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# Efficiency of a Subsurface Constructed Wetland System Using Native Southwestern U.S. Plants

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Abstract

A small-scale 3-cell (in series) subsurface (SSF) constructed wetland that used 16 previously untested native Arizona plants was found to be effective in the treatment of secondary waste at high elevation (2350 m) in Northern Arizona. Fifteen of the 16 plant species survived in at least one of the cells in the system. Plant survival was dependent on their position in the cells, with increased survival rates downstream from the effluent input to cell 1, on water depth, and on individual species selection. The wetland was effective in removing both chemical pollutants (total kjeldahl nitrogen, ammonia, nitrate, total kjeldahl phosphorus and phosphate) and bacteriological indicator organisms of human pathogens (total coliforms and fecal coliforms). The fecal coliform counts of the effluent exiting the third cell were below the recreational full-body contact (swimming) standard (200 cfu/100 ml) in 14 out of the 15 months of operation. The total Kjeldahl nitrogen and total phosphorus concentrations were reduced by 84% and 73%, respectively compared to nutrients entering the system. The loss of nitrogen suggests that a combined nitrification/denitrification process is active in the wetland. However, after 9 months of operation, nitrate levels began to increase beyond the target of 1 mg/L indicating that nitrification rates are exceeding denitrification rates and that the wetland cells are aerobic. The constructed wetland system effectively conserves water. Because it is used to irrigate plantings near the constructed wetland, the nutrient concentrations in the effluent aid plant growth.

## Introduction

Subsurface (SSF) constructed wetlands are achieving more widespread use for control of nonpoint source pollution (Wolf *et al.*, 1986; Kadlec and Knight, 1996), yet because the technology is still relatively new, its application and efficiency at small scales have not been widely investigated under diverse climatic regimes. High elevation systems pose problems in particular, because system designs and plants used in the system must tolerate freezing temperatures. As of 1992, when the Environmental Protection Agency inventoried the operating constructed wetlands in the United States, there was no consensus guiding design, system configuration, water or media depths, length to width ratio, level of pretreatment, or type of vegetation used in constructed wetlands (Brown and Reed, 1994). Hence, there is a need for data demonstrating the efficiency of wetlands under various conditions.

Among the many factors that control efficiency of wetlands for nutrient and bacteria removal is vegetation type (Hammer, 1989). Wetland plants have species-specific efficiencies regarding their abilities to aerate water (Stengel, 1993), grow within the constraints of the artificial cells (Adcock and Ganf 1994), uptake heavy metals (Taylor and Crowder, 1983), and uptake nutrients (e.g., Lakshman, 1979; Gersberg *et al.*, 1986; Bavor and Andel, 1994; House *et al.*, 1994).

Despite the fact that other plant species have been identified for potential use in wetlands, a survey conducted by Brown and Reed (1994) indicated that 49% of SSF systems in the U.S. have used only bulrush (*Scirpus* sp.), while one-third of free water surface (FWS) systems have used only cattails (*Typha* sp.). Because some species, such as *Scirpus* ,*Typha,* and water hyacinth (*Eichhornia crassipes),* which have been well-documented for use in constructed wetlands are not present in all waterways, their use is discouraged to prevent escape to riparian areas where they are naturally absent and may become noxious weeds (Guntenspergen *et al.*, 1989; Chambers and McComb, 1994). To counter this problem, plants native to the vicinity of constructed wetlands are being promoted for use. For example, 70 Arizona native plant species have been identified for potential use in wetlands (Knight *et al.*, 1995). Yet because there has been little documentation of the feasibility and effectiveness of using native plants in all regions of the country, there is a need for further research.

The goal of this study was to examine the efficiency for nutrient, total coliform and fecal coliform reduction of a subsurface constructed wetland system using native plants of the high elevation southwest.

We specifically addressed these questions: 1) Will a constructed wetland system efficiently function to remove bacterial and nutrients from domestic wastewater in a high elevation setting where diurnal temperatures fluctuate and winter temperatures are cold? 2) Does the wetland design maximize plant survival? 3) Will 16 previously untested high elevation meadow species survive in the SSF constructed wetlands?

## Methods

We conducted this study in the constructed wetlands at The Arboretum at Flagstaff, 8 km from Flagstaff, Arizona at an elevation of 2350m. Over 11,000 people visit the arboretum annually; 75% of the visitation comes in the months of May through October. The constructed wetlands serving this population consisted of 3 cells (12.2 m X 5.4 m X 1m, Fig. 1) lined with impermeable plastic polyvinyl chloride 0.08 cm mesh liner and layered with 14 cm fine (0.5 – 1.0 cm) and 28 cm coarse (7 – 10 cm) gravel. Wastewater enters each cell through triton-shaped pipes extending 3 m into each cell. Spaced at 0.5, 6.7, and 11.5 m intervals within each cell are collection pipes that may serve to aerate the system. Wastewater from the Arboretum grounds traveled to a settling septic tank before it was pumped to the wetlands. From Dec. 1, 1995 through Feb. 31, 1996, wastewater flowed through the first cell only, because construction on the second two cells was not completed. Upon completion of cells 2 and 3 in Mar. 1996, wastewater flowed through cells 1, 2, and 3 sequentially.

Freezing temperatures disrupted the operation of the system during this study, because effluent exited the system through a drip irrigation line that was only buried 40 cm below ground level. When temperatures were $\leq -2^{\circ}C$, effluent froze in the irrigation line preventing outflow. Resident wastewater remained in the system until water in the outflow lines thawed. In Flagstaff, nighttime freezing temperatures ($\leq -2^{\circ}C$) can occur from Oct. through June, however, daytime temperatures typically rise above $0^{\circ}C$. We operated the system for as many hours per day as feasible. From Dec. 24, 1996 through Feb. 15, 1997, we shut down the system completely, because daytime temperatures did not rise above $0^{\circ}C$ and there was no way to flush water from the system. Periodically, throughout Oct. to June outflow was disrupted. Thus, we were unable to sample in April 1996 and January 1997.

Ideally wetlands should be designed as natural integrated systems with diverse and heterogenous flora (Moshiri, 1993). To mimic natural wetlands, we planted native emergent wetland

species into the gravel of each cell. We collected all species from high elevation wet meadows that experience saturated soils for much of the year and climatic variation similar to Flagstaff, i.e., diurnal shifts in temperature $\geq 10^{o}C$ sometimes from freezing temperatures to well above freezing. The number of plants of a given species planted in each of the 3 cells varied (Table 1) and the planting pattern was random, such that species were scattered along the entire length of the cell. We planted Cell 1 in Oct. 1995 before the system received wastewater, whereas we planted cells 2 & 3 in June 1996 after wastewater had flowed through the system for 10 weeks. We delayed planting cells 2 & 3, because their construction was not completed until March 1996 and nighttime temperatures did not rise above freezing until June. We assessed plant survival through Oct. 1996 before dormancy occurred.

We examined differences in plant survival using regression analysis to determine whether plant survival depended on position within the constructed wetlands. We measured plant survival along 60 rows spaced 30-40 cm along the 3 cells; each cell had 20 rows. The first position closest to the input was assigned the number 1, whereas the last position closest to the exit was row 60.

Monthly from Dec.1995 through Feb.1997, we collected water samples (Protocol 9060 A; APHA, 1989) from the transfer boxes at the input to cell 1 and from the exit boxes of cells 1, 2 and 3, preserved and stored them for analysis (Protocol 9060 B; APHA, 1989). We filtered samples (0.45µm filter) in the field for nitrate ($(NO_3^- + NO_2^-) - N$), ammonia ($NH_3$ - N), and ortho-phosphate ($PO_4^{3-}$ - P) analysis and acidified them with sulfuric acid. We also collected triplicate, unfiltered water samples for Kjeldahl digestion to determine total Kjeldahl nitrogen (TKN) and total Kjeldahl phosphorus (TP) concentrations (U.S. EPA, 1979). The reaction for total Kjeldahl nitrogen recovers only amine-based N; inorganic nitrates and nitrites are not measured in TKN. We stored all samples at 4°C until analyzed (within 28 days). We employed standard colorimetric methods to analyze ($(NO_3^- + NO_2^-)$ - N (copper-cadmium reduction), $NH_3$ - N (alkaline phenol and hypochlorite reaction) and $PO_4^{3-}$ -P (antimony-phospho-molybdate reduction in the presence of ascorbic acid, U.S. EPA, 1979).

To examine processes contributing to nutrient removals, we calculated a nitrogen mass balance by multiplying TKN and TP levels by hydrological loading. We estimated hydrologic loading into the SSF wetland by adding 19L/day/visitor and 76L/day/employee (figures provided by Arboretum facilities management). We calculated outflow by subtracting evapotranspiration rates previously measured for

grasses at The Arboretum at Flagstaff (Albrecht, 1993) from inflow plus precipitation.

We enumerated total coliforms (TC) using the Standard Total Coliform Membrane Filter Procedure (APHA, 1989; 9222B) and fecal coliforms (FC) using the Fecal Coliform Membrane Filtration Procedure (Protocol 9222 D.; APHA, 1989).

We analyzed these data using a nested analysis of variance on each of the 5 nutrients measured, TC, and FC, where sampling point was the nested factor and time was the main effect. TC and FC counts were log transformed before analysis. The analysis for Dec. 1995 through Feb. 1996 when wastewater flowed through only cell 1 was separate from the Mar. 1996 through Feb.1997 analysis when wastewater flowed through the three cells sequentially. All p values we report reflect Bonferroni adjustment for multiple tests on experimental samples.

To determine whether there was a relationship between weather and visitation at the arboretum and nutrient and bacteria levels, we performed Pearson correlation analyses between precipitation and FC and $PO_4^{3-}$ and between visitation and FC and $PO_4^{3-}$.

## Results

### Native Plant Survival

Position within the system accounted for 57% of the variation in native plant survival ($F = 79.49$, $p < 0.0001$). Plants at the input ends of the cell tended to have greater mortality than those at the output ends of the cells, and those in cells 2 and 3 had far greater survival than those in cell 1.

Native plant survival also varied with species and planting cell. Fifteen of the 16 species tested survived through October 1996 in at least one of the three cells, whereas one species did not survive the test planting in cell 1 (Table 1). The greatest mortality occurred in cell 1; survival did not exceed 37.5% for any of the nine species planted and one species suffered complete failure. In contrast, survival in cells 2 and 3 was markedly higher; 7 of 14 species had survival > 60% in cell 2, and 9 of 13 species had survival > 60% in cell 3.

### Nutrients

Water quality tests indicated that most nutrient levels were significantly reduced, but the

magnitude of reduction depended upon cell and month sampled. Mean nitrogen (TKN) was significantly reduced by 67-99% from input to exit from cell 3 (Dec-Feb $F = 2267$, $p < 0.0001$; Mar-Feb $F = 7552$, $p < 0.0001$, Fig. 2) and ammonium was reduced by 59-99.8% (Dec.-Feb. $F = 13496$, $p < 0.0001$; Mar.- Feb. $F= 4654$, $p < 0.0001$, Fig. 2). Mean phosphorus (TP) was reduced by 38-97% from input to exit from cell 3 (Dec.-Feb. $F = 885$, $p < 0.0001$; Mar.-Feb. $F = 2633$, $p < 0.0001$, Table 2, Fig. 3) and phosphate was reduced by 29-99.8% (Dec-Feb $F = 2360$, $p < 0.0001$; Mar.-Feb. $F = 1399$, $p < 0.0001$, Fig. 3). Ammonia concentrations accounted for essentially all TKN in most input samples (86-100%, Fig. 2), while $PO_4^{3-}$-P accounted for most of the measured TP (69-100%, Fig 3). There were significant reductions in nutrients from cell 1 to cell 2 and from cell 2 to cell 3.

While nutrient levels dropped as wastewater passed through the cells, nitrate levels significantly increased as the system was operational for a longer period of time. There were no significant differences in incoming or exiting ($NO_3^-$ + $NO_2^-$)-N in the first 3 months of operation (Dec-Feb $F = 11.61$, $p > 0.05$). Input and output numbers were very close to zero. However, ($NO_3^-$ + $NO_2^-$)-N exiting the system climbed to a peak in October 1996 (Mar-Feb $F= 122.64$, $p < 0.0001$, Fig. 2). Ammonia levels decreased as nitrate levels increased, indicating that ammonia was converted to nitrate, but nitrate was not completely assimilated or denitrified before exiting the system.

The mass balance for 1996 (Table 2) indicated that nitrogen and phosphorus removal from the SSF wetland decreased when flow exceeded 50,000 L/month, containing a corresponding increase in waste flow entering the system. The number of visitors and employees using the system had the greatest direct influence on flow through the SSF wetland and inverse influence on retention time. Therefore, high visitation in June and July probably contributed to greater coliform counts (discussed below) and higher concentrations of TKN, ammonia, TKP and phosphate although no correlations were significant.

Bacteria

The constructed wetlands significantly reduced the TC and FC counts > 99% in all months (TC $F = 1080$, $p < 0.0001$, Table 3; Dec.-Feb. $F= 141$, $p < 0.0001$; Mar.-Feb. FC $F = 855$, $p < 0.0001$, Table 4). The FC bacterial levels exiting the SSF wetland were below the recreational full-body contact (swimming) standard (< 200 FC/100 mL; Mueller, 1984) in all months except July 1996.

## Discussion

Our results indicate that the small-scale SSF constructed wetland system at The Arboretum at Flagstaff is significantly reducing TKN, $NH_3$, TKP, $PO_4^{3-}$, TC and FC levels. Even under winter conditions when the system was frozen at night, nutrient and bacteria levels were reduced. The low ammonium levels in the effluent indicate the system was effectively converting ammonia to nitrate and that oxygen was not limited in the first 15 months of operation. This differs from most other studied SSF systems that have not always effectively oxidized ammonia (Brown and Reed, 1994; Hammer and Knight, 1994; but see House *et al.*, 1994) due to oxygen limitation (Urbanc-Bercic, 1994). Compared to nitrification, denitrification is less efficient in our system. Nitrate exiting the system increased during fall 1996 after approximately one year of operation. Ideally, nitrate levels exiting the system should not exceed 1 mg/L. The comparatively higher nitrate levels observed in this SSF constructed wetland system may be the result of a low organic carbon supply and/or a relative lack of anaerobic microenvironments provided by biofilms growing on the sediment matrix - a condition known in young systems (Hammer and Knight, 1994). Peak performance of wetland treatment systems should not be expected for two to three growing seasons after the system has matured and a complex biofilm of nitrifying and denitrifying bacteria has been established (Bastian and Hammer, 1993).

The mass balance equation indicated that the most important process contributing to nitrogen removal in the SSF wetland system was bacterial nitrification/denitrification. In other systems, aboveground nitrogen removal as biomass has been reported between 150-200 mg N/$m^2$/yr (Gersberg *et al.*, 1983) and 27-190 mg N/ $m^2$/day (Stephenson *et al.*, 1980). Annual uptake of N varied between herbaceous species (20.8 g/ $m^2$/yr) and woody species (3.0 g/$m^2$/yr N, Johnston, 1993) and the presence of vegetation increased the efficiency of ammonia removal (Gilbert *et al.*, 1986). For example, Gersberg *et al.* (1986) found that the presence of reeds and bulrushes in wetland beds increased ammonia removal efficiency by 67-83% compared to beds without vegetation, however N removal was attributed primarily to sequential nitrification-denitrification, rather than absorption. Based on Johnston's (1993) estimate of 20.8 g N assimilated per $m^2$ herbaceous plant cover, bacterial nitrification/denitrification accounted for ≥ 95% of nitrogen removal from the SSF wetland examined in this study. Current pH levels are close to neutral indicating that significant losses of $NH_3$ through volatilization would not be expected. Thus,

denitrification constitutes the largest potential source of N removal from wetlands; 0-134 g/ $m^2$/yr (Johnston 1993) and 372 g/$m^2$/yr (this study).

TKP and $PO_4^{3-}$ removal was significant and adequate in all months, except July and September 1996. Increased summer input due to high visitation and monsoon precipitation, which decreased retention time, may have been responsible for these pulses that exceeded the capacity of the system. In comparison to our system, House *et al.* (1994) had more efficient P removal in a mound component of an upland-wetland designed for a single family home, but their system removed N less efficiently than our system. The documented effectiveness of wetlands has been very site specific (Hammer, 1989).

The SSF constructed wetland system not only efficiently cleansed wastewater at The Arboretum at Flagstaff, but it provided a feasible method for reclaiming water for use on plantings in the vicinity. The low levels of nitrate and phosphate remaining in the effluent serve as a nutrient source that promotes plant growth (e.g., Butler et al., 1993). This reclaimed water saves approximately $60/month at our site. Nutrients within the effluent save approximately $10/month in fertilizer costs. In the arid southwest, constructed wetlands can be a useful mechanism for water conservation.

Overall the SSF constructed wetlands efficiently removed nutrients and bacteria from wastewater, however some problems exist. These problems can be alleviated through changes in management and future construction. When excess input to the system can be predicted (i.e., when visitation or precipitation is high) it is possible to adjust inflow to the system so that system capacity is not exceeded. For example, inflow can be shunted to a leach field if visitation exceeds 700 people in a single day. If visitation continues to rise, the system may need to be expanded to accommodate higher input. Expansion of the system to a fourth cell would allow the wetland to be fully functional throughout the year, because the fourth cell could store winter outflow from the first three cells.

Acknowledgments

We wish to thank Christine Crabill and Ravin Donald for invaluable assistance with TC and FC tests, Tom Huntsberger of the Analytical Chemistry Lab at Bilby Research Center, Northern Arizona University for performing the chemical analyses, Dave Robbins of Environmental Consultants International for advice during the design phase of construction, Jan Busco and Tara Bymoen for propagating the plants used in this study, Dr. R.D. DeLaune, Joseph S. Meyer and an anonymous reviewer for helpful comments on the manuscript, and to the following crew for assisting with planting the wetlands: W. Albrecht, T. Bymoen, C. Casey, B. Dunevitz, M. Gibson, S. Irwin, K. Kesler, P. Lee, G. Morris, C. O'Brien, M. Parliman, G. Schmittle, C. Stallings, D & S. Verity, D. Walters, and D. Williams. Funding for the constructed wetlands was provided by the Arizona Department of Environmental Quality and the Environmental Protection Agency through 319h Matching Grants. The wetland system was designed by WFM Engineering.

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Figure 1. Design of the SF Constructed Wetlands at The Arboretum at Flagstaff

Figure 2. Total Kjeldahl nitrogen, ammonium, and nitrate entering and exiting the constructed wetlands from December 1995 through February 1997.

Figure 3. Total Kjeldahl Phosphorus and Phosphate entering and exiting the constructed wetlands from December 1995 through February 1997.

Table 1. The total number of individuals planted, the number surviving to October 1996, and the percentage survival of native species in the SF Constructed Wetlands at The Arboretum at Flagstaff.

| Species | Cell 1 #Planted | Survival (%) | Cell 2 #Planted | Survival (%) | Cell 3 #Planted | Survival (%) |
|---|---|---|---|---|---|---|
| *Salix arizonica* | 25 | 32 | 38 | 79 | 41 | 56 |
| *Mimulus cardinalis* | * | | 39 | 15 | 25 | 12 |
| *Hypericum formosum* | 38 | 10.5 | 8 | 12.5 | 8 | 25 |
| *Sidalcea neomexicana* | 39 | 18 | * | | 7 | 86 |
| *Dugaldia (Helenium) hoopseii* | 40 | 22.5 | 16 | 75 | 17 | 65 |
| *Lobelia cardinalis* | * | | 16 | 25 | 21 | 24 |
| *Achillea millifolium* | * | | 6 | 83 | 10 | 70 |
| *Carex subfusca* | 40 | 25 | 58 | 60 | 60 | 63 |
| *Carex scoparia* | 40 | 37.5 | 34 | 71 | 35 | 77 |
| *Carex ebenea* | * | | 9 | 44 | 10 | 60 |
| *Agastache pallidiflora* | * | | 19 | 58 | 21 | 76 |
| *Viola adunca* | 39 | 0 | 15 | 20 | * | |
| *Ranunculus macounii* | * | | 3 | 100 | * | |
| *Geranium fremontii* | * | | 7 | 43 | 7 | 71 |
| *Iris missouriensis* | 40 | 0 | * | | * | |
| *Potentilla diversifolia* | * | | 11 | 82 | 13 | 77 |

- Not planted in cell.

Table 2. Hydrological and chemical mass balance of the SSF wetlands from Dec. 1995 - Dec. 1996.

**Hydrological analysis**

| Date | Visitor flow (L) | Empl. flow (L) | Flow in (L)[1] | Ppt.-flow (L) | ET (L) | Flow out (L)[2] |
|---|---|---|---|---|---|---|
| Dec-95 | 9500 | 16492 | 25992 | 314 | 0 | 26306 |
| Jan-96 | 0 | 18848 | 18848 | 248 | 0 | 19096 |
| Feb-96 | 3002 | 19836 | 22838 | 1439 | 1918 | 22358 |
| Mar-96 | 11134 | 21204 | 32338 | 1240 | 6152 | 27426 |
| May-96 | 23712 | 23560 | 47272 | 0 | 12714 | 34558 |
| Jun-96 | 50806 | 41040 | 91846 | 17 | 14884 | 76979 |
| Jul-96 | 52573 | 42408 | 94981 | 4283 | 12304 | 86960 |
| Aug-96 | 28139 | 42408 | 70547 | 2216 | 10253 | 62510 |
| Sep-96 | 20121 | 22800 | 42921 | 9708 | 7938 | 44691 |
| Oct-96 | 14611 | 23560 | 38171 | 1935 | 6767 | 33339 |
| Nov-96 | 2052 | 22800 | 24852 | 3837 | 1985 | 26704 |
| Dec-96 | 7828 | 21204 | 29032 | 1555 | 0 | 30587 |

**Chemical Analysis**

| Date | TKN in (g) | TKN out (g) | % N removal | TP in (g) | P out (g) | % P removal |
|---|---|---|---|---|---|---|
| Dec-95 | 1086 | 24 | 98 | 86 | 24 | 72 |
| Jan-96 | 735 | 47 | 94 | 80 | 29 | 63 |
| Feb-96 | 827 | 44 | 95 | 93 | 26 | 72 |
| Mar-96 | 1012 | 18 | 98 | 122 | 8 | 93 |
| May-96 | 2638 | 26 | 99 | 301 | 8 | 97 |
| Jun-96 | 5832 | 520 | 91 | 560 | 156 | 72 |
| Jul-96 | 6896 | 1313 | 81 | 614 | 382 | 38 |
| Aug-96 | 3725 | 1211 | 67 | 472 | 93 | 80 |
| Sep-96 | 2691 | 568 | 79 | 299 | 104 | 65 |
| Oct-96 | 2248 | 320 | 86 | 232 | 17 | 93 |
| Nov-96 | 1402 | 395 | 72 | 166 | 16 | 91 |
| Dec-96 | 1690 | 370 | 78 | 204 | 23 | 89 |

[1]flow in = visitor flow (19 L/visitor x # visitors) + employee flow (76 L/employee x # employees x # days/month)

[2]flow out = flow in + precipitation (ppt) - evapotranspiration (ET)

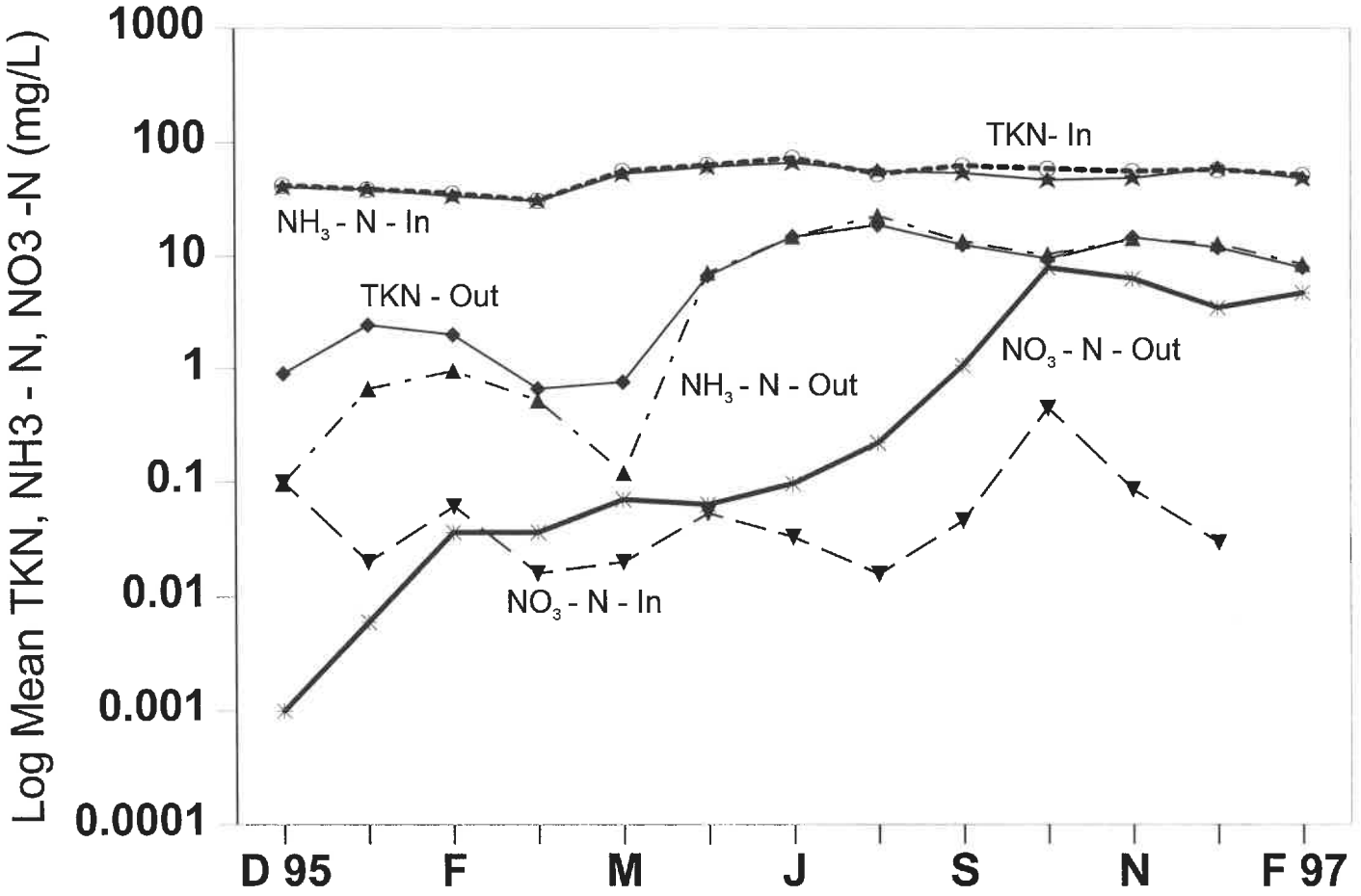
Table 3. Mean Total Coliform Counts (colony forming units/100 ml) sampled monthly at the input and output transfer boxes of the constructed wetlands. Different letters within a row indicate significant differences as determined by orthogonal contrasts. The parentheses contain log mean ± 1 SE. Analysis of variance was performed on log transformed data.

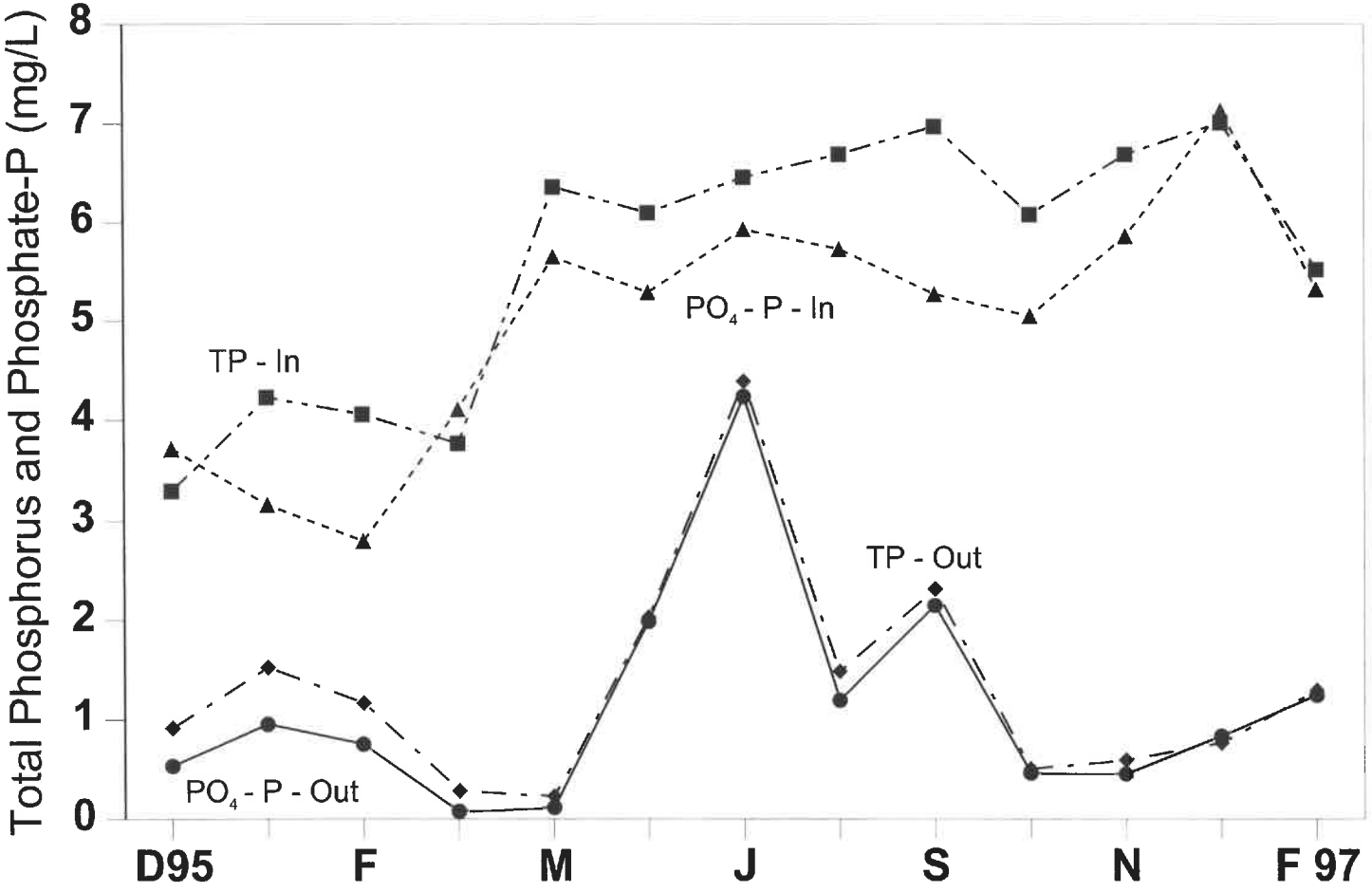
| Date | Input Cell 1 | Output Cell 1 | Output Cell 2 | Output Cell 3 |
|---|---|---|---|---|
| Dec. 1995 | present | present | | |
| Jan. 1996 | 770,000[a] (5.89 ± 0.42) | 2264[b] (3.35 ± 0.42) | | |
| Feb. 1996 | 2,500,000[a] (6.39 ± 0.42) | 763[b] (2.88 ± 0.42) | | |
| Mar. 1996 | 487,000[a] (5.69 ± 0.11) | 1423[b] (3.15 ± 0.11) | *not determined | 1490[b] (3.17 ± 0.11) |
| May 1996 | 4,100,000[a] (6.61 ± 0.11) | 16,800[b] (4.23 ± 0.11) | 280[c] (2.45 ± 0.11) | 2[d] (0.30 ± 0.11) |
| June 1996 | 6,800,000[a] (6.79 ± 0.11) | 230,000[b] (5.21 ± 0.11) | 18,000[c] (4.19 ± 0.11) | 10,100[d] (3.66 ± 0.11) |
| July 1996 | 8,000,000[a] (6.9 ± 0.11) | 170,000[b] (5.23 ± 0.11) | 14,000[c] (4.13 ± 0.11) | 3,500[d] (3.54 ± 0.11) |
| Aug. 1996 | 8,600,000[a] (6.59 ± 0.11) | 63,000[b] (4.79 ± 0.11) | 1916[c] (3.26 ± 0.11) | 1506[cd] (3.14 ± 0.11) |
| Sept. 1996 | 6,700,000[a] (6.82 ± 0.11) | 230,000[b] (5.34 ± 0.11) | 13,000[c] (4.09 ± 0.11) | 3900[d] (3.58 ± 0.11) |
| Oct. 1996 | 2,400,000[a] (6.38 ± 0.11) | 4900[b] (3.67 ± 0.11) | 3100[b] (3.49 ± 0.11) | 578[c] (2.75 ± 0.11) |
| Nov. 1996 | 6,900,000[a] (6.47 ± 0.11) | 9878[b] (3.98 ± 0.11) | *not determined | *not determined |
| Dec. 1996 | 9,300,000[a] (6.63 ± 0.11) | 6100[b] (3.77 ± 0.11) | 2600[c] (3.41 ± 0.11) | 700[d] (2.84 ± 0.11) |
| Jan. 1997 | System Frozen | | | |
| Feb. 1997 | 3,300,000[a] (6.52 ± 0.11) | 14,000[b] (4.11 ± 0.11) | 2400[c] (3.37 ± 0.11) | 280[d] (2.63 ± 0.11) |

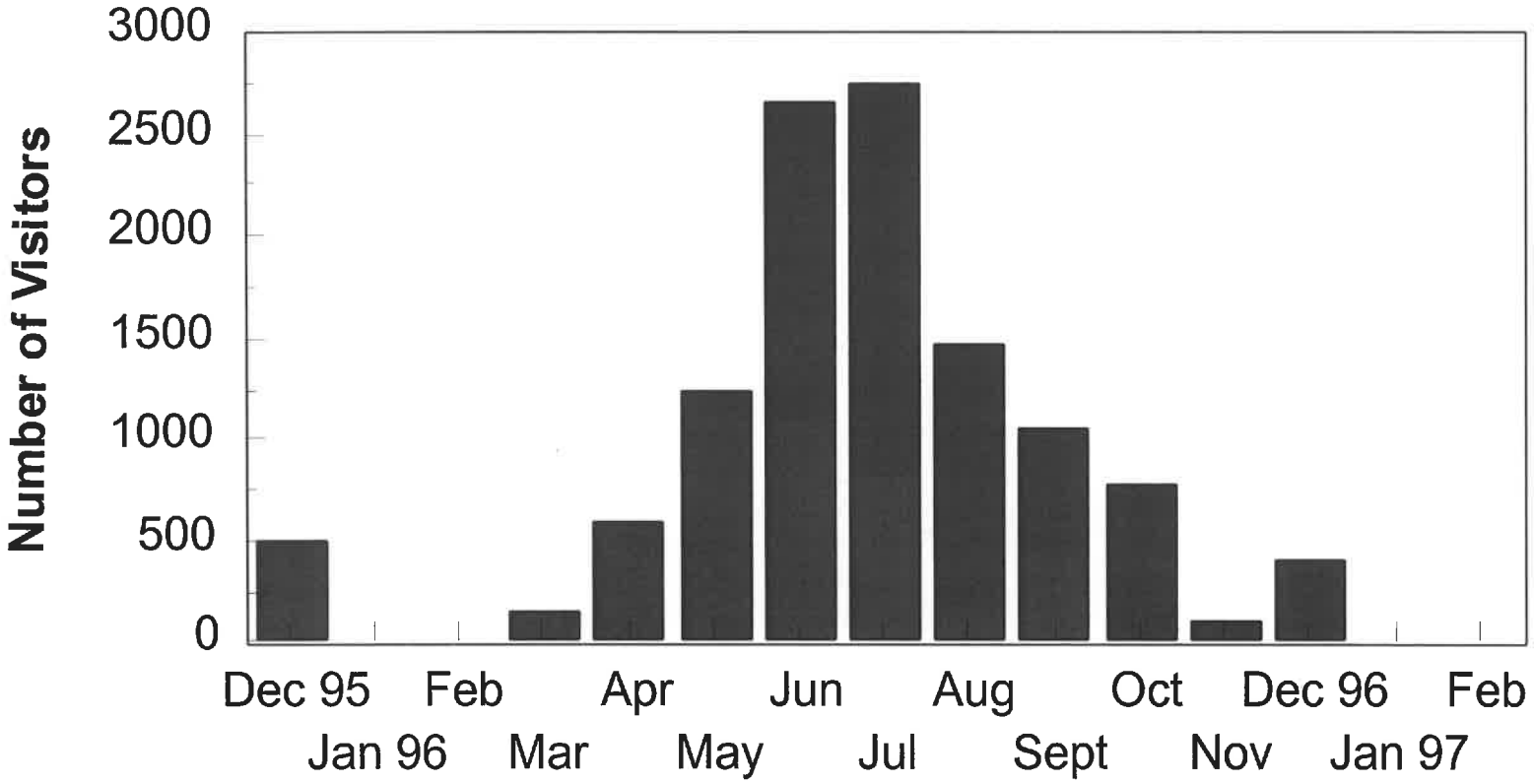
*Contaminated samples.

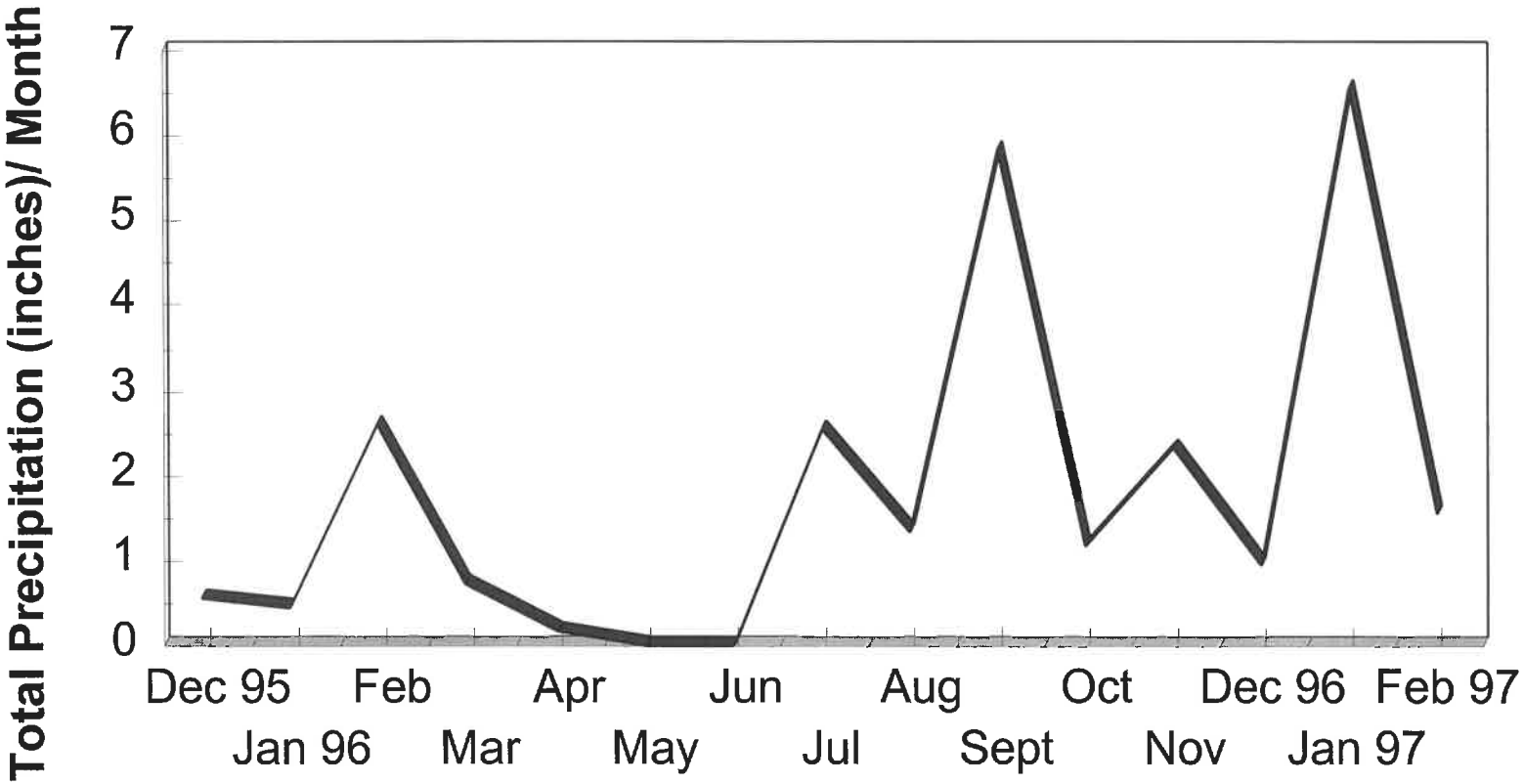
Table 4. Mean Fecal Coliform Counts (colony forming units/100ml) sampled monthly at the input and output transfer boxes of the constructed wetlands. Different letters within a row indicate significant differences. The parentheses contain log mean ± 1 SE. Analysis of variance was performed on log transformed data.

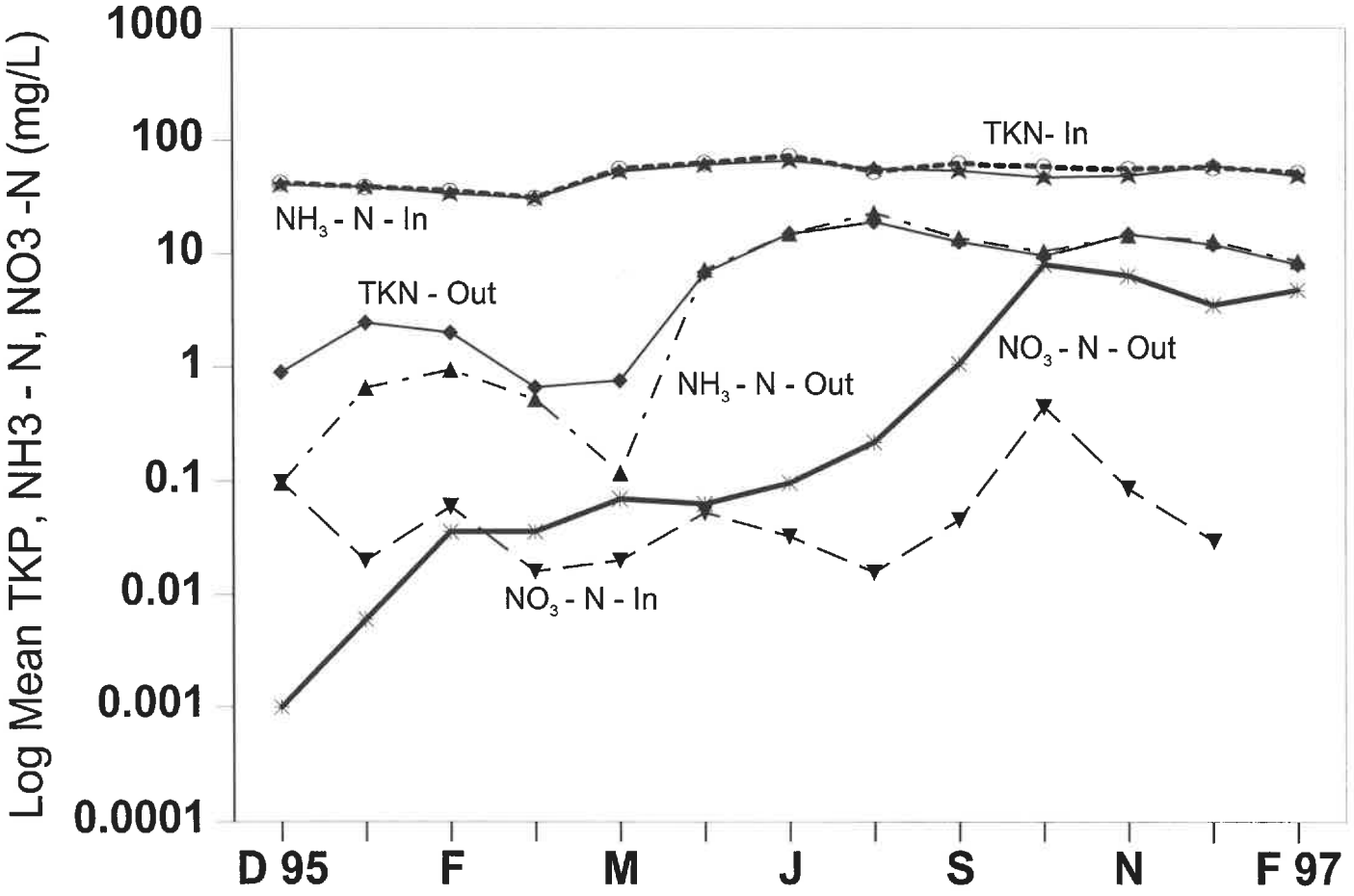
| Date | Input Cell 1 | Output Cell 1 | Output Cell 2 | Output Cell 3 |
|---|---|---|---|---|
| Dec. 1995 | 1720[a] | 4[b] | | |
| | (3.24 ± 0.32) | (0.60 ± 0.32) | | |
| Jan. 1996 | 13,960[a] | 40[b] | | |
| | (4.14 ± 0.32) | (1.60 ± 0.32) | | |
| Feb. 1996 | 250,000[a] | 58.7[b] | | |
| | (5.39 ± 0.32) | (1.77 ± 0.32) | | |
| Mar. 1996 | 153,000[a] | 219.7[b] | 69.3[c] | 6.8[d] |
| | (5.18 ± 0.16) | (2.34 ± 0.16) | (1.83 ± 0.16) | (0.81 ± 0.16) |
| May 1996 | 433,000[a] | 9040[b] | 158[c] | 2[d] |
| | (4.65 ± 0.16) | (3.95 ± 0.16) | (2.16 ± 0.16) | (0.45 ± 0.16) |
| June 1996 | 240,000[a] | 2300[b] | 293[c] | 149[c] |
| | (5.38 ± 0.16) | (3.35 ± 0.16) | (2.45 ± 0.16) | (2.17 ± 0.16) |
| July 1996 | 3,100,000[a] | 44,000[b] | 8000[c] | 1760[d] |
| | (6.49 ± 0.16) | (4.64 ± 0.16) | (3.89 ± 0.16) | (3.24 ± 0.16) |
| Aug. 1996 | 690,000[a] | 7900[b] | 496[c] | 31[d] |
| | (5.84 ± 0.16) | (3.89 ± 0.16) | (2.69 ± 0.16) | (1.48 ± 0.16) |
| Sept. 1996 | 340,000[a] | 29,000[b] | 1080[c] | 115[d] |
| | (5.58 ± 0.16) | (4.16 ± 0.16) | (3.03 ± 0.16) | (2.05 ± 0.16) |
| Oct. 1996 | 230,000[a] | 750[b] | 20[c] | 5[d] |
| | (4.33 ± 0.16) | (2.82 ± 0.16) | (1.35 ± 0.16) | (0.77 ± 0.16) |
| Nov. 1996 | 15,000[a] | 40[b] | 7[c] | 3[c] |
| | (4.15 ± 0.16) | (1.60 ± 0.16) | (0.30 ± 0.16) | (0.38 ± 0.16) |
| Dec. 1996 | 240,000[a] | 21[b] | 2.3[c] | 1.5[c] |
| | (5.36 ± 0.16) | (1.32 ± 0.16) | (0.36 ± 0.16) | (0.36 ± 0.16) |
| Jan. 1997 | System Frozen | | | |
| Feb. 1997 | 140,000[a] | 17[b] | 8[c] | 2[c] |
| | (5.26 ± 0.16) | (1.23 ± 0.16) | (0.89 ± 0.16) | (0.30 ± 0.16) |

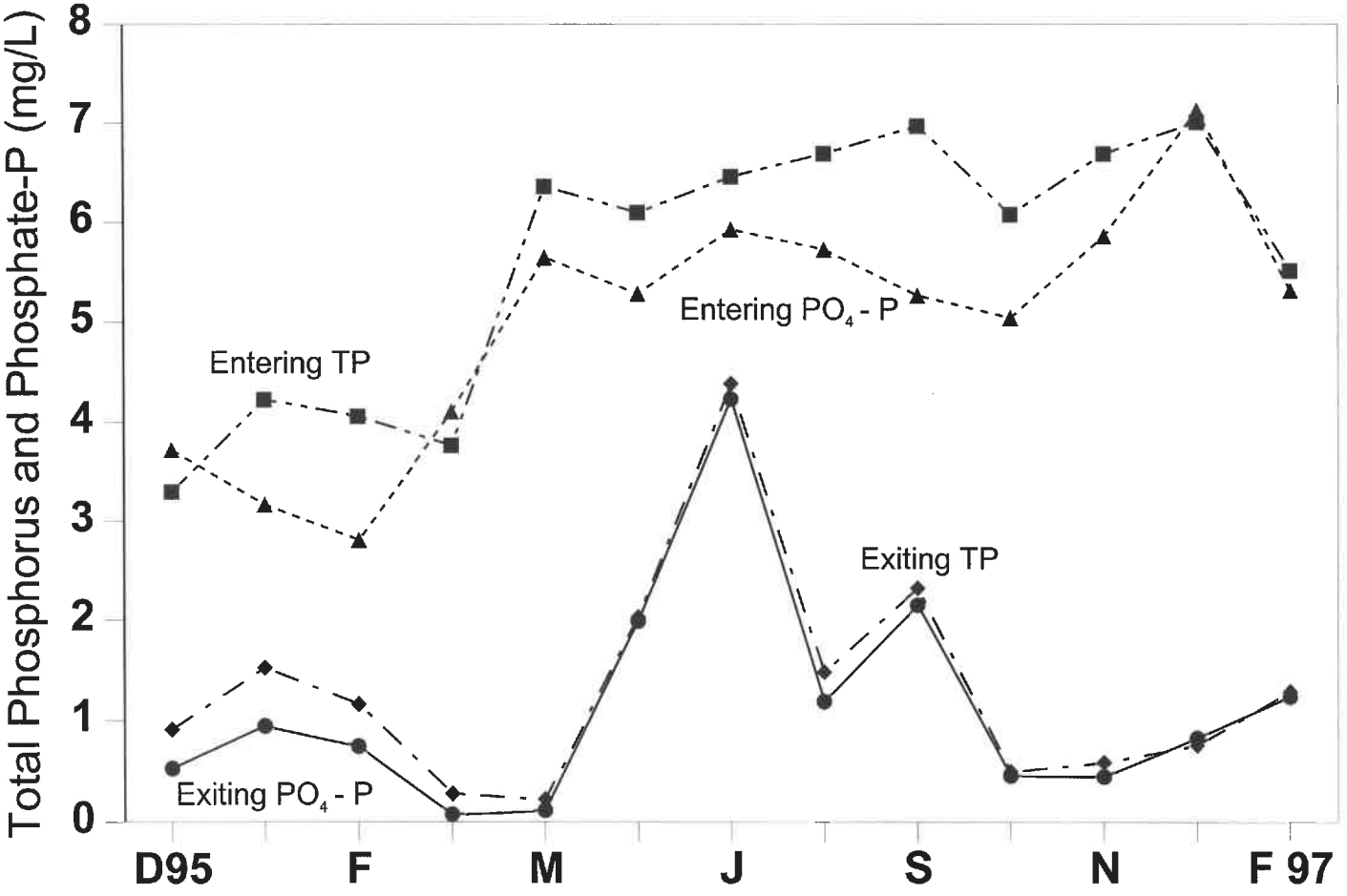

Log Mean TKN, NH3 - N, NO3 -N (mg/L)
1000
100
10
1
0.1
0.01
0.001
0.0001
D 95
F
M
J
S
N
F 97
TKN- In
NH3 - N - In
TKN - Out
NH3 - N - Out
NO3 - N - Out
NO3 - N - In

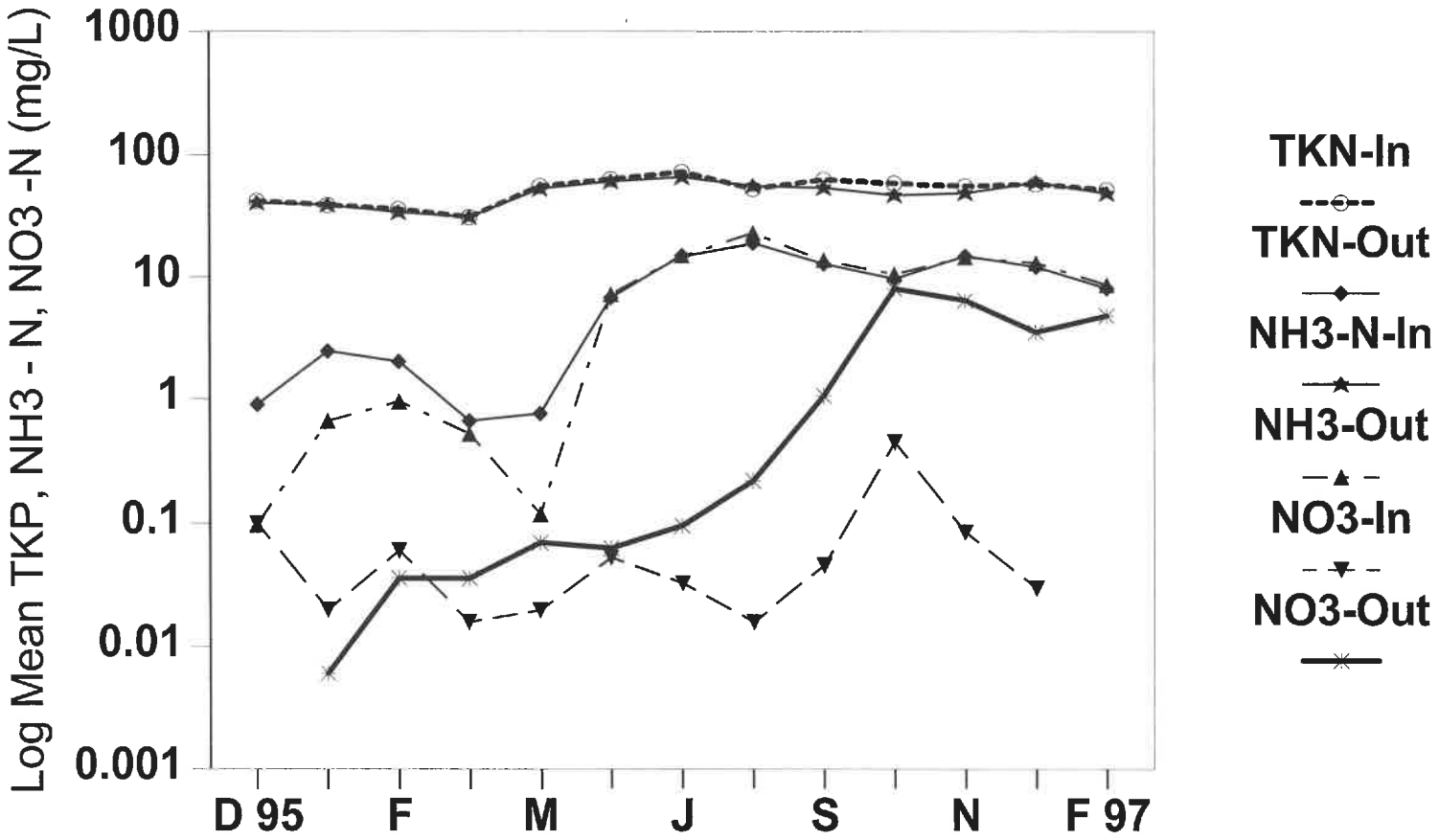

Total Phosphorus and Phosphate-P (mg/L)
8
7
6
5
4
3
2
1
0
D95
F
M
J
S
N
F 97
TP - In
PO4 - P - In
TP - Out
PO4 - P - Out


Number of Visitors
3000
2500
2000
1500
1000
500
0
Dec 95
Jan 96
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec 96
Jan 97
Feb


Total Precipitation (inches)/ Month
7
6
5
4
3
2
1
0
Dec 95
Jan 96
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec 96
Jan 97
Feb 97


Log Mean TKP, NH3 - N, NO3 -N (mg/L)
1000
100
10
1
0.1
0.01
0.001
0.0001
D 95
F
M
J
S
N
F 97
TKN- In
NH3 - N - In
TKN - Out
NH3 - N - Out
NO3 - N - Out
NO3 - N - In


Total Phosphorus and Phosphate-P (mg/L)
8
7
6
5
4
3
2
1
0
D95
F
M
J
S
N
F 97
Entering TP
Entering PO4 - P
Exiting TP
Exiting PO4 - P


Log Mean TKP, NH3 - N, NO3 -N (mg/L)
1000
100
10
1
0.1
0.01
0.001
D 95
F
M
J
S
N
F 97
TKN-In
TKN-Out
NH3-N-In
NH3-Out
NO3-In
NO3-Out