County, and the Town of Danby, Tompkins County, New York (Figure 3-1). Since 1985, the 21.5-hectare landfill has been the sole receptor of all the non-hazardous solid waste from Tompkins County and the town of Spencer, New York. Approximately 6.6×10^4 metric tons per year of residential, commercial, and industrial waste was received at the landfill until its closure in May 1992 (Kenneth Teeter, Resource Engineering, Cortland, New York, written correspondence, 1991). A perimeter leachate collection system is currently in place at the landfill. This system is designed to intercept and collect landfill leachate, which is then stored in a buried tank. The leachate is pumped into trucks and transported to the Ithaca Area Wastewater Treatment Plant for processing.

C.1.2 Climate

The climate of Tompkins County is humid continental with an average annual precipitation of 89.9 cm, based on 30 years of records at the Cornell University weather station in Ithaca, New York (National Oceanic and Atmospheric Administration, 1990). Monthly precipitation is distributed relatively evenly throughout the year and is generally in the form of snow from mid-December to mid-March. The average annual temperature is 7.7°C. Summer temperatures may exceed 32°C and winter temperatures may drop below -22°C.

Figure 3-1. Location of the Tompkins County municipal solid-waste landfill.

C.1.3 Determination of Design Criteria for This Study

At the start of this research, no documented studies had been done in constructed wetlands for landfill leachate treatment. The first step in designing the Tompkins County field site was to evaluate a small-scale system carried out in a greenhouse. Small wetland beds (62-l tubs) were used to determine plant and substrate effects on treatment of leachate (Kopka, 1990). This greenhouse study suggested that constructed wetlands were effective at reducing heavy metals, iron, nutrients, organic carbon, and biochemical oxygen demand (BOD). The results from the greenhouse study were used as a starting point from which to scale up to a field installation.

New York State's regulatory agency, the Department of Environmental Conservation (NYSDEC), required certain items to be included in the project design. A double liner system with leak detection was required. This included a 0.3-m compacted clay liner, a leak detection system, and a high-density polyethylene liner.

As a starting point, retention time was based on decreasing the BOD concentrations to below the 30-mg/l discharge standard for drinking water. A summer average leachate BOD concentration of 120 mg/l and a degradation rate of 8 mg/l/day gave a 15 day retention time. The rooting depth of *Phragmites australis* of approximately 0.6 meters was chosen as the substrate depth. A total volume of 1800 l per day per bed was to be treated, so a length of 30 m and width of 3.5 m was required. The bottom of the beds was minimally sloped (0.5 percent) to facilitate draining the beds. The top slope of the substrate was horizontal to allow for flooding (if required) for weed control.

The height of the water level, the amount of water to be treated, and the length of the bed defined the minimum flow rate and thus the conductivity required for the beds. This conductivity clearly excluded use of a clay matrix as proposed by Dr. Kikuth (Boon, 1986). Clogging had been observed in greenhouse work (Kopka, 1990) as well as in many full-scale subsurface flow systems (Beauchamp and others, 1988). For this study we chose a range of materials, readily available, to be used as substrate.

C.1.4 Construction of Plots

Four wetland plots were constructed at the Tompkins County municipal solid-waste landfill. A clay pad was built by placing 1.2 m of clay down in 15-cm lifts with compaction after each lift. Sand-cone compaction tests were performed after each 15-cm lift and in-place nuclear density tests were performed every second 15-cm lift to verify compaction.

Four beds were sculpted into the clay pad. The beds are 30 m long and 0.8 to 1 m deep. They were constructed in a trapezoidal shape having a depth of 0.8 to 1 m, top width of 3.4 m, bottom width of 2 m, bottom slope of 0.5 percent, and side slope of 45 degrees. A v-notch was excavated at the outlet of each bed to allow for installation of the leak detection pipes and leachate outflow pipes. Each bed was lined with geotextile. This stabilized the excavated beds and prevented mixing of the clay with the leak-detection sand layer described below (Figures 3-2 and 3-3).

A 10-cm, corrugated, perforated sewer drain pipe wrapped in geotextile fabric was installed along the bottom of each bed and covered with 15 cm of sand. The pipes were designed to act as a leak detection system for the high density polyethylene (HDPE) liner. Each pipe was connected to a leak detection riser pipe installed in instrument shelter boxes at the outflow end of each bed.

A 1.5-mm, black HDPE liner was installed, lining two beds as one unit. As a result the berms between the two bed units were covered with the liner also. The liner was welded by heat extrusion and all seams were vacuum tested.

Perforated 10 cm schedule-40 polyvinyl chloride (PVC) pipes were installed across the outflow end of each bed. The pipes were wrapped in geotextile¹ and connected to riser pipes at one end. The riser pipes were installed for sampling treated leachate from each bed and to allow cleaning. The pipes were booted through the HDPE liner and extended into the instrument shelter boxes.

1. This fabric was later removed when it was thought to inhibit leachate flow out of the beds.

Figure 3-2. Plan of constructed-wetland research plots at Tompkins County municipal solid-waste landfill.

Figure 3-3. Cross section of a constructed wetland plot, Tompkins County municipal solid-waste landfill.

A leachate collection system installed around the perimeter of the landfill collects leachate and drains it into two 113-m³ tanks at the base of the landfill. From the tanks it is pumped through approximately 670 m of pressurized PVC pipe at approximately a 2 percent slope, to a coal-tar-epoxy-coated, 7.6-m³ tank at the study site. This tank was installed on a railroad tie platform to allow distribution to the four beds via gravity. The tank is equipped with a three-float system. The low float activates the "call for water" switch and leachate is pumped to the tank. The high float signals the flow to be discontinued. The high-high float acts as a safety feature to discontinue flow to the tank.

A 5-cm PVC pipe runs from the outlet end of the 7.6-m³ tank to a distribution box, where it is split into four separate lines. Each line contains a valve to regulate flow, a water meter to measure inflow, and a solenoid valve. The solenoid valve will shut down flow to a bed during electrical power failure or when failure in the effluent distribution system occurs. If the water level in an outflow tank reaches 1 m and the sump pump has failed to turn on, then the alarm will be activated and flow to the problem bed will be discontinued.

From the distribution box leachate flows into a perforated pipe installed across the head of each bed. Large gravel (2-4 cm in diameter) was placed in the first and last 1.3 m of each bed to allow lateral mobility of the leachate entering and exiting the beds. Bed I was filled with coarse gravel (average diameter 2-4 cm) while Bed IV was filled with pea gravel (average diameter 0.5 cm). Beds II and III were filled with a sand/gravel mixture (average diameter 0.5-1 cm). All of the substrates were largely carbonate materials. Due to the coarse nature of the materials used as substrate, the residence time of the leachate in the beds was controlled by valves on each inflow pipe. A section measuring 1.4-1.5 m long at both the inlet and outlet ends of each bed was filled with coarse gravel to allow for even distribution and drainage of the wastewater. During the spring of 1990, *Phragmites australis* was planted in Beds I, III, and IV, while Bed II was left unplanted as a control. The bed designation, substrate used, grain-size analysis of the substrates, and planting scheme are outlined in Tables 3-1 and 3-2.

<u>Bed No.</u>	<u>Substrate</u>	<u>Vegetation</u>
I	2- to 4-cm gravel	<i>Phragmites australis</i>
II	0.5- to 1-cm gravel mixed with 0.05-cm sand	Unplanted
III	0.5- to 1-cm gravel mixed with 0.05-cm sand	<i>Phragmites australis</i>
IV	0.5-cm (pea) gravel	<i>Phragmites australis</i>

Table 3-1. Bed designation, substrate used, and planting scheme for the constructed wetland research plots, Tompkins County municipal solid-waste landfill.

During substrate placement, 5-cm slotted Teflon™ wells were installed down the midline of each bed (Figure 3-4). The wells are 1 m long, have 0.6 m of slotting, and are capped on the bottom. A total of five wells were installed approximately 6 m apart in each bed. These wells allowed in-plot sampling of field parameters and selected water-quality constituents in order to determine the portion of the bed involved in the treatment process. These wells also provided locations at which to measure the height of the water table.

The treated leachate enters the instrument shelter boxes through the outflow piping previously described. The leachate flows through a PVC valve (to regulate flow), a water meter to measure outflow, and then through a flexible hose. When the valves are open, the water level in each bed corresponds to the height of the flexible hose. Hydraulic controls at the head and foot of each plot maintain continuous subsurface flow.

The leachate exits each instrument shelter box through 10-cm PVC pipes and enters coal-tar-epoxy-coated, 2.8-m³ tanks. When the water level in an individual tank reaches approximately 0.8 m, the sump pump in the tank is activated and the treated leachate is pumped through 5-cm PVC pipe back into the leachate collection system. A pressure transducer, installed in each tank, activates the closure of the influent solenoid valve if water levels exceed 1 m in the tank.

	Bed I	Beds II and III	Bed IV
<u>Size (mm)</u>	<u>(Coarse Gravel)</u>	<u>(Sand and Gravel)</u>	<u>(Pea Gravel)</u>
>38.1	0	0	0
38.1-25.4	1.9	0	0
25.4-19.1	31.3	1.4	0
19.1-12.7	55.5	8.2	1.8
12.7-2.00	10.9	54.1	91.6
2.00-1.00	0	18.5	2.1
1.00-0.425	0	10.8	1.3
0.425-0.250	0	2.5	0.3
0.250-0.106	0	1.6	0.4
0.106-0.075	0	0.5	0.3
<0.075	0.3	2.4	2.2

Table 3-2. Grain-size analysis of three substrates used the in the constructed wetland plots, Tompkins County municipal solid-waste landfill (weight percent in each size range).

Figure 3-4. Layout and designation of constructed wetland in-plot sampling wells, Tompkins County municipal solid-waste landfill.

Leachate applications began in July 1990, with subsurface flow maintained at a rate of 2,000 liters per day per bed and a residence time of 15 days. This flow regime was maintained until October 1991 with only short periods of no flow.

Winterizing the study site was required the year-round functioning of the constructed wetland. Wherever possible pipes, tanks, and boxes were backfilled with a minimum of 1.3 m of soil. The location of the distribution box precluded it from being adequately backfilled; therefore, the sides were covered with 1.25-cm styrofoam sheeting. The distribution box and four instrument shelter boxes were also equipped with infrared heat lamps. The pipes from the distribution box to each bed were equipped with heat tape along the bottom, wrapped in insulation, and then wrapped in plastic.

C.1.5 Vegetation

Rhizomes of *Phragmites australis* with small amounts of native soil and some shoot material attached were planted in April 1990 at a depth of 12-15 cm, just above the free water table. A nominal spacing of 1 m was followed. During the two-month establishment time (May-June), chemical fertilizer at a rate of 10 kg/ha each of N, P, and K was added and the water level in the planted substrates maintained at or just below the rhizomes. Figure 3-5 shows the four constructed wetland beds in October 1991.

C.2 MONITORING

C.2.1 Sampling Methods

C.2.1.1 Sampling Raw Leachate, Pore Water, and Treated Leachate

All pore-water wells and outflow wells were sampled with a Teflon™ bailer dedicated to the project. Each well was bailed sufficiently to insure that the sample represented a fresh pore-water source. Prior to sample collection, the Teflon™ bailer was (1) washed thoroughly with a glassware soap solution and a stiff brush, (2) rinsed with tap water, and (3) rinsed with deionized water. A separate Teflon™ bailer, used only for sampling organic constituents, was (1) washed

Figure 3-5. Constructed wetland beds, Tompkins County municipal solid-waste landfill, October 1991. *Top*, Beds I and II; *Bottom*, Beds III and IV.

thoroughly with a glassware soap solution and a stiff brush, (2) rinsed with tap water, (3) rinsed with methanol, and (4) rinsed with ultrapure, water free of organic contaminants (provided by Cornell University's Geneva Experiment Station Laboratory). In the field, the bailer and bailing rope were rinsed thoroughly with deionized water (or ultrapure water in the case of sampling for organics) between samples. The bailer and each collection bottle were rinsed two to three times with sample water prior to actual sample collection.

Samples were collected in appropriately cleaned sample bottles. After the samples had been collected, those that required filtration were immediately filtered and the appropriate preservative was added. The bottles were chilled in ice. See Table 3-3 for the required bottles, volumes, preservatives, and filtering scheme for each constituent. Sample bottles used to collect the volatile organic compounds (VOC) samples were filled so that a meniscus formed at the mouth of the sample bottles. Two duplicate VOC samples, one field spike sample, and one sample for a laboratory spike were collected per sampling site in 40-ml amber glass vials. The caps were attached so that no bubbles or headspace were present.

All required filtration was done in the field. Nutrient, alkalinity, biochemical oxygen demand (BOD), and metal samples were filtered through a 0.45- μ m cellulose membrane filter. A peristaltic pump was used to push the sample through the filter. Dissolved organic carbon (DOC) required vacuum filtration through a 0.45- μ m silver filter. The filtration setups were washed with a glassware soap solution and rinsed first with tap water, then deionized water prior to use. Approximately 500 ml of sample were filtered through the system; this filtered portion was used to rinse the filter flask and sample bottles. A sufficient volume for analysis was then filtered. Between samples, the filtration setups were rinsed with deionized water.

Table 3-3. Bottles, volumes, preservatives, and filtering scheme for each constituent analyzed at Tompkins County municipal solid-waste landfill.

<u>Constituent</u>	<u>Volume</u>	<u>Preservative</u>	<u>Bottle</u>	<u>Filter Used</u>
NO ₃ , NO ₂ , P, orthophosphate, NH ₄	250 ml	H ₂ SO ₄ (pH<2)	brown plastic	0.45 µm, cellulose membrane
<u>Metals</u> (Al, Ba, B, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Ag, K, Na, Se, Zn, Hg)	250 ml	HNO ₃ (pH<2)	acid-rinsed clear plastic	0.45 µm, cellulose membrane
Dissolved Organic Carbon (DOC)	250 ml	Cool, 4°C	amber glass	0.45 µm, silver
Volatile Organic Compounds (VOC)	40 ml	Cool, 4°C	amber glass septum vial with Teflon cap liner	none (no air)
Sulfate	250 ml	Cool, 4°C	clear plastic	0.45 µm, cellulose membrane
BOD(5-day)	100 ml	Cool, 4°C	clear plastic	none

Each sample bottle was labeled with the following information:

- 1) a unique sample identification number,
- 2) the date and time of sampling,
- 3) constituents to be analyzed,
- 4) preservatives added, and
- 5) the sampler's initials.

Preprinted labels (Figure 3-6) were used to facilitate sample labeling.

For each batch of samples, one duplicate sample, one blank, and one standard reference sample were submitted for analysis. A random duplicate sample was collected with care being taken to obtain as near a duplicate as possible. Sufficient volumes were submitted to the analyzing lab so that split sampling could be done. Preservation blanks were submitted for analysis and consisted of deionized water with the sample quantity of preservative as normally would be added to the leachate samples. Standard reference samples for nutrients and trace metals were provided by the U.S. Geological Survey in Lakewood, Colorado, and were submitted with each batch of samples.

A chain-of-custody program was maintained. The program began with sample collection. Each time a batch of samples was collected, a form was initiated stating where and when the samples were collected, with a cross reference to a number on each sample container (Figure 3-7). The sample collector delivered the samples directly to the responsible person in the laboratory. The person receiving the samples in turn signed the batch ledger to acknowledge receipt of the samples. Proper disposal of the samples was noted on the ledger. These forms were returned to the U.S. Geological Survey to maintain proof of a chain-of custody.

LANDFILL LEACHATE PROJECT/USGS
INFLOW /OUTFLOW 1 2 3 4
UNIQUE NO: _____ BY: _____
DATE: _____ TIME: _____
METALS--8 OZ ACID RINSED BOTTLE
(FILTER, HNO₃ TO pH < 2)

Figure 3-6. Example of labels used in sample identification.

(Please Return form upon disposal of batch to:
U.S. Geological Survey, 521 W. Seneca St., Ithaca, NY 14850)

Figure 3-7. Chain-of-custody form used for sample tracking.

C.2.1.2 Plant-tissue Sampling

The standing crop of the *Phragmites australis* plants was sampled from five quadrats, 25 cm on each side, from each of the planted beds. A native stand of *Phragmites australis*, growing at the Cornell University Pond and Marsh Facility in Ithaca, NY, was also sampled as a control. All living plant material was removed from the quadrat; carefully washed with deionized water; sorted by roots, shoots, and rhizomes, dried at 80°C for 48 hours, and dry weights were recorded. All samples were subsequently ground to a fine powder in a Wiley mill for chemical analysis.

C.2.1.3 Substrate Sampling

Substrate samples were collected and analyzed before leachate application in June 1989 to determine the natural concentration of surficial metals, as well as in October 1990 and July 1991 after application of the leachate. Approximately 2 to 3 kg of bed material was initially sampled at 9, 15, and 21 m from the entry point of the leachate in each bed. Subsequent sampling included bed material 27 m from the leachate entry point.

C.2.1.4 Precipitation Measurements

A tipping-bucket rain gauge connected to pulse recorder was installed on the site to record precipitation. The rain gauge was mounted on a wooden pallet and was heated for winter use. The pulse recorder registered instantaneous precipitation and allowed calculation of cumulative precipitation. A wind screen was installed around the rain gauge to prevent bias from wind turbulence around the opening of the gauge. Evapotranspiration (ET) was calculated from the equation

$$ET = \text{Inflow} + \text{precipitation} - \text{outflow}$$

Change in storage was assumed to be equal to 0. General climatic and hydrologic conditions for the period of study are shown in Table 3-4.

Table 3-4. Air temperature and precipitation at Tompkins County municipal solid-waste landfill, plus pore-water mean temperature and evapotranspiration at four constructed-wetland research plots, 1990-91.
(Temperature is expressed in degrees Celsius; precipitation and evapotranspiration in centimeters.)

Characteristic	Season		
	Summer (July 27 - Oct. 9, 1990)	Winter (Oct. 10, 1990 - Apr. 30, 1991)	Summer (May 1 - Aug. 1, 1991)
Landfill vicinity			
Air temperature (mean high)	22.7	7.5	25.6
Precipitation	23.8	64.3	26.9
Bed I (coarse gravel, planted)			
Pore-water mean temperature	19.9	7.2	22.1
Evapotranspiration	29.8	20.9	48.5
Bed II (sand and gravel, unplanted)			
Pore-water mean temperature	19.5	6.4	22.0
Evapotranspiration	28.7	4.2	29.2
Bed III (sand and gravel, planted)			
Pore-water mean temperature	20.4	6.6	21.8
Evapotranspiration	24.7	3.5	22.1
Bed IV (pea gravel, planted)			
Pore-water mean temperature	20.2	7.3	22.8
Evapotranspiration	11.1	20.9	28.1

C.2.2 Field Measurements

C.2.2.1 Water Quality

Field measurements of dissolved oxygen (DO), pH, temperature, and specific conductance (SC) of raw leachate and outflow from the four beds were taken biweekly and were recorded on project field forms (Figures 8). Oxygen was determined using a Yellow Springs Instrument 54A meter and electrode with appropriate temperature correction. The pH was determined using an Orion meter by standard methods (American Public Health Association, 1985). Specific conductance and temperature were determined using a Yellow Springs Instrument analog conductivity meter, corrected to 25°C. Calibrations for each instrument were recorded in a bound field notebook. Measurements on the pore water from the five wells in each bed were taken monthly. Platinum redox electrodes (Mueller and others, 1985) were placed at two locations in each bed at depths of 15 and 30 cm, and pore-water redox potentials were measured biweekly along with pore-water pH.

C.2.2.2 Hydraulic Conductivity

The primary objective of this portion of the project was the development of an experimental procedure for determining the saturated hydraulic conductivity of each constructed wetland bed that was relatively simple, yet provided sufficient information. The procedure needed also to fit the constraints provided by the fixed geometry of the beds.

The basic experiment was to drain each bed and record the cumulative outflow volume while measuring the water table height in the five monitoring wells at various times. First, the inflow and outflow valves were closed in order to try to achieve an initial water table shape that was horizontal. The riser pipe in the drain system, which is located downstream from the valve (Figure 3-3) and controls the depth of the water above the drain was lowered to below the drain elevation. The initial elevation of the water in each in-plot well were recorded. At time=0, the outlet valve was opened; the cumulative drainage volume and water table heights were recorded at various times during the drainage.

Tompkins County Landfill Leachate Project

(17000)

Inflow / Outflow 1 2 3 4

2	199			
Med	Year	Month	Day	Time

Temp.= SC= DO= pH= Bar(mm/hg)=
(P00010) (P00095) (P00300) (P00400) (P00025)

Alk FEP= Carb Alk= HCO3=
(P00410) (P99430) (P99440)

In Bed Sampling

Inflow	A	B	C	D	E
Time					
Temp.					
DO					
pH					
SC					
Unique No.					

Unique No.	Bottle Type	Label	Treatment	Constituent
-N	8 oz brown	FC	Filter, H2SO4, Chill	Nutrients
-M	8 oz acid	FA	Filter, HNO3 to pH < 2	Metals
-S	2 oz regular	FU	Filter, Untreated	SO4
-D	4 oz glass	DOC	Silver filter, Chill	Diss organics
	16 oz reg	BOD	Untreated, Chill	O2 Demand

Figure 3-8. Field form used for recording sampling information and field analysis of pH, specific conductance, dissolved oxygen, and alkalinity, Tompkins County municipal solid-waste landfill.

Accumeter: _____ @ _____
(gallons) (time)

Raingage Interrogated: Yes / No File name: _____

Weather: _____

Remarks: _____

pH Probe Type: _____

Hach Titrator No: _____

pH Meter No: _____

Titrant Lot No: _____

*****Use filtered sample*****

Sample volume: _____ ml

Sample volume: _____ ml

Titrant: _____ N

Titrant: _____ N

Run 1

Run 2

Counter	pH	Counter	pH

Counter	pH	Counter	pH

Figure 3-8. (continued).

The hydraulic conductivity of the bed was determined by two methods. One method consisted of modeling the outflow data using the model developed by Sanford (1992) for the prediction of the cumulative drainage volume from hill slopes. The other method used Darcy's Law to measure the hydraulic conductivity of the constructed wetland segments between each monitoring well.

C.2.2.2.1. Hillslope Method. The model used to determine the hydraulic conductivity for each experiment was derived by Sanford (1992) and is based on the Boussinesq approximation for flow in porous media overlying a sloping impermeable layer. The resulting equation is

$$V = V^* \left\{ \frac{1 - \exp \left[-t \frac{3 h(0,0) K_s \cos \beta}{s L^2} \left(1 - \frac{V^*}{V_i} \right) \right]}{1 - \frac{V^*}{V_i} \exp \left[-t \frac{3 h(0,0) K_s \cos \beta}{s L^2} \left(1 - \frac{V^*}{V_i} \right) \right]} \right\} \quad (1)$$

where

$$V_i = s w L h(0,0) \quad (2)$$

$$V^* = s w L [h(0,0) - h(0,t)] + \frac{1}{2} s w L^2 \tan \beta \quad (3)$$

and

V = cumulative drainage volume at any time [cm^3]

s = drainable porosity [cm^3/cm^3]

t = time at which drainage volume is calculated [s]

β = slope of impermeable layer [cm/cm]

L = length of bed [cm]

w = width of bed [cm]

K_s = saturated hydraulic conductivity [cm/s]

$h(0,0)$ = height of water table at $x = 0$ and $t = 0$ [cm]

$h(0,t)$ = height of the water table at $x = 0$ and $t > 0$ [cm].

In equation (3), the first term on the right ($s w L[h(0,0) - h(0,t)]$) represents the potential volume of water which can drain from the system due to the drawdown of the water table at $x = 0$. The second term on the right ($\frac{1}{2} s w L^2 \tan\beta$), represents the potential volume of water that can drain due to the initial slope of the water table .

The only unknown in the above equation, when applied to the drainage experiments, is the value of K_g . A range of values of conductivity are used in equation (1) until the predicted outflow curve fits the actual outflow curve. The value of K_g that produces the best fit to the actual data is the hydraulic conductivity of the substrate for that particular drainage experiment.

The application of equation (1) to determine the hydraulic conductivity of the various substrates is straightforward. All the geometry variables (length, width, and slope) are known for each bed. The drainable porosity of the matrix (s) was measured by dividing the total amount of water that drained during the course of the experiment by the total volume of substrate that drained. For the two sand-and-gravel beds a slightly different procedure was followed because of the large differences in drainable porosity and permeability between the gravel segments at both ends of the bed and the sand-and-gravel substrate in which the water table was measured. As a result of these differences, it was necessary to account for the volume of water drained from the coarse gravel segment at the outlet end of the beds. This was done by estimating the initial volume of water in the coarse gravel segment and subtracting this volume from all points on the curve of cumulative drainage volume versus time. The first 75 to 90 minutes of the drainage curves were ignored because during this time the drainage from the more permeable gravel dominated the outflow. The length of the coarse gravel segment was subtracted from the total length of the bed.

To apply equation (1), it was necessary to know the elevation of the water table directly above the drain. In the pea gravel, this elevation is assumed to be the same as that measured in Well A (the well nearest the drain). The water table height above the drain in the two sand-and-gravel beds was assumed to be 0 at all times since the coarse gravel segment drains much faster than the sand-and-gravel matrix.

Once these various corrections are made, the hydraulic conductivity of the substrates for each experiment is calculated using equation (1). Comparing the conductivities for each substrate

at different times shows the changes that have occurred over time.

C.2.2.2.2 Darcy's Law Method. The second method for measuring saturated hydraulic conductivity uses the water table height information recorded in each of the five monitoring wells (Figure 3-4). The volume of substrate drained during the time period between measurements of the water height can be determined for the entire bed and for the segments between each well. The volume of water flowing past each well during the time between measurements can be estimated by multiplying the total volume of substrate drained upslope of the well by the drainable porosity. Since the elevation differences of the water table between adjacent wells are known, the hydraulic conductivity of the segment between each well can then be found using Darcy's Law,

$$K_s = \frac{Q_i L}{A (H_i - H_o)} \quad (4)$$

where K_s = saturated hydraulic conductivity,
 Q_i = inflow rate,
 L = length of the measuring section,
 A = cross-sectional area,
and $[H_i - H_o]$ = difference in water level between the inflow and outflow;

This technique involves the collection of more data than desired and requires more skill in interpreting the data than the hillslope modeling method described above, but the results act as a check.

C.2.2.2.3 Timing of Experiments

The drainage experiments were performed on all beds five times over a period of 26 months in order to determine the changes in conductivity that had occurred (Table 3-5). The first experiment was run in the summer of 1989, when the reeds had been planted but no significant growth had occurred. The only water in the beds at this time was rainwater or water pumped in from a nearby ditch. The second experiment was run in the fall of 1989 after the reeds had

experienced one growing season. Again, the beds had yet to have any leachate added. The third experiment was run in the spring of 1990 after the plants had gone through a winter and had begun new growth. This experiment was the last performed before the addition of leachate in June 1990. The fourth drainage experiment was run in the spring of 1991 after the first winter of leachate addition, soon after the plants had begun their new growth for the year. The final experiment was performed in the fall of 1991. At this time the beds had received nearly a full season of leachate. Just prior to the final drainage experiment, the four beds were flushed with fresh water, which was done as part of the following tracer experiment.

C.2.2.2.4 Tracer Experiment

Saturated hydraulic conductivity measurements during the two and a half years prior to the tracer experiment found that the sand-and-gravel beds were largely clogged. This will be discussed in depth in the results section of this report (Section D.3). The planted pea gravel in Bed IV experienced a decrease in hydraulic conductivity, but the lowest value of 40 cm/min was adequate to maintain subsurface flow. No changes in hydraulic conductivity in the planted coarse gravel substrate of Bed I were measured. The measured reductions in hydraulic conductivity raised questions as to how the lowered permeability affects the residence time and whether the water flows preferentially through certain portions of the substrate.

To examine if preferential flow occurs, a tracer experiment was performed. A tracer is normally added in the inflow water, and its concentration is measured in the effluent. By using the outflow concentration in the convective-dispersive equation, an average residence time may be calculated for the tracer.. If the tracer moves through the system more quickly than the "design" residence time, it will prove that preferential flow is occurring in some portion of the system.

The major problem encountered in designing the tracer experiment was selecting which tracer would be the best to use in conjunction with the chemicals present in the leachate. The leachate in the bed had a very high chloride concentration (around 1,000 mg/l) and correspondingly high specific conductance (6000 to 8000 $\mu\text{S}/\text{cm}$), which precluded the use of a nonadsorbed anion

Table 3-5. Water heights above the drain [h(0,0)], drainable porosities (s), and volume corrections for all drainage experiments.

TIME OF EXPERIMENT	<u>PEA GRAVEL</u>		<u>COARSE GRAVEL</u>	
	h(0,0) (m)	s	h(0,0) (m)	s
SUMMER 1989	0.67	0.33	NA*	0.36
FALL 1989	0.67	0.34	NA	0.38
SPRING 1990	0.73	0.33	NA	0.36
LEACHATE ADDITION BEGUN SUMMER 1990				
SPRING 1991	0.63	0.37	NA	0.36
FALL 1991	0.71	0.27	NA	0.33

TIME OF EXPERIMENT	<u>UNPLANTED SAND AND GRAVEL</u>				<u>PLANTED SAND AND GRAVEL</u>			
	h(0,0) (m)	s	V _g [†] (m ³)	V _p [‡] (m ³)	h(0,0) (m)	s	V _g (m ³)	V _p (m ³)
SUMMER 1989	0.65	0.14	1.0	0.2	0.67	0.12	1.1	0.0
FALL 1989	0.63	0.16	1.3	0.0	0.68	0.17	0.5	0.4
SPRING 1990	0.46	0.19	0.6	0.3	0.63	0.12	0.8	0.2
LEACHATE ADDITION BEGUN SUMMER 1990								
SPRING 1991	0.53	0.10	0.6	0.7	0.60	0.09	NA	NA
FALL 1991	0.58	NA	NA	NA	0.66	0.05	0.6	0.15

* Not applicable

† Volume of water in coarse gravel

‡ Volume of water in initial profile above the top of the substrate

(Cl⁻ or Br⁻) as the tracer. Because of this problem, clean water was chosen as a tracer. The clean water (chloride concentrations near 0 mg/l and specific conductance near 0 µS/cm) traveled through the beds causing measurable dilutions in the leachate chloride concentration. This had the additional advantage of providing information about the time frame for cleaning out the bed (a practice which may increase the hydraulic conductivity) could be obtained. The fresh water was added by filling the feed tank once a day using a fire tanker for two weeks. During the time of the dilution experiment, influent and effluent samples were collected and analyzed for Cl⁻, and the inflow and outflow volumes were recorded. Effluent was collected using an automatic sampler. Each sample consisted of a composite of four subsamples collected at 1.5 hour intervals.

Prior to the beginning of the dilution experiment, outflow samples were collected for one week during normal operations. These samples were used to determine the flow pattern and the background concentrations of chloride in the effluent.

To provide further information on how wastewater flows through the substrate, the specific conductance of the leachate in the subsurface was measured at intervals of 7.6 cm beneath the water surface in each of the five inplot wells. Specific conductance measurements were also taken prior to the dilution experiment to determine if the wastewater underwent any stratification within the substrate during normal operations. Progressively higher specific conductance values (density increases with increasing specific conductance) with depth would indicate stratification within the substrate.

C.2.3 Analytical Methods

C.2.3.1 Water Samples

All biweekly leachate samples were analyzed for nutrients, metals, and organic carbon by Cornell University Soil, Crops, and Atmospheric Sciences Department's Nutrients Analysis Laboratory. Nitrate (NO₃⁻), ammonium (NH₄⁺), and total soluble phosphate (PO₄⁻³) were analyzed colorimetrically according to U.S. Environmental Protection Agency (1979) guidelines. The Fe(III)/Fe(II) iron couple was measured using a modification of the technique used by Stucki

(1981), which allows determination of total iron and Fe(II) in solution as an Fe-orthophenanthroline complex with photoreduction of Fe(III) to Fe(II). Organic carbon was measured with a carbon analyzer, which oxidizes carbon compounds in the water to carbon dioxide (CO_2) and then reduces the CO_2 to methane (CH_4) for detection (American Public Health Association, 1985). BOD was determined by standard methods (American Public Health Association, 1985). Alkalinity was determined in the field by using a potentiometric titration with sulfuric acid (H_2SO_4) at a concentration of 1.6 N (American Public Health Association, 1985). Platinum redox electrodes were placed at depths of 15 and 45 cm at two locations in each bed for biweekly measurement of pore-water redox potentials (Mueller and others, 1985). Each redox potential was converted to standard conditions by adding 244 millivolts to the reading. All other elements in water were determined by inductively coupled plasma (ICP) spectrometry (American Public Health Association, 1985).

Mean values of water quality data were used to calculate loading of constituents into and out of the beds. For data sets that contained values below the detection limits (frequently at more than one reporting limit), the mean was estimated by the log-probability regression method of Helsel and Cohn, 1988.

C.2.3.2 Plant-tissue Samples

Shoot counts in each bed were taken monthly in three previously established meter-square quadrats, and mean values reported for each planted bed. On September 20, 1991 (before first frost), biomass estimates were made by removing all living plant material from five three meter-square quadrats established at the beginning of the project in each bed. Samples were divided into roots, rhizomes, and shoots; these were washed carefully in tap water and dried at 80°C for over 48 hours, and mean dry weight determined for each tissue type. All samples were ground to a powder (fine enough to pass through a 40-mesh screen) in a Wiley mill for chemical analysis.

Nitrogen in plant tissue was determined by the Kjeldahl method. For other elements, subsamples were ashed overnight in quartz crucibles at 500°C , treated with nitric acid (HNO_3), dried, heated to 400°C , and cooled. The residue was dissolved in 1-M hydrochloric acid (HCl),

diluted, and tissue elements analyzed by ICP spectroscopy.

Fresh roots and rhizomes were cut into 1-mm sections in preparation for electron microscopy. They were immediately plunged into liquid propane to freeze them, and freeze-dried overnight. Individual sections were mounted on scanning stubs and coated with gold.

Samples were analyzed and scanned using an AMR-100A scanning electron microscope and the Tracer Northern TN-2000 X-ray attachments.

C.2.3.3 Substrate Samples

Don Siegel (Syracuse University Geology Department) evaluated two processes of metal-sediment bonding: metals bound to the carbonate sediment by loose surficial bonds, and metals bound by organics. From each bulk sample of substrate, a subsample of approximately 200 grams was taken for analysis. Metals for which solutions were analyzed were potassium (K), iron (Fe), aluminum (Al), chromium (Cr), strontium (Sr), manganese (Mn), barium (Ba), copper (Cu), nickel (Ni), zinc (Zn), and lead (Pb).

The sequential extractions were done by immersing the samples in two reagents, the first to release metals weakly adsorbed to sediment surfaces (Robinson, 1985) and the second to release metals bound to organic matter (Anderson, 1963). A major difficulty was encountered because the substrate consisted of limestone rather than soils containing aluminosilicate minerals and clays. Virtually all widely used sequential extraction procedures have been developed for soils with high proportions of clay minerals, sesquioxides, and silicate minerals, all of which have substantial cation exchange and sorptive capacities. Purely carbonate soils have never been investigated for potential metal sorption because of their small surface charges relative to the aluminosilicate minerals more commonly found in soils. Consequently, standard procedures had to be modified to insure that organically bound and weakly sorbed metals could be distinguished from the metals in the carbonate minerals themselves (Donald Siegel, written communication, 1992).

To remove weakly adsorbed metals, a 0.1 M solution was prepared of ammonium citrate $[(\text{NH}_4)_3\text{C}_6\text{H}_5\text{O}_7]$, adjusted to pH of 8.4 with ammonium hydroxide (NH_4OH). 200-mg samples

were immersed in a known weight of this solution for 20 minutes at room temperature. The ammonium citrate solutions were then filtered through a 0.455-micron-pore filter and saved for later analysis. The samples were washed with deionized water after filtering to remove all of the ammonium citrate and to retain all of the fine material for the next extraction. A substantial amount of silt-to-clay-sized carbonate particles, a by-product of the crushing process, occurs in the sediments used as the substrate. This finer-grained material has a surface area that is greater by orders of magnitude than an equal weight of the coarse material, and consequently has a greater tendency for possible sorption (Donald Siegel, written communication, 1992).

The remaining fine material was then analyzed for metals bound to organic matter. The common method used to destroy organic matter to release organically-bound metals is to use a hydrogen peroxide (H_2O_2)-nitric acid (HNO_3) mixture. This combination of reagents, however, produced a low pH, which dissolved the limestone. Consequently, an alkaline reagent mixture had to be used. The reagent mixture consisted of a sodium hypochlorite (NaOCl) solution adjusted to a pH of 9.5 immediately prior to use. After the ammonium citrate extraction, the same samples were immersed in known weights of the sodium hypochlorite solution and heated to boiling for 15 minutes to oxidize the organic matter. The reagent was then filtered and retained for later metal analysis (Donald Siegel, written communication, 1992).

Metal concentrations were analyzed by direct-current plasma emission spectroscopy. Reagent blanks were used to correct for possible reagent interferences. Metal concentrations were then expressed as milligrams of metal bound per gram of sample, after appropriate dilution corrections were made.

D. RESULTS AND DISCUSSION

D.1 CONSTITUENT LOAD REDUCTION

Concentrations of selected constituents in untreated leachate, and their total load and percent decrease in load after leachate moved through the four beds over an approximately 15-day residence time, are given in Table 4-1. Comparison among the columns indicates the effects on load decrease of the substrate type, the presence or absence of plants, and the season. The untreated leachate, treated leachate water, and in-plot pore water were sampled for a number of metals and nutrient; the results are included in Appendices A and B respectively. Select constituents, including metals such as Fe and Mn and nutrients such as NH_4^+ , K^+ , and P, that were consistently above detection limits and of general interest will be discussed in this section.

Dissolved oxygen values in the leachate were recorded throughout the study. Values never exceeded 1.1 mg/l, which was below the minimum detection limit of the meter used. Growth conditions in the root zone were anaerobic (having a redox potential of -200 to -250 mv as shown in Figure 4-1), saturated with leachate at a mean pH of 7.2.

Organic compounds present in the leachate (mainly petroleum by-products and phenols) are of concern in the use of constructed wetlands for leachate treatment. Volatile organic compounds (VOC) were sampled for twice during the study, but interference with the analytical technique by the leachate matrix required us to forgo VOC analysis and subsequent discussion.

D.1.1 Effect of Precipitation

The daily precipitation at the Tompkins County municipal solid-waste landfill from July 13, 1990, through October 17, 1991, is shown in Table 4-2. Precipitation diluted the untreated leachate that was applied to the constructed wetlands. Therefore a water balance was calculated for the entire system so removal of constituent chemicals could be evaluated by their total load reduction. Inflow, outflow, precipitation, and evapotranspiration volumes for each of four constructed wetland beds are included in Appendix C.

Table 4-1. Total applications and mean percent decreases in (A) chemical loads and in (B) volume of leachate, flowing through constructed wetland research plots at Tompkins County municipal solid-waste landfill, 1990-91. (Numbers in parentheses are standard error: standard error = standard deviation/ $\sqrt{n}$. pH is given in standard units, specific conductance in μ siemens at 25°C; all other concentrations are in mg/l. Loads are given in Kg.)

A. CONSTITUENTS	Concentration in untreated leachate			BED I Coarse gravel, planted		BED II Sand and gravel, unplanted		BED III Sand and gravel, planted		BED IV Pea gravel, planted	
	Max.	Min.	Mean	Total load ^a applied	Mean percent decrease	Total load ^a applied	Mean percent decrease	Total load ^a applied	Mean percent decrease	Total load ^a applied	Mean average decrease
pH											
Jul 13-Oct 9, 1990	7.38	7.17	7.28(0.04)								
Oct 10, 1990-Apr 30, 1991 ^b	7.24	6.80	7.10(0.07)								
May 1-Aug 1, 1991	7.85	7.08	7.34(0.11)								
Sept 20-Oct 17, 1991	7.42	7.38	7.40(0.02)								
Specific Conductance											
Jul 13-Oct 9, 1990	8430	6810	7480(215)								
Oct 10, 1990-Apr 30, 1991 ^b	5930	4460	5380(246)								
May 1-Aug 1, 1991	8300	6740	7390(289)								
Sept 20-Oct 17, 1991	7590	5010	6300(1290)								
NH₄⁺											
Jul 13-Oct 9, 1990	380	268	320(14.6)	49.6(2.27)	19.8	50.7(2.31)	66.8	45.6(2.08)	72.5	27.6(1.26)	34.3
Oct 10, 1990-Apr 30, 1991 ^b	223	146	184(11.9)	36.4(2.36)	1.5	35.3(2.28)	-22.0	39.8(2.58)	-45.4	42.7(2.76)	19.9
May 1-Aug 1, 1991	393	234	312(25.6)	40.1(3.28)	52.5	42.6(3.49)	66.3	32.1(2.63)	69.1	40.1(3.28)	37.9
Sept 20-Oct 17, 1991	335	241	288(47.0)	19.6(3.20)	72.6	26.9(4.38)	54.0	21.0(3.43)	65.7	20.4(3.32)	65.0
K											
Jul 13-Oct 9, 1990	401	281	322(17.0)	50.1(2.65)	19.9	51.1(2.70)	53.3	46.0(2.43)	63.0	27.9(1.47)	31.0
Oct 10, 1990-Apr 30, 1991 ^b	210	161	182(8.45)	36.1(1.68)	-3.2	35.0(1.62)	-47.8	39.5(1.83)	-76.1	42.4(1.96)	14.6
May 1-Aug 1, 1991	1070	225	545(128)	70.0(16.4)	55.6	74.4(17.5)	54.2	56.0(13.2)	48.6	70.0(16.4)	32.6
Sept 20-Oct 17, 1991	277	235	256(21.0)	17.4(1.43)	71.2	23.9(1.96)	39.8	18.7(1.53)	50.7	18.1(1.48)	51.4

^a Total load is load (kg) of constituent entering the bed during the period listed.

^b No flow from January 10 through March 16, 1991.

^c No mean value available

Table 4-1.—Continued.

A. CONSTITUENTS	Concentration in untreated leachate			BED I Coarse gravel, planted		BED II Sand and gravel, unplanted		BED III Sand and gravel, planted		BED IV Pea gravel, planted	
	Max.	Min.	Mean	Total ^a load applied	Mean percent decrease	Total ^a load applied	Mean percent decrease	Total ^a load applied	Mean percent decrease	Total ^a load applied	Mean average decrease
Total Fe											
Jul 13-Oct 9, 1990	12.8	1.55	4.29(1.88)	0.67(0.293)	27.8	0.68(0.299)	96.1	0.61(0.269)	96.5	0.37(0.163)	89.8
Oct 10, 1990-Apr 30, 1991 ^b	24.0	4.29	9.60(3.00)	1.90(0.595)	-41.1	1.84(0.577)	55.8	2.07(0.651)	31.4	2.22(0.698)	15.1
May 1-Aug 1, 1991	4.65	1.60	2.48(0.456)	0.32(0.059)	-26.7	0.34(0.062)	76.7	0.26(0.047)	49.9	0.32(0.059)	-24.8
Sept 20-Oct 17, 1991	2.42	0.89	1.66(0.765)	0.11(0.052)	65.7	0.15(0.071)	84.1	0.12(0.056)	90.3	0.12(0.054)	78.8
Mn											
Jul 13-Oct 9, 1990	2.25	1.00	1.73(0.180)	0.27(0.028)	21.7	0.27(0.029)	76.7	0.25(0.026)	73.6	0.15(0.016)	28.7
Oct 10, 1990-Apr 30, 1991 ^b	8.50	2.66	4.50(0.847)	0.90(0.168)	2.5	0.87(0.163)	62.3	0.98(0.184)	42.0	1.05(0.197)	17.8
May 1-Aug 1, 1991	3.47	0.55	1.59(0.422)	0.20(0.054)	28.1	0.22(0.058)	83.9	0.16(0.043)	75.9	0.20(0.054)	5.8
Sept 20-Oct 17, 1991	0.97	0.85	0.91(0.060)	0.06(0.004)	47.4	0.085(0.006)	72.5	0.066(0.004)	74.7	0.064(0.004)	0.5
Biochemical Oxygen Demand											
Jul 13-Oct 9, 1990	168	89.2	118 (13.1)	18.3(2.03)	48.4	18.7(2.07)	63.4	16.8(1.87)	62.2	10.2(1.13)	58.5
Oct 10, 1990-Apr 30, 1991 ^b	315	266	292(7.38)	57.9(1.46)	-8.3	56.1(1.42)	7.9	63.3(1.60)	-41.6	68.0(1.72)	24.2
May 1-Aug 1, 1991	301	45.5	118 (38.7)	15.2(4.97)	34.4	16.1(5.29)	30.3	12.2(3.98)	43.4	15.2(4.98)	24.8
Sept 20-Oct 17, 1991	298	103	201(97.5)	13.6(6.63)	89.2	18.7(9.09)	89.2	14.6(7.12)	89.5	14.2(6.89)	87.2
Organic Carbon											
Jul 13-Oct 9, 1990	866	130	435(122)	67.6(18.9)	-17.6	69.1(19.3)	14.8	62.2(17.4)	40.5	37.6(10.5)	23.9
Oct 10, 1990-Apr 30, 1991 ^b	662	232	345(64.8)	68.5(12.9)	0.2	66.4(12.5)	-5.5	74.9(14.1)	-37.4	80.3(15.1)	-10.8
May 1-Aug 1, 1991	494	269	371(33.3)	47.6(4.28)	35.5	50.6(4.54)	33.5	38.1(3.42)	27.4	47.7(4.28)	6.7
Sept 20-Oct 17, 1991	388	378	383(4.95)	26.1(0.337)	68.5	35.8(0.462)	30.3	28.0(0.362)	38.4	27.1(0.350)	42.6
P											
Jul 13-Oct 9, 1990	0.52	0.16	0.27(0.060)	0.042(0.009)	28.1	0.043(0.010)	73.4	0.039(0.009)	74.6	0.023(0.005)	62.0
Oct 10, 1990-Apr 30, 1991 ^b	0.13	0.03	0.10(0.014)	0.016(0.003)	-60.0	0.015(0.003)	-3.4	0.017(0.003)	-34.8	0.018(0.003)	41.7
May 1-Aug 1, 1991	0.35	0.08	0.17(0.042)	0.022(0.005)	59.6	0.023(0.006)	63.7	0.017(0.004)	75.2	0.022(0.005)	68.4
Sept 20-Oct 17, 1991	0.06	<0.02	0.06(---)	0.004(0.000)	75.3	0.006(0.000)	64.6	0.004(0.000)	56.5	0.004(0.000)	67.2
B. LEACHATE VOLUME											
Jul 13-Oct 9, 1990					27.8		20.8		23.2		39.5
Oct 10, 1990-Apr 30, 1991 ^b					0.0		0.0		0.0		0.0
May 1-Aug 1, 1991					26.4		7.5		0.0		0.0
Sept 20-Oct 17, 1991					--- ^c		26.0		26.9		48.8

^a Total load is load (kg) of constituent entering the bed during the period listed.^b No flow from January 10 through March 16, 1991.^c No mean value available

Figure 4-1. Mean redox potential at depths of 15 cm and 30 cm in four constructed wetland beds at Tompkins County municipal solid-waste landfill, 1990-91.

Table 4-2. Daily precipitation (in cm) at Tompkins County municipal solid-waste landfill, July 1990 through October 1991.

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1	0.38	0.48	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.56	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.08	0.00	0.00	0.28
3	0.00	0.00	0.08	0.00	0.00	0.00	0.03	0.00	1.42	0.00	0.00	0.00	0.00	0.69	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	3.05	0.00	0.00	1.04	0.00	0.00	0.58	0.41	0.00	0.41	0.25
5	0.05	0.10	0.00	2.13	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	1.57	0.00	0.00	0.03
6	0.58	2.13	0.79	0.00	0.79	0.00	0.05	0.48	0.00	0.23	1.07	0.00	0.97	0.08	0.05	1.02
7	0.30	0.03	0.30	0.00	0.00	0.00	0.03	0.43	0.00	0.00	0.00	0.00	3.45	0.00	0.00	0.00
8	0.00	0.03	0.05	0.03	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
9	0.69	0.00	0.00	0.05	0.05	0.00	0.05	0.00	0.00	0.10	0.13	0.00	0.00	1.35	0.00	0.00
10	0.00	0.00	0.89	0.64	1.91	0.00	0.00	0.00	0.00	0.03	0.18	0.00	0.00	1.09	0.00	0.00
11	0.00	0.00	0.00	0.10	1.30	0.00	0.81	0.00	0.00	0.00	0.00	0.66	0.00	0.03	0.03	0.48
12	0.91	0.00	0.00	3.33	0.10	0.00	0.99	0.00	0.00	0.00	0.00	2.95	0.00	0.00	0.00	0.23
13	0.66	0.00	0.00	1.83	0.25	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.10
14	0.00	2.67	0.00	0.41	0.00	0.10	0.03	1.22	0.76	0.38	0.05	0.00	3.84	0.00	0.00	0.03
15	0.00	0.00	2.41	0.00	0.00	0.00	0.00	0.00	0.53	0.56	0.00	0.23	0.00	0.10	0.20	0.00
16	1.12	0.00	0.00	0.00	0.00	0.76	1.42	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	2.59
17	0.00	0.71	0.30	0.00	0.76	0.15	0.18	0.00	0.00	0.00	0.15	0.00	0.00	0.03	1.27	0.00
18	0.00	0.00	0.03	0.00	0.00	0.33	0.00	0.23	0.46	0.00	0.00	0.00	0.00	0.00	0.18	---
19	0.00	0.84	0.00	1.91	0.00	1.45	0.00	0.46	0.08	0.00	0.00	0.00	0.00	0.74	3.20	---
20	0.00	0.18	0.33	0.00	0.00	0.00	0.00	0.28	0.00	0.64	0.00	0.00	0.00	2.16	0.03	---
21	1.75	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.59	0.00	0.00	0.61	0.86	0.00	---
22	0.00	0.03	0.38	0.00	0.00	0.58	0.00	0.00	0.84	0.97	0.00	0.00	0.05	0.00	0.00	---
23	0.81	0.03	0.00	0.79	0.97	0.94	0.00	0.00	0.79	0.00	0.00	0.00	0.05	0.00	0.05	---
24	0.38	0.00	0.05	6.07	0.00	2.31	0.00	0.00	0.58	0.71	0.00	0.00	0.00	0.00	0.97	---
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	---
26	0.00	0.00	0.18	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.08	---
27	0.00	0.00	1.65	0.00	0.03	0.00	0.00	0.00	1.37	0.05	0.10	0.00	0.00	0.00	0.00	---
28	0.00	0.33	0.00	0.03	0.00	0.51	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---
29	1.24	3.40	0.08	0.30	0.00	0.00	0.00	---	0.00	0.10	0.03	0.00	0.00	0.00	0.00	---
30	0.00	0.00	0.28	0.00	0.00	0.64	0.20	---	0.00	0.33	0.03	0.00	0.03	0.00	0.00	---
31	1.02	0.00	---	0.00	---	1.47	0.00	---	0.00	---	0.13	---	0.00	0.00	---	---
Total	9.89	11.16	7.80	18.03	6.72	12.32	3.79	3.76	8.23	6.77	1.95	4.98	11.16	7.36	7.41	5.01

Concentrations of Fe and Mn (Figure 4-2A) and dissolved organic carbon (Figure 4-2B) in raw leachate increased with decreased precipitation, especially after periods of slow percolation and low leachate collection. Concentrations of BOD in the leachate increased with increases in precipitation during the fall of 1990 (Figure 4-2B). However, in the the summer of 1991, the increase in BOD concentration is not associated with high precipitation. Relatively soluble constituents such as NH_4^+ and K^+ were diluted by increasing flow (Table 4-1, Figure 4-2C).

The dilution of leachate by precipitation caused a pronounced stratification of the fluid (due to density differences) within the gravel Beds I and IV, but no stratification with depth was observed within the sand-and-gravel Beds II and III. The relatively low hydraulic conductivity of the sand-and-gravel substrate in Beds II and III resulted in overland flow and preferential flow through a layer of relatively high hydraulic conductivity (gravel layer due to settling out of sand over time) near the surface. The stratification within the gravel Beds I and IV reduced the volume of substrate actually in contact with the leachate and therefore reduced retention times in Beds I and IV. The stratification phenomenon is discussed in depth later (in section D.3, Hydraulic Conductivity).

D.1.2 Pollutant Load Removal

D.1.2.1 Effect of Season on Removal

D.1.2.1.1 Total Biochemical Oxygen Demand, Dissolved Ammonium and

Potassium. Maximum BOD removal for each bed ranged from 87.2 percent (Bed IV) to 89.5 percent (Bed III), all occurring in the fall of 1991 (Table 4-1). Minimum BOD load removals occurred in the 1990-91 winter, with Beds I and III showing an increase of BOD (Figure 4-3A). The sharp decrease in BOD removal in all beds during the 1990-91 winter is attributed to the decrease in microbial activity as bed temperatures dropped. Rates of BOD removal increased as bed temperatures increased in summer 1991 and reached their maximum removal in fall 1991.

Figure 4-2. Precipitation and concentrations of select constituents in untreated leachate at Tompkins County municipal solid-waste landfill, July 1990 through October, 1991:

A. dissolved iron and manganese,

B. total biochemical oxygen demand and dissolved organic carbon, and

C. dissolved ammonium and potassium.

(continued on next page)

Figure 4-2. -Continued.

Figure 4-3. Removal rates of selected dissolved constituents in four constructed wetland beds at Tompkins County municipal solid-waste landfill, 1990 through 1991: A. biochemical oxygen demand, B. ammonium, C. potassium, D. iron, E. manganese, and F. phosphorus.

(continued on next page)

C. DISSOLVED POTASSIUM

D. DISSOLVED IRON

Figure 4-3.—Continued.

E. DISSOLVED MANGANESE

F. DISSOLVED PHOSPHORUS

Figure 4-3.—Continued.

Seasonal changes in temperature strongly affected removal of NH_4^+ and K^+ in the two sand-and-gravel beds (II and III), as shown in Table 4-1 and in Figure 4-3B and 4-3C. Rates of NH_4^+ and K^+ removal in these beds was greatest during the warmer seasons (54.2 percent and 63.0 percent for K^+ ; 66.8 percent and 72.5 percent for NH_4^+ , respectively). Both NH_4^+ and K^+ were released during the 1990-91 winter. Maximum removals for these ions in the gravel beds I and IV occurred during the fall of 1991.

D.1.2.1.2 Iron, Manganese, and Phosphorus. Maximum removal of Fe, Mn, and P from leachate during each season was 96.5 percent, 83.9 percent, and 75.2 percent, respectively (Table 4-1). The initial removal rate of Fe in Bed I (coarse gravel) was low (27.8 percent) and continued to decline, showing releases of Fe through summer 1991. However, removal increased to 65.7 percent in the fall of 1991 (Figure 4-3D), perhaps in association with increasing plant biomass in that bed. The gravel bed IV also showed a release of Fe in the summer of 1991. For the sand-and-gravel beds II and III, Fe removal ranged from a maximum of 96.1 percent and 96.5 percent, respectively, in the summer of 1990 to a minimum of 55.8 percent and 31.4 percent, respectively, in the fall of 1991.

Removal of Mn fluctuated seasonally, possibly due to reduced microbiological activity in the colder months, even though the surface area of the substrate appears to have been the major control. The greatest load removal of Mn occurred in the spring and summer months with maximum removals of 83.9 percent and 75.9 percent in Beds II and III, respectively (Figure 4-3E). Removal of Mn in Beds I, II, and III was at a minimum during the 1990-91 winter, ranging from 2.5 percent in Bed I to 62.3 percent in Bed II. Bed IV started out with a Mn removal rate of 28.7 percent in the summer of 1990 and declined throughout the rest of the research period, with minimum removal of 0.5 percent occurring in the fall of 1991.

Removal rates of P varied by season with minimum removal rates for all four beds in the 1990-91 winter (Table 4-1). Beds I and II actually showed a release of phosphorus during this period (Figure 4-3F). P load removal for summer 1990, summer 1991, and fall 1991 were fairly

consistent over the four beds (ranging from 41.7 percent to 75.3 percent), with the exception of Bed I in the fall of 1991 (removal rate was 28.1 percent). P loading was low throughout the year, and the load removal in the beds could be attributed to coprecipitation with metals (in all beds) and plant uptake (in Beds I, III, and IV).

D.1.2.1.3 Leachate Volume Reduction. Leachate volume was decreased through evapotranspiration (Beds I, III, and IV) and evaporation (Bed II) by as much as 49 percent (Table 4-1, Figure 4-4). Warm weather exerted the greatest effect in the gravel (coarser) beds I and IV. No volume reduction occurred during the 1990-91 winter in any of the beds.

D.1.2.2 Effect of Substrate on Removal

D.1.2.2.1 Total Biochemical Oxygen Demand, Dissolved Ammonium and

Potassium. Maximum BOD removal in all four beds ranged from 87.2 percent to 89.2 percent (Table 4-1). There was not a significant difference in overall BOD load removal in any of the three substrates. The coarse gravel (Bed I) showed the least BOD removal during the summer of 1990 and 1990-91 winter but showed comparable removals during the summer and fall of 1991, possibly because it supported the greatest *Phragmites australis* production during the second growing season (Figure 4-3A and Figure 4-5). A general decrease in BOD removal in all beds during the 1990-91 winter is attributed to a sharp decrease in microbial activity as bed temperatures dropped.

Average rates of NH_4^+ and K^+ removal during summer 1990 were greatest in the sand-and-gravel beds (II and III), 53.3 percent to 72.5 percent, respectively (Figures 4-3B,4-3C). Initially, cation exchange could have been a strong control on NH_4^+ and K^+ concentrations in the beds; if so, the finer-grained substrate in beds II and III would have greater removal rates until the sites available for cation exchange had been filled. Over time, the substrate had less of an effect on load removals. In the fall of 1991, removal of NH_4^+ in Beds I, II, III, and IV was occurring at similar rates, 72.6 percent, 54.0 percent, 65.7 percent, and 65.0 percent, respectively. Nitrification (biochemical oxidation of NH_4^+ to nitrate, NO_3) was occurring in Beds II, III and IV

Figure 4-4. Leachate volume reduction in four constructed wetland beds at Tompkins County municipal solid-waste landfill, 1990 through 1991. (Values for all beds in winter 1990-91, and for Beds III and IV in summer 1991, were 0.)

throughout the study period as indicated by increasing concentrations of $\text{NO}_3\text{-N}$ (Appendix A; NO_3 is equal to $\text{NO}_3 + \text{NO}_2\text{-N}$ minus $\text{NO}_2\text{-N}$).

D.1.2.2.2 Phosphorus. Removal rates of P fluctuated seasonally, although the surface area of the substrate appears to be the major control. The fine-textured substrate in Beds II and III initially had greater P removal (73.4 percent and 74.6 percent respectively, in the summer of 1990) as shown in Figure 4-3F. Over time, removal of P was less dependent upon substrate, as shown by the gradual leveling out of differences in removal rates. During the summer and fall of 1991 P removal in all beds ranged from 56.5 percent to 75.3 percent (Figure 4-3F). The small-gravel bed (IV) still had substantial P removal during the 1990-91 winter (41.7 percent) compared to the release of P occurring than in the other beds.

D.1.2.2.3 Iron and Manganese. The sand-and-gravel substrate beds (II and III) showed consistently higher removal rates of Fe throughout the sampling period. Removal rates of Fe and Mn ranged from 31.4 percent to 96.5 percent and of Mn from 42.0 percent to 83.9 percent (Mn) throughout the year in Beds II and III (Table 4-1, Figure 4-3D, 4-3E).

The initial removal rate of Fe in the coarse gravel (Bed I) was low and continued to decrease through summer 1991, actually showing release of Fe in the 1990-91 winter and 1991 summer. Fe removal dramatically increased in Bed I in the fall of 1991 to 65.7 percent, perhaps in association with increasing plant biomass in that bed (Figure 4-5).

Mn removal was low throughout the year in both the gravel beds (I and IV) ranging from a low of 0.5 percent in bed IV to a high of 47.4 percent in bed I (both during the fall of 1991). Mn removal was affected somewhat by the seasons but was affected much more significantly by the particle size (and thus surface area) of the substrate. Much higher rates of Mn removal were associated with the greater adsorptive surface area in the finer-textured substrate (Beds II and III). Mn removal in the sand-and-gravel beds ranged from a low of 42.0 percent in bed III during the 1990-91 winter to a high of 89.9 percent in Bed II during the summer of 1991.

D.1.2.2.4 Metals Adsorbed to Substrate. The results of the sequential metals extractions are shown in Table 4-3. Effectively, no trace metals were sorbed to the coarse-grained carbonate clasts (rock fragments). Concentrations of sorbed metals were less than 10 µg per gram of substrate, except for K; the results for this metal may reflect minor levels of K in the sodium-hypochlorite leach solution, rather than metal bound on the sediment. What little exchange capacity exists in the carbonate substrates probably is within the very fine-grained rock flour adhering to the coarser particles. The results obtained probably were quite different if a substrate of aluminosilicate minerals would have been used in the experiments, as such minerals are associated with high cation exchange capacities.

D.1.2.3 Effect of Plants on Removal

D.1.2.3.1 Total Biochemical Oxygen Demand, Dissolved Ammonium and

Potassium. Outflow from the planted sand-and-gravel Bed III differed little chemically from that of the unplanted sand-and-gravel Bed II (Table 4-1), but removal rates from the planted bed were usually slightly higher. In the second (1991) growing season, the planted sand-and-gravel substrate (Bed III) showed a higher percent reduction in BOD than the unplanted sand-and-gravel substrate in Bed II (43.4 percent and 30.3 percent, respectively). Comparison of the unplanted plot (Bed II) with the planted sand-and-gravel plot (Bed III) showed no other obvious effects of plants on BOD reduction.

During the spring and summer, when plant productivity was at its peak, removal of NH_4^+ was slightly higher in the planted sand-and-gravel Bed III than in the unplanted Bed II (Table 4-1, Figure 4-3B). During the 1990-91 winter, both beds released NH_4^+ .

K^+ removal was greater in the planted sand-and-gravel Bed III during the summer of 1990 and fall of 1991 than in the unplanted sand-and-gravel Bed II (Figure 4-3C). The sharp decrease in NH_4^+ and K^+ removal in both Beds II and III during the 1990-91 winter is attributed to the decrease in microbial activity as bed temperatures dropped and plant activity became dormant.

Table 4-3. Metals extracted from substrate at Tompkins County municipal solid-waste landfill constructed wetlands beds.
(All values are in milligrams constituent per gram of substrate.)

PRE-LEACHATE APPLICATION

Ammonium citrate extraction

	<u>Fe</u>	<u>Sr</u>	<u>Al</u>	<u>K</u>	<u>Pb</u>	<u>Mn</u>	<u>Ba</u>	<u>Zn</u>	<u>Ni</u>	<u>Cu</u>
Bed I										
9 m from influent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed III										
9 m from influent	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Bed IV										
9 m from influent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Sodium hypochlorite extraction

	<u>Fe</u>	<u>Sr</u>	<u>Al</u>	<u>K</u>	<u>Pb</u>	<u>Mn</u>	<u>Ba</u>	<u>Zn</u>	<u>Ni</u>	<u>Cu</u>
Bed I										
9 m from influent	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed III										
9 m from influent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed IV										
9 m from influent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(continued on next page)

Table 4-3.—Continued.

FALL 1990

Ammonium citrate extraction

	<u>Fe</u>	<u>Sr</u>	<u>Al</u>	<u>K</u>	<u>Pb</u>	<u>Mn</u>	<u>Ba</u>	<u>Zn</u>	<u>Cr</u>	<u>Cu</u>
Bed I										
9 m from influent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed II										
9 m	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Bed III										
9 m from influent	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00
Bed IV										
9 m from influent	0.00	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00

Sodium hypochlorite extraction

	<u>Fe</u>	<u>Sr</u>	<u>Al</u>	<u>K</u>	<u>Pb</u>	<u>Mn</u>	<u>Ba</u>	<u>Zn</u>	<u>Cr</u>	<u>Cu</u>
Bed I										
9 m from influent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed II										
9 m	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Bed III										
9 m from influent	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Bed IV										
9 m from influent	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00

Table 4-3.—Continued.**FALL 1991*****Ammonium citrate extraction***

	Fe	Sr	Al	K	Pb	Mn	Ba	Zn	Cu
Bed I									
9 m from influent	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed II									
9 m	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00
Bed III									
9 m from influent	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.11	0.00
21 m	0.00	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.01	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Bed IV									
9 m from influent	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00

Sodium hypochlorite extraction

	Fe	Sr	Al	K	Pb	Mn	Ba	Zn	Cu
Bed I									
9 m from influent	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bed II									
9 m	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Bed III									
9 m from influent	0.00	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Bed IV									
9 m from influent	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
15 m	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
21 m	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
27 m	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00

D.1.2.3.2 Iron, Manganese, and Phosphorus. Bed II (unplanted) showed significantly greater removal of Fe than the planted sand-and-gravel Bed III (76.7 percent, as opposed to 49.9 percent) during the summer of 1991 (Table 4-1, Figure 4-3D), even though the loading rate to Bed II was 22.0 percent higher (0.34 kg verses 0.26 kg). Significant clogging in the substrate had occurred by the summer of 1991, in both the sand-and-gravel beds, and overland flow was readily observed in Bed II. Significant Fe stains (orange) were present on the surface of Bed II, demonstrating that oxidation of Fe was occurring there. This precipitation of iron oxide (FeO) may account for the greater Fe removal in Bed II.

Removal rates during the 1990-91 winter, after plant productivity stopped, showed similar results. Even with similar loading rates, the unplanted Bed II removed more Fe (55.8 percent) than the planted sand-and-gravel Bed III (31.4 percent). The limited number of samples in the winter does not conclusively indicate that the unplanted bed is better for winter treatment.

Though Mn removal rates were usually highest in the unplanted bed, there was not a significant difference in removal of Mn for the planted verses unplanted sand-and-gravel Beds II and III, except during the 1990-91 winter (Figure 4-3E). In these two beds, removal of Mn ranged from a low of 42.0 percent (Bed III, 1990-91 winter) to a high of 83.9 percent (Bed II, summer 1991). During the 1990-91 winter, Mn removal in the unplanted Bed II was significantly higher than in Bed III (62.3 percent, as opposed to 42.0 percent).

During the summer (1990 and 1991), P removal was slightly higher in the planted sand-and-gravel Bed III than in the unplanted Bed II (Figure 4-3F). Removal rates significantly decreased as bed temperatures dropped in the 1990-91 winter. Loading rates of P were very low throughout the study (ranging from 0.004 to 0.04 kg, Table 4-1) so the treatment potential of the wetlands may not have been adequately demonstrated by this project.

D.1.2.3.3 Leachate Volume Reduction

Leachate volume reduction was not significantly affected by the presence or absence of plants. The unplanted Bed II actually had a greater volume reduction in the summer of 1991 (7.5

percent) than the planted sand-and-gravel Bed III (0 percent, Figure 4-4). This reduction could be explained by the standing water over most of the surface area of Bed II during the 1991 summer (due to clogging of the substrate and subsequent overland flow), allowing for greater evaporation.

D.2 PLANT HEALTH AND FUNCTION

Phragmites australis was easily established on the relatively coarse-textured substrates used for leachate treatment as long as a small amount of native soil was placed with the rhizomes at planting. The presence of small, intact shoots on the rhizomes was also conducive to successful plant establishment.

Live shoot counts throughout the 1991 growing season are presented in Figure 4-5, which shows a continual increase with time in production of new shoots in all beds. This increase is expected of indeterminate wetland plants like *Phragmites*. Shoot density just before frost peaked (about 155 shoots per m²) for Bed III.

Perhaps of greater importance than shoot density for indicating overall plant health and function is biomass. As shown in Figure 4-5, shoot biomass on September 20 ranged from 0.74 to 1.52 kg/m². The greatest biomass was measured not in Bed III, but in Bed I where the reeds were growing on coarse gravel.

Another indicator of plant health is evapotranspiration (ET), the measurement of which allowed some evaluation of root and leaf function, not only for photosynthesis but also for water and elemental absorption. Cumulative ET is presented in Figure 4-6. The maximum ET loss measured in Bed I represented a rate of about 0.5 cm/day for the May-July period. For some reason, probably having to do with overall leaf canopy area, the greater number of shoots in Bed III had less impact on ET than the total shoot biomass in Bed I. Root biomass was not significantly different among the three planted beds, but root plus rhizome biomass was clearly greater for Bed I. As pointed out by Bedford and others (1991), oxygen release at root surfaces by most emergent wetland plants has little effect on dissolved oxygen levels in the substrate beyond the immediate rhizosphere region.

Figure 4-5. Biomass of *Phragmites australis* stems, roots, and rhizomes in three leachate-treatment plots at Tompkins County municipal solid-waste landfill, 1991.

Tissue contents of the major plant nutrients N and K were not particularly elevated (Table 4-4) considering the elevated levels of NH_4^+ and K in the leachate bathing the roots. The identical leachate dominating the root zone pore water in all beds resulted in identical nutrient and metal contents of the reed tissues among the beds. Therefore, overall mean values for elemental content for all the beds are presented in Table 4-3.

Of the major nutrients, only P appeared to be possibly limiting; the low leachate concentration restricted plant absorption and resulted in tissue levels below not only the controls but also below growth-limiting tissue concentrations of 0.1 percent (Hutchinson, 1975). Plant levels of Ca were not appreciably different in the constructed beds and control, with greater concentrations in the roots in both control and leachate-treatment plants.

Metal ion contents of reed tissues are also presented in Table 4-4. In most cases, there is little difference in tissue concentrations between reeds from the control and reeds from the leachate treatment beds, except for root tissues, though much lower levels of Al than the control roots. Growth in the leachate beds seemed to have caused increased levels of Pb, Cd, and Cu in root tissues. This was not observed for the rhizome and shoot tissues, compared to the control. In all cases, root tissues contained much greater metal concentrations than did rhizomes or shoot tissue.

Fe was especially concentrated in root samples from both controls and leachate beds. As is commonly observed, these roots exhibited an orange, oxidized iron color in or on their surfaces, sometimes referred to as an iron plaque when visibly layered on the roots of wetland plants. The cause of such depositions is thought to be oxygen movement across the root cortex into the rhizosphere when oxygen supply to the roots from tops is sufficient (Conlin and Crowder, 1988). In this anaerobic environment, there would be little other source of oxygen or iron oxidation potential.

Figure 4-6. Cumulative evapotranspiration for *Phragmites australis* growing on leachate treatment beds, including the unplanted bed; May-September 1991.

Table 4-4. Elemental analysis of *Phragmites australis* tissue grown on leachate treatment beds (September 1991) and control from Cornell Pond and Marsh Facility (November, 1993).

Element	Control			Constructed Beds		
	Roots*	Rhizomes*	Tops	Roots*	Rhizomes*	Tops
N (%)	0.72(.14) [†]	0.24(.01)	0.94(.25)	2.03(.10)	1.85(.11)	1.77(.12)
P (%)	0.09(.02)	0.05(.01)	0.05(.01)	0.05(.01)	0.03(.01)	0.04(.01)
K (%)	0.83(.02)	0.74(.01)	0.87(.12)	0.75(.04)	0.84(.06)	0.83(.09)
Ca (%)	0.44(.24)	0.14(.08)	0.11(.06)	0.71(.10)	0.08(.01)	0.13(.01)
Fe (mg/kg)	2,215(1,711)	156(80)	167(69)	3,640(643)	199(34.9)	94.2(12.1)
Mn (mg/kg)	196(66)	129(13)	84.2(31.8)	266(19)	37.7(3.5)	87.5(8.4)
Zn (mg/kg)	45.4(24.8)	13.2(1.6)	14.8(3.2)	46.3(3.6)	12.2(.83)	16.6(1.2)
Cu (mg/kg)	13.3(9.3)	2.55(.27)	2.71(.35)	63.5(8.7)	6.46(.30)	2.88(.34)
Pb (mg/kg)	3.81(3.40)	0.30(.11)	0.28(.08)	12.2(4.2)	0.24(.06)	0.09(.03)
Al (mg/kg)	1,366(1,216)	59.1(44)	66.8(36.2)	1,260(138)	102(14)	31.4(4.4)
Cd (mg/kg)	0.12(.06)	0.06(.06)	0.08(.04)	0.25(.08)	0.10(.04)	0.05(.02)

* Washed with tap water to remove attached soil.

[†] Values for standard error (+/-) are shown in parentheses.

The actual amounts of nutrient and metal uptake by plants are presented in Table 4-5 and compared to total influent quantities. Distribution of any one element in different tissues was similar among beds. P was the only major nutrient which accumulated levels approached total input levels. This would be expected from the very low, growth-limiting concentrations of P reported above for tissues of *Phragmites*. Zn and Cu also showed plant accumulation that was an appreciable fraction of total influent loads, but Zn accumulated in shoots while Cu accumulated in roots and rhizomes.

For most element in Table 4-5, shoots contained the greatest load, followed by rhizomes and roots, respectively. This was a function primarily of the relative biomass of each tissue. Exceptions to this element loading pattern were exhibited by Fe, Cu, and Pb, which accumulated in the root tissues and rhizomes, and Cd, which accumulated in rhizomes. This was a function of the relatively high concentrations of these elements measured in (or on) the roots (Table 4-4). Similar trends in roots of *Phragmites* in lakes were reported by Schierup and Larsen (1981) for Cu, Pb, and Cd. The heavy iron plaque on the roots reported here may have produced a greater apparent root accumulation of the very insoluble Cu and Pb by adsorption to the plaques. Also, Tanton and Crowdy (1971) suggested that the endodermis may be a major barrier for the translocation of these heavy metals.

Hydrated iron oxide ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) films on or in root surfaces could have a filtering function for certain readily-adsorbed but soluble ions that move to the root surface in the evapotranspiration stream. In the case of heavy metals, an adsorptive function by the iron plaque would protect plant tissue from accumulating toxic concentrations. The results in Tables 4-4 and 4-5 indicate that such a function may be working for Pb, Cu, and Cd.

The site of the iron deposition and associated metals was examined in cross sections of roots and rhizomes by scanning electron microscopy and X-ray microanalysis. Surface views of roots from control plants and roots from the leachate beds in Figure 4-7 show the thickness and complexity of the plaque on the root surfaces from the beds. Both the control roots and the

Table 4-5. Nutrient and metal load per bed in plant biomass, September 1991, compared to total influent leachate load per bed, May-August 1991.

	N	P	K	Fe	Mn	Zn	Cu	Pb	Cd
Bed I	-----kg-----			-----g-----			-----mg-----		
Shoots	2.42	0.05	1.14	12.9	12.0	2.27	394	12.3	6.84
Rhizomes	1.97	0.03	0.87	20.6	3.9	1.26	669	24.8	10.4
Roots	0.18	0.005	0.07	36.0	2.6	0.46	629	121	2.48
TOTAL	4.57	0.085	2.08	69.5	18.5	3.99	1692	158.1	19.72
Influent	40.1	0.089	70.0	1,695	204	3.85	2,568	8,989	<1,284
Bed III									
Shoots	1.72	0.04	0.81	9.2	8.5	1.61	280	8.7	4.86
Rhizomes	1.30	0.02	0.59	14.0	2.6	0.85	453	16.8	7.02
Roots	0.16	0.004	0.06	29.5	2.2	0.38	514	98.8	2.02
TOTAL	3.18	0.064	1.46	52.7	13.3	2.84	1,247	124.3	13.90
Influent	32.1	0.072	56.0	1,357	163	3.08	2,056	7,197	<1,028
Bed IV									
Shoots	1.18	0.03	0.55	6.3	5.8	1.10	192	6.0	3.33
Rhizomes	0.73	0.01	0.33	7.9	1.5	0.33	256	9.5	3.96
Roots	0.15	0.004	0.05	26.2	1.9	0.48	457	87.8	1.80
TOTAL	2.06	0.044	0.93	40.4	9.2	1.91	905	103.3	9.09
Influent	40.1	0.090	70.0	1696	204	3.86	2570	8995	<1285

Figure 4-7. Surface views of *Phragmites australis* roots and rhizomes. Note the absence of root hairs on the rhizome. **A.** control root surfaces; **B.** root surface from the leachate treatment beds; **C.** rhizome surface from the leachate treatment beds.

(continued on next page)

Figure 4-7. -Continued.

leachate treated rhizomes are relatively clean. Again, this suggests oxygen release at root surfaces and the resultant accumulation of oxidized Fe and other materials as water is absorbed by the roots. Rhizomes evidently do not release oxygen to the rhizosphere nor absorb water to any extent.

The result of root tissue analysis in Table 4-4 represent washed roots. Obviously appreciable quantities of Fe and other metals still reside on or in the tissues even after a thorough wash with tap water. Considering that the analytical results are for bulk root tissue, the question remains as to whether the iron plaque and associated metals reside only on the surface or inside the tissue also. In other words, is this metal retention by roots primarily physical/chemical (on the surface) or also physiological in nature (deposited across the cortex and stele)?

X-ray spectra of points across a typical root cross section are presented in Figure 4-8. The spectra show a sharp decrease in metal peaks between the surface and cortex, except for Ca and K. There was a further drop in relative metal concentration between the cortex and stele, as indicated by very weak spectral peaks at the endodermis.

These results indicate that Fe is concentrated at the root surface in the plants grown on leachate treatment beds. There is also some small indication of Cu, Zn, and Mn in the root surface spectra, but no evidence of Pb or Cd. Bulk chemical analysis showed elevated levels of all the above. The Pb and Cd measured by chemical analysis may have been located on root surfaces, but not at concentrations detectable with X-ray microanalysis.

Figure 4-8. X-ray spectra at points traversing a *Phragmites australis* root. A. root cross section from the leachate beds; B. X-ray spectra at point 1, surface; C. X-ray spectra at point 2, cortex; D. X-ray spectra at point 3, stele.

D.3 HYDRAULIC CONDUCTIVITY

D.3.1 Determination of K_s Using Hillslope Theory

In the following sections, the results of using equation (1) to measure the saturated hydraulic conductivity of each bed are presented. Only the first and last experiments from each plot are discussed (summer 1989 and fall 1991, except for the unplanted sand-and-gravel bed, for which the experiment of spring 1991 is also discussed). Summaries of the results from all drainage experiments for each bed (Sanford, 1992) are presented in Table 4-6.

D.3.1.1 Planted Coarse Gravel (Bed I)

The outflow curves from the five experiments run on the planted coarse-gravel bed are shown in Figure 4-9. The experiments run in summer and fall 1989, spring 1990, and spring 1991 produced drainage curves that are nearly straight lines. For the fall 1991 experiment, the initial height of the water table was nearly 15 cm lower than the average height for the other four experiments, resulting in an outflow curve that differs from the others. During the drainage for all experiments, the elevation of the water table was nearly the same at all well locations, which indicates that the head loss in the bed was small compared to the head loss at the outlet point. Thus, the flow rates of the experiments were controlled by the drain system and not by the substrate in the bed.

The dependency of the flow rate on the outlet point can be further illustrated by examining the outflow curve from spring 1990 (Figure 4-9). This curve is a straight line with a considerably lower slope than the curves for the other experiments. The smaller slope is a result of the partial clogging of a filter fabric, which had been wrapped around the drainage pipe during the construction of the beds. The fabric was removed shortly after this experiment and as a result, the drainage curve from spring 1991 was similar to the two from 1989. The only evidence that some clogging may be occurring in the coarse gravel bed is that the drainable porosity decreased from 0.36 to 0.33 over the two-year period (Table 3-5).

Table 4-6. Comparison of hydraulic conductivities determined by the hillslope method with the average values determined by Darcy's Law.

HYDRAULIC CONDUCTIVITIES (cm/s)						
TIME	Pea Gravel		Unplanted Sand and Gravel		Planted Sand and Gravel	
	Hill-slope	Darcy's Law	Hill-slope	Darcy's Law	Hill-slope	Darcy's Law
SUMMER 1989	6.0	7.2 (2.8)*	0.22	0.27 (0.17)	0.12	0.15 (0.03)
FALL 1989	6.0	6.2 (2.3)	0.18	0.25 (0.22)	0.17	0.12 (0.07)
SPRING 1990	4.7	7.7 (2.8)	0.22	0.20 (0.12)	0.12	0.17 (0.08)
SPRING 1991	6.3	5.3 (2.5)	0.03	0.03 (0.02)	----	----
FALL 1991	4.0	5.7 (0.5)	Clogged†	Clogged	0.023	0.028 (0.017)

--- Hydraulic conductivity was not calculated

* +/- Standard Deviation

† The unplanted sand and gravel was completely clogged in the fall 1991; hydraulic conductivity could not be measured

Figure 4-9. Outflow curves from all five drainage experiments for bed I, coarse gravel.

D.3.1.2 Unplanted Sand and Gravel (Bed II)

The outflow curves from the drainage experiments performed on the unplanted sand-and-gravel bed (Figure 4-10) indicate that less water can drain from the bed over time and suggest that clogging is occurring. The curves presented in Figure 4-10 are the actual data and have not yet been corrected for the high-conductivity, coarse-gravel segment located at the outflow end of the bed. The values of the geometry terms used in equation (1) in modeling the experiments are: $L = 32$ m (total length minus the length of the coarse-gravel segment), $w = 2.4$ m, $\beta = 0.005$, and $h(0,t) = 0$. The values of drainable porosity and of the correction volume for the coarse-gravel segment are given in Table 3-5.

For both the unplanted and planted sand-and-gravel beds, the length of time between the closing of the inflow valve and the beginning of the drainage experiment was not sufficient for the initial water table profile to become horizontal. However, the flow had stopped for a short period of time and it cannot be assumed that the initial water-table slope was parallel to the bed slope, either. The potential drainage volume due to the initial water-table profile was estimated by using the water elevations measured at time=0 in the monitoring wells to calculate the volume of saturated substrate above the horizontal. In Sanford (1992), it was shown that for cases where the initial profile is not parallel to the impermeable layer, equation (3) can be corrected by replacing the second term on the right side with the volume of water contained in the initial profile above a horizontal plane having the elevation of the water table above the drain at time=0. The volume of saturated substrate was then multiplied by the drainable porosity to find the volume of drainable water. The volumes of drainable water above the horizontal in the initial water-table profiles for each of the experiments performed on the unplanted sand-and-gravel bed are given in Table 3-5.

The results of using equation (1) to fit the outflow curves for the drainage experiments performed on the unplanted sand-and-gravel bed in summer 1989 and spring 1991 are shown in Figure 4-11. Presented along with the data, which have been corrected for the volume of water in the coarse gravel segment, are three predicted curves calculated by using values of K_s that varied by 0.017 cm/s. This is done in order to illustrate the large change in predicted values that occurs

Figure 4-10. Outflow curves from all five drainage experiments for Bed II, unplanted sand and gravel.

with only a small change in hydraulic conductivity. In both cases, the middle value of K_s produces the best fit to the data.

The hydraulic conductivity of the unplanted sand-and-gravel bed was found to be nearly the same for the first three drainage experiments, summer and fall of 1989 and spring of 1990 (0.18 - 0.22 cm/s; Figure 4-11 and Table 4-6). However, after a year of leachate addition, the hydraulic conductivity decreased to 0.03 cm/s. There are no data from the drainage experiment of fall 1991 because the estimated volume of water contained in the coarse gravel segment was roughly the same as the total amount of water measured to have drained from the bed. This, along with the observation that there was no further addition to the outflow volume after three hours of drainage, indicates that the unplanted sand-and-gravel bed was almost completely clogged.

D.3.1.3 Planted Sand and Gravel (Bed III)

The actual outflow curves from the planted sand-and-gravel bed are presented in Figure 4-12. As was evident with the outflow curves from the unplanted sand-and-gravel bed, the amount of water that could drain from this bed over a given time also decreased greatly over the two-year period of the experiments. The geometry terms used in equation (1) for the modeling of the outflow from the planted sand-and-gravel bed are: $L = 32$ m, $w = 2.5$ m, $\beta = 0.005$, and $h(0,t) = 0$. The values of drainable porosity, the volumes of drainable water in the initial profile above the horizontal, and the correction volumes for the coarse-gravel segment are given in Table 3-5.

The corrected outflow curves are shown in Figure 4-13 with three predicted curves for the experiments from summer 1989 and fall 1991. As before, the middle value of K_s is the one chosen as the value providing the closest fit to actual measurements. The hydraulic conductivity of the bed determined from the three experiments conducted before the addition of leachate ranged from 0.12 to 0.17 cm/s (Figure 4-13 and Table 4-6). After more than one year of leachate addition and plant growth, the hydraulic conductivity decreased to 0.023 cm/s in fall 1991, indicating that clogging had occurred. There are no data from spring 1991 since there was a time during the middle of the experiment when no outflow occurred.

Figure 4-11. Actual and modeled outflow curves for Bed II, unplanted sand and gravel . A. summer 1989 B. spring 1991.

Figure 4-12. Outflow curves from all five drainage experiments for Bed III, planted sand and gravel.

Figure 4-13. Actual and modeled outflow curves for Bed III, planted sand and gravel. A. summer 1989. B. fall 1991.

D.3.1.4 Planted Pea Gravel (Bed IV)

All outflow curves from the planted pea gravel beds are plotted together in Figure 4-14. Measurements for the drainage experiments were made for five to six hours. The values of the geometry terms used for all experiments in equation (1) are: $L = 33$ m, $w = 2.4$ m, and $\beta = 0.005$. A list of the initial heights of the water table above the drain and the values of drainable porosity for each experiment are given in Table 3-5.

Before equation (1) can be used to fit the outflow curve, it is necessary to calculate the potential drainage volume given by equation (3). The second term on the right side of equation (3) is the drainage potential due to the initial shape of the water table being parallel to the slope of the impermeable layer. However, the experiments were run so that the initial water table was not parallel to the bottom slope. For the pea gravel bed (unlike the sand-and-gravel beds), there was sufficient time for the water table to become horizontal between the times the inflow valve was closed and the drainage experiment was started; therefore, the drainage potential due to the initial water-table profile was 0.

Figure 4-15 contains the results of fitting the modeled outflow curves to the actual data using equation (1). As can be seen, the two curves are extremely close. The two experiments run in 1989 had hydraulic conductivities measured at 6.0 cm/s, which is within the range of values expected for this size of gravel (Table 4-6). The conductivity was slightly lower in spring 1990 (4.7 cm/s) and then increased to its original value in spring 1991 (6.3 cm/s). The value of K_s of the pea-gravel bed decreased to 4.0 cm/s in fall 1991 (Figure 4-15B). This decrease was expected because the bed had a full spring and summer of leachate addition. The increase in the value of K_s in spring 1990 was not expected (Table 4-6) but does correspond to an increase in the measured value of drainable porosity (Table 3-5). It is possible that the increase was a result of freeze-thaw

Figure 4-14. Outflow curves from all five drainage experiments for Bed IV, planted pea gravel.

Figure 4-15. Actual and modeled outflow curves for Bed IV, planted pea gravel.
A. summer 1989. B. fall 1991.

action over the winter forming some preferential flow channels and of the cold weather reducing bacterial growth. As the summarized results in Table 4-6 indicate, the hydraulic conductivity of the pea-gravel bed generally decreased with time, especially after leachate addition began. However, in all cases it remained sufficiently high so that no overland flow occurred.

D.3.2 Determination of K_s Using Darcy's Law

The values of saturated hydraulic conductivity for segments of substrate between the in-plot wells in each constructed wetland bed were determined using Darcy's Law following the procedure discussed C.2.2.2.2. Examples of the data are shown in Tables 4-6 and 4-7 for the drainage experiments from fall 1989 for the planted pea-gravel and the unplanted sand-and-gravel beds. There are no measurements for the planted coarse-gravel bed since there was no measurable difference in water-table elevation between adjacent wells for any of the drainage experiments. The average values for each bed for all experiments are presented and compared with the hydraulic conductivities measured using the hillslope theory in Table 4-6. A schematic plan of a bed used in this study is shown in Figure 3-4. For each bed, the monitoring wells are labeled A through E, with A being the nearest to the outflow end and E being nearest to the inflow end. Segment 1 refers to the segment of substrate between wells A and B, Segment 2 is between wells B and C, segment 3 is between wells C and D, and segment 4 is between wells D and E. No measurements were made for the segment of the bed between Well A and the drain since the height of the water table was not measured above the drain. Measurements also were not made for the segment between well E and the inflow end. For determining the volume of substrate drained, it was assumed that the water-table elevation throughout this segment was the same as that measured in well E. The first 50 to 90 minutes of drainage were ignored in order to eliminate the effects of the segment of coarse gravel at the outlet end of each bed.

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Table 4-7. Bed IV (Pea Gravel): Hydraulic conductivity of substrate segments calculated by using Darcy's Law (in cm/s).

Time Interval (Minutes)	Hydraulic Conductivity Of Substrate Segments				Average For Interval
	Segment 1	Segment 2	Segment 3	Segment 4	
75 - 90	4.3	6.4	8.4	3.6	5.7
90 - 120	4.4	6.2	8.6	3.8	5.8
120 - 150	4.6	6.5	8.5	4.1	5.9
150 - 180	4.9	6.4	8.6	3.9	6.0
180 - 210	5.0	6.4	8.6	4.2	6.0
210 - 240	5.1	6.8	10.1	4.0	6.5
240 - 270	5.1	6.6	11.5	3.8	6.8
270 - 300	5.2	7.0	11.6	4.0	7.0

Table 4-8. Bed II (Unplanted Sand and Gravel): Hydraulic conductivity of substrate segments calculated by using Darcy's Law (in cm/s).

Time Interval (Minutes)	Hydraulic Conductivity of Substrate Segments				Average For Interval
	Segment 1	Segment 2	Segment 3	Segment 4	
75 - 90	0.28	0.25	1.18	0.43	0.53
90 - 120	0.25	0.20	0.83	0.40	0.42
120 - 150	0.15	0.12	0.42	0.18	0.22
150 - 180	0.15	0.10	0.37	0.17	0.20
180 - 210	0.15	0.10	0.37	0.17	0.20
210 - 240	0.17	0.10	0.35	0.17	0.20
240 - 270	0.15	0.08	0.28	0.15	0.17
270 - 300	0.15	0.08	0.30	0.15	0.17
300 - 330	0.13	0.08	0.25	0.17	0.17

The hydraulic conductivities measured using this method indicate that all three beds experienced some degree of clogging. In the following section, a comparison of the two methods will be made.

D.3.3 Comparison of the Two Methods

For the sand-and-gravel beds, the hydraulic conductivities estimated by modeling the outflow curves are not significantly different from the values found by using Darcy's Law for the segments between wells (Table 4-6). The fundamental difference between the two methods lies in the fact that using Darcy's Law requires the manipulation of a great deal of data.

The comparison of the values of hydraulic conductivity determined by the two methods for the pea gravel shows a much greater discrepancy for some of the experiments (Table 4-6). Due to the high hydraulic conductivity of the pea gravel, the difference in water-table height between adjacent wells was small, ranging from 0.3 cm to 3.0 cm for the various segments. With such small differences, an error of just a few millimeters in measuring the height of the water table can result in a large difference in the calculated value of K_s . Moreover, since the predicted outflow curves fit the actual data well, the best-fit value of K_s is taken as a more accurate representation of the average conductivity of the substrate as a whole.

The use of equation (1) to determine hydraulic conductivity by producing a best fit to the drainage curves from the rock-reed filters requires that only a simple drainage experiment be performed. A comparison of values of conductivity measured several months apart indicates the amount of clogging of the substrates that has occurred.

Equation (1) predicts the outflow from the pea-gravel bed quite well because pea gravel is a relatively homogeneous substrate. Variability in both the vertical and horizontal directions are minimal. For the sand-and-gravel beds, the best-fit curve does not match the data nearly as well due to the nonhomogeneous nature of the matrix. Rainfall hitting the surface of the substrate causes finer grains to wash out of the upper few centimeters of the substrate, forming a layer of higher conductivity near the top. The fine grains are washed deeper into the substrate. The

addition of fine grains along with the addition of particles filtered out of the leachate reduce the conductivity of the deeper portion of the substrate. The last column in Table 4-7 (which shows the Darcy's Law data for the unplanted sand-and-gravel bed from fall 1989), contains average values of K_s for each time interval. The values of hydraulic conductivity decrease for the later time intervals, as the water table penetrates deeper into the substrate. This general trend was also observed for the remainder of the drainage experiments performed on both sand-and-gravel beds (Sanford, 1992). As a result of the variable hydraulic conductivity, the drainage model (equation 1) does not reproduce the drainage curve as well as for the pea gravel substrate. However, the model fits the data well enough to allow changes in hydraulic conductivity over time to be measured.

D.3.4 Tracer Experiment Data

D.3.4.1 Pre-dilution Chloride Data

The chloride concentrations in the outflow water together with the rainfall are presented for Beds I, III, and IV in Figure 4-16 for the week before the tracer experiment. No data was collected for Bed II due to an electrical malfunction of the sampler. Chloride concentration measured in the influent leachate on August 7, 1991 was found to be 26.1 milliequivalents per liter (mEq/l); the concentration measured on August 16 was 23.5 mEq/l. Immediately after the large rainfall on August 18 and August 20, 1991, the concentration of chloride in the effluent dropped sharply. The concentration decreased most in Bed III (sand-and-gravel mixture, having the lowest hydraulic conductivity) followed by Bed I (coarse gravel, having the highest hydraulic conductivity) and then Bed IV (pea gravel). Even the small rain on August 16 lowered the chloride concentration in the effluent from Bed III while it had no effect on Beds I and IV. For all beds, the chloride concentration increased to nearly its original level in less than half a day after the rain stopped.

Figure 4-16. Chloride concentrations in the effluent for one week prior to the dilution experiment and the rainfall during that period.

D.3.4.2 Predilution Specific Conductance

Measurements of specific conductance of the wastewater in each in-plot well during normal operations were taken on August 20, 1991 (Figure 4-17), before the rainfall that occurred on that day and two days after the major rainfall that occurred on August 18. The specific conductance pattern was distinctly different between the sand-and-gravel beds (II and III) and the gravel beds (I: coarse gravel; IV: pea gravel). The low-hydraulic-conductivity Beds II and III had specific conductance values that were uniformly high, 6,000-7,000 $\mu\text{S}/\text{cm}$. The high-hydraulic-conductivity Beds I and IV exhibit a pronounced vertical stratification of specific conductance throughout the length of the bed, with the greatest values of 6,000-7,000 $\mu\text{S}/\text{cm}$ occurring near the bottom of the substrate and the lowest values (~ 1000 $\mu\text{S}/\text{cm}$) occurring just below the surface. The average specific conductance of the influent leachate during the summer was 7,390 $\mu\text{S}/\text{cm}$.

The predilution chloride outflow and specific conductance data suggest that there are two methods of short circuiting (causing preferential flow) within the rock-reed filters. One type occurs in the sand-and-gravel beds (II and III). Due to the low hydraulic conductivity there is very little infiltration of rainwater in the substrate, as shown by the uniformly high specific conductance. As a result, all water flows directly overland to the outlet, reducing the chloride concentration immediately (Figures 4-16 and 4-17). The other type of short-circuiting is caused by density differences within the bed. In Beds I and IV the rain water is "floating" on top of the denser leachate. The specific conductance profile of Bed I indicates that the rain flowed over the denser leachate towards the tile drain at the end of the plot, causing a moderate lowering of the chloride concentration. The pea gravel (Bed IV) behaved almost completely as a plug-flow system (fluid particles pass through the wetland and are discharged in the same sequence in which they enter) and consequently most rain was retained in the bed with a minimum of preferential flow on August 20. The tracer dilution experiment described below confirms these findings.

Figure 4-17. Specific conductance measurements taken in each bed prior to the dilution experiment. Measurements made on August 20, 1991.

D.3.4.3 Dilution Experiment—Effluent Chloride Concentrations

Plots of the chloride concentration and outflow rate versus time since the start of fresh water addition are presented in Figure 4-18 for all four beds. The inflow to all beds during the dilution experiment was characterized by a steady rate with short periods of increased inflow rates. The outflow rates shown in Figure 4-18 reflected this pattern. For the two sand-and-gravel beds (II and III), an increase in the outflow rate was accompanied by a decrease in the chloride concentration of the effluent. The small increase in outflow rate from Bed III around day 7 halved the effluent concentration by the next day. Once the flow rate returned to its steady rate, the concentration rebounded to higher levels. This concentration pattern is typical for soils in which short-circuiting or preferential transport occurs (Lawes and others, 1882; Steenhuis and others, 1991). At low flow rates, the outflow concentration equals matrix water concentration near the outlet; at high flow rates, the outflow concentration reflects to a degree the input concentration of the water (which was < 1 mEq/l for the experiment). For Bed IV (pea gravel) the concentration was independent of flow rate, which is typical for systems with little or no preferential flow. In Bed I there was only a minor effect of flow rate on concentration outflow patterns, also indicating little if any preferential flow.

D.3.4.4 Dilution Experiment—Quantitative Estimates

To obtain quantitative estimates of the transport parameters and to compute the residence time in each of the four reed beds, the nonlinear least-squares inversion method (CXTFIT) of Parker and van Genuchten (1984) was used. The model chosen was the one-dimensional convection-dispersion equation using the assumptions of steady-state flow, no retardation, no adsorption, and no sinks or sources of chloride present. Outflow volumes were converted to fractions of total water in the plot (i.e., pore volumes). For Bed I, inflow rather than outflow was used. The fraction of the bed that participated in the flow process and the dispersion coefficient (D , in m^2/hr) were determined by fitting the least-squares to the breakthrough curves (BTC) from each bed. Due to the preferential flow in Beds II and III, only the portion of each BTC that

Figure 4-18. Chloride concentrations measured in the effluent during the dilution experiment. Also plotted are the flow rates and the curve which was fitted to the data by CXTFIT.

represented flow through the substrate was used. The resulting fitted curves are shown in Figure 4-18.

The input data and fitted values from CXTFIT are given in Table 4-9. The same pattern emerges as for the predilution experiments. In the gravel beds (I and IV) there was very little preferential flow (nearly 80 percent of the substrates participated in flow). For the sand-and-gravel beds (II and III), the convective-dispersive equation did not, as expected, fit the data very well. For the portions of the BTC used there was significant short-circuiting, with only 22 percent of the substrate in Bed II and 49 percent of Bed III participating in flow. The resulting dispersion values were within the ranges of typical values reported in the literature (e.g., Gelhar and others, 1992).

D.3.4.5 Dilution Experiment—Specific Conductance

Specific conductance measurements of the leachate within the four beds were taken 11 days after the beginning of the dilution experiment (Figure 4-19). Additional measurements were taken on day 13 in Beds III and IV because the last two deliveries of water (beginning on day 11) were run through these two beds only (Figure 4-20). The pronounced stratification that was evident in the predilution measurements was not observed because the less dense fluid (clean water) displaced the denser fluid (leachate).

After 11 days the value for specific conductance in Bed I was around 1,000 $\mu\text{S}/\text{cm}$ for all locations. This lower specific conductance throughout the bed indicates that most of the initial leachate present in the bed had been flushed out, confirming that plug-flow occurred before that date.

The inflow rate to Bed IV was much slower than to Bed I and therefore, unlike Bed I, on days 11 and 13 there was still leachate in the bed. The specific conductance measurements from Bed IV indicate that dilution was occurring from the inlet to the outlet (exemplifying the plug-flow concept) and show much less stratification than was present before the dilution experiment (Figure 4-17).

Table 4-9. Results of modeling using CXTFIT for each bed.

	BED I	BED II	BED III	BED IV
SUBSTRATE MATERIAL	Planted Coarse Gravel	Unplanted Sand and Gravel	Planted Sand and Gravel	Planted Pea Gravel
INITIAL CHLORIDE CONCENTRATION (mEq/l)	20.5	28	34	22.5
TIME PERIOD USED IN CXTFIT (days)	0 - 7	0 - 2.5	0 - 2.5	0 - 14
FRACTION OF BED USED IN FLOW	0.78	0.22	0.49	0.79
DISPERSION COEFFICIENT (m ² /hr)	1.0	6.4	5.5	2.5

Figure 4-19. Specific conductance measured in all four beds on day 11 of the dilution experiment.

Figure 4-20. Specific conductance measured in Beds III and IV on day 13 of the dilution experiment.

The specific conductance measurements from Bed II on day 11 show that there was still no vertical stratification but that the leachate within the bed was more dilute towards the outflow end. The low readings from the in-plot well at 10 m are due to ponding of water around the well allowing contamination by surface water. The closest well to the inlet (5 m) shows no evidence of any dilution throughout its entire depth. The well closest to the outlet (25 m) exhibits the greatest amount of dilution (excluding the well at 10 m). Water thus flows over the surface of the substrate to the outlet end where it infiltrates and flows to the drain at the bottom of the bed.

In Bed III, in contrast to Bed II, the specific conductance measurements from days 11 and 13 show that dilution was occurring at both the inlet and outlet ends of the bed. This is especially evident from the data collected on day 13. The observed pattern indicates substantial overland flow of water to the outlet, which resulted in the lowering of the specific conductance from 6,000 $\mu\text{S}/\text{cm}$ to 1,000 $\mu\text{S}/\text{cm}$ in the well closest to the outlet. The decrease in specific conductance seen in the wells at 5 and 10 m from the inlet indicates that there is a minor amount of subsurface flow of the influent.

D.3.5 Hydraulic Conductivity and Tracer Experiment: General Discussion

All measurements made on the four rock-reed filters indicate that the substrates became less permeable with time. Due to the initially high hydraulic conductivities of the coarse-gravel and pea-gravel substrates, the reduction in conductivity (37 percent for the pea gravel) did not result in overland flow. On the other hand, the significant reduction of permeability of the sand-and-gravel beds (nearly 100 percent for the unplanted bed and 86 percent for the planted bed) resulted in the flow through the system being almost entirely overland, which could produce a severe reduction in treatment efficiency.

The observation of the clogging of the sand-and-gravel substrate in the experimental constructed wetlands is consistent with the results of controlled-environment experiments conducted on a smaller constructed wetland using the sand-and-gravel substrate (Sanford, Kopka, Peverly, Steenhuis, Surface, and Lavine, 1990) in laboratory experiments, the substrate became

clogged after two years of leachate addition. The clogging occurred in spite of the reeds growing in the substrate. The thick and extensive root and rhizome system developed by the reeds neither increased nor maintained the hydraulic conductivity. The results of the drainage experiments performed on the unplanted and planted sand-and-gravel beds at the landfill also yield the same conclusion on the ineffectiveness of the reeds to maintain conductivity.

It has been suggested in the literature that it may take several years for a wetland treatment system to fully develop and for the reeds to stabilize hydraulic conductivity (Kickuth, 1982). At the time of this study the constructed wetlands had been in operation for slightly more than two years; therefore, with a few more years of growth, the hydraulic conductivity of the sand-and-gravel substrates may increase. This, however, does not seem likely. Brix (1987) summarizes the performance of eight reed-bed treatment systems in Denmark that are used to treat domestic wastewater. Seven systems used local soils as the substrate. The remaining system used a gravel substrate. After the first two years of operation, all systems except for the gravel system and one soil system had significant overland flow. The soil system that had no overland flow was operated at a very low hydraulic loading rate. Brix and Schierup (1989) report that after more than four years of operation of the Danish reed beds, overland flow still predominates.

Recent review articles on the use of reed beds for the treatment of wastewater have concluded, based on the occurrence of overland flow in most systems using fine substrates such as soils, that coarse sands or gravel are the optimal substrates to use in order to provide sufficient hydraulic conductivity from the beginning of operation (Reed and others, 1988; Conley and others, 1991). These review articles support the results of this project, in which the optimal substrate is a fine gravel since the pea gravel experienced little reduction of permeability while the sand-and-gravel substrates were nearly completely clogged after only one year of leachate addition.

There were two types of preferential flow observed in the constructed wetlands of this study. One was the result of density differences within the fluid leachate, which can occur due to the addition of rainwater or a more concentrated influent. The other was the result of clogging of the pore space within the substrate. The density stratification was most important within the gravel substrates (Beds I and IV), which have high hydraulic conductivities and thus little resistance to

flow at the flow rates present in the system. Density stratification becomes less important when a less dense liquid is displaced by a more dense fluid such as concentrated leachate.

There are several ramifications of density stratification. A major concern is that it can reduce the residence time that the wastewater stays in contact with the substrate. For example, if the denser leachate is flowing through only the bottom half of the substrate, beneath a diluted and less dense layer, then the residence time is one-half the designed value, which can greatly decrease treatment efficiency. Another problem is the effect of density stratification on the analyses made on the concentration of chemical constituents in the effluent. If the effluent is sampled soon after a rainstorm, the chemical concentrations will be much less than the concentrations of the same constituents in the substrate, thereby suggesting a much greater treatment efficiency than what is actually occurring. This problem can be avoided by measuring treatment efficiency based on influent loading rates of the constituent in question. A related problem arises in the sampling of pore water for analysis. Integrated samples collected from an in-plot well consist of a mixture of fluid from all depths. Analyses will show the concentration of a chemical to be lower than it actually is in the flowing segment of the wastewater since the concentrated part of the sample (from the dense lower layer) has been diluted by the less dense upper layer. This was seen in Bed I just prior to the dilution experiment: the chloride concentration of the influent was 23.5 mEq/l and of the effluent was 16.8 mEq/l, while pore-water concentrations from the five in-plot wells ranged from 2.1 to 10.9 mEq/l.

The problems associated with preferential flow caused by clogged substrates are similar to some of the problems associated with density stratification. A similarly rapid decrease in concentration in the effluent occurs following a rainstorm due to the overland flow of the rainwater. An extreme example is seen in the chloride concentrations measured in effluent samples collected during normal operations from Bed III (Figure 4-16). Another associated problem is the lowering of treatment efficiency due to the reduced residence time of wastewater in the system when preferential and overland flow cause wastewater to bypass the treatment zone within the substrate.

An important finding of this study is that the tracer experiment did not yield sufficient information to interpret the effects of density stratification and clogging on the flow characteristics of wastewater through the beds. The specific conductance measurements were vital for determining that preferential flow occurs within the gravel beds due to density differences. The specific conductance data were also instrumental in determining that in the sand-and-gravel beds, overland flow dominated the system and little or no wastewater flowed through the substrate.

D.4 MAINTENANCE

Leachate was delivered to the beds by pumping from a 155 m³ collection tank at one end of the landfill through approximately 670 m of pipe up a 2 percent slope to the research plots. This made the availability of leachate dependent on electricity, on equipment working properly, pipe integrity, and protection from freezing for the entire system. Delivery of leachate was impeded by equipment failure and broken delivery lines from January through March 1991. Even after a broken pump was fixed, ground conditions made it difficult to locate the break in the underground pipe. The system was finally brought back on-line in late March.

Passive systems should be designed whenever possible to avoid the pitfalls encountered in this project. The problems inherent in pumped systems could be avoided by designing a gravity-fed leachate delivery system. This would require adequate space for siting the wetland treatment area downhill from the leachate collection system. Piping should be minimized and adequately buried to prevent freezing.

Water flow meters were used to measure volumes going onto and coming off of each bed. These were needed to compute the water budget for each plot but also presented some problems. The water meters had screens at the intake end to prevent large pieces of debris from fouling the metering mechanism. A black slime formed in these screens, impeding flow through the meters. To prevent clogging of the meters, weekly (and sometime more frequent) cleaning was required. The screens were finally removed during the last few months of the project to end this maintenance problem.

D.5 FINAL DISPOSITION OF TREATMENT PLOTS

What should be done with constructed wetlands once their treatment efficiency declines substantially or the need for their use is no longer required? In some cases, the constructed wetlands have actually become a resource after use. The Tennessee Valley Authority has proposed mining the substrate from wetlands constructed for treating acid mine drainage to recover marketable metals (Donald Hammer, Tennessee Valley Authority, oral communication, 1992). Dr. Rhinhold Kickuth holds a U.S. patent on recovering phosphate deposits from constructed wetlands used in sewage treatment (Kickuth, 1982). For landfill leachate treatment systems, the options are:

- to leave the wetland system in place after leachate delivery ceases by maintaining an adequate water table to keep the plants alive,
- to dig up the substrate and landfill it
- to cap the system in place to prevent precipitation from remobilizing any contaminants that remain in the wetland.

Between August 1 and September 20, 1991, all of the beds were drained for a hydraulic conductivity experiment. Iron removal significantly increased during the period immediately following drainage (Fall 1991). This drainage seemed to rejuvenate the substrate (possibly through reaeration of the pores). Such an "intermittent flow" approach has been suggested by Brix (1992) as a way to enhance treatment.

D.6 FUTURE APPLICATIONS

The management of municipal solid-waste landfills has become more highly regulated in recent years, and the trend towards increased regulation appears to be continuing. Landfill leachate containment, collection, and treatment are key issues in granting permits for new landfills and determining remediation efforts at old landfills. Constructed wetlands may offer a viable alternative to the current options of hauling leachate to a sewage treatment plant or constructing a package treatment plant on-site.

The constructed wetland system built at the Tompkins County municipal solid-waste landfill is only one of many possible designs that could be considered. Results from this study and subsequent research by other scientists suggest that a multiple-cell system may improve treatment efficiencies. Pretreatment with an overland flow cell could prevent clogging in later subsurface-flow polishing cells, while also promoting volatilization of NH_4^+ and volatile organic compounds and oxidation of Fe. Intermittent flow (alternate filling and draining) in the subsurface flow cells may enhance treatment and extend the longevity of the bed.

A large component that the Tompkins County project did not address is the microbial environment. The mechanisms for treatment of various constituents could be further refined by identifying the types of microbes present (i.e., sulfate reducers and nitrifiers, aerobic, anaerobic, and facultative organisms), and with what part of the system these microbes are associated (roots, rhizomes, substrate).

D.7 ENERGY SAVINGS CALCULATION

The energy required to treat Tompkins County landfill leachate using the conventional activated sludge process was calculated by methods outlined in Fenn and others, 1975, and Thornthwaite and Mather, 1957. The calculations are presented in Appendix D, and a summary of the energy required for each process of treatment is presented in Table 4-10.

The 21.5-hectare landfill with 15.3 cm of percolation per year generates 3.3×10^7 liters of leachate annually. Assuming an annual BOD loading of 6,074 kg/year, the energy required to treat the leachate using conventional activated sludge treatment with land application of the solids would be 1.4×10^9 Btu/year plus 16,545 l of diesel fuel, and 15,164 kWh/year of electricity (Table 4-10). The pilot-scale research beds were designed to treat 8.4 percent of the total leachate generated annually (2.8×10^6 l). The annual total energy required to treat this volume of leachate is shown in Table 4-10.

Table 4-10. Summary of energy used to treat Tompkins County landfill leachate using conventional activated sludge process.
[Annual leachate generated was calculated assuming 15.3 cm of percolation over the 21.5 hectare landfill. The research plots were designed to treat 7,570 liters per day]

<u>Process</u>	<u>Treatment of Total Leachate Generated Annually (33,000,000 l/year)</u>	<u>Treatment of Leachate Applied to Research Plots (2,800,000 l/year)</u>	<u>Energy Use per Thousand Liters Treated</u>
Treating Wastewater Using Conventional Activated Sludge Process	15,164 kWh/year	1,274 kWh/year	0.46 kWh/1000 l
Trucking Leachate to Treatment Plant	16,450 l (4,345 gal.) diesel fuel/year	1,380 l (365 gal.) diesel fuel/year	
Drying Sludge	1.3×10^9 Btu/year	1.1×10^8 Btu/year	
Land Application of Sludge	1×10^8 Btu/year	8.4×10^6 Btu/year	
Hauling Dried Sludge to Land Application Site	95 l (25 gal.) diesel fuel/year	8 l (2 gal.) diesel fuel/year	

Based on the energy calculations (Table 4-10), it appears that the energy requirements for this constructed wetland system are approximately the same as the cost for conventional activated sludge treatment. The cost of the constructed wetland system could be decreased by redesigning the system with gravity feed and increased contact time with the substrate. A properly designed system that treated to discharge standards could be permitted for an onsite discharge permit and would eliminate hauling costs. There is also a savings in construction when scaling up to full size. It is logistically easier to construct a larger wetland with bull dozers than a pilot scale wetland with a back hoe. Volume discounts are offered for gravel, liners, and pipe when jobs are larger and would also result in a cost savings.

F. CONCLUSIONS

Constructed wetlands could provide a treatment system for municipal solid-waste landfill leachate that decreases contaminant concentrations and total leachate volume and at the same time, require little maintenance or management. Constructed wetlands that contain *Phragmites australis* (common reed) can reduce BOD and remove Fe, Mn, NH_4^+ , and other plant nutrients from landfill leachate to an appreciable degree.

Treatment effectiveness was highly variable depending on the type of substrate and bed temperature (season). The most efficient treatment overall occurred in summer in the sand-and-gravel substrate (Beds II and III), particularly for Fe, Mn, NH_4^+ , and K^+ . Microbial activity and cation exchange are possible mechanisms in reduction of BOD and removal of NH_4^+ and K^+ , as indicated by the reduced treatment efficiency and even nutrient loss from the beds when bed temperatures dropped.

Between July 1990 and September 1991, hydraulic conductivity of the substrate materials, decreased from 37 to 80 percent in all but Bed I, in which hydraulic conductivity exceeded 16.7 cm/s. The decrease in hydraulic conductivity was sufficient to cause overland flow in the sand-and-gravel Beds II and III. This overland flow may account for the greater Fe removals observed in Bed II. The use of coarse gravel as a substrate provides extremely high conductivity but does not provide acceptable treatment of the leachate. Specific conductance measurements indicated that significant stratification of the leachate occurs in the substrate due to density differences of the leachate compared to rainwater.

The crushed limestone substrates used in this experiment provided less cation exchange capacity than would have substrates of clay minerals, sesquioxides and silicate minerals. The metal adsorption to substrate would probably have been enhanced if substrates of aluminosilicate minerals were used in the experiment, as such minerals are associated with high cation exchange capacities.

The results suggest that the best substrate for use in a subsurface flow constructed wetland is pea gravel (0.5-cm-diameter stone). This substrate has sufficiently high hydraulic conductivity to prevent overland flow and, although density stratification was observed, the specific conductance measurements suggest that the flow through the substrate is a combination of density effects and plug-flow displacement. The significant volume undergoing displacement flow will offset some of the problems associated with the density flow.

Plants did not alter hydraulic conductivity of the substrate and no increase in root-zone aeration by plants was indicated, other than a greater removal of BOD in the planted sand-and-gravel Bed III than in the unplanted sand-and-gravel Bed II in summer 1991. NH_4^+ removal was greater in the planted Bed III during summer 1990, summer 1991, and fall 1991 and K^+ removal was greater in this bed in summer 1990 and fall 1991, when compared with the unplanted sand-and-gravel Bed II.

Phragmites australis grew well on constructed wetlands used for landfill leachate treatment. Coarse gravel (2- to 4-cm) was a better growth medium than pea gravel (1 cm) or a sand/gravel mixed substrate. *Phragmites* growth may have been limited by insufficient quantities of P as indicated by high plant concentrations compared to total soluble influent loads of P.

Flow of substrate pore water (leachate) to the root absorptive surfaces as a result of evapotranspiration created a buildup of particulate material, consisting of clay minerals, precipitated Fe (and other metals), and microbes. Fe precipitation may have been caused by oxygen release from the roots. Roots and/or their iron plaque, may have acted as filters for metal movement into rhizomes and tops. Metal concentration was not increased in rhizomes or tops compared to controls, except for Pb. Rhizomes showed no surface debris and therefore no evidence for oxygen release to the rhizosphere or water uptake. Relative metal concentration decreased in roots as X-ray point analysis moved from the surface to the cortex to the stele, indicating a physiological mechanism for protecting tissues from excess metal accumulation as well as the physical or chemical filtering occurring at the root surface.

The analysis of VOC was not accomplished due to interference with the analytical technique by the leachate matrix. Future research on the fate of VOC in a constructed wetland could be

accomplished by either adding VOC to the untreated leachate in quantities sufficient to overcome the matrix interference or to spend significantly more money for ultra low detection limit analysis of VOC.

It appears that the energy requirements for this constructed wetland system are approximately the same as the cost for conventional activated sludge treatment. The cost of the constructed wetland system could be decreased by redesigning the system with gravity feed and increased contact time with the substrate and discharging treated water onsite to eliminate hauling costs.

APPENDIX A

**ANALYSIS OF UNTREATED AND TREATED LEACHATE FOR FOUR
CONSTRUCTED WETLAND BEDS AT TOMPKINS COUNTY MUNICIPAL SOLID-
WASTE LANDFILL, JUNE 1990 THROUGH OCTOBER 1991**

Appendix A. Constituent Concentrations of Inflow.

Constituent	Units	7-27-90 (1355)	8-9-90 (1530)	8-23-90 (1245)	9-6-90 (1430)	9-20-90 (1300)	10-5-90 (1245)
Temperature	°C	23.5	22.1	20.3	24.2	17.8	17.6
Spec. Conductance	µS @ 25°C	6810	7330	7510	8430	7380	7390
Dissolved Oxygen	mg/l	---	---	---	0.8	1.1	0.5
pH	std pH units	7.28	7.17	---	7.21	7.35	7.38
Bar. Pressure	mm Hg	---	---	---	740	738	736
Fixed End. Alk.	mg/l CaCO ₃	2585	2770	---	3350	2880	2410
Carbonate Alk.	mg/l CaCO ₃	2630	2850	---	3260	2750	2450
HCO ₃ , Dissolved	mg/l	3210	3480	---	3980	3360	2990
Al, Dissolved	mg/l	0.20	0.15	0.22	0.11	0.11	0.17
B, Dissolved	mg/l	2.50	2.20	2.40	5.55	6.99	6.10
Ba, Dissolved	mg/l	0.60	0.62	<0.01	0.40	0.41	0.38
Ca, Dissolved	mg/l	167	196	203	163	189	193
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	0.02	0.02	<0.01
Co, Dissolved	mg/l	0.01	0.01	0.01	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	0.01	0.02	0.02	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	0.03	0.02	0.02	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	12.8	6.50	0.70	1.55	2.44	1.77
K, Dissolved	mg/l	281	308	301	401	332	312
Mg, Dissolved	mg/l	120	131	134	164	160	156
Mn, Dissolved	mg/l	2.00	2.25	1.80	1.00	1.44	1.87
Na, Dissolved	mg/l	637	723	703	875	758	699
Ni, Dissolved	mg/l	0.10	0.09	0.09	0.11	0.11	<0.11
Pb, Dissolved	mg/l	0.02	<0.01	<0.01	0.11	<0.11	<0.11
Zn, Dissolved	mg/l	0.03	0.01	<0.01	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	312	316	321	380	320	268
NO ₃ +NO ₂ -N, Diss.	mg/l	0.41	0.57	0.42	0.76	0.78	0.50
NO ₂ -N, Dissolved	mg/l	0.02	0.02	<0.01	0.02	0.08	0.05
PO ₄ -P, Dissolved	mg/l	0.02	0.04	0.03	0.08	0.09	0.02
Phosphorus, Dissolved	mg/l	0.16	0.37	0.52	0.25	0.16	0.16
Cl, Dissolved	mg/l	841	896	938	1060	884	501
Organic C, Dissolved	mg/l	295	740	866	130	373	209
SO ₄ -S, Dissolved	mg/l	2.20	1.60	13.3	0.32	11.3	7.44
BOD ₅ , Total	mg/l	143	168	119	91	97	89
BOD ₅ , Dissolved	mg/l	---	147	91	67	89	---

Appendix A. Constituent Concentrations of Inflow (continued).

Constituent	Units	10-17-90 (1300)	10-31-90 (1500)	11-16-90 (1200)	11-29-90 (1130)	12-14-90 (1135)	12-14-90 (1140)
Temperature	°C	20.8	15.0	12.9	10.8	6.8	(dupl.)
Spec. Conductance	µS @ 25°C	5160	4460	5000	5930	5840	---
Dissolved Oxygen	mg/l	0.5	0.4	1.1	0.6	---	---
pH	std pH units	7.19	7.00	7.14	7.14	7.24	---
Bar. Pressure	mm Hg	742			741	749	---
Fixed End. Alk.	mg/l CaCO ₃	2115	1590	1840	2170	2270	---
Carbonate Alk.	mg/l CaCO ₃	2180	1610	1850	2320	2400	---
HCO ₃ , Dissolved	mg/l	2660	1970	2260	2840	2930	---
Al, Dissolved	mg/l	0.27	0.22	0.18	0.20	0.21	0.19
B, Dissolved	mg/l	4.21	2.55	2.44	2.33	2.88	2.66
Ba, Dissolved	mg/l	0.68	0.67	0.66	0.65	0.60	0.64
Ca, Dissolved	mg/l	255	132	182	193	204	191
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	4.29	7.44	7.66	9.65	4.53	4.14
K, Dissolved	mg/l	210	173	161	175	211	203
Mg, Dissolved	mg/l	155	83.2	104	110	123	115
Mn, Dissolved	mg/l	4.90	2.66	3.63	3.79	3.77	3.52
Na, Dissolved	mg/l	536	475	443	482	527	517
Ni, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Pb, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Zn, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	170	146	167	212	220	226
NO ₃ +NO ₂ -N, Diss.	mg/l	0.30	0.25	0.43	0.45	0.46	0.46
NO ₂ -N, Dissolved	mg/l	0.03	0.01	0.02	0.01	0.01	0.01
PO ₄ -P, Dissolved	mg/l	0.02	0.01	<0.01	0.02	0.01	0.01
Phosphorus, Dissolved	mg/l	0.10	<0.02	<0.02	0.06	0.08	0.09
Cl, Dissolved	mg/l	662	625	580	640	668	648
Organic C, Dissolved	mg/l	280	232	263	336	264	333
SO ₄ -S, Dissolved	mg/l	2.12	2.96	6.85	6.59	7.13	6.97
BOD ₅ , Total	mg/l	292	266	283	287	310	---
BOD ₅ , Dissolved	mg/l	292	252	280	306	325	---

Appendix A. Constituent Concentrations of Inflow (continued).

Constituent	Units	12-27-90 (1245)	1-10-91 (1415)	3-30-91 (1155)	4-12-91 (1120)	5-23-91 (1200)	6-7-91 (1140)
Temperature	°C	2.0	1.0	6.2	11.9	21.0	21.0
Spec. Conductance	µS @ 25°C	5430	5190	6060	5890	6850	6740
Dissolved Oxygen	mg/l	0.5	0.7	---	0.8	---	---
pH	std pH units	7.31	7.12	6.88	6.80	7.08	7.29
Bar. Pressure	mm Hg	756	752	735	735	735	735
Fixed End. Alk.	mg/l CaCO ₃	2200	1790	2380	2170	2640	2380
Carbonate Alk.	mg/l CaCO ₃	2420	2100	2750	2430	2800	2430
HCO ₃ , Dissolved	mg/l	2950	2560	3360	2970	3420	2970
Al, Dissolved	mg/l	<0.11	0.31	0.30	0.20	0.18	0.15
B, Dissolved	mg/l	2.88	2.66	2.55	2.34	1.50	1.66
Ba, Dissolved	mg/l	0.73	0.87	0.92	1.00	0.56	0.76
Ca, Dissolved	mg/l	209	337	355	300	226	152
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.01	<0.01	0.03	0.02
Cr, Dissolved	mg/l	<0.11	<0.11	<0.01	<0.01	0.07	0.04
Cu, Dissolved	mg/l	<0.11	<0.11	<0.01	<0.01	0.02	0.01
Fe, Dissolved	mg/l	17.9	22.9	49.5	24.0	2.43	2.16
K, Dissolved	mg/l	214	125	182	168	225	235
Mg, Dissolved	mg/l	124	130	140	131	129	112
Mn, Dissolved	mg/l	3.55	6.99	9.47	8.50	3.47	1.82
Na, Dissolved	mg/l	501	394	495	485	497	556
Ni, Dissolved	mg/l	<0.11	<0.11	0.05	0.05	0.1	0.11
Pb, Dissolved	mg/l	<0.11	<0.11	<0.01	<0.01	<0.01	<0.01
Zn, Dissolved	mg/l	<0.11	<0.11	<0.01	<0.01	0.05	0.02
NH ₄ -N, Dissolved	mg/l	215	139	191	184	234	260
NO ₃ +NO ₂ -N, Diss.	mg/l	0.50	0.38	0.29	0.26	0.40	0.40
NO ₂ -N, Dissolved	mg/l	<0.01	<0.01	0.02	<0.01	<0.01	0.01
PO ₄ -P, Dissolved	mg/l	0.01	0.03	0.09	0.04	0.03	0.02
Phosphorus, Dissolved	mg/l	0.12	0.06	0.16	0.13	0.08	0.08
Cl, Dissolved	mg/l	670	525	572	745	1080	986
Organic C, Dissolved	mg/l	403	294	743	662	365	269
SO ₄ -S, Dissolved	mg/l	8.93	12.6	1.00	1.00	<0.80	2.50
BOD ₅ , Total	mg/l	316	292	140	315	301	46
BOD ₅ , Dissolved	mg/l	311	288	136	311	299	44

Appendix A. Constituent Concentrations of Inflow (continued).

Constituent	Units	6-20-91 (1150)	6-20-91 (1155)	7-3-91 (1225)	7-3-91 (1230)	7-18-91 (1135)	8-1-91 (1115)
Temperature	°C	21.0	---	22.6	---	24.8	22.0
Spec. Conductance	µS @ 25°C	6740	---	8090	---	7630	8300
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std pH units	7.15	---	7.30	---	7.37	7.85
Bar. Pressure	mm Hg	735	---	735	---	735	738
Fixed End. Alk.	mg/l CaCO ₃	2300	---	2980	---	2730	2500
Carbonate Alk.	mg/l CaCO ₃	2410	---	3050	---	2780	2530
HCO ₃ , Dissolved	mg/l	2940	2940	3720	3720	3390	3090
Al, Dissolved	mg/l	0.26	0.26	0.29	0.24	0.26	0.21
B, Dissolved	mg/l	2.72	2.67	2.94	---	2.91	3.36
Ba, Dissolved	mg/l	0.72	0.74	0.70	0.63	0.65	0.42
Ca, Dissolved	mg/l	186	185	156	147	151	92.0
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.02	0.02	0.02	0.02	<0.02	0.02
Cr, Dissolved	mg/l	0.02	0.02	0.02	0.02	0.04	0.02
Cu, Dissolved	mg/l	0.03	0.02	0.10	0.02	<0.01	0.01
Fe, Dissolved	mg/l	4.77	4.53	1.60	1.61	1.69	2.35
K, Dissolved	mg/l	505	505	635	494	1070	670
Mg, Dissolved	mg/l	128	131	153	145	144	82.0
Mn, Dissolved	mg/l	1.66	1.64	1.14	1.07	0.94	0.55
Na, Dissolved	mg/l	419	407	519	519	760	844
Ni, Dissolved	mg/l	0.14	0.14	0.16	0.15	0.14	0.16
Pb, Dissolved	mg/l	0.09	0.09	0.01	0.11	0.08	0.08
Zn, Dissolved	mg/l	<0.01	<0.01	0.19	0.04	<0.02	<0.02
NH ₄ -N, Dissolved	mg/l	296	296	390	369	316	374
NO ₃ +NO ₂ -N, Diss.	mg/l	0.63	0.48	0.67	0.68	0.71	0.72
NO ₂ -N, Dissolved	mg/l	0.01	0.01	0.07	0.07	0.06	0.10
PO ₄ -P, Dissolved	mg/l	0.02	0.02	0.07	0.04	---	0.22
Phosphorus, Dissolved	mg/l	0.12	0.13	0.16	0.16	0.22	0.35
Cl, Dissolved	mg/l	1020	864	1310	1270	1240	1090
Organic C, Dissolved	mg/l	356	328	494	---	320	436
SO ₄ -S, Dissolved	mg/l	6.60	7.10	2.50	2.10	6.60	2.90
BOD ₅ , Total	mg/l	135	---	72	---	60	96
BOD ₅ , Dissolved	mg/l	87	---	68	---	58	46

Appendix A. Constituent Concentrations of Inflow (continued).

Constituent	Units	10-3-91 (1225)	10-17-91 (1115)
Temperature	°C	23.0	13.0
Spec. Conductance	µS @ 25°C	5010	7590
Dissolved Oxygen	mg/l	---	---
pH	std pH units	7.42	7.38
Bar. Pressure	mm Hg	735	760
Fixed End. Alk.	mg/l CaCO ₃	1930	2590
Carbonate Alk.	mg/l CaCO ₃	1970	2620
HCO ₃ , Dissolved	mg/l	2400	3200
Al, Dissolved	mg/l	0.23	0.18
B, Dissolved	mg/l	2.03	2.39
Ba, Dissolved	mg/l	0.57	0.58
Ca, Dissolved	mg/l	103	106
Cd, Dissolved	mg/l	<0.01	<0.01
Co, Dissolved	mg/l	0.02	0.02
Cr, Dissolved	mg/l	0.01	0.01
Cu, Dissolved	mg/l	0.02	0.02
Fe, Dissolved	mg/l	2.42	0.89
K, Dissolved	mg/l	235	277
Mg, Dissolved	mg/l	105	118
Mn, Dissolved	mg/l	0.97	0.85
Na, Dissolved	mg/l	530	600
Ni, Dissolved	mg/l	0.12	0.14
Pb, Dissolved	mg/l	0.05	0.04
Zn, Dissolved	mg/l	0.14	0.02
NH ₄ -N, Dissolved	mg/l	241	335
NO ₃ +NO ₂ -N, Diss.	mg/l	0.52	0.92
NO ₂ -N, Dissolved	mg/l	0.08	0.10
PO ₄ -P, Dissolved	mg/l	0.15	0.01
Phosphorus, Dissolved	mg/l	<0.02	0.06
Cl, Dissolved	mg/l	945	989
Organic C, Dissolved	mg/l	378	388
SO ₄ -S, Dissolved	mg/l	15.8	14.6
BOD ₅ , Total	mg/l	298	103
BOD ₅ , Dissolved	mg/l	28	72

Appendix A. Constituent Concentrations of Outflow: Bed I.

Constituent	Units	7-26-90 (1445)	8-9-90 (1050)	8-9-90 (1055)	8-23-90 (0930)	9-6-90 (1035)	9-20-90 (0915)
Temperature	°C	22.2	20.8	---	18.8	20.2	15.5
Spec. Conductance	µS @ 25°C	7000 6140	6600	---	---	6730	6090
Dissolved Oxygen	mg/l	---	---	---	---	0.6	0.9
pH	std pH units	6.99	7.14	---	---	7.17	7.12
Bar. Pressure	mm Hg	---	---	---	---	740	737
Fixed End. Alk.	mg/l CaCO ₃	2330	2535	---	---	2230	1890
Carbonate Alk.	mg/l CaCO ₃	2370	2580	---	---	2275	1920
HCO ₃ , Dissolved	mg/l	2890	3145	3145	---	2780	2340
Al, Dissolved	mg/l	0.12	0.09	0.09	0.08	0.11	0.11
B, Dissolved	mg/l	1.80	1.40	1.50	1.70	4.11	5.44
Ba, Dissolved	mg/l	1.47	0.98	1.08	2.06	0.81	0.83
Ca, Dissolved	mg/l	156	115	124	136	95.3	124
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	0.01	0.03
Co, Dissolved	mg/l	0.02	0.02	0.02	0.02	<0.11	<0.11
Cr, Dissolved	mg/l	0.02	0.02	0.01	0.02	<0.11	<0.11
Cu, Dissolved	mg/l	0.02	0.02	0.02	0.02	<0.11	<0.11
Fe, Dissolved	mg/l	2.00	3.25	3.50	3.05	3.00	4.44
K, Dissolved	mg/l	253	197	228	309	262	284
Mg, Dissolved	mg/l	116	88.2	100	151	104	128
Mn, Dissolved	mg/l	1.85	1.45	2.25	1.80	1.00	1.00
Na, Dissolved	mg/l	603	482	542	794	583	653
Ni, Dissolved	mg/l	0.11	0.10	0.11	0.10	0.11	0.11
Pb, Dissolved	mg/l	0.01	<0.01	0.01	<0.01	0.11	<0.11
Zn, Dissolved	mg/l	0.02	0.02	0.01	0.01	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	243	291	290	267	280	280
NO ₃ +NO ₂ -N, Diss.	mg/l	1.01	0.57	0.54	0.40	0.62	0.55
NO ₂ -N, Dissolved	mg/l	0.05	0.05	0.02	0.01	0.02	0.04
PO ₄ -P, Dissolved	mg/l	0.04	0.05	0.04	0.01	0.10	0.12
Phosphorus, Dissolved	mg/l	0.17	0.25	0.24	0.16	0.22	0.20
Cl, Dissolved	mg/l	870	783	794	951	755	815
Organic C, Dissolved	mg/l	255	577	588	805	1120	191
SO ₄ -S, Dissolved	mg/l	2.00	3.52	2.76	1.80	2.52	9.16
BOD ₅ , Total	mg/l	64	56	---	60	70	75
BOD ₅ , Dissolved	mg/l	---	42	---	56	52	62

Appendix A. Constituent Concentrations of Outflow: Bed I (continued).

Constituent	Units	10-5-90 (0840)	10-5-90 (0845)	10-17-90 (1000)	10-31-90 (0930)	11-16-90 (1015)	11-29-90 (0940)
Temperature	°C	14.4	---	14.8	9.8	10.8	8.0
Spec. Conductance	µS @ 25°C	5730	---	5280	4220	3030	3990
Dissolved Oxygen	mg/l	0.6	---	1.0	0.4	---	0.5
pH	std pH units	7.32	---	7.16	6.96	7.12	7.08
Bar. Pressure	mm Hg	736	---	742	---	---	741
Fixed End. Alk.	mg/l CaCO ₃	1910	---	1930	1530	1020	1440
Carbonate Alk.	mg/l CaCO ₃	1930	---	1990	1570	1040	1520
HCO ₃ , Dissolved	mg/l	2360	2360	2430	1910	1270	1860
Al, Dissolved	mg/l	---	0.33	<0.11	0.11	<0.11	<0.11
B, Dissolved	mg/l	3.33	3.33	4.44	1.99	1.44	1.66
Ba, Dissolved	mg/l	0.50	0.50	0.78	0.72	0.35	0.61
Ca, Dissolved	mg/l	79.3	84.2	217	137	68.1	121
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	2.95	2.94	7.77	9.66	5.13	12.53
K, Dissolved	mg/l	247	251	199	157	104	127
Mg, Dissolved	mg/l	103	109	134	76.9	46.1	69.3
Mn, Dissolved	mg/l	0.71	0.73	2.69	2.88	1.53	3.16
Na, Dissolved	mg/l	513	536	513	462	243	332
Ni, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Pb, Dissolved	mg/l	<0.11	0.13	<0.11	<0.11	<0.11	<0.11
Zn, Dissolved	mg/l	---	<0.11	<0.11	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	198	198	164	136	107	132
NO ₃ +NO ₂ -N, Diss.	mg/l	1.90	1.90	0.30	0.24	0.25	0.29
NO ₂ -N, Dissolved	mg/l	0.04	0.04	0.03	0.01	0.02	0.01
PO ₄ -P, Dissolved	mg/l	0.11	0.10	0.07	0.04	0.03	0.04
Phosphorus, Dissolved	mg/l	0.19	0.17	0.16	0.11	0.05	0.06
Cl, Dissolved	mg/l	578	637	646	508	340	432
Organic C, Dissolved	mg/l	181	137	209	205	124	201
SO ₄ -S, Dissolved	mg/l	2.68	2.12	0.84	2.36	4.13	3.53
BOD ₅ , Total	mg/l	46	---	291	223	49	281
BOD ₅ , Dissolved	mg/l	21	---	287	203	39	279

Appendix A. Constituent Concentrations of Outflow: Bed I (continued).

Constituent	Units	12-14-90 (0950)	12-27-90 (1040)	1-10-91 (1145)	1-10-91 (1150)	3-30-91 (0930)	4-12-91 (1010)
Temperature	°C	3.3	1.6	2.0	---	6.2	8.2
Spec. Conductance	µS @ 25°C	3120	1860	2210	---	315	3580
Dissolved Oxygen	mg/l	1.0	3.0	0.95	---	---	0.5
pH	std pH units	7.06	7.40	7.06	---	6.65	6.88
Bar. Pressure	mm Hg	749	756	752	---	735	735
Fixed End. Alk.	mg/l CaCO ₃	1220	739	778	---	134	1010
Carbonate Alk.	mg/l CaCO ₃	1280	775	795	---	136	1100
HCO ₃ , Dissolved	mg/l	1560	946	970	970	166	1340
Al, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	0.02	0.15
B, Dissolved	mg/l	1.33	0.77	0.55	0.66	0.04	1.05
Ba, Dissolved	mg/l	0.56	0.29	0.20	0.23	0.04	0.61
Ca, Dissolved	mg/l	109	58.5	32.3	40.8	27.7	205
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.01	<0.01
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.01	<0.01
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.01	<0.01
Fe, Dissolved	mg/l	8.49	4.11	2.22	2.66	1.84	12.4
K, Dissolved	mg/l	106	67.0	49.2	53.4	10.7	88.0
Mg, Dissolved	mg/l	57.4	29.1	14.2	18.9	5.53	78.4
Mn, Dissolved	mg/l	2.43	1.22	0.92	1.04	0.20	5.59
Na, Dissolved	mg/l	271	155	115	126	4.20	235
Ni, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.01	<0.01
Pb, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.01	<0.01
Zn, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.01	<0.01
NH ₄ -N, Dissolved	mg/l	124	56.0	0.78	0.75	7.80	87.7
NO ₃ +NO ₂ -N, Diss.	mg/l	0.25	0.15	0.15	0.16	1.03	0.17
NO ₂ -N, Dissolved	mg/l	0.01	<0.01	<0.01	<0.01	0.03	<0.01
PO ₄ -P, Dissolved	mg/l	0.04	0.01	0.03	0.03	0.01	0.04
Phosphorus, Dissolved	mg/l	0.07	<0.02	0.03	0.03	<0.02	0.07
Cl, Dissolved	mg/l	417	203	222	242	---	332
Organic C, Dissolved	mg/l	248	158	149	157	<50.0	444
SO ₄ -S, Dissolved	mg/l	3.03	2.92	2.21	2.39	3.80	1.40
BOD ₅ , Total	mg/l	156	119	24	---	5	313
BOD ₅ , Dissolved	mg/l	175	93	49	---	2	308

Appendix A. Constituent Concentrations of Outflow: Bed I (continued).

Constituent	Units	5-23-91 (1015)	6-7-91 (1015)	6-20-91 (1035)	7-3-91 (1005)	7-18-91 (0900)	8-1-91 (1010)
Temperature	°C	19.2	19.2	23.3	21.7	23.2	23.0
Spec. Conductance	µS @ 25°C	3990	5280	5110	7240	8100	7610
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std pH units	6.91	7.13	7.27	7.12	7.24	7.79
Bar. Pressure	mm Hg	735	735	735	735	735	738
Fixed End. Alk.	mg/l CaCO ₃	1580	1810	1520	2330	2610	2560
Carbonate Alk.	mg/l CaCO ₃	1700	1830	1570	2420	2690	2560
HCO ₃ , Dissolved	mg/l	2070	2230	1910	2950	3280	3120
Al, Dissolved	mg/l	0.15	0.12	0.22	0.23	0.24	0.20
B, Dissolved	mg/l	1.05	1.13	1.39	2.66	3.01	3.31
Ba, Dissolved	mg/l	0.89	0.90	0.54	1.02	1.13	1.07
Ca, Dissolved	mg/l	230	159	113	137	152	90.0
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.01	0.02	0.10	0.02	0.02	0.02
Cr, Dissolved	mg/l	0.04	0.03	0.01	0.02	0.02	<0.02
Cu, Dissolved	mg/l	0.01	0.01	0.01	0.03	0.01	<0.01
Fe, Dissolved	mg/l	7.96	5.61	3.42	2.84	3.50	1.96
K, Dissolved	mg/l	107	152	269	507	430	487
Mg, Dissolved	mg/l	78.3	95.6	73.8	123	133	140
Mn, Dissolved	mg/l	3.76	1.95	1.36	0.02	1.31	0.83
Na, Dissolved	mg/l	284	390	258	407	750	775
Ni, Dissolved	mg/l	0.06	0.08	0.08	0.14	0.15	0.15
Pb, Dissolved	mg/l	<0.01	<0.01	<0.01	0.09	0.08	0.08
Zn, Dissolved	mg/l	0.02	0.02	0.05	0.03	0.02	<0.02
NH ₄ -N, Dissolved	mg/l	99.8	139	157	248	250	306
NO ₃ +NO ₂ -N, Diss.	mg/l	0.20	0.27	0.27	0.46	0.61	0.66
NO ₂ -N, Dissolved	mg/l	0.01	0.01	0.01	0.01	0.01	0.01
PO ₄ -P, Dissolved	mg/l	0.03	0.03	0.04	0.05	---	0.16
Phosphorus, Dissolved	mg/l	0.04	0.08	0.05	0.15	0.07	0.18
Cl, Dissolved	mg/l	455	740	557	1000	1190	1020
Organic C, Dissolved	mg/l	413	202	180	482	281	362
SO ₄ -S, Dissolved	mg/l	1.80	0.90	1.70	1.10	2.40	2.20
BOD ₅ , Total	mg/l	278	125	63	51	63	47
BOD ₅ , Dissolved	mg/l	257	127	9	21	42	33

Appendix A. Constituent Concentrations of Outflow: Bed I (continued).

Constituent	Units	8-1-91 (1015)	10-3-91 (1030)	10-17-91 (1010)
Temperature	°C	---	22.5	12.0
Spec. Conductance	µS @ 25°C	---	5160	6650
Dissolved Oxygen	mg/l	---	---	---
pH	std pH units	---	7.25	7.34
Bar. Pressure	mm Hg	---	735	760
Fixed End. Alk.	mg/l CaCO ₃	---	694	2110
Carbonate Alk.	mg/l CaCO ₃	---	708	2160
HCO ₃ , Dissolved	mg/l	3120	864	2630
Al, Dissolved	mg/l	0.20	0.28	0.18
B, Dissolved	mg/l	3.20	1.75	1.80
Ba, Dissolved	mg/l	1.18	1.01	1.17
Ca, Dissolved	mg/l	89.0	125	105
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.02	0.02	0.03
Cr, Dissolved	mg/l	<0.02	<0.01	0.01
Cu, Dissolved	mg/l	<0.01	0.01	0.01
Fe, Dissolved	mg/l	2.14	1.67	1.39
K, Dissolved	mg/l	494	180	218
Mg, Dissolved	mg/l	140	90.0	102
Mn, Dissolved	mg/l	0.82	1.63	0.95
Na, Dissolved	mg/l	777	480	550
Ni, Dissolved	mg/l	0.15	0.12	0.16
Pb, Dissolved	mg/l	0.08	0.04	0.05
Zn, Dissolved	mg/l	<0.02	0.05	0.03
NH ₄ -N, Dissolved	mg/l	301	171	254
NO ₃ +NO ₂ -N, Diss.	mg/l	0.65	1.00	15.0
NO ₂ -N, Dissolved	mg/l	0.01	0.10	0.03
PO ₄ -P, Dissolved	mg/l	0.11	0.04	0.04
Phosphorus, Dissolved	mg/l	0.15	0.03	0.05
Cl, Dissolved	mg/l	1170	702	931
Organic C, Dissolved	mg/l	387	267	384
SO ₄ -S, Dissolved	mg/l	2.60	16.5	16.9
BOD ₅ , Total	mg/l	---	32	85
BOD ₅ , Dissolved	mg/l	---	14	47

Appendix A. Constituent Concentrations of Outflow: Bed II.

Constituent	Units	7-27-90 (1040)	8-9-90 (1315)	8-23-90 (1110)	9-6-90 (1145)	9-20-90 (1000)	9-20-90 (1005)
Temperature	°C	23.5	21.2	19.4	22.4	15.6	---
Spec. Conductance	µS @ 25°C	2950	4130	4200	4730	5130	---
Dissolved Oxygen	mg/l	---	---	---	1.00	1.30	---
pH	std pH units	6.92	7.11	---	7.36	7.53	---
Bar. Pressure	mm Hg	---	---	---	740	737	---
Fixed End. Alk.	mg/l CaCO ₃	750	855	---	749	1520	---
Carbonate Alk.	mg/l CaCO ₃	758	869	---	750	1540	---
HCO ₃ , Dissolved	mg/l	925	1060	---	915	1880	---
Al, Dissolved	mg/l	0.10	0.12	0.08	<0.11	<0.11	0.11
B, Dissolved	mg/l	0.30	0.60	1.40	2.11	4.00	4.11
Ba, Dissolved	mg/l	0.40	0.59	0.81	0.21	0.64	0.64
Ca, Dissolved	mg/l	177	131	106	36.6	42.1	40.9
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.02	0.02	0.03	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	0.02	0.02	0.02	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	0.03	0.04	0.04	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	0.07	0.11	0.10	<0.11	<0.11	<0.11
K, Dissolved	mg/l	19.0	55.0	125	121	236	224
Mg, Dissolved	mg/l	59.7	59.4	81.6	46.6	107	106
Mn, Dissolved	mg/l	0.65	0.36	0.30	0.11	0.33	0.33
Na, Dissolved	mg/l	392	382	502	338	653	630
Ni, Dissolved	mg/l	0.08	0.09	0.11	<0.11	0.22	0.22
Pb, Dissolved	mg/l	0.01	<0.01	<0.01	<0.11	<0.11	<0.11
Zn, Dissolved	mg/l	0.01	0.03	0.03	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	1.96	36.4	97.0	75.0	170	160
NO ₃ +NO ₂ -N, Diss.	mg/l	33.7	20.5	11.6	19.5	32.0	32.0
NO ₂ -N, Dissolved	mg/l	5.83	4.04	0.53	6.60	12.4	12.4
PO ₄ -P, Dissolved	mg/l	<0.01	<0.01	<0.01	0.01	0.02	0.02
Phosphorus, Dissolved	mg/l	0.03	0.06	0.07	0.05	0.08	0.08
Cl, Dissolved	mg/l	490	534	668	430	792	776
Organic C, Dissolved	mg/l	175	430	480	680	166	202
SO ₄ -S, Dissolved	mg/l	6.88	6.12	7.52	5.28	11.4	8.96
BOD ₅ , Total	mg/l	28	35	42	40	35	---
BOD ₅ , Dissolved	mg/l	---	14	49	31	24	---

Appendix A. Constituent Concentrations of Outflow: Bed II (continued).

Constituent	Units	10-5-90 (0935)	10-17-90 (1035)	10-17-90 (1040)	10-31-90 (1030)	11-16-90 (1030)	11-29-90 (1000)
Temperature	°C	12.5	16.5	---	8.8	9.7	8.0
Spec. Conductance	µS @ 25°C	6480	5800	---	4620	3970	4610
Dissolved Oxygen	mg/l	1.65	0.60	---	0.30	---	0.50
pH	std pH units	7.76	7.61	---	7.55	7.66	7.63
Bar. Pressure	mm Hg	736	742	---	---	---	741
Fixed End. Alk.	mg/l CaCO ₃	2160	---	---	1700	1330	1570
Carbonate Alk.	mg/l CaCO ₃	2180	---	---	1730	1340	1610
HCO ₃ , Dissolved	mg/l	2660	---	---	2110	1640	1960
Al, Dissolved	mg/l	1.21	<0.11	<0.11	0.11	<0.11	<0.11
B, Dissolved	mg/l	4.99	5.43	5.43	1.11	2.22	2.33
Ba, Dissolved	mg/l	0.71	0.51	0.51	0.53	0.37	0.52
Ca, Dissolved	mg/l	77.6	42.2	42.1	26.2	60.2	77.1
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	0.51	0.63	0.58	0.66	0.43	4.93
K, Dissolved	mg/l	309	288	279	202	151	172
Mg, Dissolved	mg/l	149	133	134	35.7	87.1	105
Mn, Dissolved	mg/l	0.55	0.64	0.64	0.55	0.89	1.32
Na, Dissolved	mg/l	699	688	653	535	407	454
Ni, Dissolved	mg/l	0.19	0.15	0.15	<0.11	<0.11	<0.11
Pb, Dissolved	mg/l	<0.11	0.14	<0.11	<0.11	<0.11	<0.11
Zn, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	230	186	197	166	130	160
NO ₃ +NO ₂ -N, Diss.	mg/l	1.80	0.40	0.40	0.29	2.66	0.37
NO ₂ -N, Dissolved	mg/l	2.00	0.03	0.04	<0.01	0.50	0.01
PO ₄ -P, Dissolved	mg/l	0.02	0.01	0.01	<0.01	<0.01	0.01
Phosphorus, Dissolved	mg/l	0.12	0.09	0.09	0.07	0.03	0.04
Cl, Dissolved	mg/l	956	914	900	585	450	522
Organic C, Dissolved	mg/l	169	153	221	241	180	220
SO ₄ -S, Dissolved	mg/l	5.56	6.44	5.76	4.28	5.16	4.62
BOD ₅ , Total	mg/l	66	12	---	138	102	294
BOD ₅ , Dissolved	mg/l	23	21	---	166	103	310

Appendix A. Constituent Concentrations of Outflow: Bed II (continued).

Constituent	Units	12-14-90 (1010)	12-27-90 (1100)	1-10-91 (frozen)	3-30-91 (0950)	4-12-91 (1030)	5-23-91 (1030)
Temperature	°C	2.9	2.5	---	6.8	9.1	22.2
Spec. Conductance	µS @ 25°C	4740	3010	---	1040	3390	2710
Dissolved Oxygen	mg/l	0.65	1.50	---	---	0.55	---
pH	std pH units	7.52	7.66	---	6.92	7.36	7.59
Bar. Pressure	mm Hg	749	756	---	735	735	735
Fixed End. Alk.	mg/l CaCO ₃	1690	927	---	395	908	1100
Carbonate Alk.	mg/l CaCO ₃	1790	959	---	398	1040	1190
HCO ₃ , Dissolved	mg/l	2180	1170	---	486	1270	1450
Al, Dissolved	mg/l	<0.11	<0.11	---	0.03	0.05	0.10
B, Dissolved	mg/l	2.11	1.66	---	0.32	0.92	1.00
Ba, Dissolved	mg/l	0.56	0.25	---	0.08	0.35	0.37
Ca, Dissolved	mg/l	96.6	35.0	---	20.8	88.5	75.0
Cd, Dissolved	mg/l	<0.01	<0.01	---	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	---	<0.01	<0.01	0.01
Cr, Dissolved	mg/l	<0.11	<0.11	---	<0.01	<0.01	0.03
Cu, Dissolved	mg/l	<0.11	<0.11	---	<0.01	<0.01	0.01
Fe, Dissolved	mg/l	4.46	2.77	---	2.30	5.60	1.34
K, Dissolved	mg/l	155	110	---	52.5	101	131
Mg, Dissolved	mg/l	99.6	49.9	---	17.2	74.9	80.4
Mn, Dissolved	mg/l	1.58	0.88	---	0.41	1.75	0.64
Na, Dissolved	mg/l	434	256	---	66.0	235	338
Ni, Dissolved	mg/l	<0.11	0.28	---	0.01	<0.01	0.07
Pb, Dissolved	mg/l	<0.11	<0.11	---	<0.01	<0.01	<0.01
Zn, Dissolved	mg/l	<0.11	<0.11	---	<0.01	<0.01	0.01
NH ₄ -N, Dissolved	mg/l	152	101	---	41.3	85.9	193
NO ₃ +NO ₂ -N, Diss.	mg/l	0.39	0.24	---	2.15	0.15	0.21
NO ₂ -N, Dissolved	mg/l	0.01	<0.01	---	0.17	<0.01	0.01
PO ₄ -P, Dissolved	mg/l	<0.01	<0.01	---	0.01	0.01	0.01
Phosphorus, Dissolved	mg/l	0.05	0.02	---	<0.02	0.04	0.05
Cl, Dissolved	mg/l	525	320	---	60.3	354	664
Organic C, Dissolved	mg/l	298	203	---	99.4	314	263
SO ₄ -S, Dissolved	mg/l	4.91	2.77	---	4.00	2.00	2.00
BOD ₅ , Total	mg/l	205	36	---	0	312	298
BOD ₅ , Dissolved	mg/l	267	85	---	3	306	287

Appendix A. Constituent Concentrations of Outflow: Bed II (continued).

Constituent	Units	5-23-91 (1035)	6-7-91 (1035)	6-20-91 (1050)	7-3-91 (1045)	7-18-91 (0930)	7-18-91 (0935)
Temperature	°C	---	19.6	25.1	22.1	24.5	---
Spec. Conductance	µS @ 25°C	---	4760	5590	5520	5560	---
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std pH units	---	7.78	7.70	7.38	7.45	---
Bar. Pressure	mm Hg	---	735	735	735	735	---
Fixed End. Alk.	mg/l CaCO ₃	---	1220	510	1640	923	---
Carbonate Alk.	mg/l CaCO ₃	---	1250	515	1700	943	---
HCO ₃ , Dissolved	mg/l	1450	1520	628	2070	1150	1150
Al, Dissolved	mg/l	0.09	0.08	0.12	0.16	0.11	0.12
B, Dissolved	mg/l	0.94	0.89	0.71	2.81	1.90	2.01
Ba, Dissolved	mg/l	0.30	0.29	0.16	0.80	0.42	0.42
Ca, Dissolved	mg/l	74.7	35.9	26.1	64.4	34.0	35.0
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.01	0.03	0.01	0.03	<0.02	<0.02
Cr, Dissolved	mg/l	0.03	0.03	0.01	0.02	<0.02	<0.02
Cu, Dissolved	mg/l	0.01	0.01	0.01	0.06	0.01	0.02
Fe, Dissolved	mg/l	1.48	0.32	0.32	1.30	0.24	0.25
K, Dissolved	mg/l	126	133	123	536	280	250
Mg, Dissolved	mg/l	77.5	75.7	37.4	130	66.0	67.2
Mn, Dissolved	mg/l	0.62	0.18	0.10	0.35	0.19	0.20
Na, Dissolved	mg/l	322	337	142	508	560	570
Ni, Dissolved	mg/l	0.06	0.09	0.06	0.24	0.13	0.14
Pb, Dissolved	mg/l	<0.01	<0.01	<0.01	0.09	<0.02	<0.02
Zn, Dissolved	mg/l	0.01	0.02	0.01	0.09	0.02	0.02
NH ₄ -N, Dissolved	mg/l	96.3	95.4	80.6	146	114	114
NO ₃ +NO ₂ -N, Diss.	mg/l	0.28	2.78	7.38	4.12	2.08	2.10
NO ₂ -N, Dissolved	mg/l	<0.01	0.33	1.21	0.29	0.67	0.59
PO ₄ -P, Dissolved	mg/l	<0.01	0.01	0.01	0.02	---	---
Phosphorus, Dissolved	mg/l	0.05	0.05	0.02	0.10	0.05	0.06
Cl, Dissolved	mg/l	611.90	580	310	1480	1230	1270
Organic C, Dissolved	mg/l	286.3	174	196	439	165	183
SO ₄ -S, Dissolved	mg/l	1.32	1.80	3.30	7.60	5.7	5.6
BOD ₅ , Total	mg/l	298	26	66	18	100	---
BOD ₅ , Dissolved	mg/l	287	30	6	5	18	---

Appendix A. Constituent Concentrations of Outflow: Bed II (continued).

Constituent	Units	8-1-91 (1030)	10-3-91 (1100)	10-17-91 (1020)	10-17-91 (1025)
Temperature	°C	23.0	22.0	8.5	---
Spec. Conductance	µS @ 25°C	6260	4160	5780	---
Dissolved Oxygen	mg/l	---	---	---	---
pH	std pH units	7.74	7.67	7.97	---
Bar. Pressure	mm Hg	738	735	760	---
Fixed End. Alk.	mg/l CaCO ₃	1390	1120	1940	---
Carbonate Alk.	mg/l CaCO ₃	1350	1140	1960	---
HCO ₃ , Dissolved	mg/l	1650	1390	2390	2390
Al, Dissolved	mg/l	0.14	0.13	0.11	0.16
B, Dissolved	mg/l	2.82	1.31	1.49	1.26
Ba, Dissolved	mg/l	0.59	0.41	0.38	0.36
Ca, Dissolved	mg/l	44.0	54.0	48.0	46.0
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.03	0.01	0.02	0.02
Cr, Dissolved	mg/l	<0.02	<0.01	0.01	0.01
Cu, Dissolved	mg/l	0.02	0.02	0.04	0.04
Fe, Dissolved	mg/l	0.19	0.24	0.41	0.36
K, Dissolved	mg/l	450	163	206	194
Mg, Dissolved	mg/l	115	68.0	84.0	80.0
Mn, Dissolved	mg/l	0.22	0.38	0.22	0.20
Na, Dissolved	mg/l	741	410	480	470
Ni, Dissolved	mg/l	0.18	0.09	0.10	0.10
Pb, Dissolved	mg/l	0.08	0.04	0.04	0.05
Zn, Dissolved	mg/l	0.05	0.04	0.02	0.03
NH ₄ -N, Dissolved	mg/l	109	116	216	176
NO ₃ +NO ₂ -N, Diss.	mg/l	15.0	2.32	2.43	2.85
NO ₂ -N, Dissolved	mg/l	6.68	0.40	0.59	0.56
PO ₄ -P, Dissolved	mg/l	0.05	0.02	0.01	0.01
Phosphorus, Dissolved	mg/l	0.12	0.02	0.03	0.03
Cl, Dissolved	mg/l	948	554	731	719
Organic C, Dissolved	mg/l	358	288	337	344
SO ₄ -S, Dissolved	mg/l	8.40	11.3	8.00	7.90
BOD ₅ , Total	mg/l	32	16	35	---
BOD ₅ , Dissolved	mg/l	14	7	0	---

Appendix A. Constituent Concentrations of Outflow: Bed III.

Constituent	Units	7-27-90 (1140)	8-9-90 (1400)	8-23-90 (1135)	9-6-90 (1300)	9-20-90 (1115)	10-5-90 (1020)
Temperature	°C	23.2	21.0	19.2	22.2	15.5	13.6
Spec. Conductance	µS @ 25°C	3300	3350	3120	4020	3850	5960
Dissolved Oxygen	mg/l	---	---	---	0.90	1.70	1.95
pH	std. pH units	6.97	7.10	---	7.43	7.20	7.66
Bar. Pressure	mm Hg	---	---	---	740	738	736
Fixed End. Alk.	mg/l CaCO ₃	788	678	---	1080	994	1820
Carbonate Alk.	mg/l CaCO ₃	808	685	---	1080	1010	1840
HCO ₃ , Dissolved	mg/l	986	836	---	1320	1230	2240
Al, Dissolved	mg/l	0.11	0.10	0.09	<0.11	0.11	<0.11
B, Dissolved	mg/l	<0.10	0.30	1.40	3.33	2.88	4.44
Ba, Dissolved	mg/l	0.56	0.34	0.54	0.39	0.36	0.58
Ca, Dissolved	mg/l	189	125	91.1	36.7	33.8	92.1
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	0.01	0.01	<0.01
Co, Dissolved	mg/l	0.02	0.02	0.02	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	0.01	0.01	0.01	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	0.04	0.03	0.03	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	0.05	0.08	0.05	<0.11	<0.11	0.49
K, Dissolved	mg/l	27.0	22.0	74.0	156	138	261
Mg, Dissolved	mg/l	67.4	41.8	48.6	56.6	56.4	138
Mn, Dissolved	mg/l	0.50	0.25	0.20	0.44	0.44	0.76
Na, Dissolved	mg/l	432	314	414	490	490	641
Ni, Dissolved	mg/l	0.08	0.06	0.08	0.11	0.11	0.11
Pb, Dissolved	mg/l	0.02	0.01	<0.01	0.11	<0.11	<0.11
Zn, Dissolved	mg/l	0.02	0.02	0.02	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	11.2	10.1	60.0	110	110	198
NO ₃ +NO ₂ -N, Diss.	mg/l	51.6	52.2	13.9	8.00	26.0	1.40
NO ₂ -N, Dissolved	mg/l	12.9	8.69	3.25	5.30	6.00	0.33
PO ₄ -P, Dissolved	mg/l	<0.01	<0.01	<0.01	0.01	0.01	0.02
Phosphorus, Dissolved	mg/l	0.04	0.03	0.05	0.10	0.06	0.11
Cl, Dissolved	mg/l	571	398	516	650	601	766
Organic C, Dissolved	mg/l	198	220	390	340	120	205
SO ₄ -S, Dissolved	mg/l	4.76	5.48	5.08	6.88	10.2	5.68
BOD ₅ , Total	mg/l	35	35	46	51	32	54
BOD ₅ , Dissolved	mg/l	---	18	35	38	12	---

Appendix A. Constituent Concentrations of Outflow: Bed III (continued).

Constituent	Units	10-17-90 (1130)	10-31-90 (1130)	10-31-90 (1135)	11-16-90 (1100)	11-29-90 (1020)	11-29-90 (1025)
Temperature	°C	16.2	12.8	---	11.0	7.6	---
Spec. Conductance	µS @ 25°C	4880	4440	---	3840	4230	---
Dissolved Oxygen	mg/l	0.30	0.40	---	---	0.55	---
pH	std. pH units	7.60	7.76	---	7.71	7.64	---
Bar. Pressure	mm Hg	742	---	---	---	741	---
Fixed End. Alk.	mg/l CaCO ₃	1430	1620	---	1250	1440	---
Carbonate Alk.	mg/l CaCO ₃	1490	1650	---	1270	1500	---
HCO ₃ , Dissolved	mg/l	1820	2010	2010	1550	1840	1840
Al, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
B, Dissolved	mg/l	4.21	2.77	2.88	1.99	1.99	2.22
Ba, Dissolved	mg/l	0.42	0.48	0.47	0.35	0.48	0.47
Ca, Dissolved	mg/l	97.7	70.2	70.3	49.6	65.3	70.2
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	0.62	3.22	3.11	0.84	4.95	5.36
K, Dissolved	mg/l	209	197	195	143	160	158
Mg, Dissolved	mg/l	136	100	103	82.1	86.4	93.6
Mn, Dissolved	mg/l	1.56	1.33	1.33	0.89	1.28	1.36
Na, Dissolved	mg/l	536	540	531	380	435	429
Ni, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Pb, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Zn, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	148	152	160	128	146	150
NO ₃ +NO ₂ -N, Diss.	mg/l	1.20	0.28	0.26	0.62	0.35	0.35
NO ₂ -N, Dissolved	mg/l	0.30	0.01	0.01	0.03	0.01	0.01
PO ₄ -P, Dissolved	mg/l	0.01	0.01	<0.01	<0.01	<0.01	0.01
Phosphorus, Dissolved	mg/l	0.06	0.08	0.07	<0.02	0.04	0.04
Cl, Dissolved	mg/l	612	575	585	460	512	512
Organic C, Dissolved	mg/l	252	169	181	183	301	188
SO ₄ -S, Dissolved	mg/l	4.88	2.88	3.28	4.43	4.27	4.18
BOD ₅ , Total	mg/l	252	136	---	113	220	---
BOD ₅ , Dissolved	mg/l	214	136	---	100	250	---

Appendix A. Constituent Concentrations of Outflow: Bed III (continued).

Constituent	Units	12-14-90 (1045)	12-27-90 (1135)	1-10-91 (1255)	3-30-91 (1020)	4-12-91 (1040)	5-23-91 (1115)
Temperature	°C	3.7	0.9	1.4	6.1	9.0	21.5
Spec. Conductance	µS @ 25°C	4360	3220	1970	559	2320	3880
Dissolved Oxygen	mg/l	0.50	0.60	0.90	---	0.45	---
pH	std. pH units	7.56	7.58	7.60	7.35	7.21	7.41
Bar. Pressure	mm Hg	749	756	752	735	735	735
Fixed End. Alk.	mg/l CaCO ₃	1500	428	713	225	603	1210
Carbonate Alk.	mg/l CaCO ₃	1600	446	740	226	700	1270
HCO ₃ , Dissolved	mg/l	1940	544	903	276	854	1550
Al, Dissolved	mg/l	<0.11	<0.11	<0.11	0.05	0.05	0.09
B, Dissolved	mg/l	2.11	0.66	1.11	0.18	0.58	0.92
Ba, Dissolved	mg/l	0.49	0.12	0.20	0.04	0.19	0.34
Ca, Dissolved	mg/l	89.0	15.6	21.2	13.2	49.8	65.4
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	0.01
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	0.03
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	0.01
Fe, Dissolved	mg/l	6.53	1.22	2.22	1.13	3.05	1.64
K, Dissolved	mg/l	158	47.1	73.2	35.2	82.8	121
Mg, Dissolved	mg/l	93.4	19.8	37.6	9.06	55.7	75.1
Mn, Dissolved	mg/l	1.54	0.44	0.77	0.25	1.10	0.62
Na, Dissolved	mg/l	427	109	174	25.0	135	285
Ni, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	0.06
Pb, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	<0.01
Zn, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	0.01
NH ₄ -N, Dissolved	mg/l	144	50.0	75.0	25.9	64.9	92.8
NO ₃ +NO ₂ -N, Diss.	mg/l	0.35	0.41	0.18	0.81	0.14	0.22
NO ₂ -N, Dissolved	mg/l	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PO ₄ -P, Dissolved	mg/l	<0.01	<0.01	0.01	0.02	0.01	0.01
Phosphorus, Dissolved	mg/l	0.04	<0.02	<0.01	<0.02	0.04	0.03
Cl, Dissolved	mg/l	482	125	245	9.80	237	566
Organic C, Dissolved	mg/l	325	143	111	<50.0	222	163
SO ₄ -S, Dissolved	mg/l	4.43	2.87	3.20	4.40	3.48	2.40
BOD ₅ , Total	mg/l	189	38	16	2	312	171
BOD ₅ , Dissolved	mg/l	238	35	52	12	251	245

Appendix A. Constituent Concentrations of Outflow: Bed III (continued).

Constituent	Units	6-7-91 (1055)	6-7-91 (1100)	6-20-91 (1105)	7-3-91 (1115)	7-18-91 (1045)	8-1-91 (1050)
Temperature	°C	19.9	---	25.9	22.1	26.9	23.0
Spec. Conductance	µS @ 25°C	4700	---	5400	6690	4040	7000
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std. pH units	7.76	---	7.75	7.12	7.18	7.32
Bar. Pressure	mm Hg	735	---	735	735	735	738
Fixed End. Alk.	mg/l CaCO ₃	1100	---	885	1660	731	962
Carbonate Alk.	mg/l CaCO ₃	1130	---	902	1700	740	967
HCO ₃ , Dissolved	mg/l	1380	1380	1100	2070	903	1180
Al, Dissolved	mg/l	0.09	0.08	0.11	0.16	0.10	0.13
B, Dissolved	mg/l	0.96	1.04	0.90	2.77	1.12	2.51
Ba, Dissolved	mg/l	0.34	0.34	0.18	0.89	0.32	0.43
Ca, Dissolved	mg/l	36.8	36.7	31.1	74.8	28.0	39.0
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.02	0.02	0.01	0.02	<0.02	0.02
Cr, Dissolved	mg/l	0.03	0.03	0.01	0.01	<0.02	<0.02
Cu, Dissolved	mg/l	0.01	0.01	0.03	0.05	0.01	0.02
Fe, Dissolved	mg/l	0.46	0.48	0.46	1.68	2.23	0.37
K, Dissolved	mg/l	149	150	154	509	240	370
Mg, Dissolved	mg/l	81.6	82.2	44.8	141	46.5	79.0
Mn, Dissolved	mg/l	0.21	0.21	0.14	0.61	0.25	0.28
Na, Dissolved	mg/l	372	372	166	519	420	672
Ni, Dissolved	mg/l	0.09	0.09	0.07	0.25	0.09	0.16
Pb, Dissolved	mg/l	<0.01	<0.01	<0.01	0.08	<0.02	<0.02
Zn, Dissolved	mg/l	0.03	0.02	<0.01	0.05	<0.02	0.03
NH ₄ -N, Dissolved	mg/l	102	93.7	72.8	162	44.8	61.0
NO ₃ +NO ₂ -N, Diss.	mg/l	0.74	0.76	2.69	1.33	7.20	38.4
NO ₂ -N, Dissolved	mg/l	0.04	0.02	1.34	0.15	4.13	10.0
PO ₄ -P, Dissolved	mg/l	0.02	0.02	0.01	0.01	---	0.04
Phosphorus, Dissolved	mg/l	0.05	0.04	0.02	0.06	<0.01	0.08
Cl, Dissolved	mg/l	928	870	352	1340	513	989
Organic C, Dissolved	mg/l	202	226	152	414	256	286
SO ₄ -S, Dissolved	mg/l	1.40	1.20	3.20	6.20	4.00	7.40
BOD ₅ , Total	mg/l	16	---	82	35	51	14
BOD ₅ , Dissolved	mg/l	24	---	16	5	14	14

Appendix A. Constituent Concentrations of Outflow: Bed III (continued).

Constituent	Units	10-3-91 (1115)	10-17-91 (1045)
Temperature	°C	22.0	11.0
Spec. Conductance	µS @ 25°C	4150	3580
Dissolved Oxygen	mg/l	---	---
pH	std. pH units	7.66	7.85
Bar. Pressure	mm Hg	735	760
Fixed End. Alk.	mg/l CaCO ₃	1180	953
Carbonate Alk.	mg/l CaCO ₃	1160	959
HCO ₃ , Dissolved	mg/l	1410	1170
Al, Dissolved	mg/l	0.12	0.07
B, Dissolved	mg/l	1.29	0.87
Ba, Dissolved	mg/l	0.42	0.36
Ca, Dissolved	mg/l	48.0	25.0
Cd, Dissolved	mg/l	<0.01	<0.01
Co, Dissolved	mg/l	0.01	0.02
Cr, Dissolved	mg/l	<0.01	<0.01
Cu, Dissolved	mg/l	0.03	0.04
Fe, Dissolved	mg/l	0.22	0.15
K, Dissolved	mg/l	149	141
Mg, Dissolved	mg/l	58.0	48.0
Mn, Dissolved	mg/l	0.35	0.18
Na, Dissolved	mg/l	380	360
Ni, Dissolved	mg/l	0.09	0.09
Pb, Dissolved	mg/l	<0.02	<0.02
Zn, Dissolved	mg/l	0.06	0.02
NH ₄ -N, Dissolved	mg/l	121	106
NO ₃ +NO ₂ -N, Diss.	mg/l	1.88	4.75
NO ₂ -N, Dissolved	mg/l	1.05	1.14
PO ₄ -P, Dissolved	mg/l	0.01	0.01
Phosphorus, Dissolved	mg/l	0.03	<0.02
Cl, Dissolved	mg/l	499	455
Organic C, Dissolved	mg/l	256	286
SO ₄ -S, Dissolved	mg/l	10.6	4.80
BOD ₅ , Total	mg/l	10	38
BOD ₅ , Dissolved	mg/l	0	64

Appendix A. Constituent Concentrations of Outflow: Bed IV.

Constituent	Units	7-27-90 (1300)	8-9-90 (1425)	8-23-90 (1205)	9-6-90 (1345)	9-6-90 (1350)	9-20-90 (1200)
Temperature	°C	22.5	21.8	19.6	24.6	---	16.8
Spec. Conductance	µS @ 25°C	4550	5770	4620	6450	---	5500
Dissolved Oxygen	mg/l	---	---	---	0.60	---	1.80
pH	std. pH units	7.07	7.01	---	7.15	---	7.08
Bar. Pressure	mm Hg	---	---	---	740	---	738
Fixed End. Alk.	mg/l CaCO ₃	1620	1810	---	2360	---	1990
Carbonate Alk.	mg/l CaCO ₃	1640	1830	---	2370	---	2010
HCO ₃ , Dissolved	mg/l	2000	2230	---	2900	2900	2450
Al, Dissolved	mg/l	0.09	0.08	0.10	0.11	0.11	0.11
B, Dissolved	mg/l	0.80	0.70	2.30	4.77	4.77	4.55
Ba, Dissolved	mg/l	0.94	0.96	1.33	1.21	1.25	1.07
Ca, Dissolved	mg/l	89.9	88.6	117	72.6	68.9	62.7
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	0.01	0.02	0.01
Co, Dissolved	mg/l	0.03	0.03	0.04	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	0.01	0.01	0.02	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	0.03	0.02	0.02	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	0.13	0.28	0.52	1.00	1.11	0.22
K, Dissolved	mg/l	155	147	229	290	285	239
Mg, Dissolved	mg/l	67.8	73.7	118	116	115	109
Mn, Dissolved	mg/l	0.95	0.98	1.40	1.33	1.33	1.22
Na, Dissolved	mg/l	412	422	635	735	735	607
Ni, Dissolved	mg/l	0.13	0.12	0.17	0.11	0.22	0.11
Pb, Dissolved	mg/l	0.01	0.01	<0.01	0.11	0.11	<0.11
Zn, Dissolved	mg/l	0.03	0.02	0.02	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	157	168	168	280	280	240
NO ₃ +NO ₂ -N, Diss.	mg/l	8.03	7.99	4.50	0.62	0.53	5.30
NO ₂ -N, Dissolved	mg/l	4.47	0.83	0.09	0.03	0.02	0.25
PO ₄ -P, Dissolved	mg/l	<0.01	<0.01	<0.01	0.04	0.03	0.02
Phosphorus, Dissolved	mg/l	0.09	0.10	0.10	0.12	0.14	0.09
Cl, Dissolved	mg/l	498	594	658	880	888	761
Organic C, Dissolved	mg/l	198	---	740	425	105	227
SO ₄ -S, Dissolved	mg/l	5.76	3.80	2.68	4.80	5.20	7.76
BOD ₅ , Total	mg/l	55	35	49	68	---	33
BOD ₅ , Dissolved	mg/l	---	28	28	49	---	32

Appendix A. Constituent Concentrations of Outflow: Bed IV (continued).

Constituent	Units	10-5-90 (1120)	10-17-90 (1215)	10-31-90 (1410)	11-16-90 (1115)	11-16-90 (1130)	11-29-90 (1110)
Temperature	°C	16.6	20.2	15.0	10.7	---	7.6
Spec. Conductance	µS @ 25°C	4220	3220	3620	4450	---	4980
Dissolved Oxygen	mg/l	0.90	0.70	0.50	---	---	0.40
pH	std. pH units	7.24	7.47	7.02	7.27	---	7.05
Bar. Pressure	mm Hg	736	742	---	---	---	741
Fixed End. Alk.	mg/l CaCO ₃	1280	864	819	1640	---	1700
Carbonate Alk.	mg/l CaCO ₃	1280	877	820	1690	---	1800
HCO ₃ , Dissolved	mg/l	1560	1070	1000	2060	2060	2200
Al, Dissolved	mg/l	0.11	<0.11	<0.11	<0.11	<0.11	0.20
B, Dissolved	mg/l	3.33	2.33	1.33	2.22	2.22	2.22
Ba, Dissolved	mg/l	0.58	0.34	0.42	0.60	0.60	0.98
Ca, Dissolved	mg/l	55.8	36.5	67.5	108	106	156
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Fe, Dissolved	mg/l	0.23	<0.11	2.44	2.46	2.28	11.2
K, Dissolved	mg/l	178	133	86.6	144	141	154
Mg, Dissolved	mg/l	83.9	55.3	46.8	85.5	83.0	111
Mn, Dissolved	mg/l	0.96	0.54	1.44	2.52	2.49	4.50
Na, Dissolved	mg/l	443	315	233	428	420	430
Ni, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
Pb, Dissolved	mg/l	0.32	<0.11	<0.11	<0.11	<0.11	<0.11
Zn, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	154	113	70.0	149	152	152
NO ₃ +NO ₂ -N, Diss.	mg/l	13.6	5.70	0.13	3.20	3.25	0.37
NO ₂ -N, Dissolved	mg/l	0.22	0.33	0.01	0.10	0.08	0.01
PO ₄ -P, Dissolved	mg/l	0.01	0.02	<0.01	<0.01	<0.01	0.01
Phosphorus, Dissolved	mg/l	0.06	0.02	0.03	0.05	0.05	0.04
Cl, Dissolved	mg/l	501	317	314	530	472	552
Organic C, Dissolved	mg/l	105	113	181	188	222	307
SO ₄ -S, Dissolved	mg/l	5.08	3.84	1.56	5.69	5.65	4.60
BOD ₅ , Total	mg/l	32	10	140	48	---	295
BOD ₅ , Dissolved	mg/l	30	20	78	51	---	312

Appendix A. Constituent Concentrations of Outflow: Bed IV (continued).

Constituent	Units	12-14-90 (1100)	12-27-90 (1205)	1-10-91 (1320)	3-30-91 (1110)	4-12-91 (1100)	4-12-90 (1105)
Temperature	°C	4.0	2.8	0.8	6.7	9.6	---
Spec. Conductance	µS @ 25°C	4530	2850	2670	817	4200	---
Dissolved Oxygen	mg/l	0.40	1.10	1.00	---	0.70	---
pH	std. pH units	7.18	7.38	7.38	7.27	7.00	---
Bar. Pressure	mm Hg	749	756	752	735	735	---
Fixed End. Alk.	mg/l CaCO ₃	1600	684	879	367	1270	---
Carbonate Alk.	mg/l CaCO ₃	1690	710	926	374	1550	---
HCO ₃ , Dissolved	mg/l	1580	866	1130	456	1890	1890
Al, Dissolved	mg/l	0.14	<0.11	<0.11	0.03	0.10	0.10
B, Dissolved	mg/l	2.11	0.88	1.11	0.28	0.92	0.86
Ba, Dissolved	mg/l	0.84	0.30	0.35	0.08	0.46	0.45
Ca, Dissolved	mg/l	144	46.7	54.1	25.3	146	144
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	<0.01
Cr, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	<0.01
Cu, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	<0.01
Fe, Dissolved	mg/l	9.32	2.33	3.22	1.52	7.10	7.30
K, Dissolved	mg/l	156	60.2	66.2	40.6	78.8	76.6
Mg, Dissolved	mg/l	91.2	24.6	34.8	12.0	70.0	68.2
Mn, Dissolved	mg/l	4.07	0.88	1.77	1.00	4.80	4.90
Na, Dissolved	mg/l	430	143	161	41.0	70.0	170
Ni, Dissolved	mg/l	<0.11	<0.11	<0.11	0.01	<0.01	<0.01
Pb, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	<0.01
Zn, Dissolved	mg/l	<0.11	<0.11	<0.11	<0.01	<0.01	<0.01
NH ₄ -N, Dissolved	mg/l	152	61.0	80.0	34.6	66.7	75.4
NO ₃ +NO ₂ -N, Diss.	mg/l	0.33	4.81	0.22	0.97	0.14	0.15
NO ₂ -N, Dissolved	mg/l	0.01	0.23	<0.01	0.08	<0.01	<0.01
PO ₄ -P, Dissolved	mg/l	<0.01	<0.01	0.01	0.01	0.01	0.02
Phosphorus, Dissolved	mg/l	0.04	<0.02	0.03	<0.02	0.04	0.05
Cl, Dissolved	mg/l	502	233	200	18.9	464	411
Organic C, Dissolved	mg/l	376	198	92.4	<50.0	697	623
SO ₄ -S, Dissolved	mg/l	4.66	2.12	4.37	2.40	2.84	3.00
BOD ₅ , Total	mg/l	265	138	261	2	308	---
BOD ₅ , Dissolved	mg/l	227	40	257	2	296	---

Appendix A. Constituent Concentrations of Outflow: Bed IV (continued).

Constituent	Units	5-23-91 (1140)	6-7-91 (1115)	6-20-91 (1125)	7-3-91 (1140)	7-18-91 (1110)	8-1-91 (1100)
Temperature	°C	22.0	20.2	24.7	22.1	24.5	23.0
Spec. Conductance	µS @ 25°C	4480	6310	3300	6160	7170	7300
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std. pH units	6.93	7.10	7.13	7.02	7.16	7.25
Bar. Pressure	mm Hg	735	735	735	735	735	738
Fixed End. Alk.	mg/l CaCO ₃	1670	1810	1350	2060	2100	2160
Carbonate Alk.	mg/l CaCO ₃	1830	1850	1350	2120	2130	2220
HCO ₃ , Dissolved	mg/l	2230	2260	1650	2590	2600	2710
Al, Dissolved	mg/l	0.14	0.11	0.19	0.20	0.20	0.18
B, Dissolved	mg/l	0.95	1.29	1.76	2.72	2.80	3.20
Ba, Dissolved	mg/l	0.71	1.10	0.83	1.34	1.17	1.15
Ca, Dissolved	mg/l	191	133	106	129	95	80
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.02	0.03	0.02	0.03	0.03	0.03
Cr, Dissolved	mg/l	0.04	0.03	0.01	0.02	0.03	<0.02
Cu, Dissolved	mg/l	0.01	0.01	0.03	0.03	0.01	<0.01
Fe, Dissolved	mg/l	8.88	4.19	0.88	0.82	0.81	1.88
K, Dissolved	mg/l	143	166	279	504	630	350
Mg, Dissolved	mg/l	88.6	97.3	80.2	125	135	128
Mn, Dissolved	mg/l	2.98	1.64	1.03	1.09	0.89	0.81
Na, Dissolved	mg/l	335	469	301	442	830	788
Ni, Dissolved	mg/l	0.08	0.12	0.18	0.23	0.25	0.22
Pb, Dissolved	mg/l	<0.01	<0.01	<0.01	0.10	0.08	0.08
Zn, Dissolved	mg/l	0.01	0.02	<0.01	0.06	0.05	<0.02
NH ₄ -N, Dissolved	mg/l	130	180	131	237	194	221
NO ₃ +NO ₂ -N, Diss.	mg/l	0.24	0.31	7.60	2.61	0.56	0.84
NO ₂ -N, Dissolved	mg/l	0.01	0.01	0.39	0.11	0.03	0.08
PO ₄ -P, Dissolved	mg/l	0.01	0.02	0.01	0.01	---	0.03
Phosphorus, Dissolved	mg/l	0.02	0.05	0.02	0.06	0.09	0.06
Cl, Dissolved	mg/l	618	870	644	1350	1370	1180
Organic C, Dissolved	mg/l	271	261	234	539	271	375
SO ₄ -S, Dissolved	mg/l	1.24	1.00	1.50	2.80	3.80	2.80
BOD ₅ , Total	mg/l	294	47	54	32	35	40
BOD ₅ , Dissolved	mg/l	290	30	21	12	21	23

Appendix A. Constituent Concentrations of Outflow: Bed IV (continued).

Constituent	Units	10-3-91 (1040)	10-3-91 (1045)	10-17-91 (1100)
Temperature	°C	21.0	---	11.0
Spec. Conductance	µS @ 25°C	2120	---	6380
Dissolved Oxygen	mg/l	---	---	---
pH	std. pH units	7.21	---	7.29
Bar. Pressure	mm Hg	735	---	760
Fixed End. Alk.	mg/l CaCO ₃	1680	---	1670
Carbonate Alk.	mg/l CaCO ₃	1700	---	1700
HCO ₃ , Dissolved	mg/l	2080	2080	2070
Al, Dissolved	mg/l	0.18	0.33	0.19
B, Dissolved	mg/l	1.48	1.54	1.54
Ba, Dissolved	mg/l	0.95	1.08	1.19
Ca, Dissolved	mg/l	107	108	108
Cd, Dissolved	mg/l	<0.01	<0.01	<0.01
Co, Dissolved	mg/l	0.02	0.02	0.02
Cr, Dissolved	mg/l	<0.01	<0.01	<0.01
Cu, Dissolved	mg/l	0.06	0.06	0.05
Fe, Dissolved	mg/l	0.89	0.80	0.23
K, Dissolved	mg/l	187	186	193
Mg, Dissolved	mg/l	92.0	95.0	100
Mn, Dissolved	mg/l	1.35	1.38	1.40
Na, Dissolved	mg/l	440	450	500
Ni, Dissolved	mg/l	0.11	0.24	0.14
Pb, Dissolved	mg/l	0.05	0.06	0.06
Zn, Dissolved	mg/l	0.07	0.24	0.06
NH ₄ -N, Dissolved	mg/l	133	136	173
NO ₃ +NO ₂ -N, Diss.	mg/l	8.63	6.92	14.1
NO ₂ -N, Dissolved	mg/l	2.57	0.96	0.25
PO ₄ -P, Dissolved	mg/l	0.01	0.01	0.01
Phosphorus, Dissolved	mg/l	0.02	0.03	0.04
Cl, Dissolved	mg/l	331	626	812
Organic C, Dissolved	mg/l	295	316	366
SO ₄ -S, Dissolved	mg/l	23.5	19.1	11.9
BOD ₅ , Total	mg/l	19	---	59
BOD ₅ , Dissolved	mg/l	9	---	47

APPENDIX B

**ANALYSIS OF SUBSTRATE PORE WATER FROM IN PLOT WELLS FOR
FOUR CONSTRUCTED WETLAND BEDS AT TOMPKINS COUNTY MUNICIPAL
SOLID-WASTE LANDFILL, JUNE 1990 THROUGH OCTOBER 1991**

Appendix B. Constituent Concentrations of Bed I: In-plot well A, 30 m downstream of inflow.

Constituent	Units	7-26-90 (1100)	8-9-90 (1030)	8-23-90 (0930)	9-7-90 (1210)	9-24-90 (1145)	10-18-90 (1140)
Temperature	°C	22.4	21.8	18.4	21.2	14.6	15.4
Spec. Conductance	µS @ 25°C	2130	1790	2330	1280	990	3360
Dissolved Oxygen	mg/l	---	---	---	0.6	0.6	1.2
pH	std. pH units	6.96	7.09	---	7.01	7.23	7.10
Bar. Pressure	mm Hg	---	---	---	735	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	445	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	450	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	549	---	---
Al, Dissolved	mg/l	---	---	---	<0.11	---	---
B, Dissolved	mg/l	---	---	---	0.66	---	---
Ba, Dissolved	mg/l	---	---	---	0.04	---	---
Ca, Dissolved	mg/l	---	---	---	46.66	---	---
Cd, Dissolved	mg/l	---	---	---	<0.01	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.22	---	---
K, Dissolved	mg/l	---	---	---	36.9	---	---
Mg, Dissolved	mg/l	---	---	---	14.2	---	---
Mn, Dissolved	mg/l	---	---	---	0.44	---	---
Na, Dissolved	mg/l	---	---	---	105	---	---
Ni, Dissolved	mg/l	---	---	---	<0.11	---	---
Pb, Dissolved	mg/l	---	---	---	0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	33.0	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	1.40	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.09	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	99.6	---	---
Organic C, Diss.	mg/l	---	---	---	<50.0	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	4.20	---	---
BOD ₅ , Total	mg/l	---	---	---	7.00	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well A (continued).

Constituent	Units	10-31-90 (0839)	11-19-90 (1000)	11-19-90 (1005)	11-29-90 (1225)	12-14-90 (1240)	12-27-90 (1023)
Temperature	°C	8.3	5.1	---	9.2	3.2	1.4
Spec. Conductance	µS @ 25°C	607	687	---	464	365	320
Dissolved Oxygen	mg/l	0.5	---	---	0.8	0.9	3.2
pH	std. pH units	7.47	7.16	---	8.30	7.96	7.31
Bar. Pressure	mm Hg	---	---	---	741	749	756
Fixed End. Alk.	mg/l CaCO ₃	---	318	---	---	---	236
Carbonate Alk.	mg/l CaCO ₃	---	325	---	---	---	235
HCO ₃ , Dissolved	mg/l	---	397	---	---	---	287
Al, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
B, Dissolved	mg/l	---	0.33	0.33	---	---	0.11
Ba, Dissolved	mg/l	---	0.12	0.12	---	---	0.09
Ca, Dissolved	mg/l	---	28.8	27.4	---	---	17.9
Cd, Dissolved	mg/l	---	<0.01	<0.01	---	---	<0.01
Co, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Cr, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Cu, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Fe, Dissolved	mg/l	---	0.67	0.66	---	---	0.22
K, Dissolved	mg/l	---	23.1	22.6	---	---	17.7
Mg, Dissolved	mg/l	---	6.58	5.98	---	---	3.11
Mn, Dissolved	mg/l	---	0.51	0.49	---	---	0.44
Na, Dissolved	mg/l	---	61.4	61.6	---	---	40.4
Ni, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Pb, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Zn, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
NH ₄ -N, Dissolved	mg/l	---	23.7	26.0	---	---	16.0
NO ₃ +NO ₂ -N, Diss.	mg/l	---	0.69	0.71	---	---	1.24
NO ₂ -N, Dissolved	mg/l	---	0.07	0.13	---	---	0.02
PO ₄ -P, Dissolved	mg/l	---	0.02	0.02	---	---	0.01
Phosphorus, Dissolved	mg/l	---	<0.02	<0.02	---	---	<0.02
Cl, Dissolved	mg/l	---	67.0	67.9	---	---	27.9
Organic C, Diss.	mg/l	---	100	159	---	---	54.6
SO ₄ -S, Dissolved	mg/l	---	4.62	4.96	---	---	2.96
BOD ₅ , Total	mg/l	---	3.50	---	---	---	3.00
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well A (continued).

Constituent	Units	6-20-91 (1030)	7-3-91 (1000)	7-24-91 (1000)	8-1-91 (1000)	8-20-91 (1000)	10-3-91 (1030)
Temperature	°C	21.5	21.3	24.2	23.0	21.5	22.5
Spec. Conductance	µS @ 25°C	3120	6260	4910	6570	1400	4530
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std. pH units	7.10	6.88	---	7.08	---	7.19
Bar. Pressure	mm Hg	735	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well B, 24 m downstream of inflow.

Constituent	Units	7-26-90 (1100)	8-9-90 (1030)	8-23-90 (0930)	9-7-90 (1245)	9-24-90 (1150)	10-18-90 (1145)
Temperature	°C	22.7	22.0	19.1	21.2	14.8	15.4
Conductance	µS @ 25°C	4000	3600	2020	1170	1450	5670
Dissolved Oxygen	mg/l	---	---	---	0.9	0.6	0.85
pH	std. pH units	6.99	7.14	---	7.14	7.38	7.18
Bar. Pressure	mm Hg	---	---	---	735	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	436	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	440	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	537	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	1.11	---	---
Ba, Dissolved	mg/l	---	---	---	<0.01	---	---
Ca, Dissolved	mg/l	---	---	---	40.9	---	---
Cd, Dissolved	mg/l	---	---	---	<0.01	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.11	---	---
K, Dissolved	mg/l	---	---	---	36.2	---	---
Mg, Dissolved	mg/l	---	---	---	12.7	---	---
Mn, Dissolved	mg/l	---	---	---	0.44	---	---
Na, Dissolved	mg/l	---	---	---	93.3	---	---
Ni, Dissolved	mg/l	---	---	---	<0.11	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	39.0	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	1.30	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.10	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	91.7	---	---
Organic C, Diss.	mg/l	---	---	---	<50.0	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	3.40	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well B (continued).

Constituent	Units	10-31-90 (0842)	11-29-90 (1230)	12-14-90 (1245)	12-27-90 (1030)	6-20-91 (1035)	7-3-91 (1005)
Temperature	°C	8.8	8.4	3.5	1.3	21.3	21.2
Spec. Conductance	µS @ 25°C	3940	1800	1040	464	3450	6380
Dissolved Oxygen	mg/l	0.4	0.9	0.6	3.1	---	---
pH	std. pH units	7.31	8.07	7.67	7.37	7.17	6.95
Bar. Pressure	mm Hg	---	741	749	756	735	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well B (continued).

Constituent	Units	7-24-91 (1005)	8-1-91 (1005)	8-20-91 (1005)	10-3-91 (1035)
Temperature	°C	23.2	23.0	21.5	23.0
Spec. Conductance	µS @ 25°C	5810	5950	3340	4520
Dissolved Oxygen	mg/l	---	---	---	---
pH	std. pH units	---	7.23	---	7.32
Bar. Pressure	mm Hg	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---
B, Dissolved	mg/l	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---
K, Dissolved	mg/l	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well C, 18 m downstream of inflow.

Constituent	Units	7-26-90 (1100)	8-9-90 (1030)	8-23-90 (0930)	9-7-90 (1315)	9-24-90 (1155)	10-18-90 (1150)
Temperature	°C	23.0	22.1	19.0	21.2	14.4	15.2
Spec. Conductance	µS @ 25°C	6210	5310	2590	2440	3280	5090
Dissolved Oxygen	mg/l	---	---	---	0.80	0.40	0.35
pH	std. pH units	7.10	7.26	---	7.27	7.31	7.27
Bar. Pressure	mm Hg	---	---	---	735	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	744	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	765	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	933	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	1.44	---	---
Ba, Dissolved	mg/l	---	---	---	0.16	---	---
Ca, Dissolved	mg/l	---	---	---	63.22	---	---
Cd, Dissolved	mg/l	---	---	---	<0.01	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.66	---	---
K, Dissolved	mg/l	---	---	---	86.1	---	---
Mg, Dissolved	mg/l	---	---	---	37.9	---	---
Mn, Dissolved	mg/l	---	---	---	0.66	---	---
Na, Dissolved	mg/l	---	---	---	222	---	---
Ni, Dissolved	mg/l	---	---	---	<0.11	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	84.0	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	1.70	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.10	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.07	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.07	---	---
Cl, Dissolved	mg/l	---	---	---	236	---	---
Organic C, Diss.	mg/l	---	---	---	<50.0	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.00	---	---
BOD ₅ , Total	mg/l	---	---	---	30.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well C (continued).

Constituent	Units	10-31-90 (0844)	11-19-90 (1030)	11-29-90 (1233)	12-14-90 (1250)	12-27-90 (1040)	12-27-90 (1045)
Temperature	°C	9.0	4.6	8.4	3.0	1.0	(dupl.)
Spec. Conductance	µS @ 25°C	4710	1680	3340	1900	844	---
Dissolved Oxygen	mg/l	0.35	---	0.75	0.60	1.75	---
pH	std. pH units	7.15	7.07	7.98	7.65	7.67	---
Bar. Pressure	mm Hg	---	---	741	749	756	---
Fixed End. Alk.	mg/l CaCO ₃	---	897	---	---	158	---
Carbonate Alk.	mg/l CaCO ₃	---	943	---	---	160	---
HCO ₃ , Dissolved	mg/l	---	1150	---	---	195	---
Al, Dissolved	mg/l	---	<0.11	---	---	<0.11	<0.11
B, Dissolved	mg/l	---	1.11	---	---	0.11	0.11
Ba, Dissolved	mg/l	---	0.38	---	---	0.04	0.05
Ca, Dissolved	mg/l	---	76.2	---	---	7.88	8.77
Cd, Dissolved	mg/l	---	<0.01	---	---	<0.01	<0.01
Co, Dissolved	mg/l	---	<0.11	---	---	<0.11	<0.11
Cr, Dissolved	mg/l	---	<0.11	---	---	<0.11	<0.11
Cu, Dissolved	mg/l	---	<0.11	---	---	<0.11	<0.11
Fe, Dissolved	mg/l	---	5.79	---	---	<0.11	<0.11
K, Dissolved	mg/l	---	80.5	---	---	15.2	15.6
Mg, Dissolved	mg/l	---	42.2	---	---	<0.11	<0.11
Mn, Dissolved	mg/l	---	1.91	---	---	0.33	0.29
Na, Dissolved	mg/l	---	191	---	---	18.2	19.6
Ni, Dissolved	mg/l	---	<0.11	---	---	<0.11	<0.11
Pb, Dissolved	mg/l	---	<0.11	---	---	<0.11	<0.11
Zn, Dissolved	mg/l	---	<0.11	---	---	<0.11	<0.11
NH ₄ -N, Dissolved	mg/l	---	80.4	---	---	15.0	14.0
NO ₃ +NO ₂ -N, Diss.	mg/l	---	1.02	---	---	1.38	1.35
NO ₂ -N, Dissolved	mg/l	---	0.07	---	---	0.02	0.03
PO ₄ -P, Dissolved	mg/l	---	0.03	---	---	0.02	<0.01
Phosphorus, Dissolved	mg/l	---	0.05	---	---	<0.02	<0.02
Cl, Dissolved	mg/l	---	285	---	---	18.4	18.3
Organic C, Diss.	mg/l	---	257	---	---	56.8	<50.0
SO ₄ -S, Dissolved	mg/l	---	8.03	---	---	4.97	4.53
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well C (continued).

Constituent	Units	6-20-91 (1040)	7-3-91 (1010)	7-24-91 (1010)	8-1-91 (1010)	8-20-91 (1010)	10-3-91 (1040)
Temperature	°C	20.8	21.3	23.0	22.5	21.5	23.0
Spec. Conductance	µS @ 25°C	5570	7130	6680	6530	5250	4610
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std. pH units	7.29	7.02	---	7.28	---	7.74
Bar. Pressure	mm Hg	735	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well D, 12 m downstream of inflow.

Constituent	Units	7-26-90 (1100)	8-9-90 (1030)	8-23-90 (0930)	9-7-90 (1345)	9-7-90 (1400)	9-24-90 (1200)
Temperature	°C	22.1	22.2	19.0	21.0	(dupl.)	14.8
Spec. Conductance	µS @ 25°C	7000	5940	2470	3610	---	4380
Dissolved Oxygen	mg/l	---	---	---	1.10	---	0.40
pH	std. pH units	7.08	7.45	---	7.42	---	7.35
Bar. Pressure	mm Hg	---	---	---	735	---	737
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1370	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1390	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	1690	---	---
Al, Dissolved	mg/l	---	---	---	0.11	<0.11	---
B, Dissolved	mg/l	---	---	---	2.44	2.33	---
Ba, Dissolved	mg/l	---	---	---	0.34	0.33	---
Ca, Dissolved	mg/l	---	---	---	85.0	83.4	---
Cd, Dissolved	mg/l	---	---	---	<0.01	<0.01	---
Co, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cr, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cu, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Fe, Dissolved	mg/l	---	---	---	1.33	1.22	---
K, Dissolved	mg/l	---	---	---	155	146.	---
Mg, Dissolved	mg/l	---	---	---	66.3	64.3	---
Mn, Dissolved	mg/l	---	---	---	0.66	0.55	---
Na, Dissolved	mg/l	---	---	---	362	338	---
Ni, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Pb, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Zn, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	---	---	154	158	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	1.80	1.80	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.07	0.07	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.10	0.08	---
Phosphorus, Dissolved	mg/l	---	---	---	0.13	0.14	---
Cl, Dissolved	mg/l	---	---	---	419	424	---
Organic C, Diss.	mg/l	---	---	---	<50.0	<50.0	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.12	5.60	---
BOD ₅ , Total	mg/l	---	---	---	38.5	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed 1: In-plot well D (continued).

Constituent	Units	10-18-90 (1155)	10-31-90 (0846)	11-29-90 (1235)	12-14-90 (1255)	12-27-90 (1050)	6-20-91 (1045)
Temperature	°C	15.2	9.0	8.0	3.1	2.5	21.2
Spec. Conductance	µS @ 25°C	5510	5360	4360	2760	1580	5730
Dissolved Oxygen	mg/l	0.50	0.35	0.90	0.65	2.30	---
pH	std. pH units	7.24	7.16	7.82	7.56	7.47	7.74
Bar. Pressure	mm Hg	729	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well D (continued).

Constituent	Units	7-3-91 (1015)	7-24-91 (1015)	8-1-91 (1015)	8-20-91 (1015)	10-3-91 (1045)
Temperature	°C	21.3	22.8	22.0	22.0	23.0
Spec. Conductance	µS @ 25°C	7240	7430	7340	6280	4510
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.08	---	7.32	---	7.28
Far. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well E, 6 m downstream of inflow.

Constituent	Units	7-26-90 (1100)	8-9-90 (1030)	8-23-90 (0930)	9-7-90 (1445)	9-24-90 (1200)	10-18-90 (1200)
Temperature	°C	21.7	22.6	18.8	21.6	14.8	15.2
Spec. Conductance	µS @ 25°C	7130	5680	3000	5290	5970	5930
Dissolved Oxygen	mg/l	---	---	---	0.90	0.30	0.30
pH	std. pH units	7.10	7.38	---	7.39	7.26	7.36
Bar. Pressure	mm Hg	---	---	---	735	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2170	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2170	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2650	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	3.88	---	---
Ba, Dissolved	mg/l	---	---	---	0.53	---	---
Ca, Dissolved	mg/l	---	---	---	103	---	---
Cd, Dissolved	mg/l	---	---	---	0.01	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	1.88	---	---
K, Dissolved	mg/l	---	---	---	257	---	---
Mg, Dissolved	mg/l	---	---	---	110	---	---
Mn, Dissolved	mg/l	---	---	---	0.66	---	---
Na, Dissolved	mg/l	---	---	---	583	---	---
Ni, Dissolved	mg/l	---	---	---	0.11	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	249	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	1.40	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.07	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.10	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.22	---	---
Cl, Dissolved	mg/l	---	---	---	681	---	---
Organic C, Diss.	mg/l	---	---	---	120	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	2.88	---	---
BOD ₅ , Total	mg/l	---	---	---	56.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well E (continued).

Constituent	Units	10-31-90 (0849)	11-19-90 (1045)	11-29-90 (1237)	12-14-90 (1300)	12-27-90 (1100)	6-20-91 (1050)
Temperature	°C	9.9	4.5	8.4	3.0	1.1	21.3
Spec. Conductance	µS @ 25°C	5050	4450	5090	4100	1560	6370
Dissolved Oxygen	mg/l	0.30	---	0.70	0.65	1.75	---
pH	std. pH units	7.16	6.97	7.61	7.11	7.69	7.24
Bar. Pressure	mm Hg	---	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	1630	---	---	463	---
Carbonate Alk.	mg/l CaCO ₃	---	1650	---	---	480	---
HCO ₃ , Dissolved	mg/l	---	2010	---	---	586	---
Al, Dissolved	mg/l	---	0.19	---	---	<0.11	---
B, Dissolved	mg/l	---	2.11	---	---	0.44	---
Ba, Dissolved	mg/l	---	0.69	---	---	0.14	---
Ca, Dissolved	mg/l	---	170	---	---	27.6	---
Cd, Dissolved	mg/l	---	<0.01	---	---	<0.01	---
Co, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cr, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cu, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Fe, Dissolved	mg/l	---	15.9	---	---	0.56	---
K, Dissolved	mg/l	---	144	---	---	45.5	---
Mg, Dissolved	mg/l	---	94.8	---	---	13.3	---
Mn, Dissolved	mg/l	---	3.74	---	---	0.71	---
Na, Dissolved	mg/l	---	399	---	---	98.2	---
Ni, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Pb, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Zn, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	136	---	---	48.0	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	1.54	---	---	1.48	---
NO ₂ -N, Dissolved	mg/l	---	0.02	---	---	0.06	---
PO ₄ -P, Dissolved	mg/l	---	0.09	---	---	<0.01	---
Phosphorus, Dissolved	mg/l	---	0.12	---	---	<0.02	---
Cl, Dissolved	mg/l	---	530	---	---	93.2	---
Organic C, Diss.	mg/l	---	347	---	---	206	---
SO ₄ -S, Dissolved	mg/l	---	7.44	---	---	5.32	---
BOD ₅ , Total	mg/l	---	310	---	---	14.0	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed I: In-plot well E (continued).

Constituent	Units	7-3-91 (1020)	7-24-91 (1020)	8-1-91 (1020)	8-20-91 (1020)	10-3-91 (1045)
Temperature	°C	21.6	23.1	23.0	22.0	23.0
Spec. Conductance	µS @ 25°C	7510	7700	7200	6380	4690
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.19	---	7.41	---	7.27
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well A, 30 m downstream of inflow.

Constituent	Units	7-26-90 (1130)	8-9-90 (1100)	8-23-90 (1000)	9-8-90 (0910)	9-8-90 (0915)	9-24-90 (1205)
Temperature	°C	23.2	22.7	18.8	14.8	(dupl.)	13.6
Spec. Conductance	µS @ 25°C	1560	4540	6400	7820	---	6400
Dissolved Oxygen	mg/l	---	---	---	1.70	---	0.90
pH	std. pH units	6.80	7.44	---	7.89	---	7.94
Bar. Pressure	mm Hg	---	---	---	742	---	737
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2880	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2890	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	3520	---	---
Al, Dissolved	mg/l	---	---	---	0.22	0.33	---
B, Dissolved	mg/l	---	---	---	5.66	5.77	---
Ba, Dissolved	mg/l	---	---	---	0.40	0.70	---
Ca, Dissolved	mg/l	---	---	---	62.4	61.8	---
Cd, Dissolved	mg/l	---	---	---	0.02	0.02	---
Co, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cr, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cu, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Fe, Dissolved	mg/l	---	---	---	0.55	0.44	---
K, Dissolved	mg/l	---	---	---	375	381	---
Mg, Dissolved	mg/l	---	---	---	172	174	---
Mn, Dissolved	mg/l	---	---	---	0.33	0.33	---
Na, Dissolved	mg/l	---	---	---	875	840	---
Ni, Dissolved	mg/l	---	---	---	0.11	0.11	---
Pb, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Zn, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	---	---	342	348	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.06	0.04	---
Phosphorus, Dissolved	mg/l	---	---	---	0.19	0.17	---
Cl, Dissolved	mg/l	---	---	---	1060	1140	---
Organic C, Diss.	mg/l	---	---	---	225	222	---
SO ₄ -S, Dissolved	mg/l	---	---	---	4.28	3.40	---
BOD ₅ , Total	mg/l	---	---	---	56.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well A (continued).

Constituent	Units	10-18-90 (1200)	10-31-90 (0900)	11-19-90 (1110)	11-29-90 (1238)	12-14-91 (1305)	12-27-90 (1108)
Temperature	°C	15.8	8.1	3.8	6.4	0.5	2.1
Spec. Conductance	µS @ 25°C	5400	4580	5040	5390	5570	3550
Dissolved Oxygen	mg/l	0.50	0.45	---	0.30	1.00	1.85
pH	std. pH units	7.98	7.63	7.40	7.72	7.30	7.61
Bar. Pressure	mm Hg	729	---	---	741	749	756
Fixed End. Alk.	mg/l CaCO ₃	---	---	1840	---	---	1270
Carbonate Alk.	mg/l CaCO ₃	---	---	1890	---	---	1330
HCO ₃ , Dissolved	mg/l	---	---	2310	---	---	1620
Al, Dissolved	mg/l	---	---	0.34	---	---	<0.11
B, Dissolved	mg/l	---	---	2.77	---	---	1.44
Ba, Dissolved	mg/l	---	---	0.62	---	---	0.35
Ca, Dissolved	mg/l	---	---	92.2	---	---	29.5
Cd, Dissolved	mg/l	---	---	<0.01	---	---	<0.01
Co, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Cr, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Cu, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Fe, Dissolved	mg/l	---	---	5.39	---	---	1.81
K, Dissolved	mg/l	---	---	195	---	---	107
Mg, Dissolved	mg/l	---	---	139	---	---	51.1
Mn, Dissolved	mg/l	---	---	1.96	---	---	1.05
Na, Dissolved	mg/l	---	---	522	---	---	267
Ni, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Pb, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Zn, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
NH ₄ -N, Dissolved	mg/l	---	---	175	---	---	132
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	0.49	---	---	0.40
NO ₂ -N, Dissolved	mg/l	---	---	0.02	---	---	<0.01
PO ₄ -P, Dissolved	mg/l	---	---	0.01	---	---	0.01
Phosphorus, Dissolved	mg/l	---	---	0.06	---	---	0.02
Cl, Dissolved	mg/l	---	---	610	---	---	460
Organic C, Diss.	mg/l	---	---	305	---	---	294
SO ₄ -S, Dissolved	mg/l	---	---	5.73	---	---	3.92
BOD ₅ , Total	mg/l	---	---	303	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	191

Appendix B. Constituent Concentrations of Bed II: In-plot well A (continued).

Constituent	Units	6-20-91 (1055)	7-3-91 (1025)	7-24-91 (1025)	8-1-91 (1025)	8-20-91 (1025)	10-3-91 (1100)
Temperature	°C	23.0	20.8	23.5	22.0	21.0	23.2
Spec. Conductance	µS @ 25°C	6150	7430	6500	7240	6520	4410
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std. pH units	7.84	7.91	---	8.13	---	8.02
Bar. Pressure	mm Hg	735	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well B, 24 m downstream of inflow.

Constituent	Units	7-26-90 (1130)	8-9-90 (1100)	8-23-90 (1000)	9-8-90 (1025)	9-24-90 (1210)	10-18-90 (1205)
Temperature	°C	22.9	21.0	19.0	19.4	12.3	15.4
Conductance	µS @ 25°C	3300	5790	6130	7420	6540	5660
Dissolved Oxygen	mg/l	---	---	---	1.00	0.50	0.50
pH	std. pH units	6.99	7.64	---	7.67	8.11	7.90
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2330	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2330	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2840	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	5.44	---	---
Ba, Dissolved	mg/l	---	---	---	0.80	---	---
Ca, Dissolved	mg/l	---	---	---	50.7	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.22	---	---
K, Dissolved	mg/l	---	---	---	318	---	---
Mg, Dissolved	mg/l	---	---	---	142	---	---
Mn, Dissolved	mg/l	---	---	---	0.77	---	---
Na, Dissolved	mg/l	---	---	---	840	---	---
Ni, Dissolved	mg/l	---	---	---	0.22	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	230	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	0.33	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.20	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.03	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.16	---	---
Cl, Dissolved	mg/l	---	---	---	1080	---	---
Organic C, Diss.	mg/l	---	---	---	247	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.20	---	---
BOD ₅ , Total	mg/l	---	---	---	26.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well B (continued).

Constituent	Units	10-31-90 (0858)	11-29-90 (1239)	12-14-90 (1310)	12-27-90 (1115)	6-20-91 (1100)	7-3-91 (1030)
Temperature	°C	8.5	7.1	0.2	1.1	22.5	20.7
Spec. Conductance	µS @ 25°C	4830	5410	5480	2510	6210	6790
Dissolved Oxygen	mg/l	0.30	0.50	0.75	0.65	---	---
pH	std pH units	7.55	7.58	7.34	7.69	7.78	7.78
Bar. Pressure	mm Hg	---	741	749	756	735	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well B (continued).

Constituent	Units	7-24-91 (1030)	8-1-91 (1030)	8-20-91 (1030)	10-3-91 (1105)
Temperature	°C	23.2	22.0	21.0	23.0
Spec. Conductance	µS @ 25°C	6750	5210	6740	3330
Dissolved Oxygen	mg/l	---	---	---	---
pH	std. pH units	---	8.05	---	7.81
Bar. Pressure	mm Hg	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---
B, Dissolved	mg/l	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---
K, Dissolved	mg/l	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well C, 18 m downstream of inflow.

Constituent	Units	7-26-90 (1130)	8-9-90 (1100)	8-23-90 (1000)	9-8-90 (1100)	9-24-90 (1215)	10-18-90 (1210)
Temperature	°C	24.4	21.0	19.4	19.8	13.6	14.8
Spec. Conductance	µS @ 25°C	4300	5540	5000	7420	7100	6140
Dissolved Oxygen	mg/l	---	---	---	0.85	0.50	0.35
pH	std. pH units	7.26	7.64	---	7.53	8.00	7.86
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2530	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2530	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	3090	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	5.44	---	---
Ba, Dissolved	mg/l	---	---	---	0.93	---	---
Ca, Dissolved	mg/l	---	---	---	52.9	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.55	---	---
K, Dissolved	mg/l	---	---	---	327	---	---
Mg, Dissolved	mg/l	---	---	---	145	---	---
Mn, Dissolved	mg/l	---	---	---	0.88	---	---
Na, Dissolved	mg/l	---	---	---	840	---	---
Ni, Dissolved	mg/l	---	---	---	0.22	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	294	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	0.34	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.10	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.04	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.16	---	---
Cl, Dissolved	mg/l	---	---	---	1060	---	---
Organic C, Diss.	mg/l	---	---	---	265	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.72	---	---
BOD ₅ , Total mg/l	mg/l	---	---	---	23.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well C (continued).

Constituent	Units	10-31-90 (0856)	11-19-90 (1140)	11-29-90 (1240)	12-14-90 (1312)	12-27-90 (1121)	6-20-91 (1105)
Temperature	°C	8.9	3.6	7.8	1.9	1.3	22.1
Spec. Conductance	µS @ 25°C	5710	4750	5040	5620	5080	5520
Dissolved Oxygen	mg/l	0.40	---	0.70	0.50	1.45	---
pH	std. pH units	7.66	7.42	7.57	7.35	7.88	7.62
Bar. Pressure	mm Hg	---	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	1800	---	---	1420	---
Carbonate Alk.	mg/l CaCO ₃	---	1850	---	---	1480	---
HCO ₃ , Dissolved	mg/l	---	2260	---	---	1810	---
Al, Dissolved	mg/l	---	0.39	---	---	<0.11	---
B, Dissolved	mg/l	---	2.77	---	---	1.77	---
Ba, Dissolved	mg/l	---	0.71	---	---	0.52	---
Ca, Dissolved	mg/l	---	48.3	---	---	45.0	---
Cd, Dissolved	mg/l	---	<0.01	---	---	<0.01	---
Co, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cr, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cu, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Fe, Dissolved	mg/l	---	2.12	---	---	<0.11	---
K, Dissolved	mg/l	---	189	---	---	135	---
Mg, Dissolved	mg/l	---	119	---	---	74.3	---
Mn, Dissolved	mg/l	---	1.62	---	---	1.42	---
Na, Dissolved	mg/l	---	504	---	---	364	---
Ni, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Pb, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Zn, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	175	---	---	158	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	0.50	---	---	0.37	---
NO ₂ -N, Dissolved	mg/l	---	0.02	---	---	<0.01	---
PO ₄ -P, Dissolved	mg/l	---	0.04	---	---	0.03	---
Phosphorus, Dissolved	mg/l	---	0.10	---	---	0.04	---
Cl, Dissolved	mg/l	---	595	---	---	495	---
Organic C, Diss.	mg/l	---	393	---	---	362	---
SO ₄ -S, Dissolved	mg/l	---	5.13	---	---	4.20	---
BOD ₅ , Total	mg/l	---	121	---	---	175	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well C (continued).

Constituent	Units	7-3-91 (1035)	7-24-91 (1035)	8-1-91 (1035)	8-20-91 (1035)	10-3-91 (1110)
Temperature	°C	20.7	23.5	22.0	21.5	23.1
Spec. Conductance	µS @ 25°C	6130	7530	7340	6990	4320
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.56	---	7.99	---	7.74
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well D, 12 m downstream of inflow.

Constituent	Units	7-26-90 (1130)	8-9-90 (1100)	8-23-90 (1000)	9-8-90 (1200)	9-24-90 (1215)	10-18-90 (1215)
Temperature	°C	22.8	20.1	18.5	24.8	13.2	15.4
Spec. Conductance	µS @ 25°C	4660	6540	6670	8030	6780	5450
Dissolved Oxygen	mg/l	---	---	---	0.30	0.20	0.30
pH	std. pH units	7.51	7.86	---	7.77	8.08	8.22
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	3000	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	3010	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	3670	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	5.99	---	---
Ba, Dissolved	mg/l	---	---	---	0.26	---	---
Ca, Dissolved	mg/l	---	---	---	68.88	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	1.77	---	---
K, Dissolved	mg/l	---	---	---	410	---	---
Mg, Dissolved	mg/l	---	---	---	164	---	---
Mn, Dissolved	mg/l	---	---	---	0.11	---	---
Na, Dissolved	mg/l	---	---	---	875	---	---
Ni, Dissolved	mg/l	---	---	---	0.11	---	---
Pb, Dissolved	mg/l	---	---	---	0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	384	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	0.40	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.10	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.07	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.20	---	---
Cl, Dissolved	mg/l	---	---	---	1070	---	---
Organic C, Diss.	mg/l	---	---	---	321	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	4.92	---	---
BOD ₅ , Total	mg/l	---	---	---	43.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well D (continued).

Constituent	Units	10-31-90 (0854)	11-29-90 (1243)	12-14-90 (1315)	12-27-90 (1145)	6-20-91 (1110)	7-3-91 (1040)
Temperature	°C	8.7	7.5	0.5	1.0	22.1	20.2
Spec. Conductance	µS @ 25°C	4420	4860	4640	2700	6050	6420
Dissolved Oxygen	mg/l	0.50	0.85	0.40	1.70	---	---
pH	std. pH units	7.55	7.67	7.43	7.57	7.78	8.18
Bar. Pressure	mm Hg	---	741	749	756	735	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well D (continued).

Constituent	Units	7-24-91 (1040)	8-1-91 (1040)	8-20-91 (1040)	10-3-91 (1115)
Temperature	°C	22.5	22.0	21.0	23.0
Spec. Conductance	µS @ 25°C	6530	7550	5980	4070
Dissolved Oxygen	mg/l	---	---	---	---
pH	std. pH units	---	8.35	---	7.84
Bar. Pressure	mm Hg	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---
B, Dissolved	mg/l	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---
K, Dissolved	mg/l	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well E, 6 m downstream of inflow.

Constituent	Units	7-26-90 (1130)	8-9-90 (1100)	8-23-90 (1000)	9-8-90 (1235)	9-24-90 (1220)	10-18-90 (1220)
Temperature	°C	21.6	21.0	19.4	25.8	13.2	15.0
Spec. Conductance	µS @ 25°C	4690	6410	5750	7870	7040	5640
Dissolved Oxygen	mg/l	---	---	---	1.20	0.40	0.30
pH	std. pH units	7.31	7.70	---	7.62	7.35	7.87
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2810	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2840	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	3470	---	---
Al, Dissolved	mg/l	---	---	---	0.22	---	---
B, Dissolved	mg/l	---	---	---	5.77	---	---
Ba, Dissolved	mg/l	---	---	---	0.40	---	---
Ca, Dissolved	mg/l	---	---	---	94.9	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	1.33	---	---
K, Dissolved	mg/l	---	---	---	408	---	---
Mg, Dissolved	mg/l	---	---	---	163	---	---
Mn, Dissolved	mg/l	---	---	---	0.33	---	---
Na, Dissolved	mg/l	---	---	---	875	---	---
Ni, Dissolved	mg/l	---	---	---	0.11	---	---
Pb, Dissolved	mg/l	---	---	---	0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	372	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	0.38	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.10	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.07	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.23	---	---
Cl, Dissolved	mg/l	---	---	---	1060	---	---
Organic C, Diss.	mg/l	---	---	---	273	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.40	---	---
BOD ₅ , Total	mg/l	---	---	---	42	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well E (continued).

Constituent	Units	10-31-90 (0851)	11-19-90 (1230)	11-29-90 (1245)	12-14-90 (1320)	12-27-90 (1200)	6-20-91 (1115)
Temperature	°C	9.9	3.1	7.6	1.4	1.1	22.0
Spec. Conductance	µS @ 25°C	4780	5300	5560	5820	3840	5850
Dissolved Oxygen	mg/l	0.40	---	0.65	0.40	0.90	---
pH	std. pH units	7.42	7.09	7.29	7.24	7.52	7.92
Bar. Pressure	mm Hg	---	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	2000	---	1880	---	---
Carbonate Alk.	mg/l CaCO ₃	---	2100	---	1970	---	---
HCO ₃ , Dissolved	mg/l	---	2560	---	2400	---	---
Al, Dissolved	mg/l	---	0.21	---	<0.11	---	---
B, Dissolved	mg/l	---	2.66	---	2.22	---	---
Ba, Dissolved	mg/l	---	0.79	---	0.77	---	---
Ca, Dissolved	mg/l	---	176	---	94.5	---	---
Cd, Dissolved	mg/l	---	<0.01	---	<0.01	---	---
Co, Dissolved	mg/l	---	<0.11	---	<0.11	---	---
Cr, Dissolved	mg/l	---	<0.11	---	<0.11	---	---
Cu, Dissolved	mg/l	---	<0.11	---	<0.11	---	---
Fe, Dissolved	mg/l	---	18.2	---	5.16	---	---
K, Dissolved	mg/l	---	192	---	169	---	---
Mg, Dissolved	mg/l	---	131	---	129	---	---
Mn, Dissolved	mg/l	---	3.46	---	2.14	---	---
Na, Dissolved	mg/l	---	532	---	499	---	---
Ni, Dissolved	mg/l	---	<0.11	---	<0.11	---	---
Pb, Dissolved	mg/l	---	<0.11	---	<0.11	---	---
Zn, Dissolved	mg/l	---	<0.11	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	178	---	182	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	0.47	---	0.42	---	---
NO ₂ -N, Dissolved	mg/l	---	0.02	---	<0.01	---	---
PO ₄ -P, Dissolved	mg/l	---	0.02	---	<0.01	---	---
Phosphorus, Dissolved	mg/l	---	0.06	---	0.05	---	---
Cl, Dissolved	mg/l	---	668	---	622	---	---
Organic C, Diss.	mg/l	---	317	---	363	---	---
SO ₄ -S, Dissolved	mg/l	---	5.93	---	5.66	---	---
BOD ₅ , Total	mg/l	---	305	---	249	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed II: In-plot well E (continued).

Constituent	Units	7-3-91 (1045)	7-24-91 (1045)	8-1-91 (1045)	8-20-91 (1045)	10-3-91 (1120)
Temperature	°C	20.1	23.0	21.5	21.0	23.5
Spec. Conductance	µS @ 25°C	6990	7200	7530	6630	3940
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.94	---	7.64	---	7.76
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well A, 30 m downstream of inflow.

Constituent	Units	7-26-90 (1200)	8-9-90 (1130)	8-23-90 (1030)	9-8-90 (1345)	9-24-90 (1230)	10-18-90 (1225)
Temperature	°C	24.1	21.2	19.0	20.5	13.8	14.4
Spec. Conductance	µS @ 25°C	3770	4330	4730	6110	5310	5450
Dissolved Oxygen	mg/l	---	---	---	1.20	0.60	0.20
pH	std. pH units	6.73	7.09	---	7.32	7.31	7.91
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1770	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1780	---	---
HCCO ₃ , Dissolved	mg/l	---	---	---	2170	---	---
Al, Dissolved	mg/l	---	---	---	0.22	---	---
B, Dissolved	mg/l	---	---	---	5.11	---	---
Ba, Dissolved	mg/l	---	---	---	0.97	---	---
Ca, Dissolved	mg/l	---	---	---	81.7	---	---
Cd, Dissolved	mg/l	---	---	---	0.03	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	<0.11	---	---
K, Dissolved	mg/l	---	---	---	240	---	---
Mg, Dissolved	mg/l	---	---	---	121	---	---
Mn, Dissolved	mg/l	---	---	---	1.11	---	---
Na, Dissolved	mg/l	---	---	---	817	---	---
Ni, Dissolved	mg/l	---	---	---	0.22	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	142	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	2.30	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.60	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.05	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.15	---	---
Cl, Dissolved	mg/l	---	---	---	1060	---	---
Organic C, Diss.	mg/l	---	---	---	240	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	9.40	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well A (continued).

Constituent	Units	10-31-90 (0910)	11-19-90 (1300)	11-29-90 (1247)	12-14-90 (1322)	12-27-90 (1325)	6-20-91 (1120)
Temperature	°C	8.0	3.2	7.3	1.9	0.5	23.0
Spec. Conductance	µS @ 25°C	4480	5110	4730	4970	3400	5530
Dissolved Oxygen	mg/l	2.15	---	0.90	0.60	0.55	---
pH	std. pH units	7.62	7.34	7.76	7.77	7.65	7.80
Bar. Pressure	mm Hg	---	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	1860	---	---	1240	---
Carbonate Alk.	mg/l CaCO ₃	---	1940	---	---	1310	---
HCO ₃ , Dissolved	mg/l	---	2370	---	---	1600	---
Al, Dissolved	mg/l	---	0.17	---	---	<0.11	---
B, Dissolved	mg/l	---	2.66	---	---	1.77	---
Ba, Dissolved	mg/l	---	0.66	---	---	---	---
Ca, Dissolved	mg/l	---	90.4	---	---	40.6	---
Cd, Dissolved	mg/l	---	<0.01	---	---	<0.01	---
Co, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cr, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cu, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Fe, Dissolved	mg/l	---	6.31	---	---	1.67	---
K, Dissolved	mg/l	---	200	---	---	131	---
Mg, Dissolved	mg/l	---	134	---	---	81.2	---
Mn, Dissolved	mg/l	---	1.92	---	---	1.15	---
Na, Dissolved	mg/l	---	520	---	---	335	---
Ni, Dissolved	mg/l	---	0.11	---	---	<0.11	---
Pb, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Zn, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	165	---	---	117	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	0.45	---	---	0.42	---
NO ₂ -N, Dissolved	mg/l	---	0.01	---	---	<0.01	---
PO ₄ -P, Dissolved	mg/l	---	0.01	---	---	<0.01	---
Phosphorus, Dissolved	mg/l	---	0.06	---	---	<0.02	---
Cl, Dissolved	mg/l	---	598	---	---	409	---
Organic C, Diss.	mg/l	---	396	---	---	298	---
SO ₄ -S, Dissolved	mg/l	---	5.45	---	---	5.97	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well A (continued).

Constituent	Units	7-3-91 (1050)	7-24-91 (1050)	8-1-91 (1050)	8-20-91 (1050)	10-3-91 (1115)
Temperature	°C	21.0	23.1	21.5	21.0	24.0
Spec. Conductance	µS @ 25°C	6960	6660	7640	6200	4180
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.80	---	7.95	---	7.80
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well B, 24 m downstream of inflow.

Constituent	Units	7-26-90 (1200)	8-9-90 (1130)	8-23-90 (1030)	9-8-90 (1420)	9-8-90 (1425)	9-24-90 (1230)
Temperature	°C	27.4	21.3	19.3	21.0	(dupl.)	14.0
Spec. Conductance	µS @ 25°C	3300	3330	3890	5190	6150	5110
Dissolved Oxygen	mg/l	---	---	---	0.90	---	0.70
pH	std. pH units	7.27	7.27	---	7.20	---	7.69
Bar. Pressure	mm Hg	---	---	---	742	---	737
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1840	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1860	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2270	---	---
Al, Dissolved	mg/l	---	---	---	0.11	0.22	---
B, Dissolved	mg/l	---	---	---	5.00	5.22	---
Ba, Dissolved	mg/l	---	---	---	1.12	1.25	---
Ca, Dissolved	mg/l	---	---	---	97.8	103.	---
Cd, Dissolved	mg/l	---	---	---	0.03	0.02	---
Co, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cr, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cu, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Fe, Dissolved	mg/l	---	---	---	0.11	0.22	---
K, Dissolved	mg/l	---	---	---	216	252	---
Mg, Dissolved	mg/l	---	---	---	122	124	---
Mn, Dissolved	mg/l	---	---	---	1.22	1.22	---
Na, Dissolved	mg/l	---	---	---	817	910	---
Ni, Dissolved	mg/l	---	---	---	0.22	0.22	---
Pb, Dissolved	mg/l	---	---	---	<0.11	0.11	---
Zn, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	---	---	158	170	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	0.53	0.49	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.30	0.30	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.05	0.03	---
Phosphorus, Dissolved	mg/l	---	---	---	0.16	0.16	---
Cl, Dissolved	mg/l	---	---	---	1100	1100	---
Organic C, Diss.	mg/l	---	---	---	302	276	---
SO ₄ -S, Dissolved	mg/l	---	---	---	9.60	10.2	---
BOD ₅ , Total	mg/l	---	---	---	46.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well B (continued).

Constituent	Units	10-18-90 (1230)	10-31-90 (0914)	11-29-90 (1250)	12-14-90 (1325)	12-27-91 (1330)	6-20-91 (1125)
Temperature	°C	14.8	8.3	7.9	1.7	2.0	21.5
Spec. Conductance	µS @ 25°C	5290	4580	4890	5440	3370	4470
Dissolved Oxygen	mg/l	0.40	3.85	0.70	0.60	1.45	---
pH	std. pH units	7.78	7.50	7.72	7.45	7.57	7.48
Bar. Pressure	mm Hg	729	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well B (continued).

Constituent	Units	7-3-91 (1055)	7-24-91 (1055)	8-1-91 (1055)	8-20-91 (1055)	10-3-91 (1120)
Temperature	°C	20.8	22.5	21.5	20.5	24.1
Spec. Conductance	µS @ 25°C	7100	6530	7320	6710	3870
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.26	---	7.54	---	7.39
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well C, 18 m downstream of inflow.

Constituent	Units	7-26-90 (1200)	8-9-90 (1130)	8-23-90 (1030)	9-8-90 (1515)	9-24-90 (1240)	10-18-90 (1235)
Temperature	°C	27.1	21.5	19.5	21.6	14.4	15.4
Spec. Conductance	µS @ 25°C	4510	4730	5840	6540	6160	5290
Dissolved Oxygen	mg/l	---	---	---	0.90	0.50	0.15
pH	std. pH units	7.11	7.31	---	7.46	8.11	7.84
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2140	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2160	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2640	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	5.33	---	---
Ba, Dissolved	mg/l	---	---	---	0.82	---	---
Ca, Dissolved	mg/l	---	---	---	39.7	---	---
Cd, Dissolved	mg/l	---	---	---	0.03	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.22	---	---
K, Dissolved	mg/l	---	---	---	317	---	---
Mg, Dissolved	mg/l	---	---	---	121	---	---
Mn, Dissolved	mg/l	---	---	---	0.88	---	---
Na, Dissolved	mg/l	---	---	---	793	---	---
Ni, Dissolved	mg/l	---	---	---	0.22	---	---
Pb, Dissolved	mg/l	---	---	---	0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	152	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	0.69	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.60	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.05	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.15	---	---
Cl, Dissolved	mg/l	---	---	---	977	---	---
Organic C, Diss.	mg/l	---	---	---	305.6	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.76	---	---
BOD ₅ , Total	mg/l	---	---	---	46.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well C (continued).

Constituent	Units	10-31-90 (0916)	11-19-90 (1330)	11-19-90 (1335)	11-29-90 (1252)	12-14-90 (1330)	12-27-90 (1340)
Temperature	°C	8.4	3.2	(dupl.)	7.6	1.5	2.0
Spec. Conductance	µS @ 25°C	4670	4980	---	5290	5310	4960
Dissolved Oxygen	mg/l	1.35	---	---	1.50	0.95	1.10
pH	std. pH units	7.50	7.35	---	7.85	7.58	7.77
Bar. Pressure	mm Hg	---	---	---	741	749	756
Fixed End. Alk.	mg/l CaCO ₃	---	1850	---	---	---	1510
Carbonate Alk.	mg/l CaCO ₃	---	1930	---	---	---	1580
HCO ₃ , Dissolved	mg/l	---	2360	---	---	---	1930
Al, Dissolved	mg/l	---	---	---	---	---	<0.11
B, Dissolved	mg/l	---	2.66	2.44	---	---	1.88
Ba, Dissolved	mg/l	---	0.64	0.65	---	---	0.64
Ca, Dissolved	mg/l	---	110	100	---	---	53.29
Cd, Dissolved	mg/l	---	<0.01	<0.01	---	---	<0.01
Co, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Cr, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Cu, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Fe, Dissolved	mg/l	---	7.69	7.13	---	---	8.57
K, Dissolved	mg/l	---	196	180	---	---	144
Mg, Dissolved	mg/l	---	125	115	---	---	88.20
Mn, Dissolved	mg/l	---	2.42	2.23	---	---	1.32
Na, Dissolved	mg/l	---	514	485	---	---	364
Ni, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Pb, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
Zn, Dissolved	mg/l	---	<0.11	<0.11	---	---	<0.11
NH ₄ -N, Dissolved	mg/l	---	162	173	---	---	144
NO ₃ +NO ₂ -N, Diss.	mg/l	---	0.44	0.44	---	---	0.38
NO ₂ -N, Dissolved	mg/l	---	0.02	0.02	---	---	<0.01
PO ₄ -P, Dissolved	mg/l	---	0.01	0.01	---	---	0.04
Phosphorus, Dissolved	mg/l	---	0.06	0.07	---	---	0.10
Cl, Dissolved	mg/l	---	560	600	---	---	470
Organic C, Diss.	mg/l	---	295.5	348.2	---	---	297
SO ₄ -S, Dissolved	mg/l	---	5.48	5.36	---	---	5.43
BOD ₅ , Total	mg/l	---	270	---	---	---	110
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well C (continued).

Constituent	Units	6-20-91 (1130)	7-3-91 (1100)	7-24-91 (1100)	8-1-91 (1100)	8-20-91 (1100)	10-3-91 (1125)
Temperature	°C	22.0	20.6	23.0	21.0	20.5	23.0
Spec. Conductance	µS @ 25°C	6490	6910	7090	7610	6600	4430
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std. pH units	7.83	8.27	---	8.04	---	7.83
Bar. Pressure	mm Hg	735	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well D, 12 m downstream of inflow.

Constituent	Units	7-26-90 (1200)	8-9-90 (1130)	8-23-90 (1030)	9-8-90 (1555)	9-24-90 (1240)	10-18-90 (1240)
Temperature	°C	25.0	22.0	19.3	19.6	13.8	14.8
Spec. Conductance	µS @ 25°C	5400	5430	5980	6490	5770	5780
Dissolved Oxygen	mg/l	---	---	---	0.70	0.40	0.60
pH	std. pH units	7.03	7.26	---	7.45	7.55	7.61
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2180	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2200	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2680	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	5.33	---	---
Ba, Dissolved	mg/l	---	---	---	0.79	---	---
Ca, Dissolved	mg/l	---	---	---	41.3	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.33	---	---
K, Dissolved	mg/l	---	---	---	335	---	---
Mg, Dissolved	mg/l	---	---	---	128	---	---
Mn, Dissolved	mg/l	---	---	---	0.88	---	---
Na, Dissolved	mg/l	---	---	---	817	---	---
Ni, Dissolved	mg/l	---	---	---	0.22	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	228	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	0.82	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.70	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.06	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.18	---	---
Cl, Dissolved	mg/l	---	---	---	990	---	---
Organic C, Diss.	mg/l	---	---	---	273	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.00	---	---
BOD ₅ , Total	mg/l	---	---	---	49.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well D (continued).

Constituent	Units	10-31-90 (0918)	11-29-90 (1255)	12-14-90 (1333)	12-27-90 (1350)	6-20-91 (1135)	7-3-91 (1105)
Temperature	°C	8.4	7.6	2.2	1.3	22.0	20.4
Spec. Conductance	µS @ 25°C	5080	5110	5490	3350	4420	6830
Dissolved Oxygen	mg/l	0.45	0.65	0.70	1.70	---	---
pH	std. pH units	7.50	7.44	7.30	7.30	7.27	7.47
Bar. Pressure	mm Hg	---	741	749	756	735	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well D (continued).

Constituent	Units	7-24-91 (1105)	8-1-91 (1105)	8-20-91 (1105)	10-3-91 (1130)
Temperature	°C	23.0	21.0	21.0	23.1
Spec. Conductance	µS @ 25°C	7300	6410	7070	2670
Dissolved Oxygen	mg/l	---	---	---	---
pH	std. pH units	---	7.92	---	7.86
Bar. Pressure	mm Hg	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---
B, Dissolved	mg/l	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---
K, Dissolved	mg/l	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well E, 6 m downstream of inflow.

Constituent	Units	7-26-90 (1200)	8-9-90 (1130)	8-23-90 (1030)	9-8-90 (1630)	9-24-90 (1245)	10-18-90 (1245)
Temperature	°C	28.0	21.5	19.2	22.5	13.8	15.0
Spec. Conductance	µS @ 25°C	6070	5920	6790	6910	6030	6110
Dissolved Oxygen	mg/l	---	---	---	0.50	0.50	0.10
pH	std. pH units	7.39	7.40	---	7.43	8.05	7.79
Bar. Pressure	mm Hg	---	---	---	742	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	2230	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	2250	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2740	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	5.11	---	---
Ba, Dissolved	mg/l	---	---	---	0.84	---	---
Ca, Dissolved	mg/l	---	---	---	70.0	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.88	---	---
K, Dissolved	mg/l	---	---	---	309	---	---
Mg, Dissolved	mg/l	---	---	---	130	---	---
Mn, Dissolved	mg/l	---	---	---	1.11	---	---
Na, Dissolved	mg/l	---	---	---	817	---	---
Ni, Dissolved	mg/l	---	---	---	0.22	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	152	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.08	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.19	---	---
Cl, Dissolved	mg/l	---	---	---	1100	---	---
Organic C, Diss.	mg/l	---	---	---	346	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.76	---	---
BOD ₅ , Total	mg/l	---	---	---	56.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed III: In-plot well E (continued).

Constituent	Units	10-31-90 (0920)	11-19-90 (1410)	11-29-90 (1300)	12-14-90 (1335)	12-27-90 (1400)	6-20-91 (1140)
Temperature	°C	9.7	4.8	8.5	2.0	1.3	22.8
Spec. Conductance	µS @ 25°C	4710	5320	5500	4890	4740	6070
Dissolved Oxygen	mg/l	0.40	---	0.85	0.70	0.95	---
pH	std. pH units	7.26	7.16	7.23	7.26	7.34	7.25
Bar. Pressure	mm Hg	---	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	1990	---	---	1840	---
Carbonate Alk.	mg/l CaCO ₃	---	2070	---	---	1990	---
HCO ₃ , Dissolved	mg/l	---	2530	---	---	2430	---
Al, Dissolved	mg/l	---	0.15	---	---	<0.11	---
B, Dissolved	mg/l	---	2.55	---	---	2.22	---
Ba, Dissolved	mg/l	---	0.74	---	---	0.71	---
Ca, Dissolved	mg/l	---	154	---	---	99.9	---
Cd, Dissolved	mg/l	---	<0.01	---	---	<0.01	---
Co, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cr, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cu, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Fe, Dissolved	mg/l	---	19.2	---	---	5.63	---
K, Dissolved	mg/l	---	185	---	---	162	---
Mg, Dissolved	mg/l	---	121.08	---	---	115	---
Mn, Dissolved	mg/l	---	3.44	---	---	2.22	---
Na, Dissolved	mg/l	---	496	---	---	458	---
Ni, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Pb, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Zn, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	188	---	---	185	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	0.45	---	---	0.42	---
NO ₂ -N, Dissolved	mg/l	---	0.02	---	---	<0.01	---
PO ₄ -P, Dissolved	mg/l	---	0.02	---	---	0.01	---
Phosphorus, Dissolved	mg/l	---	0.10	---	---	0.05	---
Cl, Dissolved	mg/l	---	605	---	---	650	---
Organic C, Diss.	mg/l	---	290	---	---	473	---
SO ₄ -S, Dissolved	mg/l	---	4.53	---	---	5.54	---
BOD ₅ , Total	mg/l	---	292	---	---	268	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Resolution Test Chart Labels:

- 1.0
- 1.1
- 1.25
- 1.4
- 1.6
- 1.8
- 2.0
- 2.2
- 2.5
- 2.8
- 3.2
- 3.6
- 4.0

3 of 3

Appendix B. Constituent Concentrations of Bed III: In-plot well E (continued).

Constituent	Units	7-3-91 (1110)	7-24-91 (1110)	8-1-91 (1110)	8-20-91 (1110)	10-3-91 (1135)
Temperature	°C	20.6	23.9	21.5	21.5	22.5
Spec. Conductance	µS @ 25°C	6690	7160	7320	6460	2700
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	8.04	---	8.11	---	7.56
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well A, 30 m downstream of inflow.

Constituent	Units	7-26-90 (1230)	8-9-90 (1200)	8-23-90 (1100)	9-9-90 (1030)	9-24-90 (1250)	10-18-90 (1250)
Temperature	°C	26.0	23.1	19.5	19.4	14.0	15.0
Spec. Conductance	µS @ 25°C	3720	3690	4830	3760	2630	3240
Dissolved Oxygen	mg/l	---	---	---	0.60	0.90	0.50
pH	std. pH units	7.15	7.19	---	7.30	7.31	7.98
Bar. Pressure	mm Hg	---	---	---	741	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1350	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1360	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	1660	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	3.55	---	---
Ba, Dissolved	mg/l	---	---	---	0.68	---	---
Ca, Dissolved	mg/l	---	---	---	46.9	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.33	---	---
K, Dissolved	mg/l	---	---	---	195	---	---
Mg, Dissolved	mg/l	---	---	---	70.11	---	---
Mn, Dissolved	mg/l	---	---	---	0.88	---	---
Na, Dissolved	mg/l	---	---	---	513	---	---
Ni, Dissolved	mg/l	---	---	---	0.11	---	---
Pb, Dissolved	mg/l	---	---	---	0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	164	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	20.0	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	1.10	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.03	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.06	---	---
Cl, Dissolved	mg/l	---	---	---	537	---	---
Organic C, Diss.	mg/l	---	---	---	<50.0	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	5.64	---	---
BOD ₅ , Total	mg/l	---	---	---	39.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well A (continued).

Constituent	Units	10-31-90 (0930)	11-19-90 (1450)	12-14-90 (1340)	12-27-90 (1515)	12-27-90 (1520)	6-20-91 (1145)
Temperature	°C	9.0	3.9	2.9	0.0	(dupl.)	22.0
Spec. Conductance	µS @ 25°C	4180	4210	4450	847	---	5530
Dissolved Oxygen	mg/l	0.60	---	1.10	1.20	---	---
pH	std. pH units	7.14	7.22	7.47	7.18	---	7.20
Bar. Pressure	mm Hg	---	---	749	756	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	1380	---	606	---	---
Carbonate Alk.	mg/l CaCO ₃	---	1430	---	630	---	---
HCO ₃ , Dissolved	mg/l	---	1740	---	769	---	---
Al, Dissolved	mg/l	---	0.11	---	<0.11	<0.11	---
B, Dissolved	mg/l	---	2.11	---	0.99	0.88	---
Ba, Dissolved	mg/l	---	0.66	---	0.25	0.25	---
Ca, Dissolved	mg/l	---	115.97	---	37.2	32.8	---
Cd, Dissolved	mg/l	---	<0.01	---	<0.01	<0.01	---
Co, Dissolved	mg/l	---	<0.11	---	<0.11	<0.11	---
Cr, Dissolved	mg/l	---	<0.11	---	<0.11	<0.11	---
Cu, Dissolved	mg/l	---	<0.11	---	<0.11	<0.11	---
Fe, Dissolved	mg/l	---	4.21	---	0.35	0.25	---
K, Dissolved	mg/l	---	130	---	65.8	58.1	---
Mg, Dissolved	mg/l	---	84.0	---	24.4	21.1	---
Mn, Dissolved	mg/l	---	2.58	---	1.29	1.18	---
Na, Dissolved	mg/l	---	392	---	171	153	---
Ni, Dissolved	mg/l	---	<0.11	---	<0.11	<0.11	---
Pb, Dissolved	mg/l	---	<0.11	---	<0.11	<0.11	---
Zn, Dissolved	mg/l	---	<0.11	---	<0.11	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	115	---	75.0	72.0	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	11.8	---	17.5	16.9	---
NO ₂ -N, Dissolved	mg/l	---	0.71	---	0.32	0.34	---
PO ₄ -P, Dissolved	mg/l	---	<0.01	---	<0.01	<0.01	---
Phosphorus, Dissolved	mg/l	---	0.05	---	<0.02	<0.02	---
Cl, Dissolved	mg/l	---	425	---	176	186	---
Organic C, Diss.	mg/l	---	336	---	314	237	---
SO ₄ -S, Dissolved	mg/l	---	4.53	---	3.41	3.51	---
BOD ₅ , Total	mg/l	---	261	---	10.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well A (continued).

Constituent	Units	7-3-91 (1115)	7-24-91 (1115)	8-1-91 (1115)	8-21-91 (1000)	10-3-91 (1040)
Temperature	°C	21.1	23.6	22.0	21.0	23.0
Spec. Conductance	µS @ 25°C	6620	7200	7340	6120	4330
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.21	---	7.58	---	7.31
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well B, 24 m downstream of inflow.

Constituent	Units	7-26-90 (1230)	8-9-90 (1200)	8-23-90 (1100)	9-9-90 (1110)	9-24-90 (1250)	10-18-90 (1255)
Temperature	°C	24.9	23.0	19.7	18.6	14.4	15.0
Spec. Conductance	µS @ 25°C	4740	5420	5480	5530	3770	5020
Dissolved Oxygen	mg/l	---	---	---	0.80	0.60	0.55
pH	std. pH units	7.13	6.96	---	7.22	7.65	7.76
Bar. Pressure	mm Hg	---	---	---	741	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1460	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1490	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	1820	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	4.22	---	---
Ba, Dissolved	mg/l	---	---	---	0.85	---	---
Ca, Dissolved	mg/l	---	---	---	65.4	---	---
Cd, Dissolved	mg/l	---	---	---	0.02	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	0.44	---	---
K, Dissolved	mg/l	---	---	---	240	---	---
Mg, Dissolved	mg/l	---	---	---	94.7	---	---
Mn, Dissolved	mg/l	---	---	---	1.11	---	---
Na, Dissolved	mg/l	---	---	---	607	---	---
Ni, Dissolved	mg/l	---	---	---	0.11	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	200	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	30.0	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	1.60	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.04	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.08	---	---
Cl, Dissolved	mg/l	---	---	---	645	---	---
Organic C, Diss.	mg/l	---	---	---	73.6	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.24	---	---
BOD ₅ , Total	mg/l	---	---	---	59.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well B (continued).

Constituent	Units	10-31-90 (0928)	11-29-90 (1310)	12-14-90 (1345)	12-27-90 (1520)	6-20-91 (1150)	7-3-91 (1120)
Temperature	°C	9.5	8.0	3.0	1.2	23.9	21.4
Spec. Conductance	µS @ 25°C	4470	5010	4680	1300	6030	5930
Dissolved Oxygen	mg/l	0.50	0.40	1.25	2.30	---	---
pH	std. pH units	7.11	7.31	7.33	7.57	7.25	7.29
Bar. Pressure	mm Hg	---	741	749	756	735	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well B (continued).

Constituent	Units	7-24-91 (1120)	8-1-91 (1120)	8-21-91 (1005)	10-3-91 (1045)
Temperature	°C	23.9	22.5	21.0	22.0
Spec. Conductance	µS @ 25°C	6850	7370	5650	4840
Dissolved Oxygen	mg/l	---	---	---	---
pH	std. pH units	---	7.52	---	7.07
Bar. Pressure	mm Hg	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---
B, Dissolved	mg/l	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---
K, Dissolved	mg/l	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well C, 18 m downstream of inflow.

Constituent	Units	7-26-90 (1230)	8-9-90 (1200)	8-23-90 (1100)	9-9-90 (1150)	9-9-90 (1155)	9-24-90 (1255)
Temperature	°C	24.4	23.1	19.8	19.2	(dupl.)	14.7
Spec. Conductance	µS @ 25°C	6220	5950	5810	5560	---	5530
Dissolved Oxygen	mg/l	---	---	---	0.60	0.70	---
pH	std. pH units	6.93	7.01	---	7.19	---	7.66
Bar. Pressure	mm Hg	---	---	---	741	737	---
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1650	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1660	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2030	---	---
Al, Dissolved	mg/l	---	---	---	0.11	0.22	---
B, Dissolved	mg/l	---	---	---	4.88	4.88	---
Ba, Dissolved	mg/l	---	---	---	1.05	0.97	---
Ca, Dissolved	mg/l	---	---	---	83.8	82.3	---
Cd, Dissolved	mg/l	---	---	---	0.01	0.01	---
Co, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cr, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Cu, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
Fe, Dissolved	mg/l	---	---	---	1.00	1.00	---
K, Dissolved	mg/l	---	---	---	256	259	---
Mg, Dissolved	mg/l	---	---	---	112	113	---
Mn, Dissolved	mg/l	---	---	---	1.22	1.22	---
Na, Dissolved	mg/l	---	---	---	630	630	---
Ni, Dissolved	mg/l	---	---	---	0.11	0.11	---
Pb, Dissolved	mg/l	---	---	---	<0.11	0.11	---
Zn, Dissolved	mg/l	---	---	---	<0.11	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	---	---	236	196	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	14.0	14.5	---
NO ₂ -N, Dissolved	mg/l	---	---	---	0.40	0.40	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.02	0.02	---
Phosphorus, Dissolved	mg/l	---	---	---	0.11	0.09	---
Cl, Dissolved	mg/l	---	---	---	773	742	---
Organic C, Diss.	mg/l	---	---	---	116	120	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.56	6.48	---
BOD ₅ , Total	mg/l	---	---	---	56.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well C (continued).

Constituent	Units	10-18-90 (1300)	10-31-90 (0926)	11-19-90 (1510)	11-29-90 (1315)	12-14-90 (1350)	12-27-90 (1525)
Temperature	°C	15.0	9.7	5.3	7.6	3.2	2.5
Spec. Conductance	µS @ 25°C	5300	4830	5060	4470	4860	969
Dissolved Oxygen	mg/l	0.65	0.50	---	0.65	0.70	0.50
pH	std. pH units	7.28	7.15	7.09	7.26	7.26	7.84
Bar. Pressure	mm Hg	729	---	---	741	749	756
Fixed End. Alk.	mg/l CaCO ₃	---	---	1870	---	---	614
Carbonate Alk.	mg/l CaCO ₃	---	---	1940	---	---	620
HCO ₃ , Dissolved	mg/l	---	---	2370	---	---	757
Al, Dissolved	mg/l	---	---	0.20	---	---	<0.11
B, Dissolved	mg/l	---	---	2.33	---	---	1.22
Ba, Dissolved	mg/l	---	---	0.90	---	---	---
Ca, Dissolved	mg/l	---	---	164	---	---	42.7
Cd, Dissolved	mg/l	---	---	<0.01	---	---	<0.01
Co, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Cr, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Cu, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Fe, Dissolved	mg/l	---	---	11.4	---	---	0.20
K, Dissolved	mg/l	---	---	164	---	---	75.4
Mg, Dissolved	mg/l	---	---	117	---	---	25.4
Mn, Dissolved	mg/l	---	---	3.99	---	---	1.14
Na, Dissolved	mg/l	---	---	466	---	---	184
Ni, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Pb, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
Zn, Dissolved	mg/l	---	---	<0.11	---	---	<0.11
NH ₄ -N, Dissolved	mg/l	---	---	154	---	---	77
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	0.69	---	---	14.9
NO ₂ -N, Dissolved	mg/l	---	---	0.02	---	---	0.56
PO ₄ -P, Dissolved	mg/l	---	---	0.01	---	---	<0.01
Phosphorus, Dissolved	mg/l	---	---	0.07	---	---	<0.02
Cl, Dissolved	mg/l	---	---	562	---	---	181
Organic C, Diss.	mg/l	---	---	435	---	---	160
SO ₄ -S, Dissolved	mg/l	---	---	5.26	---	---	4.45
BOD ₅ , Total	mg/l	---	---	342	---	---	7.00
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well C (continued).

Constituent	Units	6-20-91 (1155)	7-3-91 (1125)	7-24-91 (1125)	8-1-91 (1125)	8-21-91 (1010)	10-3-91 (1050)
Temperature	°C	22.9	21.7	24.1	22.0	22.0	22.0
Spec. Conductance	µS @ 25°C	6480	7490	7130	7550	5210	4790
Dissolved Oxygen	mg/l	---	---	---	---	---	---
pH	std. pH units	7.17	7.25	---	7.40	---	7.04
Bar. Pressure	mm Hg	735	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well D, 12 m downstream of inflow.

Constituent	Units	7-26-90 (1230)	8-9-90 (1200)	8-23-90 (1100)	9-8-90 (1250)	9-24-90 (1300)	10-18-90 (1305)
Temperature	°C	24.3	23.3	19.5	19.0	14.9	15.2
Spec. Conductance	µS @ 25°C	6760	6010	6860	6360	6380	5270
Dissolved Oxygen	mg/l	---	---	---	1.00	0.60	1.20
pH	std. pH units	6.96	7.02	---	7.17	8.14	7.45
Bar. Pressure	mm Hg	---	---	---	741	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1810	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1840	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2250	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	4.77	---	---
Ba, Dissolved	mg/l	---	---	---	0.97	---	---
Ca, Dissolved	mg/l	---	---	---	77.2	---	---
Cd, Dissolved	mg/l	---	---	---	0.01	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	1.22	---	---
K, Dissolved	mg/l	---	---	---	283	---	---
Mg, Dissolved	mg/l	---	---	---	113	---	---
Mn, Dissolved	mg/l	---	---	---	1.11	---	---
Na, Dissolved	mg/l	---	---	---	653	---	---
Ni, Dissolved	mg/l	---	---	---	0.11	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	236	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	37.0	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	1.60	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.26	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.10	---	---
Cl, Dissolved	mg/l	---	---	---	793	---	---
Organic C, Diss.	mg/l	---	---	---	170	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	9.48	---	---
BOD ₅ , Total	mg/l	---	---	---	56.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well D (continued).

Constituent	Units	10-31-90 (0924)	11-29-90 (1320)	12-14-90 (1355)	12-27-90 (1530)	6-20-91 (1200)	7-3-91 (1130)
Temperature	°C	9.9	7.6	4.0	2.4	22.1	22.4
Spec. Conductance	µS @ 25°C	5140	4680	5060	2000	6160	6650
Dissolved Oxygen	mg/l	0.50	0.70	0.85	0.85	---	---
pH	std. pH units	7.14	7.41	7.36	7.71	7.16	7.31
Bar. Pressure	mm Hg	---	741	749	756	735	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well D (continued).

Constituent	Units	7-24-91 (1130)	8-1-91 (1130)	8-21-91 (1015)	10-3-91 (1055)
Temperature	°C	24.5	22.5	21.0	22.5
Spec. Conductance	µS @ 25°C	7070	7480	5320	4620
Dissolved Oxygen	mg/l	---	---	---	---
pH	std. pH units	---	7.53	---	7.08
Bar. Pressure	mm Hg	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---
B, Dissolved	mg/l	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---
K, Dissolved	mg/l	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well E, 6 m downstream of inflow.

Constituent	Units	7-26-90 (1230)	8-9-90 (1200)	8-23-90 (1100)	9-9-90 (1330)	9-24-90 (1300)	10-18-90 (1310)
Temperature	°C	23.5	23.5	19.7	19.0	15.2	16.0
Spec. Conductance	µS @ 25°C	6950	6910	7270	5680	7070	5370
Dissolved Oxygen	mg/l	---	---	---	0.6	0.6	0.6
pH	std. pH units	7.01	7.07	---	7.23	7.27	7.34
Bar. Pressure	mm Hg	---	---	---	741	737	729
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	1780	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	1800	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	2200	---	---
Al, Dissolved	mg/l	---	---	---	0.11	---	---
B, Dissolved	mg/l	---	---	---	4.77	---	---
Ba, Dissolved	mg/l	---	---	---	0.68	---	---
Ca, Dissolved	mg/l	---	---	---	84.8	---	---
Cd, Dissolved	mg/l	---	---	---	0.01	---	---
Co, Dissolved	mg/l	---	---	---	<0.11	---	---
Cr, Dissolved	mg/l	---	---	---	<0.11	---	---
Cu, Dissolved	mg/l	---	---	---	<0.11	---	---
Fe, Dissolved	mg/l	---	---	---	1.66	---	---
K, Dissolved	mg/l	---	---	---	294	---	---
Mg, Dissolved	mg/l	---	---	---	117	---	---
Mn, Dissolved	mg/l	---	---	---	1.00	---	---
Na, Dissolved	mg/l	---	---	---	653	---	---
Ni, Dissolved	mg/l	---	---	---	0.11	---	---
Pb, Dissolved	mg/l	---	---	---	<0.11	---	---
Zn, Dissolved	mg/l	---	---	---	<0.11	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	228	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	37.5	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	3.8	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	0.04	---	---
Phosphorus, Dissolved	mg/l	---	---	---	0.14	---	---
Cl, Dissolved	mg/l	---	---	---	739	---	---
Organic C, Diss.	mg/l	---	---	---	166	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	6.44	---	---
BOD ₅ , Total	mg/l	---	---	---	63.0	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well E (continued).

Constituent	Units	10-31-90 (0922)	11-19-90 (1525)	11-29-90 (1325)	12-14-90 (1400)	12-27-90 (1535)	6-20-91 (1205)
Temperature	°C	11.5	4.2	8.0	4.8	2.5	23.1
Spec. Conductance	µS @ 25°C	5020	5380	5460	5160	3440	6450
Dissolved Oxygen	mg/l	0.65	---	0.8	0.4	0.95	---
pH	std. pH units	7.15	6.96	7.15	7.39	7.63	7.24
Bar. Pressure	mm Hg	---	---	741	749	756	735
Fixed End. Alk.	mg/l CaCO ₃	---	1980	---	---	529	---
Carbonate Alk.	mg/l CaCO ₃	---	2100	---	---	560	---
HCO ₃ , Dissolved	mg/l	---	2560	---	---	683	---
Al, Dissolved	mg/l	---	0.18	---	---	<0.11	---
B, Dissolved	mg/l	---	2.22	---	---	0.88	---
Ba, Dissolved	mg/l	---	0.91	---	---	0.17	---
Ca, Dissolved	mg/l	---	183	---	---	28.1	---
Cd, Dissolved	mg/l	---	<0.01	---	---	<0.01	---
Co, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cr, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Cu, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Fe, Dissolved	mg/l	---	17.0	---	---	<0.11	---
K, Dissolved	mg/l	---	167	---	---	64.2	---
Mg, Dissolved	mg/l	---	105	---	---	15.5	---
Mn, Dissolved	mg/l	---	4.23	---	---	0.67	---
Na, Dissolved	mg/l	---	481	---	---	136	---
Ni, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Pb, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
Zn, Dissolved	mg/l	---	<0.11	---	---	<0.11	---
NH ₄ -N, Dissolved	mg/l	---	186	---	---	77.0	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	0.45	---	---	4.05	---
NO ₂ -N, Dissolved	mg/l	---	0.02	---	---	1.54	---
PO ₄ -P, Dissolved	mg/l	---	0.05	---	---	<0.01	---
Phosphorus, Dissolved	mg/l	---	0.12	---	---	<0.02	---
Cl, Dissolved	mg/l	---	598	---	---	137	---
Organic C, Diss.	mg/l	---	---	---	---	249	---
SO ₄ -S, Dissolved	mg/l	---	6.09	---	---	12.7	---
BOD ₅ , Total	mg/l	---	316	---	---	8.5	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---	---

Appendix B. Constituent Concentrations of Bed IV: In-plot well E (continued).

Constituent	Units	7-3-91 (1135)	7-24-91 (1135)	8-1-91 (1135)	8-21-91 (1020)	10-3-91 (1100)
Temperature	°C	22.6	25.0	23.0	21.0	22.5
Spec. Conductance	µS @ 25°C	6100	7000	7300	5760	4640
Dissolved Oxygen	mg/l	---	---	---	---	---
pH	std. pH units	7.29	---	7.73	---	7.3
Bar. Pressure	mm Hg	735	---	738	---	735
Fixed End. Alk.	mg/l CaCO ₃	---	---	---	---	---
Carbonate Alk.	mg/l CaCO ₃	---	---	---	---	---
HCO ₃ , Dissolved	mg/l	---	---	---	---	---
Al, Dissolved	mg/l	---	---	---	---	---
B, Dissolved	mg/l	---	---	---	---	---
Ba, Dissolved	mg/l	---	---	---	---	---
Ca, Dissolved	mg/l	---	---	---	---	---
Cd, Dissolved	mg/l	---	---	---	---	---
Co, Dissolved	mg/l	---	---	---	---	---
Cr, Dissolved	mg/l	---	---	---	---	---
Cu, Dissolved	mg/l	---	---	---	---	---
Fe, Dissolved	mg/l	---	---	---	---	---
K, Dissolved	mg/l	---	---	---	---	---
Mg, Dissolved	mg/l	---	---	---	---	---
Mn, Dissolved	mg/l	---	---	---	---	---
Na, Dissolved	mg/l	---	---	---	---	---
Ni, Dissolved	mg/l	---	---	---	---	---
Pb, Dissolved	mg/l	---	---	---	---	---
Zn, Dissolved	mg/l	---	---	---	---	---
NH ₄ -N, Dissolved	mg/l	---	---	---	---	---
NO ₃ +NO ₂ -N, Diss.	mg/l	---	---	---	---	---
NO ₂ -N, Dissolved	mg/l	---	---	---	---	---
PO ₄ -P, Dissolved	mg/l	---	---	---	---	---
Phosphorus, Dissolved	mg/l	---	---	---	---	---
Cl, Dissolved	mg/l	---	---	---	---	---
Organic C, Diss.	mg/l	---	---	---	---	---
SO ₄ -S, Dissolved	mg/l	---	---	---	---	---
BOD ₅ , Total	mg/l	---	---	---	---	---
BOD ₅ , Dissolved	mg/l	---	---	---	---	---

APPENDIX C

INFLOW, OUTFLOW, PRECIPITATION, AND EVAPOTRANSPIRATION DATA

FOR FOUR CONSTRUCTED WETLAND BEDS AT TOMPKINS COUNTY MUNICIPAL

SOLID-WASTE LANDFILL, JUNE 1990 THROUGH OCTOBER 1991

**Appendix C. Inflow, Outflow, Precipitation, and Evapotranspiration Data for
Bed I.**

DATE	TIME	INFLOW BED#1 (gallons)	Δ IN (gallons)	OUTFLOW BED #1 (gallons)	Δ OUT (gallons)	PRECIP FOR PERIOD (gallons)	ET (IN-OUT)Δ + PRECIP (gallons)
7/13/90	1355	9533	0	24389	0	0	0
7/27/90	1530	21113	11580	32530	8141	1797	5236
8/9/90	ave.	25764	4651	37078	4548	1913	2016
8/23/90	1400	29540	3776	41893	4815	1768	729
9/20/90	1300	47670	18130	54831	12938	3392	8584
10/5/90	1410	49718	2048	63260	8429	1952	-4429
10/9/90	945	50570	852	64885	1625	29	-744
TOTAL			41037		40496	10851	11392
10/17/90	1410	53415	2845	80200	15315	2398	-10072
10/31/90†		81646	28231	102611	22411	3471	9291
11/16/90	1210	87051	5405	114286	11675	1886	-4384
11/29/90	1400	95098	8047	118759	4473	667	4241
12/14/90§	1330	98116	3018	123633	4874	1199	-657
3/30/91	845	99172	0	139788	0	0	0
4/12/91	1200	100262	1090	146357	6569	165	-5314
4/30/91		104005	3743	156770	10413	2408	-4262
TOTAL			52379		75730	12194	-11157
5/23/91	900	110733	10471	160291	13934	667	-2796
6/7/91	1215	125190	14457	169629	9338	542	5661
6/20/91	900	129130	3940	173093	3464	1459	1935
7/3/91	1000	133081	3951	175804	2711	29	1269
7/18/91	1135	135644	2563	179900	4096	3913	2380
8/1/91‡	1145	137928	2284	181966	2066	299	517
TOTAL			33923		25196	6909	8966
9/20/91*		159536	0	206856	0	0	0
10/3/91	1225	173789	14253	209726	2870	889	12272
10/17/91		177500	3711	213523	3797	1800	1714
TOTAL			17964		6667	2689	13986

† The inflow readings for 10/31/90 are actually from 11/1/90 (at noon). The tank was empty so at some point it had stopped flowing between the time Jan Surface sampled on 10/31/90 and when Bill Sanford read the meters on 11/1/90.

§ The leachate collection system for the landfill went off line shortly after 12/14/90. The system was repaired and leachate application to the research plots resumed March 30, 1991.

‡ Bill Sanford started fresh water tracer experiments. Leachate was turned off 8/21/91

* Leachate application resumed after Bill Sanford's tracer experiments; Outflow #1 meter reading on 9/20/91 was estimated by Bill Sanford based on his last reading from his drainage experiment ending 9/20/91.

**Appendix C. Inflow, Outflow, Precipitation, and Evapotranspiration Data for
Bed II.**

DATE	TIME	INFLOW BED#2 (gallons)	Δ IN (gallons)	OUTFLOW BED #2 (gallons)	Δ OUT (gallons)	PRECIP FOR PERIOD (gallons)	ET (IN-OUT)Δ + PRECIP (gallons)
7/13/90	1355	5527	0	11056	0	0	0
7/27/90	1530	12297	6770	20432	9376	1797	-809
8/9/90	ave.	14762	2465	23004	2572	1913	1806
8/23/90	1400	22371	7609	30326	7322	1768	2055
9/20/90	1300	40090	17719	44378	14052	3392	7059
10/5/90	1410	44504	4414	52854	8476	1952	-2110
10/9/90	945	47423	2919	55109	2255	29	693
TOTAL			41896		44053	10851	8694
10/17/90	1410	48340	917	61169	6060	2398	-2745
10/31/90†		69727	21387	80347	19178	3471	5680
11/16/90	1210	71774	2047	93421	13074	1886	-9141
11/29/90	1400	81923	10149	105329	11908	667	-1092
12/14/90§	1330	91375	9452	116435	11106	1199	-455
3/30/91	845	91823	0	127760	0	0	0
4/12/91	1200	97369	5546	134974	7214	165	-1503
4/30/91		98629	1260	143498	8524	2408	-4856
TOTAL			50758		77064	12194	-14112
5/23/91	900	106316	8947	150975	16001	667	-6387
6/7/91	1215	121061	14745	163805	12830	542	2457
6/20/91	900	123907	2846	166348	2543	1459	1762
7/3/91	1000	128737	4830	167506	1158	29	3701
7/18/91	1135	131108	2371	171830	4324	3913	1960
8/1/91‡	1145	134689	3581	176510	4680	299	-800
TOTAL			36060		33012	6909	2693
9/20/91*		148188	0	196150	0	0	0
10/3/91	1225	165898	17710	209779	13629	889	4970
10/17/91		172823	6925	217079	7300	1800	1425
TOTAL			24635		20929	2689	6395

† The inflow readings for 10/31/90 are actually from 11/1/90 (at noon). The tank was empty so at some point it had stopped flowing between the time Jan Surface sampled on 10/31/90 and when Bill Sanford read the meters on 11/1/90.

§ The leachate collection system for the landfill went off line shortly after 12/14/90. The system was repaired and leachate application to the research plots resumed March 30, 1991.

‡ Bill Sanford started fresh water tracer experiments. Leachate was turned off 8/21/91

* Leachate application resumed after Bill Sanford's tracer experiments; Outflow #1 meter reading on 9/20/91 was estimated by Bill Sanford based on his last reading from his drainage experiment ending 9/20/91.

**Appendix C. Inflow, Outflow, Precipitation, and Evapotranspiration Data for
Bed III.**

DATE	TIME	INFLOW BED#3 (gallons)	Δ IN (gallons)	OUTFLOW BED #3 (gallons)	Δ OUT (gallons)	PRECIP FOR PERIOD (gallons)	ET (IN-OUT)Δ + PRECIP (gallons)
7/13/90	1355	5708	0	11307	0	0	0
7/27/90	1530	10565	4857	15178	3871	1797	2783
8/9/90	ave.	11666	1101	16442	1264	1913	1750
8/23/90	1400	17246	5580	20810	4368	1768	2980
9/20/90	1300	36338	19092	38653	17843	3392	4641
10/5/90	1410	41424	5086	49319	10666	1952	-3628
10/9/90	945	43416	1992	51133	1814	29	207
TOTAL			37708		39826	10851	8733
10/17/90	1410	47587	4171	71090	19957	2398	-13388
10/31/90†		65916	18329	106581	35491	3471	-13691
11/16/90	1210	69749	3833	119624	13043	1886	-7324
11/29/90	1400	78314	8565	131899	12275	667	-3043
12/14/90§	1330	97043	18729	156516	24617	1199	-4689
3/30/91	845	97562	0	163364	0	0	0
4/12/91	1200	98392	830	166009	2645	165	-1650
4/30/91		101199	2807	174270	8261	2408	-3046
TOTAL			57264		116289	12194	-46831
5/23/91	900	106499	8107	180091	14082	667	-5308
6/7/91	1215	118430	11931	191903	11812	542	661
6/20/91	900	122236	3806	196715	4812	1459	453
7/3/91	1000	125879	3643	198531	1816	29	1856
7/18/91	1135	126664	785	200569	2038	3913	2660
8/1/91‡	1145	128359	1695	203840	3271	299	-1277
TOTAL			27160		29570	6909	-955
9/20/91*		148435	0	231539	0	0	0
10/3/91	1225	165185	16750	243169	11630	889	6009
10/17/91		167731	2546	248329	5160	1800	-814
TOTAL			19296		16790	2689	5195

† The inflow readings for 10/31/90 are actually from 11/1/90 (at noon). The tank was empty so at some point it had stopped flowing between the time Jan Surface sampled on 10/31/90 and when Bill Sanford read the meters on 11/1/90.

§ The leachate collection system for the landfill went off line shortly after 12/14/90. The system was repaired and leachate application to the research plots resumed March 30, 1991.

‡ Bill Sanford started fresh water tracer experiments. Leachate was turned off 8/21/91

* Leachate application resumed after Bill Sanford's tracer experiments; Outflow #1 meter reading on 9/20/91 was estimated by Bill Sanford based on his last reading from his drainage experiment ending 9/20/91.

**Appendix C. Inflow, Outflow, Precipitation, and Evapotranspiration Data for
Bed IV.**

DATE	TIME	INFLOW BED#4 (gallons)	Δ IN (gallons)	OUTFLOW BED #4 (gallons)	Δ OUT (gallons)	PRECIP FOR PERIOD (gallons)	ET (IN-OUT)Δ + PRECIP (gallons)
7/13/90	1355	19444	0	20147	0	0	0
7/27/90	1530	27006	7562	24723	4576	1797	4783
8/9/90	ave.	29570	2564	28006	3283	1913	1194
8/23/90	1400	34555	4985	33693	5687	1768	1066
9/20/90	1300	37623	3068	39697	6004	3392	456
10/5/90	1410	41393	3770	43766	4069	1952	1653
10/9/90	945	42275	882	44805	1039	29	-128
TOTAL			22831		24658	10851	9024
10/17/90	1410	45920	3645	51692	6887	2398	-844
10/31/90†		77672	31752	78067	26375	3471	8848
11/16/90	1210	80414	2742	87401	9334	1886	-4706
11/29/90	1400	89566	9152	91767	4366	667	5453
12/14/90§	1330	96544	6978	101185	9418	1199	-1241
3/30/91	845	99481	0	118687	0	0	0
4/12/91	1200	100411	930	122101	3414	165	-2319
4/30/91		106669	6258	138870	16769	2408	-8103
TOTAL			61457		76563	12194	-2912
5/23/91	900	112079	11668	145677	23576	667	-11241
6/7/91	1215	130338	18259	163084	17407	542	1394
6/20/91	900	133772	3434	167361	4277	1459	616
7/3/91	1000	136609	2837	169962	2601	29	265
7/18/91	1135	138443	1834	170019	57	3913	5690
8/1/91‡	1145	140615	2172	174974	4955	299	-2484
TOTAL			33946		36104	6909	-5760
9/20/91*		164295	0	203474	0	0	0
10/3/91	1225	174139	9844	208279	4805	889	5928
10/17/91		182961	8822	215716	7437	1800	3185
TOTAL			18666		12242	2689	9113

† The inflow readings for 10/31/90 are actually from 11/1/90 (at noon). The tank was empty so at some point it had stopped flowing between the time Jan Surface sampled on 10/31/90 and when Bill Sanford read the meters on 11/1/90.

§ The leachate collection system for the landfill went off line shortly after 12/14/90. The system was repaired and leachate application to the research plots resumed March 30, 1991.

‡ Bill Sanford started fresh water tracer experiments. Leachate was turned off 8/21/91

* Leachate application resumed after Bill Sanford's tracer experiments; Outflow #1 meter reading on 9/20/91 was estimated by Bill Sanford based on his last reading from his drainage experiment ending 9/20/91.

APPENDIX D
CALCULATIONS FOR LEACHATE GENERATION AT
TOMPKINS COUNTY MUNICIPAL SOLID-WASTE LANDFILL
AND ENERGY USAGE FOR CONVENTIONAL LEACHATE TREATMENT

Appendix D. Tompkins County Municipal Solid-Waste Landfill Leachate Generation Calculation

Method taken from the following two sources:

D.G. Fenn, K.J. Hanley, and T.V. DeGeare. The Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites. U.S.EPA/530/SW-168. Cincinnati, Ohio: 1975.

(Previously published in part in C.W. Thornthwaite and J.R. Mather. Instructions and tables for computing potential evapotranspiration and the water table. Publications in Climatology, 10(3):185-290. 1957)

I. Amount of Percolation into Landfill

	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>	<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>
Temp (°F)	21.5	22.6	32.9	44.0	55.0	63.9	68.6	66.9	59.8	49.0	39.2	27.6
i	0.00	0.00	0.03	1.54	4.14	6.79	8.37	7.78	5.52	2.62	0.71	0.00
UPET	0.00	0.00	0.00	0.04	0.08	0.11	0.13	0.13	0.10	0.06	0.02	0.00
r	24.6	24.6	30.9	33.6	37.8	38.1	38.4	35.7	31.2	28.5	24.6	23.7
PET	0.00	0.00	0.00	1.34	3.02	4.19	4.99	4.64	3.12	1.71	0.49	0.00
Precip (in.)	1.82	2.00	2.27	2.91	3.31	3.77	3.45	3.44	3.53	3.25	3.08	2.57
C r/o	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
R/O	0.33	0.36	0.41	0.52	0.60	0.68	0.62	0.62	0.64	0.58	0.55	0.46
I	1.49	1.64	1.86	2.39	2.71	3.09	2.83	2.82	2.89	2.67	2.53	2.11
I-PET	1.49	1.64	1.86	1.05	-0.31	-1.10	-2.16	-1.82	-0.23	0.96	2.04	2.11
ACCWL	0.00	0.00	0.00	0.00	-0.31	-1.41	-3.57	-5.39	-5.62	0.00	0.00	0.00
ST	8.00	8.00	8.00	8.00	7.69	6.70	5.11	4.06	3.95	4.91	6.95	8.00
Δ ST	0.00	0.00	0.00	0.00	-0.31	-0.99	-1.59	-1.05	-0.11	0.96	2.04	2.11
AET	0.00	0.00	0.00	1.34	3.02	4.08	4.42	3.87	3.00	1.71	0.49	0.00
PERC (in.)	1.49	1.64	1.86	1.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$\Sigma (\text{PERC}) = 6.04 \text{ inches}$$

Where: Temp=temperature; i=monthly heat index; UPET=unadjusted potential evapotranspiration; r=monthly correction factor for sunlight duration; PET=adjusted potential evapotranspiration; Precip=monthly precipitation; C r/o=runoff coefficient; R/O=monthly runoff; I=monthly infiltration; ACCWL=accumulative water loss; ST=monthly soil moisture storage; Δ ST=change in monthly soil moisture storage; AET=actual evapotranspiration; and PERC=percolation.

Givens

1. Latitude is 42°20"
2. Precipitation and temperature data are from Ithaca Cornell University Station, NOAA

Assumed parameters

1. C r/o = 0.18, Heavy soil, grass cover, 2-7 percent side slopes.
2. Initial Storage = 8.00 inches.

II. Volume of Leachate generated annually

Landfill Surface Area = 21.5 hectares (53 acres)

Percolation into landfill is 6.04 inches annually (from Fenn and others, 1975 method)

$$53 \text{ acres} \times 43,560 \text{ ft}^2/\text{acre} \times 6.04 \text{ in} \times 1 \text{ ft}/12 \text{ in} = 1,162,000 \text{ ft}^3 \text{ leachate/year} \\ (8,692,000 \text{ gal})$$

III. Annual BOD load calculation

mean BOD of untreated leachate = 185 mg/l

$$185 \text{ mg/l} \times 8,692,000 \text{ gal} \times 1 \text{ kg}/1,000,000 \text{ mg} \times 2.2 \text{ lb/kg} \times 3.785 \text{ l/gal} \\ = 13,390 \text{ lb/year BOD}$$

IV. Energy Required to Treat Wastewater Using Conventional Activated Sludge Process

Specific Energy

$$1.1 \text{ kWh/lb BOD} \\ \times 13,390 \text{ lb/year BOD} \\ = 14,729 \text{ kWh/year}$$

Miscellaneous Energy

$$50 \text{ kWh/mgal leachate} \\ \times 8.7 \text{ mgal/year} \\ = 435 \text{ kWh/year}$$

$$\text{Total} = 15,164 \text{ kWh/year}$$

V. Trucking Energy to Haul Leachate to Treatment Plant

Assume use of a 10,000-gallon truck

$$(8,692,000 \text{ gal/year}) / (10,000 \text{ gal/trip}) = 869 \text{ trips}$$

Assume 40 mi round trip and 8 mi/gal fuel consumption

$$5 \text{ gal/trip} \times 869 \text{ trips} = 4,345 \text{ gal/year diesel fuel}$$

VI. Drying Sludge

Percent solids in untreated leachate.

Mean Specific Conductance = 6,640 $\mu\text{S}/\text{cm}$

Total Dissolved Solids (TDS) in mg/l $\sim 0.66 \times (\text{Specific Conductance})$

$$\text{TDS} = 6,640 \times 0.66 = 4,380 \text{ mg/l} (\sim 4,380 \text{ ppm})$$

$$4,380 \text{ ppm} = 0.44 \text{ percent solids}$$

Volume of sludge generated in final (treated) leachate assuming sludge of 20 percent solids.

original volume of leachate = 8,692,000 gal @ 0.44 percent solids

$\frac{0.0044}{0.20} = 2.2$ percent reduction in volume

8,692,000 gal untreated leachate x 0.022 = 191,200 gal wet sludge

Energy to dry sludge

To dry 1 ton of wet sludge @ 20 percent solids (400 lbs dry solids and 1,600 lbs water) to 95 percent solids (421 lbs total dry sludge) requires removing 1,579 lbs of water

Energy required to:

Raise temperature from 60°F to 212°F = 152 Btu/lb

Evaporate water @ 212°F = 1,122 Btu/lb

8.34 lb/gal x 191,200 gal = 1,595,000 lbs sludge to be dried per year

$\frac{1,579 \text{ lbs to evaporate}}{2,000 \text{ lbs to treat}} \times 1,595,000 \text{ lbs sludge/year} = 1,259,253 \text{ lbs/year}$

1,259,253 lbs/year x 1,122 Btu/lb = 1.4×10^9 Btu/year to dry sludge

VII. Energy used to treat dried sludge using land application

1,595,000 lb sludge/year x 421 lbs/2000 lbs wet sludge = 335,748 lbs to land apply

Energy required for land application is 250 Btu/lb

335,748 lbs x 250 Btu/lb = 8.4×10^7 Btu/year land application

VIII. Hauling dried sludge to land application site

$\frac{335,748 \text{ lbs to haul}}{8.34 \text{ lbs/gal}} = 40,258$ gal to haul

40,258 gal / 10,000 gal per trip = 4 trips/year

5 gal fuel X 4 trips = 20 gal diesel fuel/year

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