SEASONAL VARIATION IN NITROGEN LEACHING FROM SHALLOW-NARROW DRAINFIELDS

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ABSTRACT

Nitrogen removal from septic tank effluent is one of the most pressing issues in coastal areas undergoing growth and development. Seven home-sites using onsite wastewater treatment systems were monitored in coastal Rhode Island to examine N treatment and leaching. The primary treatment units at these sites include: geo-textile filters; recirculating sand filters; single pass sand filters; a fixed activated sludge treatment system; and a modular peat filter. The final treatment step of all of these systems is a pressure-dosed shallow-narrow drainfield (SND). This paper focuses on N-removal by the SND serving these sites (treatment performance of the secondary treatment units will be delivered in a separate paper). Sites vary in age from four to six years. Five suction-cup lysimeters were installed at each site, three within the SND and two within a control plot (i.e., outside the drainfield area). In the SND, lysimeters were installed in the undisturbed soils adjacent to each trench at a depth of 30 cm below the drainfield lines. Control lysimeters were placed at 70 cm below the soil surface. Soil porewater samples were collected through the lysimeters twice seasonally from the winter of 2001 until the summer of 2003 and analyzed for total N. Average concentrations of N entering the groundwater for these seven sites ranged from 2 to 41 mg/L (ppm). Six of the seven sites showed a 33 to 73% overall reduction in N levels as a result of treatment in the SND. Seasonal effects were recognized for inputs of N into the groundwater for two of the sites. There were no observed seasonal effects on the amount that N levels were reduced as a result of treatment in the SND. Porewater samples collected from the control area of two sites had considerably higher levels of total nitrogen (TN) than those below the SND. The higher N levels outside the SND are likely the result of excess fertilizer additions to the lawns.

KEYWORDS. Alternative onsite wastewater treatment, Nitrogen reduction, Shallow-narrow drainfield, Low pressure distribution.

INTRODUCTION

The major pollutants to ground and surface waters from onsite wastewater disposal systems (OSWDS) are N, P, and pathogens (Reneau et al., 1989). Nitrogen is generally considered the most mobile of the three, thus assessment of N concentrations in pore and groundwaters below an OSWDS can be used to estimate the potential for pollution from the system (Loomis, 1999). The main sources of N in domestic wastewater are feces, urine, food, and chemical wastes (Siegrist and Jenssen, 1989). The N found in wastewater is mostly organic nitrogen (NH_3-R), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and nitrogen gas (Burks and Minnis, 1994). Under aerobic conditions organic nitrogen and ammonium (the most abundant forms of N) are oxidized to nitrate (Walker et al, 1973; Lance, 1975). Nitrate is not adsorbed to the negatively charged soil particles, therefore it leaches easily, and may reach the groundwater resulting in contaminated drinking water and eutrophication of surrounding coastal waters (Stolt and Reneau, 1991; Peterson and Simpson, 1992; Burks and Minnis, 1994; Brady and Weil, 2002; Loomis et al., 2001). Most OSWDS rely on denitrification to convert nitrate to N_2 gas, which is then released to the atmosphere (Siegrist and Jenssen, 1989; Reneau et al., 1989; Stolt and Reneau,

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1991). In order for denitrification to occur certain conditions; such as an available carbon source, anaerobic conditions, and a favorable soil temperature and pH (Brady and Weil, 2002); must exist. Conventional OSWDS, however, are designed for aerobic treatment of effluent and will remove little N through denitrification.

Numerous studies have focused on the effectiveness of alternative OSWDS to remove N from domestic wastewater (Stolt and Reneau, 1991; Peterson and Simpson, 1992; Loomis et al., 2001). Most of these studies have focused on the effectiveness of secondary treatment units, such as sand filters and aeration treatment units, to remove N and have not evaluated final treatment of the wastewater. One commonly used final treatment step used for alternative systems is a shallow narrow drainfield (SND), sometimes referred to as a low pressure distribution system (Carlisle, 1980; Simon and Reneau, 1985; Stewart and Reneau, 1988). A SND consists of a series drainfield lines, placed 25-45 cm below the soil surface, that are pressure dosed with effluent from a secondary treatment unit. The SND offers many potential advantages over a conventional drainfield. By being closer to the surface, a SND creates a larger aerobic treatment zone for the effluent before it reaches the ground water or a limiting layer. Another advantage is that the system is pressure dosed and will disperse the effluent equally over the drainfield preventing overloading. Microbial and root biomass greatly decreases at a depth below 50 cm (Brady and Weil, 2002), thus by having the drainfield lines in the upper 25 to 45 cm of soil the effluent is released in a zone where roots and soil microbes are most active (Stewart and Reneau, 1988). This allows for the increased uptake and transformation of N in the wastewater. The objectives of this study were to examine the amount of N potentially entering the groundwater below SND in Rhode Island and to determine if time of year affects the groundwater inputs. Our hypothesis was that reduced biological activity would occur in the SND during winter and late fall and result in an increase in the amount of N entering the groundwater from these systems. We assumed that soil porewaters collected 30 cm below the SND lines would represent N concentrations entering the shallow groundwater in these coastal settings.

METHODOLOGY

Seven home-sites located in coastal resource areas of Rhode Island were chosen for study. The sites vary in the type of secondary treatment, age (four to six years old), placement of the drainfield lines, and loading rates (Table 1). Each site has a SND as the final treatment step for waste disposal.

Ceramic cup lysimeters were installed at each site: three directly adjacent to the trenches in the SND and two in a control area. A push probe (diameter equal to lysimeter) was used to install the lysimeters and reduce disturbance of the natural soil during installation. The base of the lysimeters was located 30 cm below the trench bottom (depth was measured from the middle of the ceramic cup). Lysimeters within the control were placed 70 cm below the soil surface at all the sites. The top of each lysimeter was 5-10 cm below the soil surface. A bucket auger (10 cm diameter) was used to excavate a space to allow access to the lysimeter. These access ports were stabilized with an appropriate sized section of PVC pipe. The PVC pipe was sealed with a #11 rubber stopper or a plastic cover. A screened PVC well was placed 90 cm from the outside of the SND at a depth of 60 cm below the trench bottom to monitor the water table level at each site. The purpose of the well was to confirm that the water table was not approaching the treatment zone of the SND and that we were collecting porewater samples (i.e. not collecting samples below the water table). Redox potential was measured at selected sites using six redox probes (electrodes) inserted along the drainfield to a depth equal to the trench bottom. Potentials were also measured at the same depth in the control area. Values were corrected by adding the standard potential of a saturated calomel reference electrode at a pH = 7 (244 mV). The soil redox potential measurements were made to determine if Eh levels were low enough in the SND for denitrification to occur (Mohn et al., 2000).

Soil-porewater samples were collected from the lysimeters on consecutive days each season from the winter of 2002 until summer 2003: a total of 14 samplings over the seven seasons. To collect the samples, a vacuum was established within each lysimeter using a field pump and portable power source. The following day the soil porewater was extracted from the lysimeter by extending a tube to the bottom and pumping the water into a labeled 120 ml bottle. Effluent was sampled from the secondary treatment unit of every system. Effluent from the LON, LIN, and MCG sites (Table 1) were collected 15 times between August 1997 and February 1999 (Sykes et al., 1999; Sykes, 2001). Effluent from the HAZ, TAR, TWE, and SIS secondary units were collected seasonally from the winter of 2002 until summer 2003. Soil porewater and effluent samples were stored in 120 ml econoware brown-glass bottles at 4^0 C until analyzed.

Soil-porewater and effluent samples were prepared for analysis by filtering them through a #2 Whatman filter using a Buchner funnel connected to a vacuum. One mL of sample was diluted by a factor of 20 and added to a 40 mL glass vial. A 5 mL liquid digestion reagent, consisting of recrystallized potassium persulfate ($K_2S_2O_8$), boric acid (H_3BO_3), and 1N sodium hydoxide (NaOH), was added to the samples. The samples were boiled in a water bath for 15 minutes and left overnight (American Public Health Association, 1995). Standards, created using potassium nitrate (KNO_3), were also digested following the same procedure. The following day the samples were analyzed for total N using a rapid flow analyzer (RFA-300, ALPKEM Corp.).

RESULTS AND DISCUSSION

Nitrogen Entering the Groundwater

Average N levels in the soil porewaters, based on seasonal sampling over a 20-month period, ranged from 2 to 42 mg/L (Figs. 1-7). Nitrogen levels from individual lysimeters ranged from 0 to 121 mg/L. Because of dry conditions during the summer of 2002, no soil-porewater samples could be obtained from the control areas of the MCG, HAZ, TAR, and LON sites and the SND from the LIN site (Figs. 1, 2, 3, 6, and 7). Concentrations of N entering the groundwater from the LIN and TAR sites were below drinking water standards (10 mg/L N) for nearly every season (Figs. 2 and 7). At the other 5 sites, N levels entering the groundwater were mostly well above the drinking water standard.

Two of the sites, LON and MCG, showed a trend suggesting seasonal effects on the amount of N entering the groundwater (Figs. 1 and 2). At these two sites porewater collected in the winter had the highest N concentrations, spring and summer months showed lower levels, and the levels increased in the fall. Although this trend was not strong, it was recognized for both years. We suspect that lower soil temperatures in the winter and fall resulted in reduced biological activity (plant growth, nutrient uptake, and microbial activity) in the SND such that more N was entering the groundwater during this time of year. Seasonal effects on the amount of N entering the groundwater were not apparent at the LIN, TAR, HAZ, SIS, and TWE sites (Figs. 3-7). Variations in the soil types within the SND, effluent N concentrations, or loading rates may have masked any seasonal patterns for these sites and contributed to the amount of variability seen in the MCG and LON sites.

Reductions in Nitrogen Levels within the SND

Reduction in N concentrations, based on seasonal effluent levels and N concentrations in the porewater samples, for the TWE, SIS, HAZ, and TAR sites range from 0 to 97%. No seasonal effect on N removal was observed. Average N concentration reductions for the entire sampling period were 53, 43, 40, and 33% for TWE, SIS, HAZ, and TAR sites, respectively. Reduced concentration levels in N can be attributed to plant uptake, denitrification, and dilution. Since our porewater samples were collected above the water table, we expect little dilution to occur within the 30 cm of soil between the disposal points in the SND and where the lysimeters were located. Lush green grass was observed in all the sites at times during the spring, fall, and summer at each site. These observations suggest that the grassroots had access to both water and nutrients over the SND and may potentially remove N during the growing season. Over time, however, N mineralization will reach some equilibrium with N uptake by the grass and this effect will likely be inconsequential. Our redox potential measurements were lower in the SND than the control and at or below potentials reported for denitrification to occur. Therefore, we expect that denitrification may be the leading factor in the reduction of N concentrations in these four sites.

Effluent levels dosed on the SND at the LON, LIN, and MCG sites were measured in 1997 through 1999 (Sykes et al., 1999; Sykes, 2001). Since, the data reported here represent N levels reaching the groundwater for 2002 and 2003, examining seasonal effects was not possible. Based on average N levels for the effluent, and our seasonal porewater measurements, reduction of N due to treatment in the SND of these three systems is estimated to range from 0 to 99%. This range in values is similar to the range for the four sites where both effluent and porewater samples were collected seasonally. The average reduction for the entire sampling period, however, was much different. Nitrogen levels in four of the seven porewater samples collected from the LON site were higher than average effluent levels recorded for an 18 month period from 1997 to 1999. At the LIN site, there was a much higher percent of reduction (73%) than observed at any of the other sites. These data suggest that effluent N levels leaving the secondary treatment unit may have increased between 1999 and 2002 at the LON site and decreased at the LIN site during the same period. These differences in N levels in the effluent are likely due to changes in water usage or occupancy by the homeowner, resulting in higher or lower levels of contaminants entering the SND.

Control Plot N Levels

Ratios of N in porewaters below the SND to N concentrations below the control plots ranged from 0.2 to 18.4. The LIN and TAR sites had ratios of less than one, meaning more N was present in porewater samples collected below the control plots than porewater extracted below the SND (Figs. 2 and 7). For the LIN site, five of the six seasonal measurements show this trend (Fig. 2). Similarly in the TAR site, levels of N in the control exceeded the SND in all cases where porewater samples could be extracted (Fig. 7). In both of these cases, the porewater entering the groundwater from the control plots was much higher than drinking water standards. This is significant, since the alternative systems at these locations have greatly reduced N additions coming from disposal of domestic wastewater to less than 10 mg/L. The lawns at these locations are plush and green suggesting the likely source of the elevated N concentrations in the control plots is excess fertilizer.

SUMMARY AND CONCLUSIONS

Alternative OSWDS are called upon in areas where soils are marginal with respect to their treatment capacity or resources are such that special requirements are in place to minimize development impacts on water quality. Numerous studies have evaluated the effectiveness of the secondary units that define the alternative OSWDS to treat wastewater. Few studies, however, have addressed the effectiveness of SND as the final treatment step in an alternative OSWDS. In our study we found that on average as much as 73% of the N leaving a secondary unit can be removed by a SND, and that between 33 and 53% of the N is commonly removed. We expected considerable seasonal variations in the N removal. These effects, however, were only observed in two of the seven sites we studied. The lack of consistent evidence of seasonal effects on N removal may be the result of variations in soil type, N concentrations in the effluent, and loading rates. Variations in water usage by the homeowner may also make seasonal effects less evident. Although as much as 73% of the N disposed of in a SND may be removed, we found that N concentrations reaching the groundwater below these systems were well above drinking water standards. These data suggest that although alternative measures were taken in these critical coastal resource areas of Rhode Island to control N additions to the groundwater from onsite waste disposal, more work needs to be done to control N entering our ground and surface waters.

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Citations for this report:
Holden, S.A., M.H. Stolt, G.W. Loomis, and A.J. Gold, 2004. Seasonal Variation in Nitrogen Leaching from Shallow- Narrow Drainfields. In *Proceedings of 10th National Symposium on Individual and Small Community Sewage Systems*. 432-440. ASAE, St. Joseph, MI.

Table 1: Study sites characteristics.

Site	**System Installation Date**	**Drainfield Line Depth** (cm)	**Secondary Treatment Unit**	**Average Loading Rate** (gpd)
LON	Spring 1997	36 - 46	Above-Grade Recirculating Sand Filter	165
LIN	Spring 1997	23 - 35	At-Grade Recirculating Sand Filter	131
MCG	Spring 1997	28 - 38	Single-Pass Sand Filter	249
TWE	Winter 1998	25 - 30	Recircualting Geo-Textile Filter	66
SIS	Spring 1999	41 - 70	Peat Filter / UV Unit	130
HAZ	Spring 1999	29 - 56	Single-Pass Sand Filter	155
TAR	Summer1999	28 - 38	Fast Activated Sludge Unit / UV Unit	236

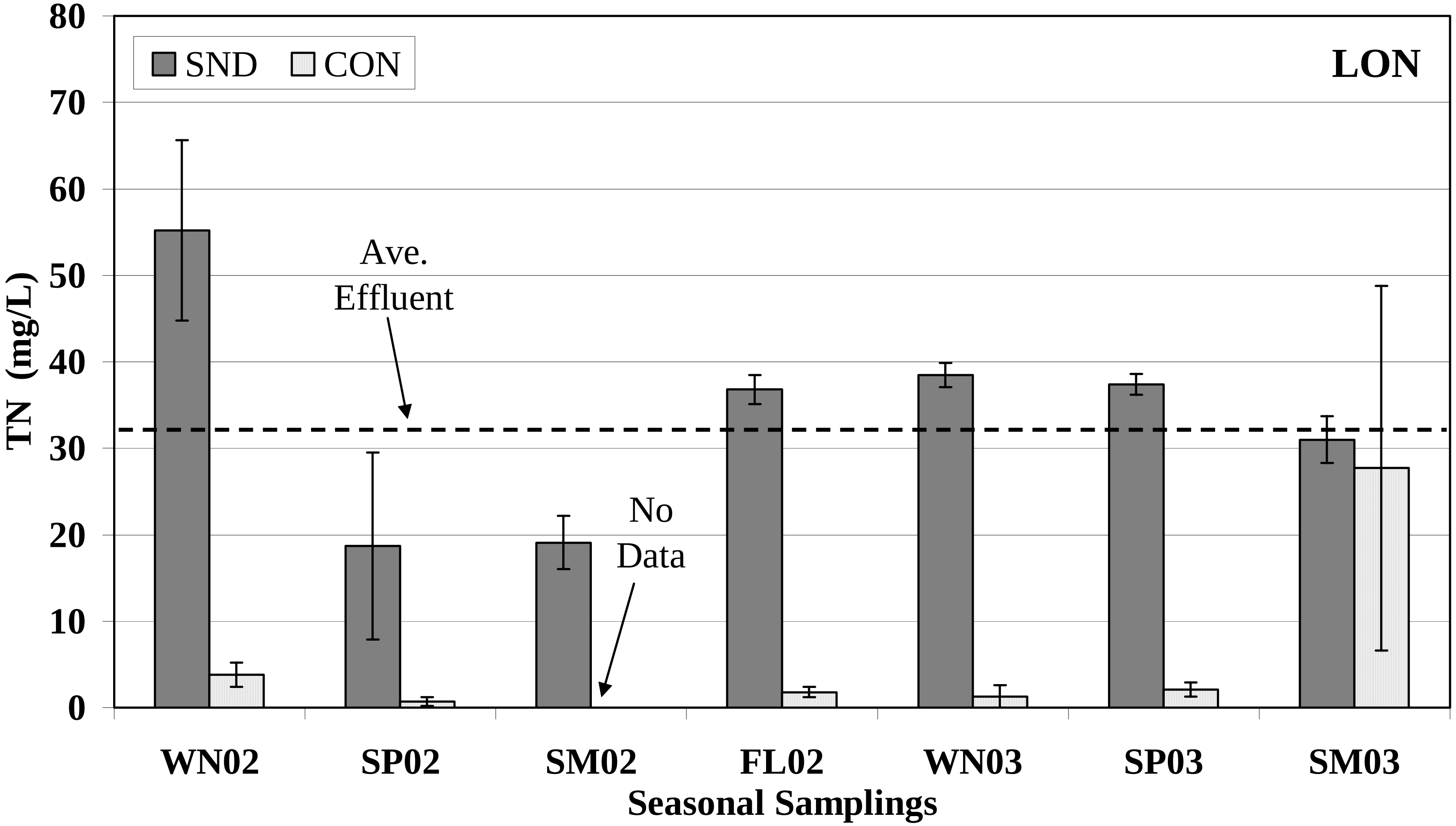

Figure 1: Total N concentrations in the porewater from the LON site. Samples were collected twice seasonally by multiple lysimeters placed 30 cm below the shallow-narrow drainfield (SND) and at a depth of 70 cm in the control area (CON). Effluent level represents average input of N from 7 samplings over 20 months (Sykes et al., 1999; Sykes 2001). Error bars represent +/- one standard deviation.

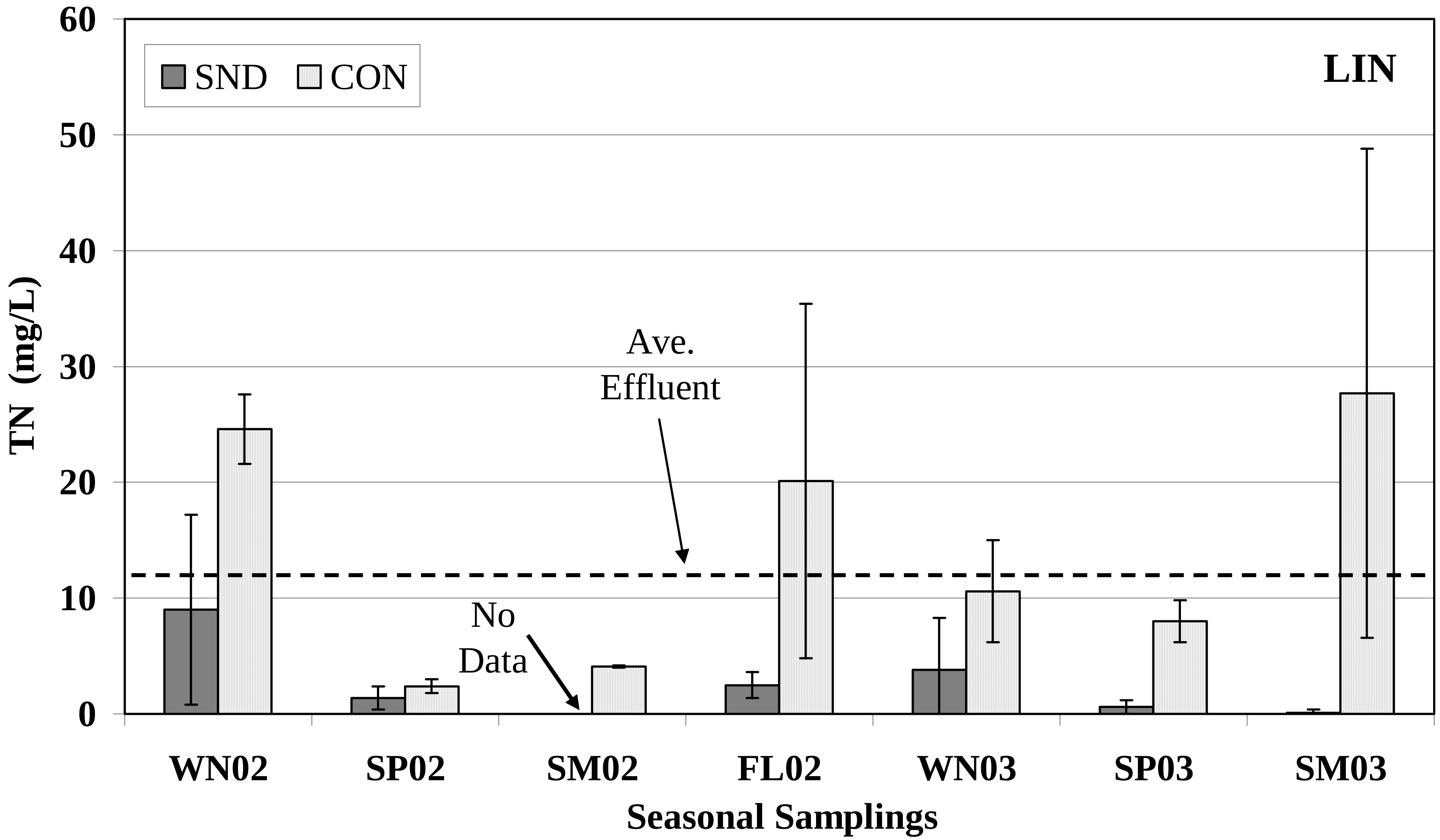

Figure 2: Total N concentrations in the porewater from the LIN site. Samples were collected twice seasonally by multiple lysimeters placed 30 cm below the shallow-narrow drainfield (SND) and at a depth of 70 cm in the control area (CON). Effluent level represents average input of N from 7 samplings over 20 months (Sykes et al., 1999, Sykes 2001). Error bars represent +/- one standard deviation.

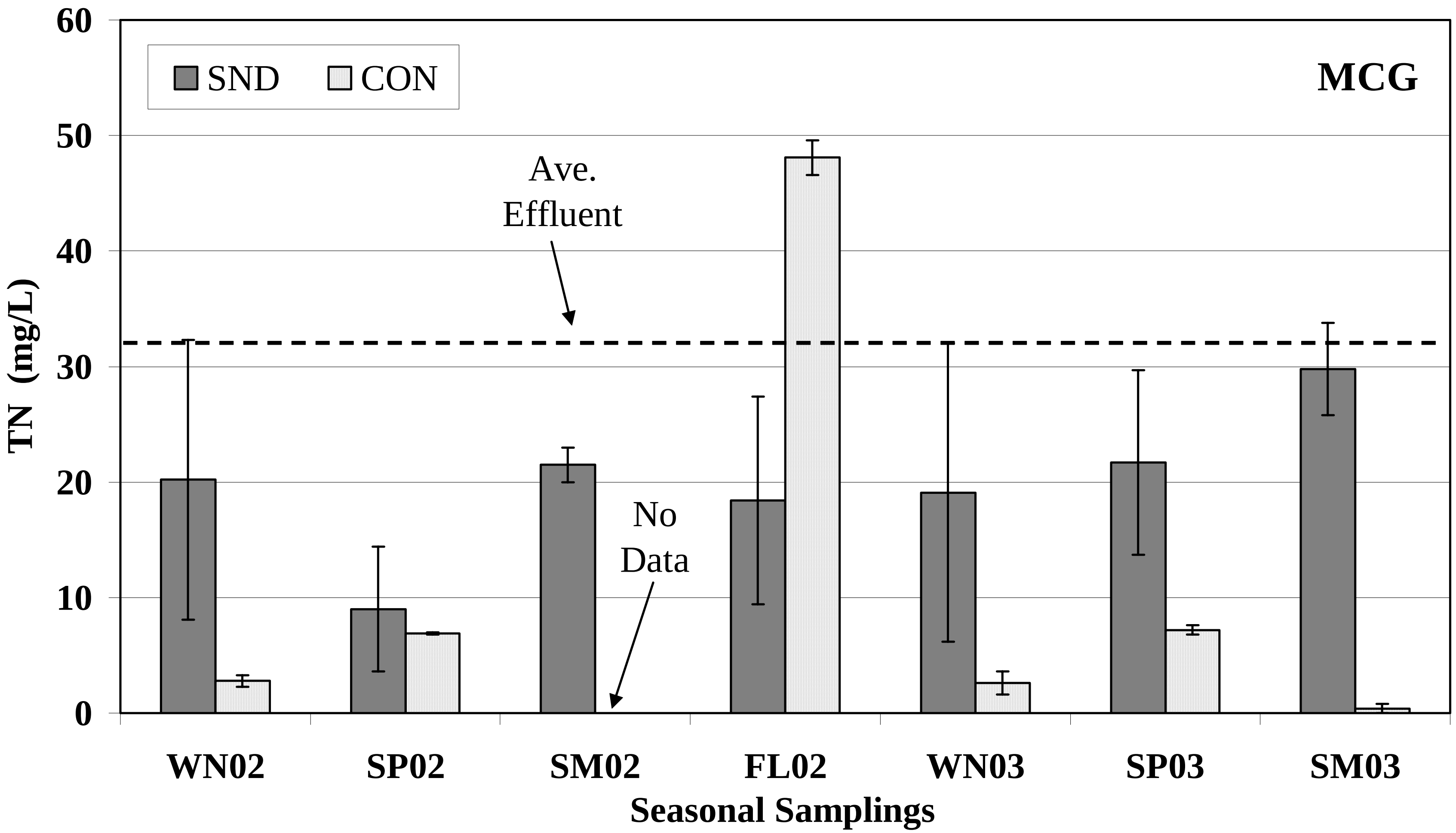

Figure 3: Total N concentrations in the porewater from the MCG site. Samples were collected twice seasonally by multiple lysimeters placed 30 cm below the shallow-narrow drainfield (SND) and at a depth of 70 cm in the control area (CON). Effluent level represents average input of N from 7 samplings over 20 months (Sykes et al., 1999; Sykes 2001). Error bars represent +/- one standard deviation.

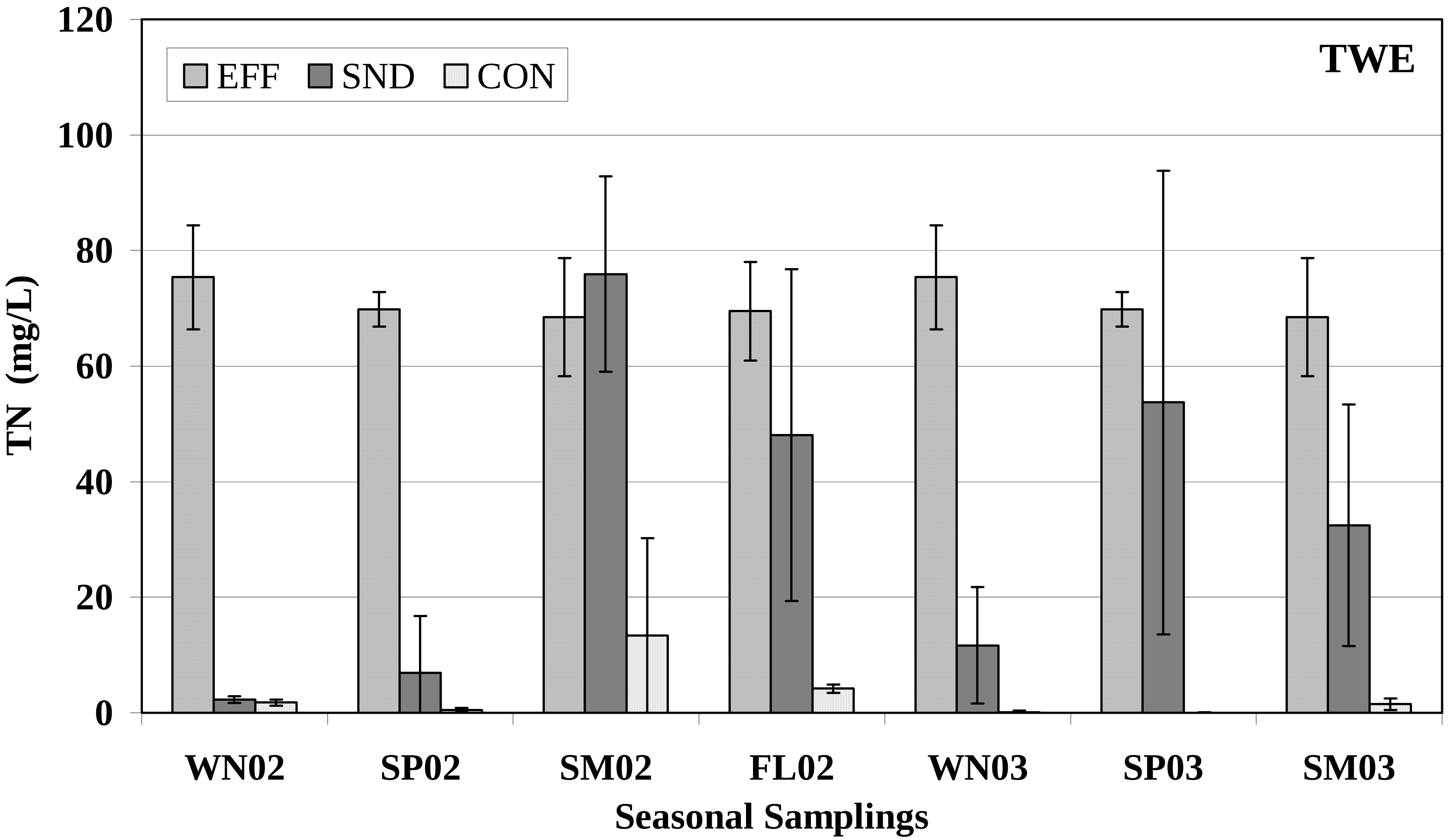

Figure 4: Total N concentrations in the porewater from the TWE site. Samples were collected twice seasonally from multiple lysimeters placed 30 cm below the shallow-narrow drainfield (SND) and at a depth of 70 cm in the control area (CON). Effluent levels (EFF) represent average seasonal input of N from 32 samplings over 41 months. Error bars represent +/- one standard deviation.

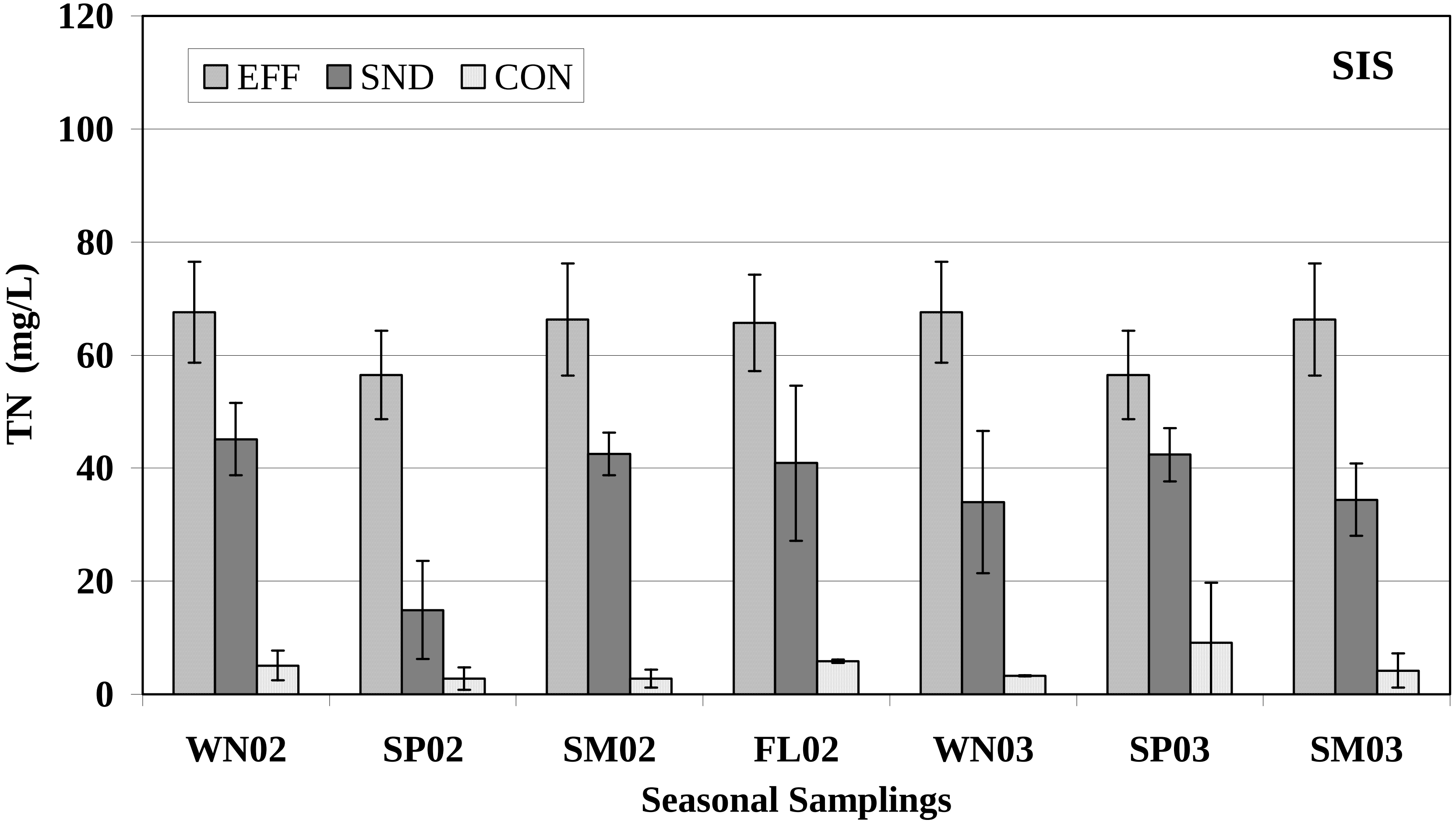

Figure 5: Total N concentrations in the porewater from the SIS site. Samples were collected twice seasonally from multiple lysimeters placed 30 cm below the shallow-narrow drainfield (SND) and at a depth of 70 cm in the control area (CON). Effluent levels (EFF) represent average seasonal input of N from 32 samplings over 41 months. Error bars represent +/- one standard deviation.

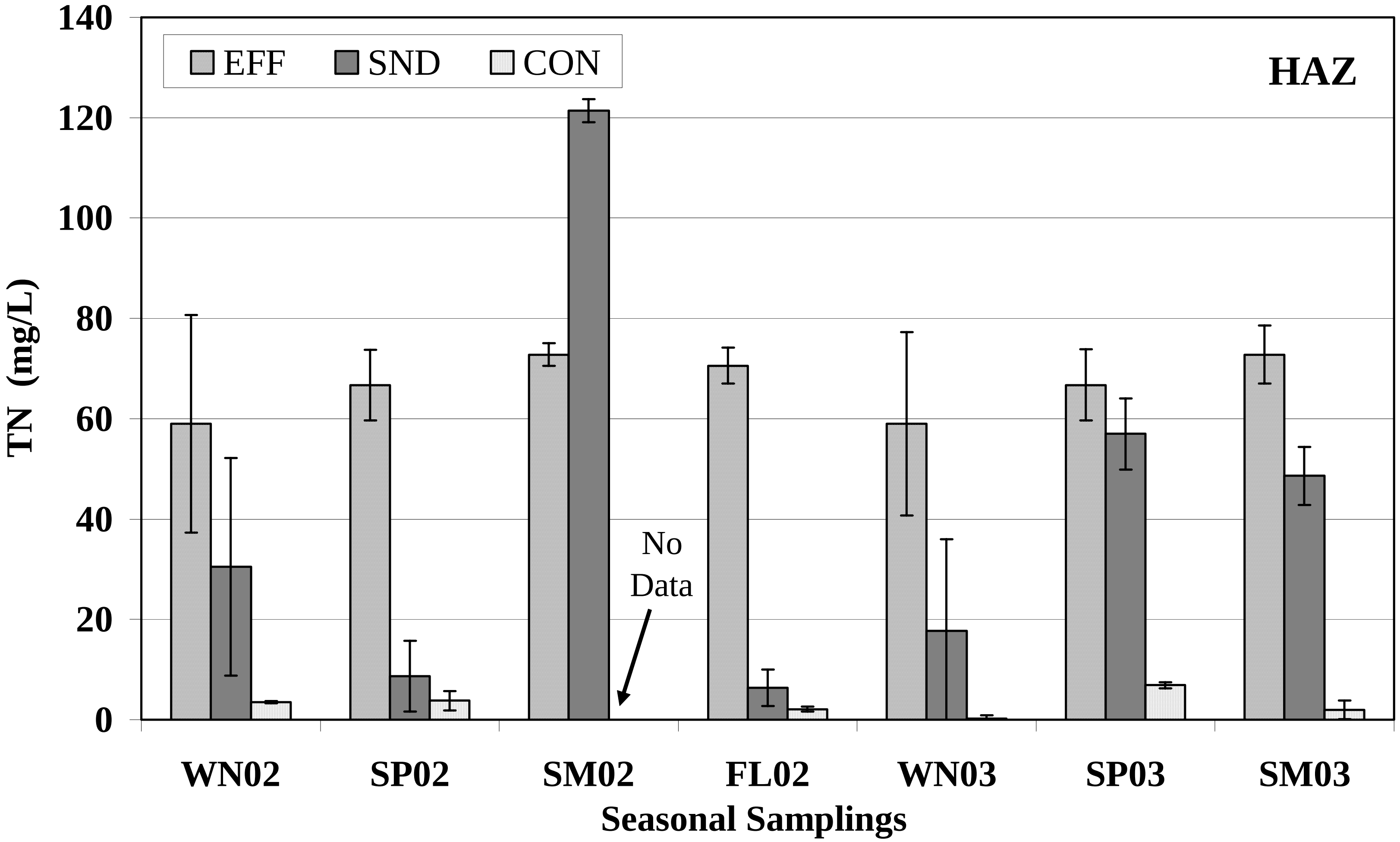

Figure 6: Total N concentrations in the porewater from the HAZ site. Samples were collected twice seasonally from multiple lysimeters placed 30 cm below the shallow-narrow drainfield (SND) and at a depth of 70 cm in the control area (CON). Effluent levels (EFF) represent average seasonal input of N from 32 samplings over 41 months. Error bars represent +/- one standard deviation.

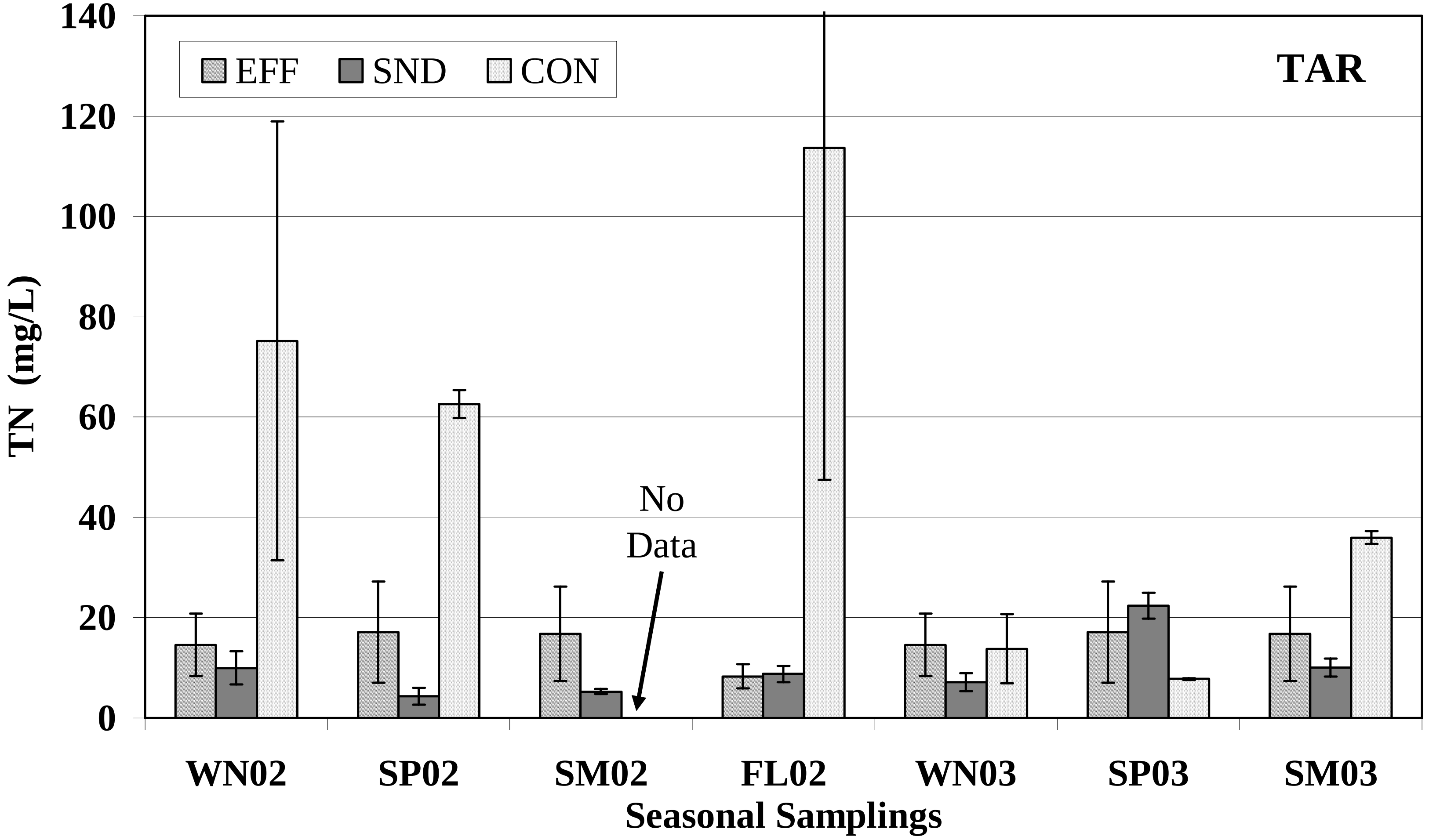

Figure 7: Total N concentrations in the porewater from the TAR site. Samples were collected twice seasonally from multiple lysimeters placed 30 cm below the shallow-narrow drainfield (SND) and at a depth of 70 cm in the control area (CON). Effluent levels (EFF) represent average seasonal input of N from 32 samplings over 41 months. Error bars represent +/- one standard deviation.